Baseline Characterization of Sandy Beach Ecosystems along the North Coast of California

Final Report

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Sandy Beach Ecosystems: Baseline Characterization of MPAs along the North Coast of California

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1 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. In northern California, sandy beaches comprise 35 % of the 832 km of shoreline habitat within the boundaries of the north coast (NC) Marine Protected Area (MPA) region (California Marine Life Protection Act Initiative 2010). A major headland feature, Cape Mendocino, is associated with a transition between two bioregions. The beaches in the region are physically diverse and include smaller pocket beaches (< 1 km in shoreline extent bounded by cliffs, high bluffs or rocky shores), which are concentrated to the south of Cape Mendocino. Prior to this study, we knew little about the ecology or ecosystem processes of California's NC sandy beaches. To our knowledge, this is the first comprehensive survey of biodiversity on beaches ever conducted in this region.

Our objectives were to provide a comprehensive, regional characterization of sandy beach and surf zone ecosystems in northern California to generate a representation of ecosystem state at the time of MPA implementation. We collected data on quantitative and qualitative metrics from 14 different beach locations to describe sandy beach and surf zone ecosystem features both inside and outside of MPAs (Figure E 1). Our study included 11 groups of organisms and specific taxa of birds, fishes and invertebrates previously identified as potential monitoring metrics of interest for sandy beach ecosystems. Our results serve as a basis for interpreting changes in key metrics that may be associated with the MPA status of beaches or the dynamics of linked ecosystems or environmental changes in the future.

Our collaborative research team included scientists and students from three public universities in California, members of the Tolowa Dee-Ni' Nation, staff from the Department of Fish and Wildlife as well as recreational and commercial fishers from the region. We combined taxonomically detailed surveys of macroinvertebrates and birds with targeted sampling of regionally important focal taxa including surf zone fishes, kelp and sand crabs; physical and biological metrics of the habitat; and activities of people on the beaches to develop an integrated understanding of the important ecosystem processes structuring northern California beaches.

Our baseline study program consisted of the following components:

- Nine monthly surveys (from September 2014 through May 2015) of birds, macrophyte wrack (detached marine vegetation such as seaweeds, surfgrasses and seagrasses that are deposited on the beach), human use and physical characteristics of 12 sandy beaches and their adjacent surf zones (6 MPA and 6 reference sites);
- A one-time, comprehensive survey of intertidal invertebrate biodiversity during summer 2014 of the 12 focal sandy beaches;
- A comprehensive baseline survey of redtail surfperch (*Amphistichus rhodoterus*), including diet analysis, at nine sandy beaches (4 MPA, 5 reference sites) over two years;
- Targeted monthly surveys of sand crabs (*Emerita analoga*) done concurrently with redtail surfperch surveys on three long beaches for three months; and

- Sampling of night smelt (*Spirinchus starksi)* spawning aggregations from nine beaches (5 MPA, 4 reference) during spring and summer over two years.

The beaches of the NC region are diverse with some of the most striking differences occurring between regions north and south of Cape Mendocino and between long beaches (> 1 km of shoreline extent) and pocket beaches (< 1 km of shoreline extent bounded by cliffs, high bluffs or rocky shores) (Figure E 2, Figure E 3). These beaches have different physical characteristics and processes influencing them, and their ecology reflects these differences (Figure E 4). Pocket beaches tend to be reflective beaches with narrower surf zones, and within the surf zone, narrow swash zone widths and swash zone periods.

The major findings of this baseline study of North Coast sandy beaches include the following:

- Our conceptual understanding of the major ecological links and processes driving the structure and dynamics of sandy beaches from prior scientific study of California beaches was reflected in the observations we made on the beaches of the North Coast.
- We found striking ecological differences among long beaches and pocket beaches. The abundance and composition of birds and macroinvertebrates differs between pocket beaches and long beaches (Figure E 2, Figure E 3). Pocket beaches have lower abundances of shorebirds and sand crabs, and more kelp wrack. On long beaches the terrestrial bird fauna consisted primarily of corvids, whereas on pocket beaches fly-catching birds such as swallows and Black Phoebe were more common.
- Strong differences were found in the composition of macrophyte wrack among the beaches located north and south of Cape Mendocino, mostly reflecting the lack of kelp in the northern bioregion. Macrophyte wrack cover, especially kelp wrack (detached brown seaweeds deposited on the beach in the order Laminariales), was greatest on southern pocket beaches. The year of this study, both cover and abundance of macrophyte wrack was relatively low across the entire region compared to the north central coast region..
- No major ecological differences were detected among beaches of different MPA status (Figure E 3).
- On long beaches the number of fresh kelp plants observed along the beach is a good predictor of total wrack cover and of kelp wrack cover (including dried-up, aged wrack) across the entire beach (Figure E 5).
- As expected, fresh kelp wrack was also correlated with the abundance, biomass and richness of wrack-associated invertebrates across both long and pocket beaches (Figure E 6).
- Diversity of beach invertebrates including insects endemic to beaches was high; we observed over 70 species. Abundance and biomass of these animals was also impressive with some beaches having up to 281,641 individuals and up to 15,334 grams per meter.
- Sand crabs and beach hoppers (talitrid amphipods, *Megalorchestia* spp.), both recommended as indicator taxa for long term monitoring, were found on every beach we studied in the region. Sand crabs dominated the total invertebrate biomass on long beaches making up 78% of intertidal biomass, while on pocket beaches they are less abundant and

made up only 2% of the biomass (Figure E 3). Talitrid amphipods were most abundant on pocket beaches making up 58% of the intertidal biomass, where kelp wrack was abundant and shorebirds were scarce. However on long beaches, talitrid amphipods made up <1% of the intertidal biomass. They also made up the majority of the wrack-associated invertebrate biomass and abundance on all beaches.

- Total shorebird species richness was strongly related to the abundance of talitrid amphipods and the species richness of all endemic beach invertebrates (Figure E 7). The diversity of wrack-associated intertidal insects is a key contributor to the relationship.

- Sand crabs are an important trophic resource for both shorebirds and redtail surfperch (Figure E 7, Figure E 8). Catch per unit effort for redtail surfperch is higher where sand crabs are more abundant. Additionally, when sand crabs are very abundant they appear to be a powerful attractant for some shorebird species (Figure E 7).

- At Mad River Beach, smaller sand crabs were strikingly abundant, although their total biomass was similar to other long beaches, perhaps reflecting a local recruitment 'hotspot'. Shorebirds, especially Western Sandpipers, were very abundant at this beach. The diet of redtail surfperch was also dominated by sand crabs at this beach, reflecting the importance of sand crabs as a trophic resource.

- People and their dogs were more abundant on pocket beaches than on long beaches, per kilometer of shoreline. However there were about half as many people (per km of shoreline) visiting pocket beaches in MPAs compared to reference beaches (Figure E 3).

- Redtail surfperch populations as represented by catch per unit effort (CPUE) did not differ across the beaches or between sampling years (Figure E 8). Nor was there a consistent difference in CPUE between reference and MPA beaches. Results from the tagging study, although limited by very low recovery rates suggest these fish may remain relatively local. The two most important prey observed in the guts of redtail surfperch during this study were sand crabs and fish eggs, mostly smelt eggs (smelt spawn on beaches). A surprising observation was the prevalence of barnacles in the guts of mostly larger fish from one beach. Although redtail surfperch appear to prefer sand crabs when they are available, they are opportunistic and will forage on the bottom capturing and scavenging infaunal and epifaunal prey as well.

- Spawning aggregations of night smelt are very patchy, and on some beaches, in some years, were not observed at all. Gold Bluffs Beach was the only beach where spawning aggregations of night smelt were consistently observed. Spawning aggregations were rare on some beaches where they used to be common, based on commercial landings records and local and traditional knowledge. Spawning aggregations were dominated by male fish, as expected. Spawning site fidelity was limited to a few specific beaches and interannual variation in abundance was high. These fish are short-lived and are likely to be sensitive to environmental conditions, including conditions on the beaches where they spawn.

- Fast facts about north coast study beaches:
  - Macrophyte wrack cover ranged from 20 cm^2 to 1.3 m^2 for every meter of beach shoreline (includes kelps, eelgrass, surfgrass and other marine seaweeds).
  - Animal wrack cover (including sand crab molts and by-the-wind sailors) ranged from 180 cm^2 to 0.45 m^2 for every meter of beach shoreline.
  - On 12 beaches surveyed over one summer we observed over 70 species of macroinvertebrates and some beaches had up to 281,641 individuals per meter of shoreline.
  - In nine monthly surveys of 12 beaches we observed 17,891 birds of 68 species, including 8,717 shorebirds of 20 species, 4,984 gulls of 7 species and 3,559 seabirds of 19 species.
  - Catch of redtail surfperch per hour of angler effort (CPUE) varied across the north coast beaches we studied from a high of 2 to less than one (= 0.15) fish per angler hour.

North Coast MPA Baseline Study Beaches

Long beaches (>1 km)

1. Pyramid Point SMCA**
2. Kellogg
3. Gold Bluffs
4. Reading Rock SMCA**
5. Mad River
6. Samoa SMCA**
7. South Somoa
8. Ten Mile North SMCA/SMR**
9. Ten Mile
10. Virgin Creek SMCA**

Pocket beaches (<u><</u>1 km)

11. Jug Handle
12. Caspar
13. Russian Gulch SMCA**
14. Van Damme SMCA**

** MPA site

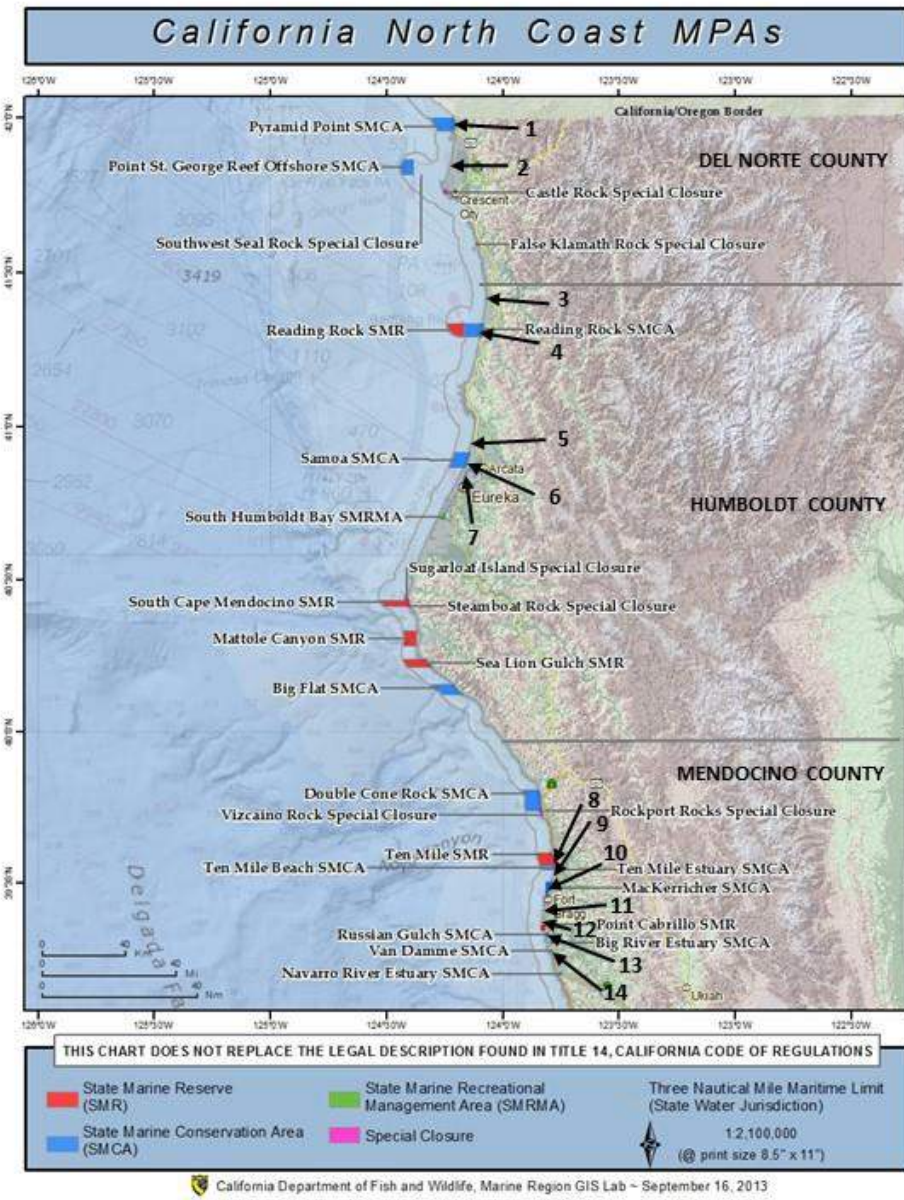

Figure E 1. Map of North Coast MPAs and study beaches and locations.

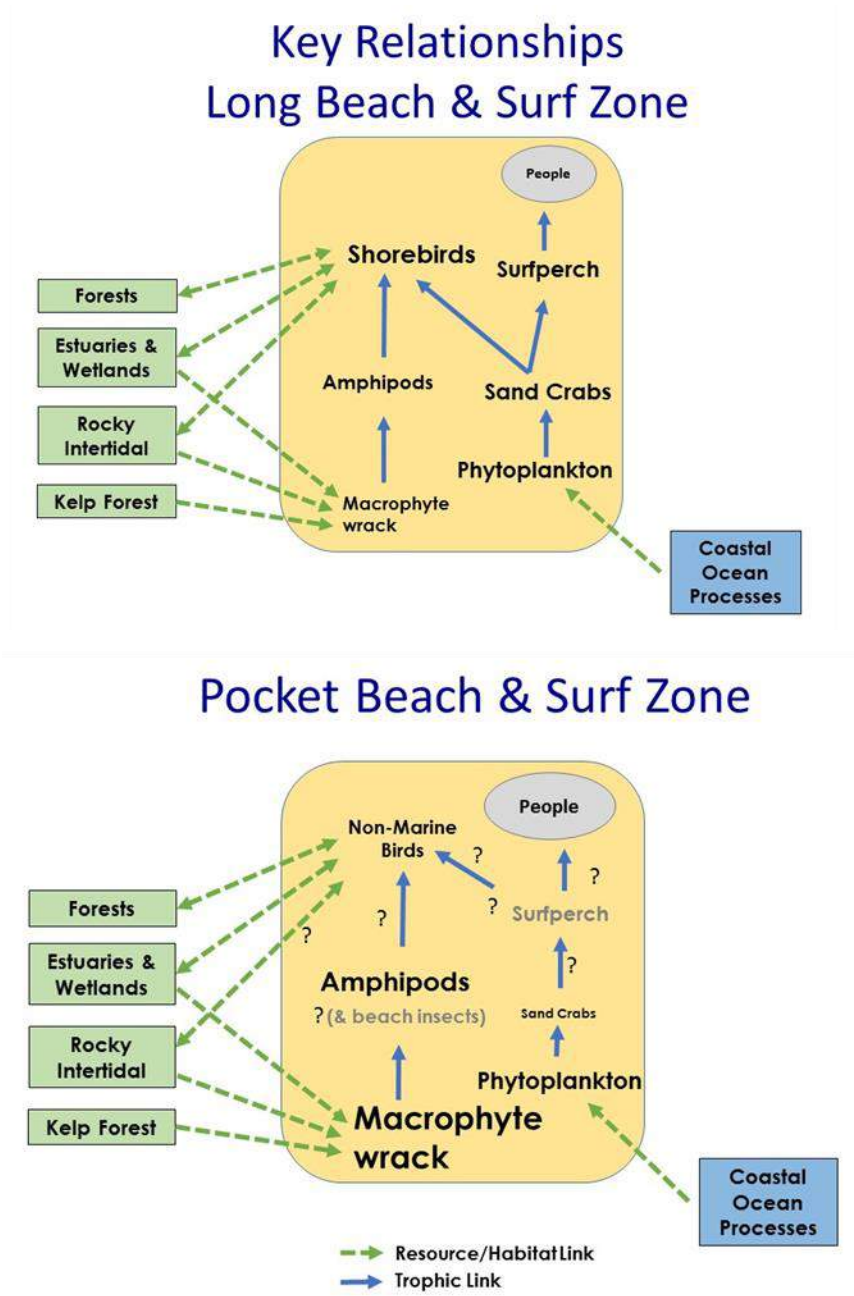

Figure E 2. Key differences in energy pathways and trophic links between long and pocket beaches

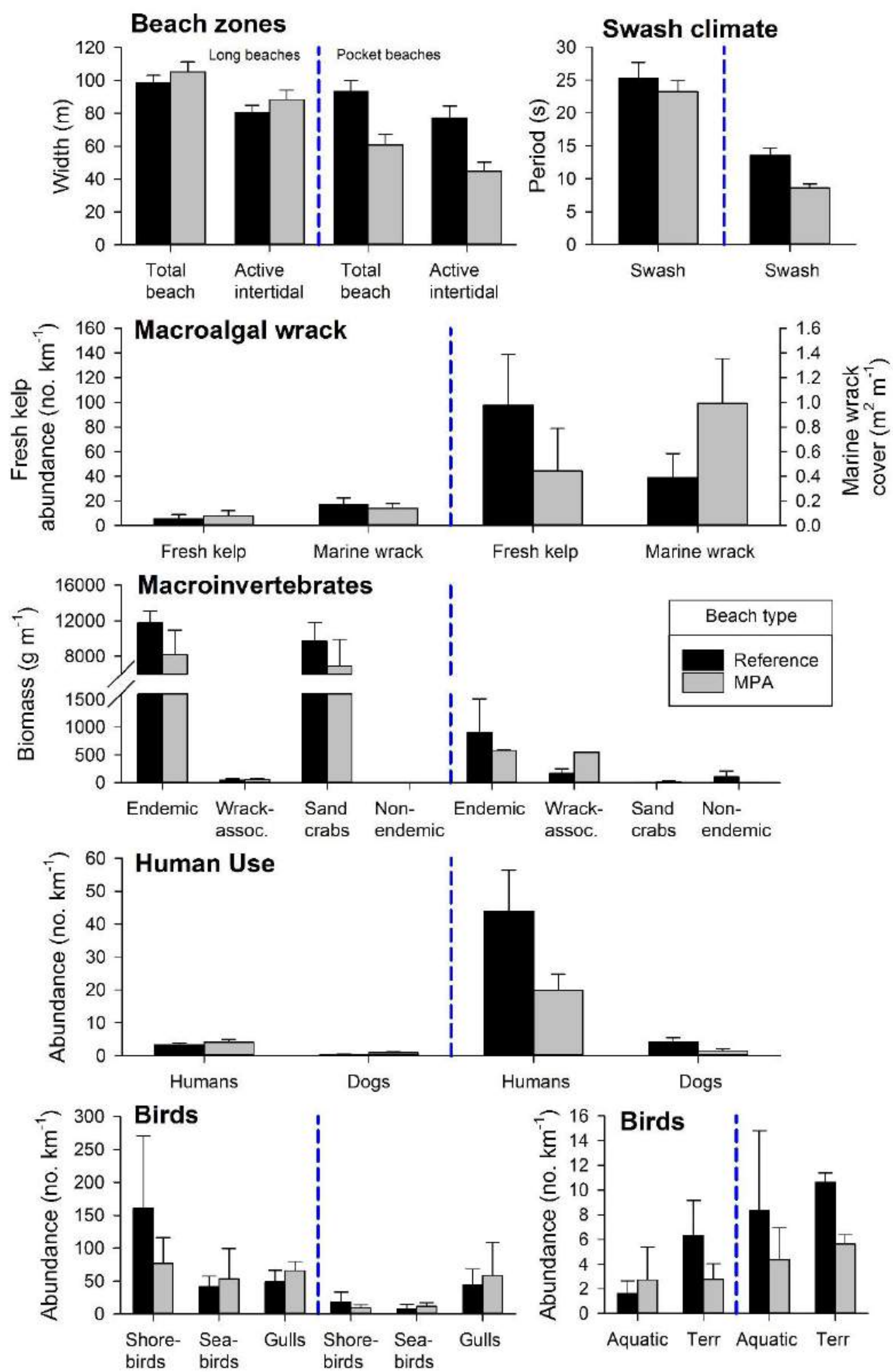

Figure E 3. Ecological comparison of MPA and reference beaches (grey and black bars, respectively), and long and pocket beaches (left and right of vertical blue dashed lines, respectively) for 12 study beaches in Northern California.

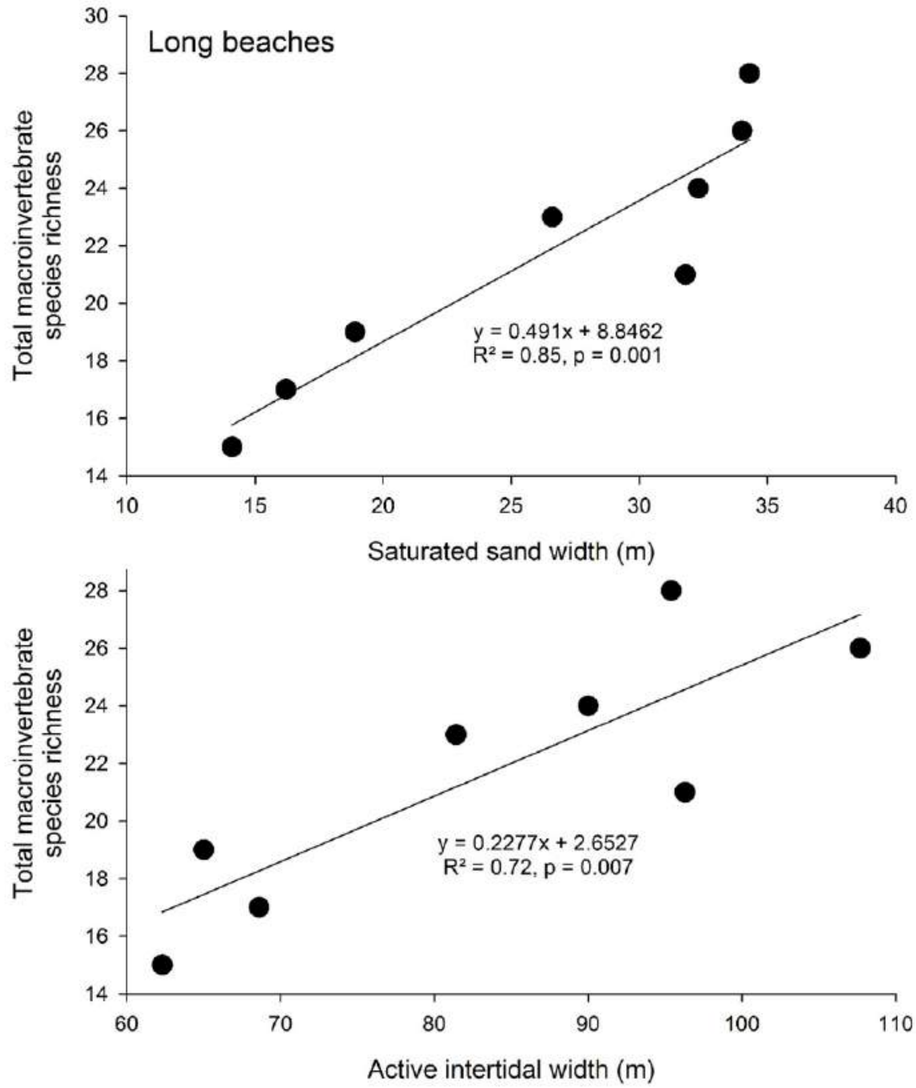

Figure E 4. Total macroinvertebrate species richness as a function of the width of two beach zones (saturated sand and active intertidal) on long beaches.

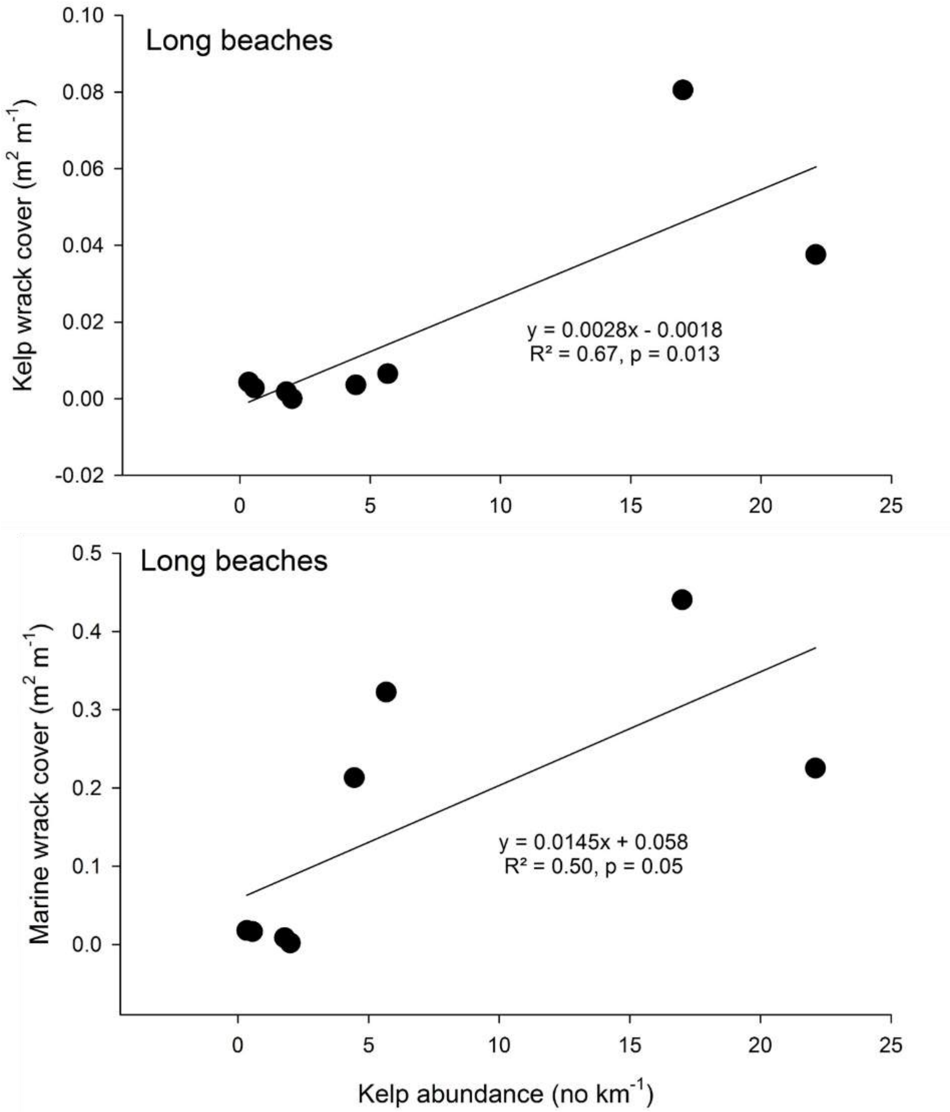

Figure E 5. Marine macrophyte wrack cover and kelp wrack cover (only) as a function of fresh kelp abundance on long beaches.

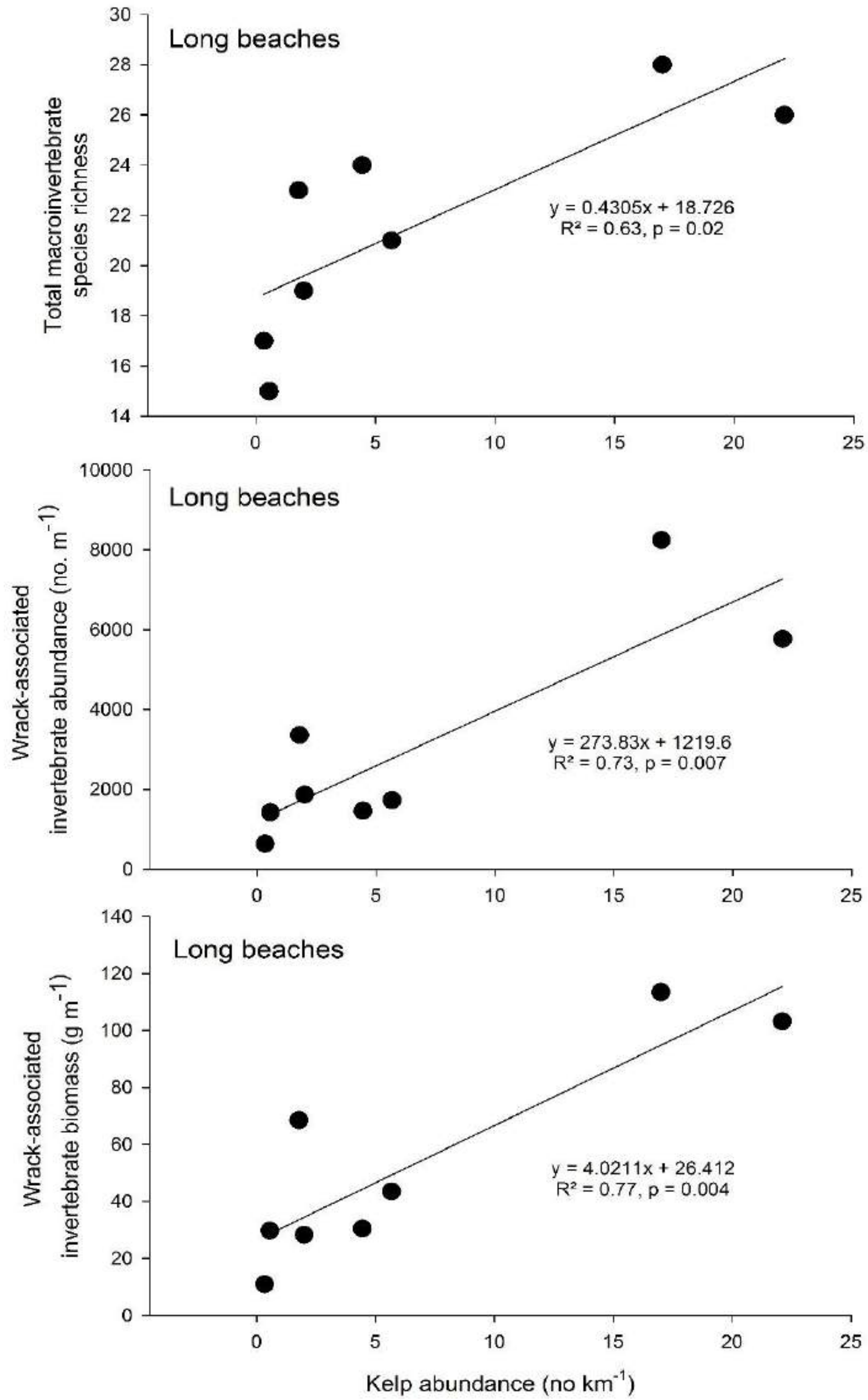

Figure E 6. Abundance, biomass and species richness of wrack-associated invertebrates as a function of fresh kelp abundance on long beaches.

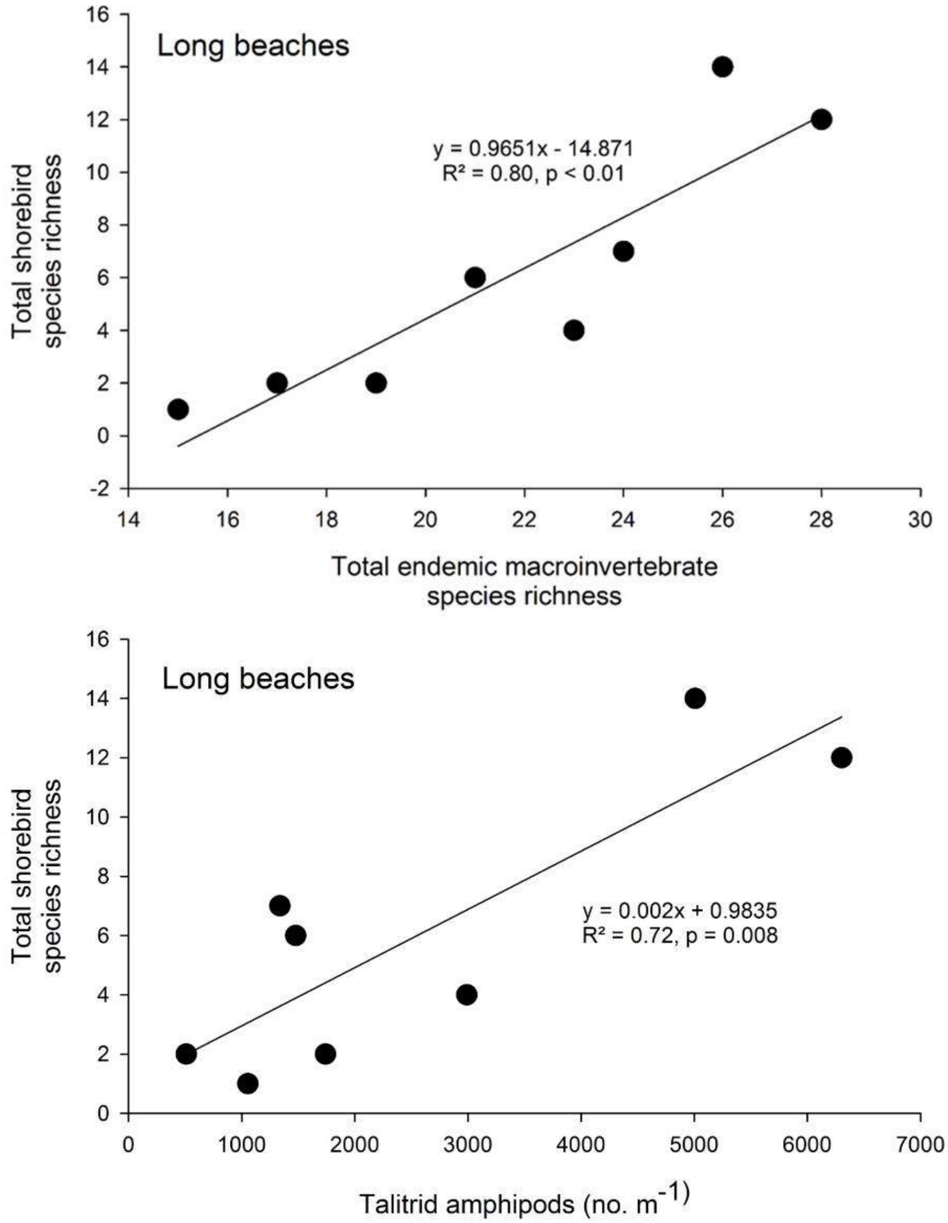

Figure E 7. Total shorebird species richness as a function of the abundance of talitrid amphipods and species richness of endemic beach macroinvertebrates on long beaches.

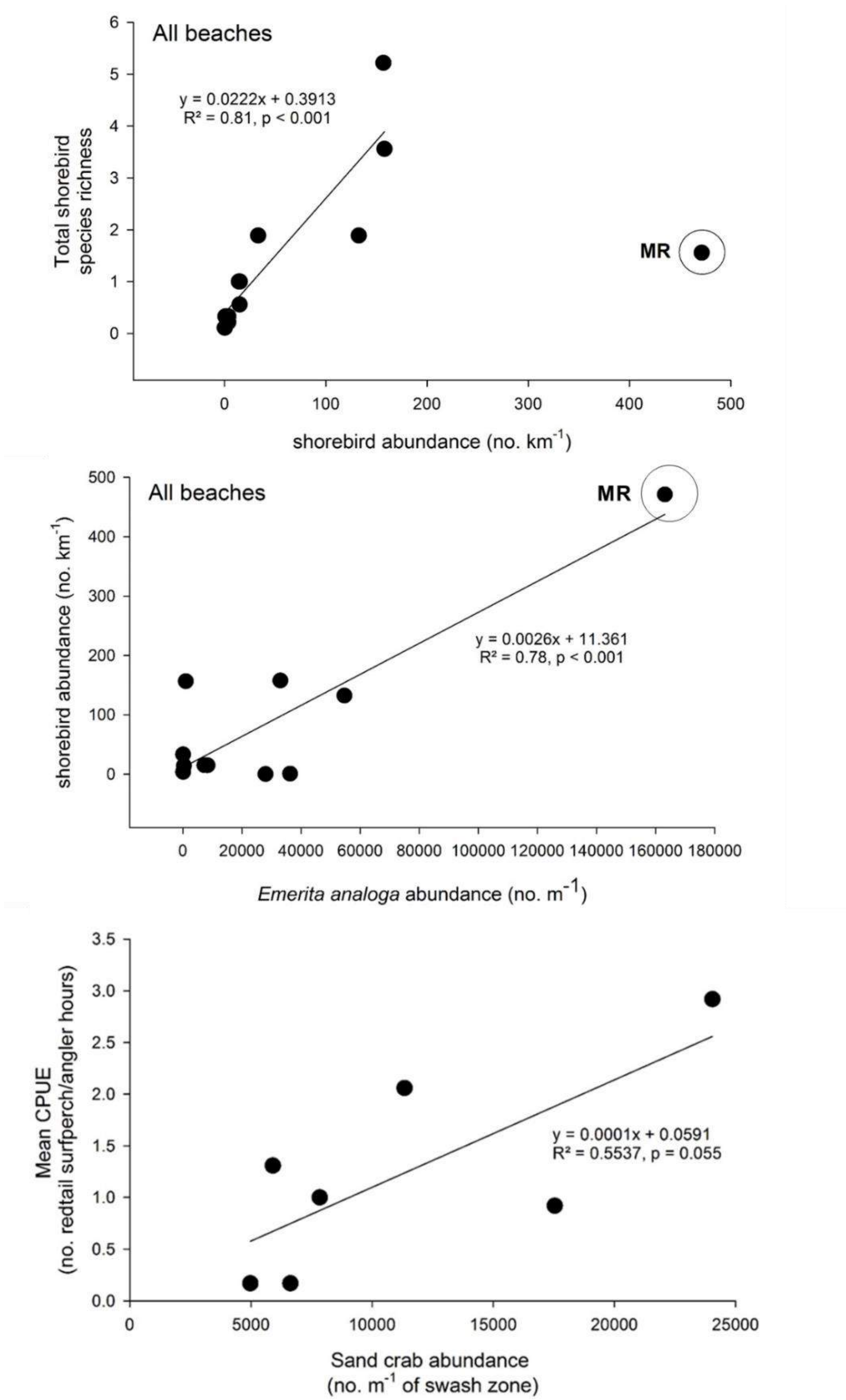

Figure E 8. Catch per unit effort of surfperch and shorebird abundance as a function of sand crab abundance and shorebird species richness as a function of shorebird abundance. The upper two panels are across all study beaches and the lower panel is from three study beaches over three months.

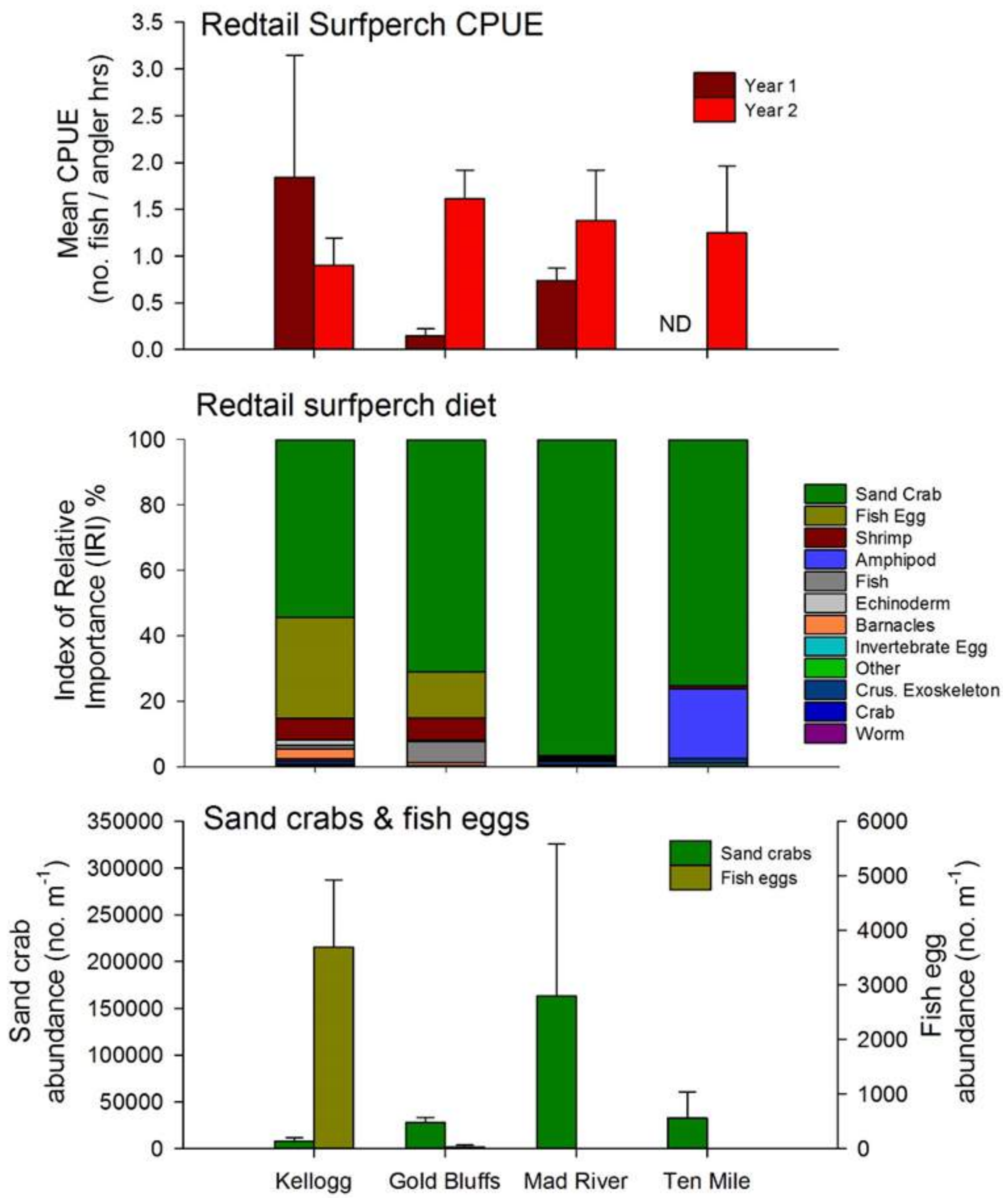

Figure E 9. Redtail surfperch abundance (as measured by catch per unit effort of fishing) and diet analysis from four long beaches in Northern California, compared to the abundance of sand crabs and fish eggs estimated from biodiversity core samples collected at the same four beaches.

2 Introduction

Sandy beaches are among the most intensely used coastal ecosystems for human recreation and are important to coastal economies (Klein et al. 2004), foraging shorebirds (Hubbard and Dugan 2003) and surf zone fishes (McLachlan and Brown 2006); however, these ecosystems are under-represented in the marine ecological literature (Schlacher et al. 2007). Sandy beaches comprise 35 % of the 832 km of shoreline habitat in the north coast (NC) Marine Protected Area (MPA) region (California Marine Life Protection Act Initiative 2010). However, prior to this study, we knew little about the ecology or ecosystem processes of California's NC sandy beaches. To our knowledge, this was the first comprehensive biodiversity survey ever conducted of the beaches in this region.

The MPA planning process for the NC region identified two bioregions located to the north and south of the mouth of the Mattole River on Cape Mendocino (Figure 1**)** About 10 % of the available sandy beach habitat (or ~ 29 km) in the NC region was protected across the 19 designated MPAs (California Marine Life Protection Act Science Advisory Team 2011). Long sandy beaches (> 1 km in shoreline extent) are found throughout the NC region, but pocket beaches (defined here as < 1 km in shoreline extent bounded by cliffs, high bluffs or rocky shores) are concentrated in the southern bioregion. We studied both types of beaches, extending research findings about pocket beaches made during baseline studies of north central coast MPA region (Nielsen et al. 2011). A diverse group of species including

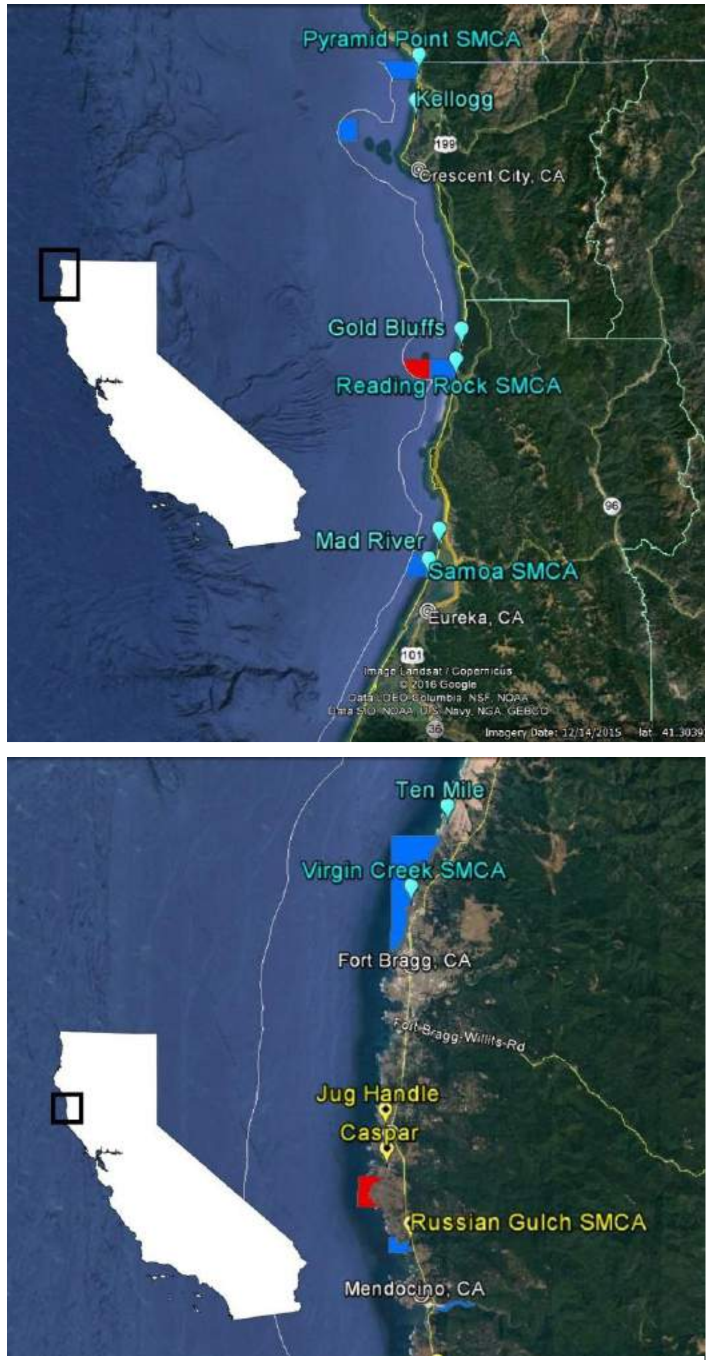

Figure 1. Sandy beaches where baseline macroinvertebrate sampling and rapid surveys of birds, wrack and human activities were conducted. Upper panel shows sites in the northern bioregion and lower panel sites in the southern bioregion of the North Coast. Yellow symbols and labels indicate pocket beaches (< 1 km) and aqua symbols and labels indicate long beaches (>1 km). All these MPA study beaches fall within the boundaries of a State Marine Conservation Area (SMCA; blue polygons). State Marine Reserves are shown as red polygons.

invertebrates, shorebirds and surf zone fishes depend on sandy beaches and surf zone ecosystems. Adjacent kelp forest, estuary and rocky intertidal ecosystems deliver important ecological subsidies of macrophyte wrack (detached marine vegetation such as seaweeds, surfgrasses and seagrasses that are deposited on the beach) and phytoplankton to these dynamic ecosystems (Leibowitz et al. 2016; Figure 2). Macrophyte wrack (= wrack) is important to the ecological functioning of sandy beaches as it forms the base of the non-plankton based food web. Wrack consuming talitrid amphipods provide sustenance for foraging shorebirds, including the threatened Western Snowy Plover, who also nests on sandy

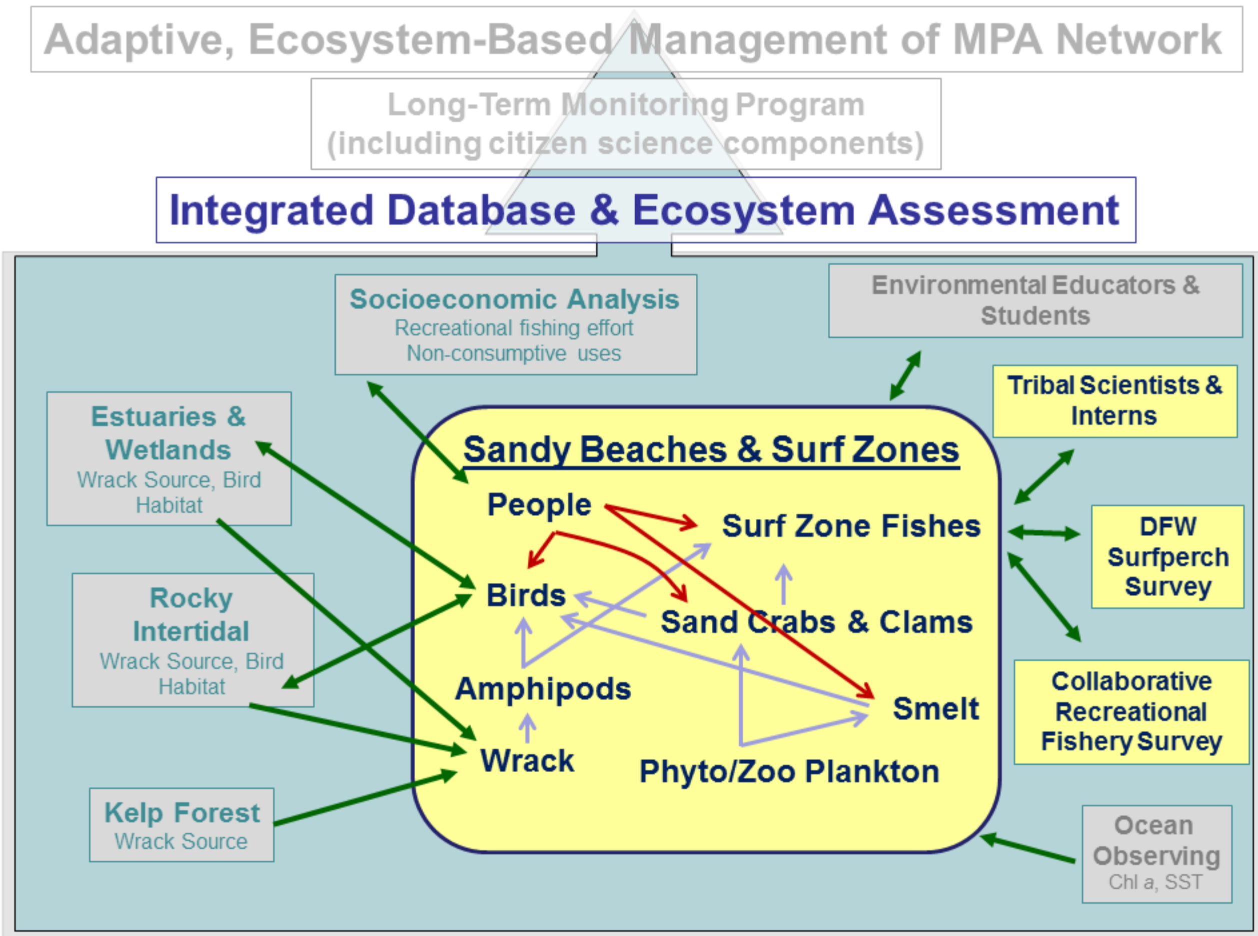

Figure 2. Links among ecosystem features, proposal components, and integrated outcomes for sandy beaches. Green arrows are links among ecosystem features; grey arrows indicate energy flow; red arrows indicate (direct) pathways of likely human impacts; blue text indicates aspects of this project; grey text or text boxes indicate entities or outcomes outside the scope of this study.

beaches in the NC region (Page et al. 2009).

Northern California's sandy beaches are part of the Pacific Flyway, one of the four principal bird migration routes in North America (Wilson 2010). California Gull, Marbled Godwit, Long-billed Curlew, Whimbrel and Black Oystercatcher, species commonly observed on NC beaches, are listed as birds of conservation concern by the Federal Wildlife Service (Morrison et al 2001; 2006; Bart et al. 2007). Sand crabs, clams and smelt feed on surf zone plankton. Shorebirds, seabirds and surfperches feed extensively on sand crabs and the diverse assemblage of macroinvertebrates, including polychaete worms, clams, amphipods and isopods, found in the different ecological zones across the beach.

Sandy beach surf zones of northern California are important foraging and spawning areas to several fishes, including juvenile and adult surfperch (Embiotocidae), adult smelt (Osmeridae), silversides (Atherinidae), and the juvenile stages of several species of flatfish (Bothidae, Pleuronectidae). Redtail surfperch is the primary species taken by recreational beach anglers in northern California. Additionally, the largest commercial landings of redtail surfperch in California are through the port of Eureka due to a small commercial hook and line fishery in the region. Redtail surfperch and smelt are traditionally fished and are also culturally important species to north coast tribes. The fishes of sandy beach surf zones have been poorly studied compared to those found over subtidal rocky reef or soft bottom habitats despite their ecological, economic and cultural importance. Previous studies indicate that sandy beach surf zones are temporally variable, dominated by a few species and provide important nursery areas for several fishes (Ross et al. 1987; Romer 1990). Our efforts focused on surfperch and smelt because of their dominance and importance to recreational and commercial beach fishers and to native tribes (i.e. Yurok and Tolowa) for subsistence and ceremonial use.

Sandy beaches are also popular areas for a wide variety of non-consumptive recreational activities such as beachcombing, jogging, nature viewing, dog-walking, surfing and other watersports. Ecological zonation is a common feature of intertidal habitats but is less visually apparent (to people) on sandy beaches than on rocky shores. In southern California and other areas where extensive coastal development encroaches on the beach, sea level rise combined with shoreline armoring results in the loss of entire ecological zones, dramatically altering the functioning of beach ecosystems (Dugan et al. 2008). Local management practices such as grooming, moving or adding sand or frequent driving on beaches can also have detrimental impacts. Several species common to beaches, such as talitrid amphipods and surfperch do not have dispersing larval forms, making these taxa more susceptible to changes in local habitat quality and beach management practices. However, most of the management practices listed above are associated with high population density, coastal development and recreational activities popular in warmer climates, which are much less prevalent in northern California. Local issues important to effective management of beach ecosystems in the NC region include: 1) watershed-related management practices influencing water quality of the beach water table; 2) subsistence, cultural, recreational and commercial fishing and gathering by local communities; 3) low-lying coastal roads and sea level rise vulnerability; 4) use of motorized vehicles on beaches; and 5) management of non-native invasive dune grasses.

2.1 Baseline characterization project objectives

The objective of this project was to provide a comprehensive, regional characterization of sandy beach and surf zone ecosystems in northern California and a representation of ecosystem state at the time of MPA implementation. This baseline for beaches is the first comprehensive study of beaches for the region. As a result, it will necessarily serve as a basis for interpretation of changes in key metrics that may be associated with the MPA status of beaches and/or linked ecosystems or environmental changes in the future.

Our collaborative research team included scientists and students from three public universities in California, members of the Tolowa Dee-Ni’ Nation, staff from the Department of Fish and Wildlife as well as recreational and commercial fishers from the region. We combined taxonomically detailed surveys of macroinvertebrates and birds with targeted sampling of regionally important focal taxa including surf zone fishes, kelp and sand crabs; physical and biological metrics of the habitat; and activities of people on the beaches to develop an integrated understanding of the important ecosystem processes structuring northern California beaches (Figure 2).

We collected data on quantitative and qualitative metrics to describe sandy beach and surf zone ecosystem features both inside and outside of MPAs. Our study included 11 groups of organisms and specific taxa of birds, fishes and invertebrates previously identified as potential monitoring metrics of interest for sandy beach ecosystems[1], plus many more invertebrates not mentioned, as well as the abundance of macrophyte wrack (Table 1). We analyzed and interpreted the data with reference to known trophic relationships and ecosystem processes for sandy beach ecosystems, as well as more recent knowledge gained by members of this team in the process of leading baseline monitoring efforts in the California's North Central and South Coast MPA regions.

Table 1. Metrics and key attributes for ecosystem assessment studied on sandy beaches in the North Coast Region.

Metrics and Key Attributes		**Indicator/Focal Species or Taxa**
Trophic Structure	Predatory Birds	Marine birds – species richness, abundance Shorebirds, Seabirds, Gulls, Aquatic/Wading birds, Terrestrial birds
	Predatory Fishes	Surf zone fishes – abundance, biomass, size structure, diet Surfperch
	Suspension Feeders	Macroinvertebrates - abundance, biomass, size structure Sand crabs
	Wrack Consumers	Wrack invertebrates - specie richness, abundance, biomass Talitrid amphipods
Productivity	Wrack	Macrophyte wrack composition, abundance, biomass
Diversity		Intertidal Macroinvertebrate and Shorebirds - species richness
Physical Habitat	Beach & Surf Zone	Beach profile, sand grain size, surf zone characteristics
Non-consumptive Use		Human use – recreational activity, zone used
Consumptive Use		Fishing

Our specific project goals included the following:

1. Quantify the diversity and abundance (biomass and numerical) of macroinvertebrates in sandy beach ecosystems for a regional, baseline characterization at the point of implementation of new MPAs in the region.
2. Survey the seasonal abundance and diversity of birds that forage on sandy beaches and in adjacent surf zones in northern California, including shorebirds, seabirds, gulls, and other aquatic and non-marine birds.

[1] https://caseagrant.ucsd.edu/sites/default/files/FINALNorthCoastBaselineProgramRFP-1.pdf, see appendix 1

3. Quantitatively describe the seasonal deposition, abundance and composition of macrophyte wrack cast onto northern California's beaches from adjacent intertidal, subtidal and wetland ecosystems that provide food and habitat for a variety of sandy beach organisms.
4. Produce a quantitative baseline characterization of the ecologically and culturally important surf zone fishes: surfperch (especially redtail surfperch) and night smelt including data on their abundance, size structure, sex ratios, feeding habits and movement patterns.
5. Conduct targeted sampling of sand crabs in conjunction with surfperch sampling to assess spatial and temporal correlations and investigate trophic connectivity. Collect quantitative and qualitative observational data on human activities (including consumptive and non-consumptive activities) in sandy beach ecosystems of the region through monthly surveys.
6. Describe the dynamic physical characteristics of regional sandy beaches and adjacent surf zones in the region over an annual cycle.
7. Collaborate with local tribal communities in monitoring activities to help build scientific monitoring capacity within their communities and support development of long-term monitoring
8. Work together with community members and organizations interested in developing or participating in monitoring programs to foster education outreach about coastal ecosystems and marine protected areas, building capacity for longer-term citizen-science monitoring of local beaches.
9. Engage local fishing communities in the MPA baseline survey, thus providing a foundation for long-term monitoring of NC MPAs using collaborative fisheries research techniques and fostering community support for MPA related management.
10. Continue to develop and strengthen collaborative working relationships among fishers, academic researchers, and state agencies (via workshops, reports, publications) in order to conduct effective fisheries research and management along the North Coast.
11. Complete a synthetic analysis of the key ecosystem metrics that describe the trophic and habitat relationships among species, as well as seasonal dynamics, and their relationship, if any, to human activities or MPA status during the timeframe of the project.

This baseline characterization of the region's beaches, including assessments of individual MPAs, constitutes a major contribution to the scientific knowledge of this region, yields new insights about the ecology of these systems and provides a solid foundation for adaptive, ecosystem-based management in the future.

3 Methods

3.1 Overview of beaches, MPA designation and approach

We conducted a variety of ecological surveys and sampling efforts on 14 sandy beaches on the northern California coast between June 2014 and December 2015 (18 months) to establish baseline conditions of ecological state inside and outside of MPAs (Table 2 and Table 3). Six of the beaches are outside of MPAs serving as references beaches, while eight are in MPAs. Seven are in designated State Marine Conservation Areas (SMCA) and one beach has a split designation in a combined SMCA/State Marine Reserve (SMR). SMRs offer the highest degree of protection with no extractive activities permitted. SMCAs allow for recreational take, some commercial take, including for surf smelt, as well as cultural and subsistence take by NC tribes. Many of the beaches are also within the boundaries of national, state or county parks (Table 2).

Table 2. Study beach names, MPA status, other designations, and locations. Beaches listed from north to south.

Beach	MPA Status	Other Designation	County	Transect Length (km)	Latitude	Longitude
Pyramid Point	SMCA	Clifford Kamph Memorial Park	Del Norte	1	41.97242	-124.20576
Kellogg Beach	Reference	Tolowa Dunes State Park	Del Norte	1	41.86688	-124.21387
Gold Bluffs	Reference	Prairie Creek Redwoods State Park/Redwood	Humboldt	1	41.35954	-124.07685
Reading Rock	SMCA	Redwood National Park	Humboldt	1	41.29742	-124.09150
Mad River	Reference	Mad River County Park	Humboldt	1	40.92908	-124.13612
Samoa	SMCA	Ma-le'l Dunes South Bureau of Land	Humboldt	1	40.86654	-124.16403
South Samoa	Reference	Samoa Beach	Humboldt		40.79938	-124.20521
Ten Mile North	SMCA/SMR	Inglenook Fen-Ten Mile Dunes Natural Preserve	Mendocino		39.55878	-123.76603
Ten Mile	Reference	MacKerricher State Park/ Inglenook Fen-Ten Mile Dunes	Mendocino	1	39.50801	-123.78513
Virgin Creek	SMCA	MacKerricher State Park	Mendocino	1	39.47263	-123.80508
Jug Handle	Reference	Jug Handle State Natural Reserve	Mendocino	0.12	39.3765	-123.81828
Caspar	Reference	Caspar Headlands State Beach	Mendocino	0.25	39.36074	-123.81689
Russian Gulch	SMCA	Russian Gulch State Park	Mendocino	0.12	39.32918	-123.80513
Van Damme	SMCA	Van Damme State Park	Mendocino	0.69	39.27443	-123.79346

The beaches are located in two bioregions (designated during the MPA planning process) north and south of Cape Mendocino. We were not able to include beaches in the Cape Mendocino area due to logistical and financial limitations. As a result, there is about 175 km between the Ten Mile North study beach in the south and the South Samoa study beach in the north. We classified ten of the beaches as long beaches and four as pocket beaches (as defined in the introduction and shown in Appendix 8.1, Photographs of Study Beaches.). Two of the eight long beaches (Ten Mile North and South Somoa) were included in the fishing surveys only. We specifically excluded estuarine beaches and those with major freshwater inputs because of the strong influence of freshwater and wave energy on species composition and abundances, and resulting ecological processes.

3.1.1 Beach sampling and survey methods

We did a one-time comprehensive biodiversity sampling of macroinvertebrates and surveys of wrack and physical characteristics of the beach and surf zone on 12 beaches during summer 2014 (Table 3, Table 4). We subsequently visited each of those 12 beaches once a month between September 2014 and May 2015 to survey birds, wrack, people and physical characteristics of the beach and surf zone (nine rapid surveys on 12 beaches (Table 3, Table 4). On nine beaches we performed fishing surveys for redtail surfperch, and on eight beaches we sampled night smelt, visiting each beach multiple times during spring, summer and fall (Table 3, Table 4). Lastly, we also conducted repeated sampling of sand crabs in the swash zone on three beaches during the summer of 2015 coinciding with redtail surfperch fishing surveys (Table 3, Table 4).

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

Beach	Beach Type, boundary	Redtail Surf Perch	Night Smelt	Biodiversity sampling	Rapid surveys	Sand crabs
Pyramid Point	Long, dunes, bluff and houses	Jun-Oct 2014 Jun-Sep 2015	Jun-Aug 2015	10-Aug-14	Sep 2014 – May 2015	-
Kellogg	Long, dunes	Jun-Oct 2014 Jun-Oct 2015	Mar-Aug 2014 May-Aug 2015	11-Aug-14	Sep 2014 – May 2015	-
Gold Bluffs	Long, dunes	Jun-Oct 2014 Jun-Oct 2015	Mar-Aug 2014 Jul-Aug 2015	13-Aug-14	Sep 2014 – May 2015	May - July 2015
Reading Rock	Long, river mouth, bluff	Jun-Sep 2014 July-Sep 2015	Mar-Aug 2014 Jul-Aug 2015	12-Aug-14	Sep 2014 – May 2015	May - July 2015
Mad River	Long, dunes	July-Sep 2014 Apr-Nov 2015	Mar-Aug 2014 May-Jun 2015	27-Jun-14	Sep 2014 – May 2015	-
Samoa	Long, dunes	Jul-Sep 2014 May-Nov 2015	Mar-Aug 2014 May-Jun 2015	26-Jun-14	Sep 2014 – May 2015	May - July 2015
South Samoa	Long, dunes, road	Apr-Dec 2015	-	-	-	-
Ten Mile North	Dunes, road, river mouth	Jun-Sep 2015	May-July 2015	-	-	-
Ten Mile	Long, bluffs	Jun-Sep 2015	May-July 2015	14-Jul-14	Sep 2014 – May 2015	-

Virgin Creek	Long, bluffs, road, stream mouth	-	-	13-Jul-14	Sep 2014 – May 2015	-
Jug Handle	Pocket, bluffs, cliff	-	-	15-Jul-14	Sep 2014 – May 2015	-
Caspar	Pocket, cliffs, road, stream mouth	-	Jun-Aug 2015	12-Jul-14	Sep 2014 – May 2015	-
Russian Gulch	Pocket, cliffs, parking lot, stream mouth	-	-	28-Jun-14	Sep 2014 – May 2015	-
Van Damme	Pocket, cliffs, parking lot mouth	-	-	29-Jun-14	Sep 2014 – May 2015	-

Table 4. Timetable of surveys and sampling conducted during the NCMPA baseline monitoring.

	Survey Type				
Date	**Redtail Surfperch**	**Night Smelt**	**Biodiversity**	**Rapid**	**Sand Crabs**
May 2014		X			
Jun 2014	X	X	X		
Jul 2014	X	X	X		
Aug 2014	X	X	X		
Sep 2014	X			X	
Oct 2014	X			X	
Nov 2014				X	
Dec 2014				X	
Jan 2015				X	
Feb 2015				X	
Mar 2015		X		X	
Apr 2015	X	X		X	
May 2015	X	X		X	X
Jun 2015	X	X			X
Jul 2015	X	X			X
Aug 2015	X	X			
Sep 2015	X				
Oct 2015	X				

3.1.2 Biodiversity Sampling

To describe the biodiversity of intertidal invertebrates on the beaches, we quantitatively sampled the intertidal macroinvertebrate community once at each of the 12 focal beaches (six MPA and six reference beaches) during daytime spring low tides in June, July and August of 2014 (Table 3, Table 4). We sampled beaches during extreme (spring) low tides during summer daylight hours when sea state is usually not stormy. By this time of year, sand has also usually been re-deposited on the beach from the off-shore sand bars that accumulate during winter storms.

The conditions and logistics during this part of the year are conducive to sampling biodiversity of beach macroinvertebrates and capturing most species likely to be living on the beach. The razor clam (*Siliqua patula*) is one notable exception as it can be found far deeper in the sand than the depth of our standard core sampling protocol. Different methods are required to obtain accurate population estimates for this species and were beyond the scope of this project.

The species richness, abundance, biomass and population characteristics of the macroinvertebrate community of the 12 focal beaches were estimated using sampling protocols similar to those used in earlier studies of California beaches (Dugan et al. 2003, Nielsen et al. 2013, Dugan et al. 2015).

Quantitative sampling was conducted on three vertical format (shore-normal) transects extending from the lower edge of terrestrial vegetation or the bluff to the lowest level exposed by swash (Figure 3) of the intertidal 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. To minimize disturbance of the mobile fauna in the lower beach along adjacent transects, transects less than 10 m apart were not used, and another random location was drawn.

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, the lowest level exposed by the receding swash (LSL) at the time of low tide. Cylindrical core samples (0.0078 m^2, 100 mm diameter) to a depth of 200 mm were taken at uniform intervals of 0.25 to 2.0 m, depending on the beach width. In instances where the sand was too compact (or where the sand was just a thin veneer over larger rocks and cobbles) to insert the corer manually to the full 200 mm depth, a reduced sample was taken and the realized depth of the core was recorded. Ten core samples from each of the 15 transect levels were combined 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).

When large amounts of coarse sediments were retained in the mesh bag, the samples were elutriated in situ, separating macroinvertebrates from the sand. Upper beach cores with retained coarse sediments were taken back to the laboratory and frozen before elutriating. This prevents the amphipods from hopping out of the sample. In the elutriation process, a moderate amount of coarse sediments containing macroinvertebrates (approximately two large handfuls) was placed in a bucket with a pour spout. Seawater was added to fill the bucket and then mixed vigorously with the sediments. We then poured the seawater rapidly into a sieve, retaining the macroinvertebrates. The process was repeated until three elutriations in a row yielded no additional macroinvertebrates. The coarse sediments were also inspected by eye, before being discarded.

All retained macroinvertebrates were placed in labeled plastic bags, chilled and transported to the laboratory for processing and preservation. All lower cores samples were preserved with buffered formalin in seawater to enable identification of soft-bodied forms including polychaete worms. To reduce the use of formalin, upper shore samples where arthropods dominate were frozen (arthropods are adequately preserved for identification by freezing). We identified, enumerated, blotted dry and weighed (to the nearest 0.0001 g) all animals retained on the sieves.

We sampled kelp flies using 50-100 standard sweeps of insect nets along the three 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 flypaper (Revenge Fly-catcher®). Two strips of flypaper 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 by taxa for all other fauna.

As in the rapid surveys described below 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 macrophyte wrack type encountered along the transect tape (allowing for analysis by beach 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.

3.1.3 Rapid Surveys

To describe the distribution, abundance and seasonal occurrence of birds, people and fresh kelp wrack, we conducted monthly daytime surveys during low tides on standard alongshore transects at 12 focal beaches, including six MPA and six reference sites (Table 3). We surveyed the beaches monthly from September 2014 through May 2015. A standard alongshore transect was established at each of the beaches. The size of these transects was always one km in length on long beaches. However shorter transects (120 – 690 m), truncated to the extent of the beach, were required for the pocket beaches (Table 3). Once established, the endpoints of the selected transects were described and their positions determined with GPS.

Across all 12 beaches (rapid survey sites) we surveyed a total of 9.18 km of beach and surf zone per month using two teams of observers who each surveyed two or three sites per day. We aimed to survey all 12 beaches over the course of five to seven days each month. Surveys were done on weekdays and constrained to low tide periods of 0.75 m (2.5 ft) MLLW or lower, spanning two hours preceding and following the low tide.

Each month we identified and counted all shorebirds, gulls, seabirds (operationally defined to include terns, cormorants and pelicans along with additional species typically observed in the surf zone such as surf scoters) and other birds, including terrestrial birds and aquatic/wading birds (e.g. herons, egrets and additional species commonly observed in pools or creek/lagoon mouths/edges protected from the surf), visible to observers while walking along the beach transects (see Table A- 3 for which taxa are operational included in the categories used in this study). This included the beach and surf zone, as well as birds flying just over or along the beach and surf zone. If there were interspersed rocks or streams that traversed the beach, birds using these habitats were also included. Counts were conducted by the same observer on each beach every month using binoculars while walking on the transect. All bird sightings were recorded on a standard data sheet. 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, surf zone, just beyond surf zone) and their behavior (feeding mode, roosting) was noted on a standard data form (Figure 3). We counted and recorded the intertidal location of any dead or oiled birds and mammals that we encountered. All people and dogs using the beach were counted, assigned an intertidal zone and their activity recorded for each transect during the surveys.

Along each along-shore transect we also counted the number of thalli of fresh kelp wrack (not dried-up, mostly intact and located below the high tide strand line) of *Nereocystis leatkeana*, *Postelsia palmaeformis* and *Macrocystis pyrifera*. To avoid over estimating their abundance due to fragmentation, we identified and enumerated only those thalli with an intact pneumatocyst for *Nereocystis,* holdfast for *Macrocystis* and stipe for *Postelsia.*

Additionally we enumerated the number of people and dogs observed along the transects and noted their activities.

Simultaneously with the alongshore surveys, we measured wrack cover along with other beach-cast materials using a line-intercept method on each of three shore-normal transects of variable length. On each of the three-shore-normal transects we quantified the extent and presence of each type of marine macrophyte wrack or animal wrack (a catch-all for molts, shells, feathers, etc. or fragments of animal detritus), driftwood, carrion, tar, trash, and any other beach-cast item was recorded. The shore-normal transects were of variable length extending from the lower edge of terrestrial vegetation or the bluff to the lowest intertidal level exposed by swash at each location. We used a line-intercept method along each transect to quantify cover for each item encountered. One edge of the track of a distance measuring wheel was used to define a reference line for enumerating wrack abundance. The presence and extent (using size categories from 1 mm to 8 m) of each type of macrophyte, driftwood, carrion, tar, trash and any other beach-cast item observed along the reference line was recorded yielding total wrack (or other) cover for each category along each transect. Physical parameters characterizing the beach, the sand and the surf zone were also collected along these transects.

For each beach, the date, observer name, start and stop times, weather conditions (average and maximum wind speeds, air temperature and wind chill) were recorded. 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.

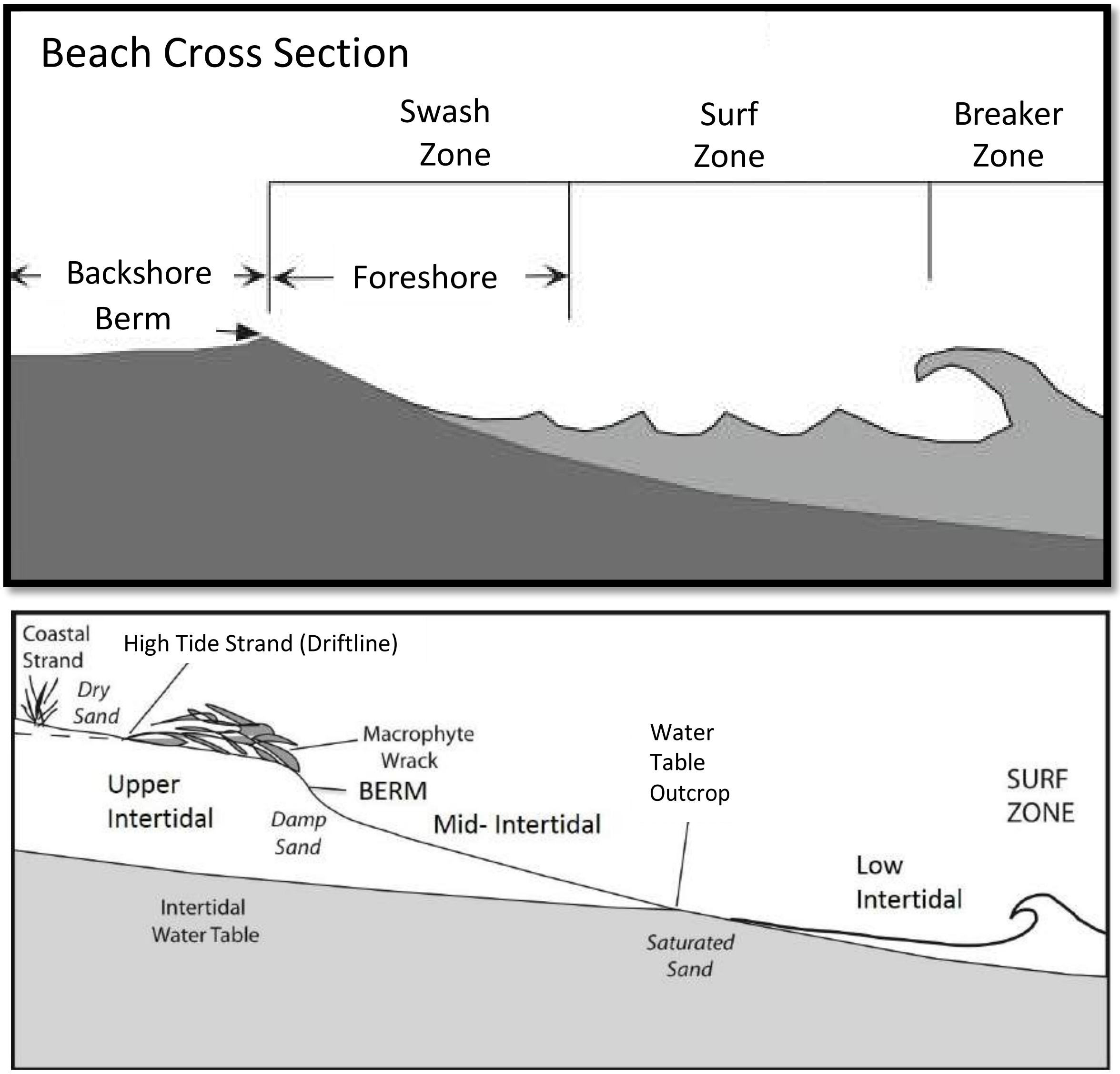

Figure 3. Profile of an exposed sandy beach. Upper panel shows zones and lower panel shows relative locations of driftline, water table outcrop, invertebrate types and coastal strand vegetation. Figure modified from Dugan & Hubbard 2010 (lower) and http://www.tulane.edu/~sanelson/Natural_Disasters/coastalzones.htm (accessed 26 Feb 2017) (upper).

We measured physical characteristics of the beach including beach zone widths and slopes, wave regime, and sediment grain size. 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 (HTS) line (Figure 3) and beach slope at these two locations on all three transects. In addition, breaker wave height and period, and swash width and period were visually estimated from the bottom of the middle transect.

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

3.1.4 Surf zone fish surveys

3.1.4.1 Redtail Surfperch

A comprehensive baseline survey of redtail surfperch was conducted at nine long sandy beaches (four MPAs and five reference sites) in the North Coast study region (Figure 4). Surfperch fishing was conducted by Humboldt State University (Dr. Tim Mulligan, Mr. Drew Barrett, and graduate student Michelle Succow), Tolowa Dee-ni' Nation (Ms. Rosa Laucci), California Department of Fish and Wildlife (CDFW) fish biologist (Ms. Kathryn Krane), and by trained Humboldt State University volunteer anglers. During 2014, six of the nine sites were sampled three times each, between the months of June and October (Table 3, Table 4, Table 5).

During 2015, a minimum of three (maximum of eight) sampling events were conducted between April and December at each of the nine sites. During all sampling events, one or two volunteers sampled with one or two fish biologists (total three anglers). The team of three anglers fished each of the nine sites for four hours during each sampling event. Specific sampling days were chosen based on tidal and weather conditions.

Fishing was conducted with either a modified "Carolina surf rig", used in low surf conditions, or a "slider sinker rig", which was used in high surf conditions. Each of these rigs was equipped with two artificially baited hooks. Upon arriving at a site, each of the three anglers moved along the beach, fishing with one of the above gears. Each sampling area was fished for a minimum of 15 minutes before moving to the next sampling area. At each sampling area where a school of fish was located, the anglers remained until the "bite" ceased. Using the same protocol, an attempt was then made to locate additional schools of fish by moving up/down the beach.

At MPA sites, surfperch were identified, enumerated, measured (total lengths to the nearest mm), sexed, tagged with anchor T-Bar tags and released at the site of capture. At reference sites, an average target of 12 individuals was sacrificed to collect data on body weight and for diet analysis. Once the target number was reached, all additional surfperch taken at reference sites were processed and released in the same way as those sampled at MPA sites. Concurrently with fish sampling, physical parameters (i.e. beach slope, wave height/period, water temperature, salinity) were measured. Summary statistics were calculated and several Analysis of Variance (ANOVA) tests were used to evaluate differences in fish CPUE, length, and sex ratios among years and locations.

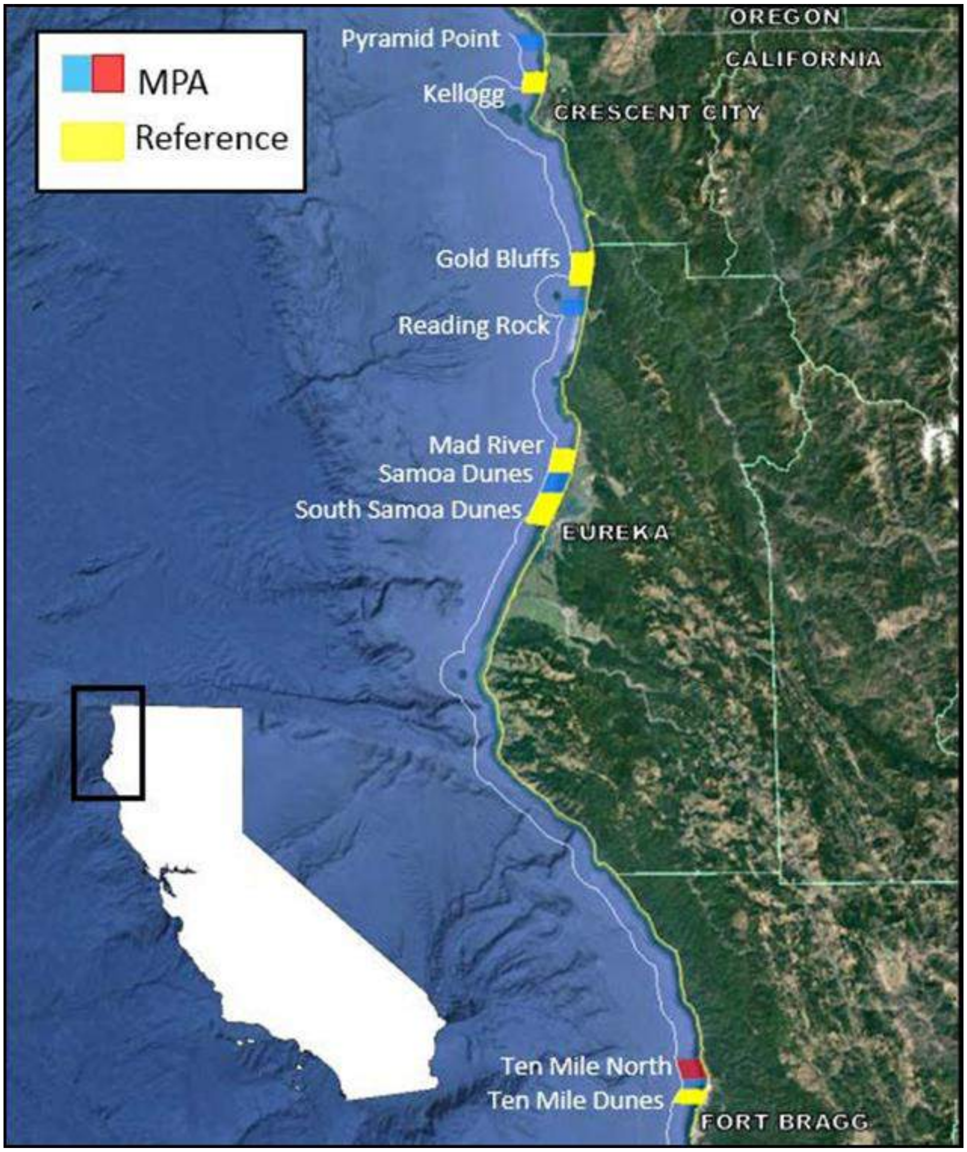

Figure 4. Marine protected areas (MPAs) and paired reference sites where redtail surfperch and night smelt were studied in the North coast region. MPAs indicated by blue (state marine conservation area) or red (marine reserve), with reference sites shown in yellow.

Table 5. Redtail surfperch sampling locations for the North Coast MPA region. Effort for year 1 and year 2 (2014, 2015). Sampling effort is total angler hours. ** indicates MPAs.

Sample site	Bioregion	Year 1 sampling effort	Year 2 sampling effort
Pyramid Point **	Northern	40	60
Kellogg	Northern	64	56
Gold Bluffs	Northern	43	40
Reading Rock **	Northern	52	40
Mad River	Northern	52	120
Samoa Dunes **	Northern	52	76
South Samoa Dunes	Northern	0	88
Ten Mile North **	Southern	0	40
Ten Mile	Southern	0	40

3.1.4.1.1 Diet analysis

Subsamples of redtail surfperch were collected at the four North Coast reference sites during 2014 and 2015 and returned to the lab for processing. The fish were kept on ice until laboratory processing, which occurred within 24 hours of capture. Total and standard lengths (1.0 mm) and total fish weight (0.1 g) were determined for each subsampled fish prior to dissection. Each gut was severed at the esophagus and anus, fixed in buffered 10 % formalin, and transferred to 40 % isopropanol prior to gut content analysis. The entire gut was used for analysis. A dissecting microscope was used for all gut content removal and identification. For each fish, gut contents were sorted and classified, with prey items being identified to an appropriate taxonomic level. Each classification was enumerated, with all individual prey being counted. Blotted wet weights (0.0001 g) were taken for each content classification with weights of < 0.0001 g being recorded as 0.0001 g. No contents were excluded from the dietary analysis based on quantity. Parasitic digenean trematodes were weighed but excluded from the analysis. The diet-analysis fish were divided into three standard length (SL) size classes: small (< 170 mm SL), medium (170 mm ≤ SL ≤ 220mm) and large (> 220 mm SL). The gut content data were analyzed with all sites combined or grouped by site and/or fish size class and the following calculations were made for each grouping;

% number = [number of items of a given classification / total number of items] * (100)

% weight = [weight of items of a particular classification / total weight of items] * (100)

% frequency of occurrence = [number of stomachs containing items of a particular classification / total number of stomachs] * (100)

These measures were then used to calculate Index of Relative Importance (IRI) for each prey item grouping for all sites combined and for each site and site / size class combination.

IRI = [% number + % weight] * [% frequency of occurrence]

For graphing purposes, IRI values were normalized to 100% for each site or for each site / size class combination.

Percent IRI = [(IRI / group IRI) * 100]

All analysis was done using SAS 9.4 (SAS Institute Inc., SAS® software).

3.1.4.2 Night Smelt

Sampling for night smelt (*Spirinchus starksi*) took place from March through August in 2014 and May through August in 2015 within five MPAs and four reference sites (Table 6). Historical accounts of spatial and temporal variability in the relative abundance of spawning night smelt have been reported over the geographic range of our study area, with particular beaches being far more consistent than others. Consequently, sites were chosen based on these historical commercial landings in the north coast region. Samples were collected on receding tides between dusk and dawn when nearshore swell height was no larger than seven feet.

*Table 6. Night smelt sampling locations for the North Coast region. Effort for year 1 and year 2 (2014, 2015). Sampling effort is total number of sampling events. ** indicates MPAs.*

Sample Site	Bioregion	Year 1 Sampling Effort	Year 2 Sampling Effort
Pyramid Point **	Northern	0	3
Kellogg	Northern	6	3
Gold Bluffs	Northern	6	3
Reading Rock **	Northern	6	3
Mad River	Northern	6	3
Samoa Dunes **	Northern	6	3
Ten Mile North **	Southern	0	3
Ten Mile	Southern	0	3

Spawning aggregations of night smelt were located by scanning the wave slope with a high-powered spotlight from a four-wheel drive vehicle in the northern bioregion. Beaches in the southern bioregion were sampled by hiking along the wave slope with a battery powered spotlight due to vehicle access restrictions on those beaches.

When spawning aggregations of night smelt were located all artificial light sources were turned off and samples were collected using an A-frame dip net hung with 3/8” stretch mesh (Figure 5). Night smelt were collected from several dip net hauls spread over the course of each observed spawning event or for a minimum of a two-hour period when spawning events lasted longer than two hours. Samples were collected from as many spawning aggregations as could be located within sample sites to ensure that the data collected were as representative of each site as possible.

Relative abundance of night smelt was assessed during each sampling trip using the Walker Scale (Figure 6), which is a method of assessing the relative abundance of beach spawning Grunion (*Leuresthes tenuis*) used extensively in southern California by the Grunion Greeters Citizen Science Program. On nights when spawning aggregations of night smelt could not be located, researchers spent a minimum of 4 hours repeatedly searching the entire length of the beach within each sample site before concluding their sampling effort. All night smelt collected during an individual sampling trip were mixed together and preserved frozen for laboratory processing.

Figure 5. Surf fishing with an A-frame dip net for night smelt.

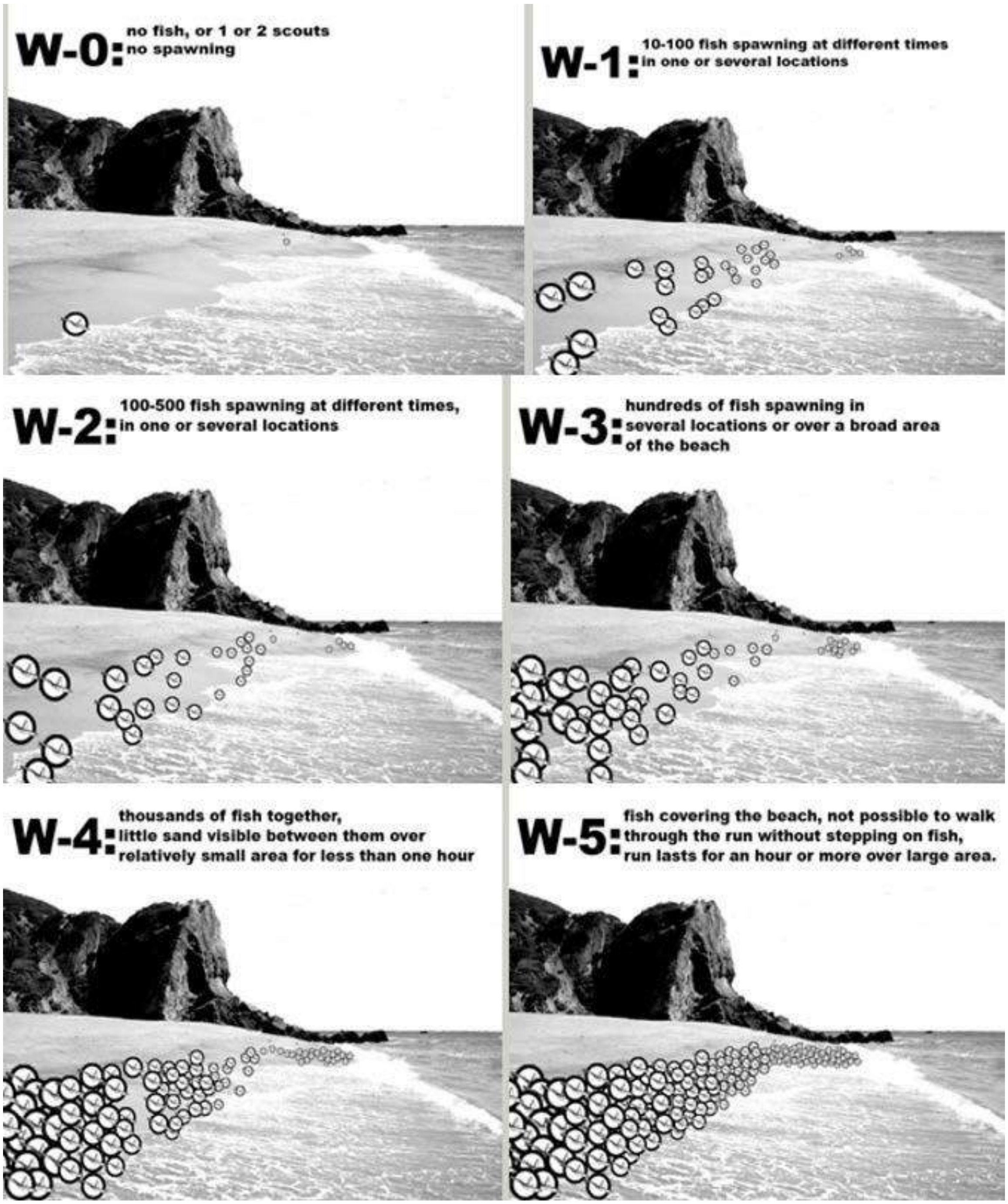

Figure 6. Walker Scale. Used for assessment of relative abundance of spawning populations of night smelt. From www.grunion.pepperdine.edu/sighting.asp.

Samples were collected by The California Commercial Beach Fisherman's Association (CCBFA) and processed by H. T. Harvey and Associates and the CDFW) in 2014 as part of a separate research project conducted with support from Collaborative Fisheries Research West. The data collected was shared with baseline project staff and used when sampling locations and protocols aligned with those developed for this baseline characterization project. In 2015 samples were collected and processed by Humboldt State University staff and members of the CCBFA solely for the purpose of supporting this project.

Randomly selected subsamples of approximately 100 night smelt collected during each sampling trip were thawed in the laboratory at room temperature, total length was measured to the nearest millimeter, fish were blot dried and weighed to the nearest 0.1 gram (2014 only), and gonads were examined for sex identification. Numbers of fish selected for subsampling, and the parameters recorded varied among years and locations due to the synthesis of data between the two projects and their differences in methods and objectives. For example, sex ratios were calculated using 2015 fish exclusively because 2014 laboratory procedures favored selection of females. Summary statistics were calculated and several Analysis of Variance (ANOVA) tests were used to evaluate differences in fish length and weight among years, sexes, and locations.

3.1.5 Targeted sand crab surveys

To investigate the trophic relationship between surfperch and sand crabs, additional surveys and sampling of sand crabs were done monthly on three NC sandy beaches concurrently with surfperch fishing surveys between May and July, 2015 (Table 3). At all sites sand crab abundance was estimated by sampling within three transects located between the distributional boundaries of the swash zone (between the high tide strand line and the lower end of the swash zone). Sampling was restricted to the swash zone because our interest was in their availability to surfperch. Transects were randomly spaced within one-hundred meters of the beach access point and 10 to 120 cores (10 cm diameter, 10 cm deep) were taken at uniform intervals of 0.25 to 1 meter depending on the width of the swash zone. Cores from each transect were pooled and placed in a mesh bag for sieving. When sampling at Samoa SMCA, individual sand crabs were counted from each sampling transect, assigned a size category (small < 10 mm; 10 mm < medium < 15 mm; or large > 15mm), then released at the site of capture. At the reference sites all individuals from each sampling transect were retained and placed in zipper-lock bags, chilled on ice, and processed at Telonicher Marine Lab (TML) to measure carapace lengths to the nearest mm. To calculate the numerical abundance of sand crabs within individual transects the total transect catch was multiplied by the core spacing, and then dividing by the area of the core to express the abundance as no. of crabs m-1 of swash zone. The biomass of individual sand crabs was calculated for reference sites by using a weight-length model ($W=aL^b$, where W is the weight in grams and L is the length in mm) generated by measuring the carapace lengths and weights of 77 individual sand crabs collected from Gold Bluffs Beach in August, 2015. Biomass was expressed as g m^{-1} of swash zone, as described above.

Average abundances per site were calculated as the average of the three transect estimates. We quantified beach slope and took sand samples to assess sand grain size at the water table outcrop (WTO).

3.1.6 Data analyses

We present our results primarily using descriptive summary statistics, contrasting responses of MPA and reference beaches, pocket and long beaches and bioregions. Because of the geology of the region, pocket beaches are more common in the southern than the northern bioregion of the NC, 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, and the suitability of proposed indicator taxa through correlation and multivariate analyses.

We used the results from our baseline surveys of exposed sandy beaches in the NC region, including data from monthly shorebird, wrack and physical characteristic surveys as well as biodiversity surveys of macroinvertebrates to examine relationships between shorebirds, invertebrates, macrophyte wrack, and the physical attributes of sandy beaches using ordinary least squares regressions. We examined functional relationships based on the following overarching hypotheses:

1. The structure of intertidal macroinvertebrate communities including species richness, abundance, and biomass on sandy beaches are related to:
   - Beach width, swash climate, sediment characteristics, beach slope, and beach type
   - Subsidies of macrophtye wrack from rocky reefs, kelp forests and estuaries
2. The cover of macrophyte wrack, especially kelp wrack and brown macroalgal wrack, is predicted by the numerical abundance of fresh kelp along the nearshore
3. The distribution, abundance and species richness of shorebirds on sandy beaches are related to:
   - Beach width, swash climate, sediment characteristics, beach slope, and beach type
   - Subsidies of macrophtye wrack from rocky reefs, kelp forests and estuaries
   - Diversity, abundance, and biomass of macroinvertebrate communities

In addition, we used multivariate approaches to better understand the similarities and differences in community structure among beaches within assemblages of macroinvertebrates and birds and in the composition of macrophyte wrack deposited on the beach. We used non-metric multi-dimensional scaling (MDS) to visualize the multivariate relationships among beaches projected onto two dimensions. To reduce the influence of extreme values we used a fourth root transformation of the data, and then calculated the Bray-Curtis similarity matrix and for an MDS analysis (minimum stress = 0.001; 100 iterations) using the Primer (ver 6.1.13) statistical package (PRIMER-E).

We tested a priori hypotheses about the differences between pocket and long beaches, beaches in southern versus northern bioregions and MPA and reference beaches with a multi-factorial PERMANOVA model using the PERMANOVA+ add-on package (ver. 1.0.3) for Primer. The model was a mixed effects model with MPA status and bioregion as fixed factors and beach type as a random factor nested within bioregion. We nested beach type within bioregion to account for the fact that pocket beaches only occurred in the southern bioregion. The PERMANOVA model was specified to use type III (partial) sums of squares and 5000 permutations of the residuals under a reduced model (Anderson & Legendre 1999, Anderson 2001, Anderson & ter Braak 2003).

As part of the multivariate and regression analyses we were also able to assess the potential usefulness of indicator variables we proposed for use in long-term monitoring. Using the MDS analyses of the macroinvertebrate and bird assemblages and macrophyte wrack composition, we examined the degree of association between the MDS axes and three proposed biotic indicator variables (sand crab, talitrid amphipod and fresh kelp wrack abundances) by graphing these as vectors on the MDS plots and examining the degree of correlation with the MDS axes. A strong association in both the univariate regression analyses and the multivariate analyses would provide evidence that these are likely to be useful indictors of sandy beach ecosystem status appropriate for long-term monitoring.

4 Results & Discussion

4.1 Physical Characteristics of the Beaches

The physical dynamics of wind and waves, and the geologic features of the coast shape the physical characteristics of beaches. The average size of sediments, steepness of the beach, etc. are interrelated and influence the ecology of beach communities, especially the infauna. Based on prior work comparing pocket and long beaches in the north central coast (NCC) MPA region, we had an a priori expectation that the physical and biological characteristics, and the ecology of pocket beaches, would differ on the NC as well. Therefore, we set the stage for our results and discussion by describing the physical characteristics of our study beaches first.

The greatest apparent sources of variation among the physical characteristics of the beaches was between pocket beaches and long beaches, and the differences in mean sand grain size between the HTS and WTO (see below for details). Mean sand grain size of sand from the HTS was less variable and smaller overall, probably due to Aeolian (wind) sorting, consistent with our expectations. Pocket beaches were narrower overall with smaller swash zones and tended to be reflective.

Unfortunately, we do not have a complete set of observations for the long beaches, but it is likely they would mostly fall into the intermediate category, based on empirical data from other beaches in California with similar physical characteristics, and our own field observations. As expected, average breaker heights were larger and swash zone periods were longer to the north. However, differences between pocket and long beaches may be somewhat confounded with latitude as all the pocket beaches we surveyed were in the southern bioregion.

4.1.1 Intertidal width and zone widths

Mean overall beach width (landward boundary to LSL = dry + damp + saturated sand) varied over three-fold, ranging from 43 m to 133 m (Van Damme and Virgin Creek, respectively) among the 12 beaches surveyed (Figure 7). The widest beaches were Virgin Creek, Mad River and Samoa, with > 110 m in overall mean width. Mean overall widths of five of the 12 beaches were greater 100 m. The mean widths of the long beaches were all > 85 m whereas the pocket beaches were all <85 m with the exception of Jug Handle (105 m). The mean widths of the upper zones (landward of the HTS = dry sand) varied over five-fold ranging from 5.7 m to 29 m (Van Damme and Gold Bluffs, respectively).

Mean active intertidal widths (HTS to LSL = damp + saturated sand) also varied over two-fold among the study beaches, ranging from 37 m to 108 m (Van Damme and Virgin Creek respectively) (Figure 8). Mean active intertidal zones equal to or exceeding 90 m occurred at four of the long study beaches, Mad River, Samoa, Ten Mile, and Virgin Creek, and one of the pocket beaches, Jug Handle.

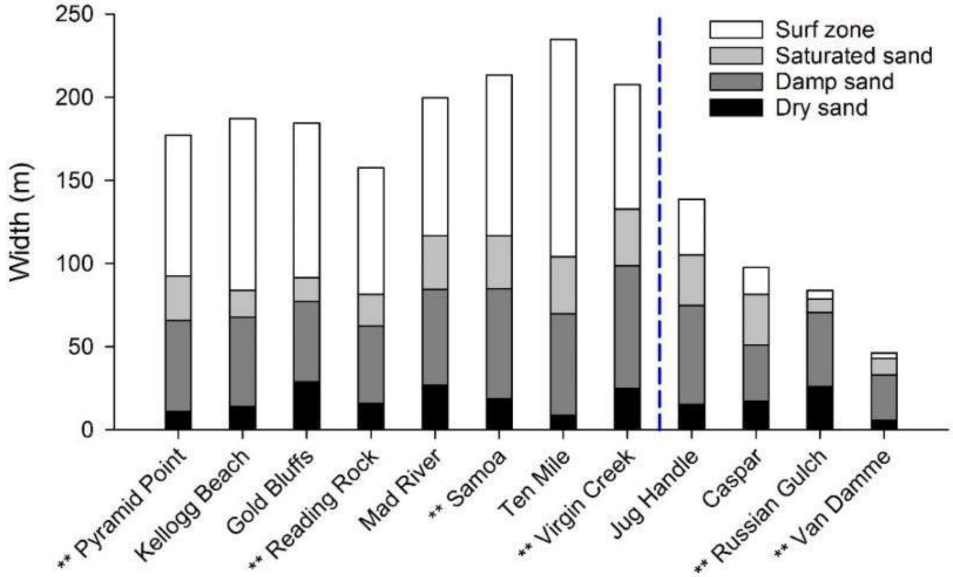

*Figure 7. Beach width. Mean widths of the dry, damp, and saturated sand zones, and surf zones from monthly rapid surveys (June 2014 to June 2015). Beaches to the left of the dashed line are all long beaches and to the right of the dashed line are all pocket beaches. Beaches are arranged from north to south along the horizontal axis. MPAs are indicated by **.*

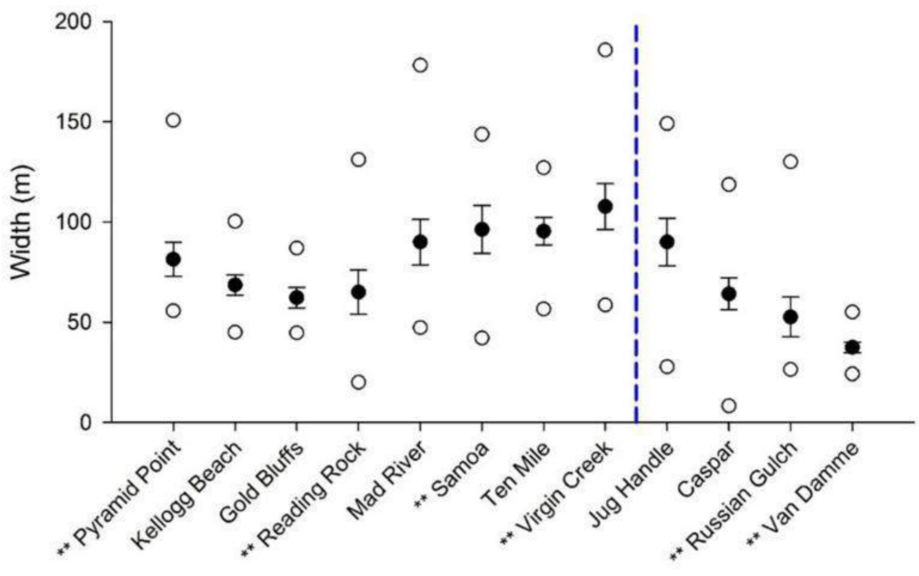

Figure 8. Active intertidal width. Overall mean (●) (±SE) and maximum (o, upper) and minimum (o, lower) widths of the active intertidal zone (damp and saturated sand, swash zones) observed in monthly surveys of the study beaches from June 2014 to June 2015. All other information as in Figure 7.

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 m to 131 m (Figure 7). Ten Mile and Kellogg Beach had the widest average surf zones (131 m and 103 m, respectively). The surf zone widths of the long beaches were all > 75m (average = 94 m, SE = 5 m), whereas the pocket beaches had much smaller surf zones widths, ranging from 34 m to 3 m (average = 14 m, SE = 3 m).

Mean swash zone widths varied over five-fold among study beaches, from 5.3 m to 30.7 m (Russian Gulch and Virgin Creek, respectively) (Figure 8). The swash zone widths of the long beaches were all > 18m (average = 23 m, SE = 1.5 m), whereas the pocket beach swash zones widths ranged from 17.6 to 5.3 m (average = 12 m, SE = 1.5 m). Mean swash zone widths exceeded 25 m on three of the study beaches, Virgin Creek, Ten Mile, and Samoa. Narrow swash zones, with mean < 15 m, were observed only at two of the pocket beaches, Russian Gulch and Van Damme (Figure 9).

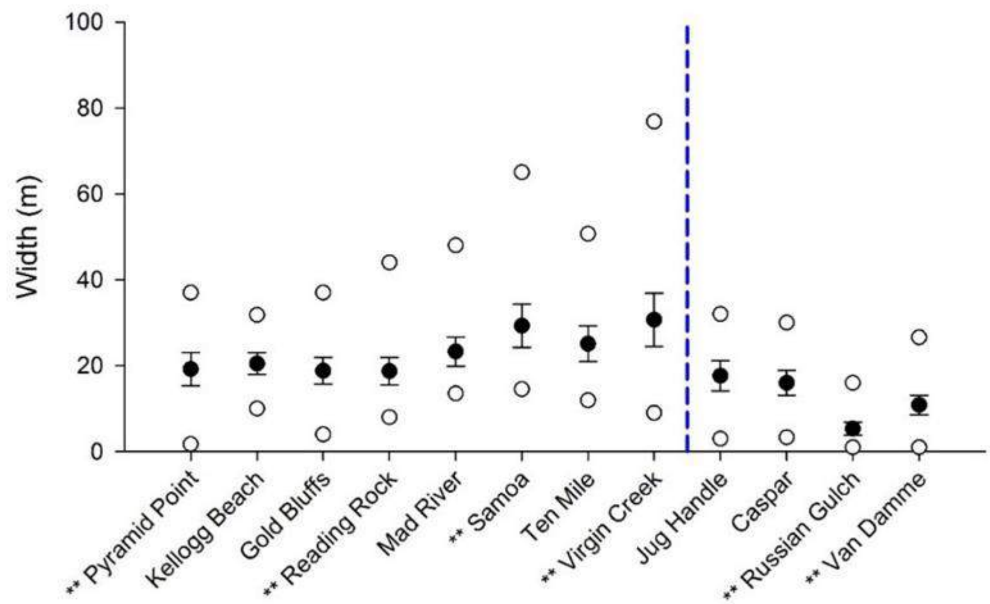

Figure 9. Swash zone width. Overall mean (●) (±SE) and maximum (o, upper) and minimum (o, lower) values of swash zone width for monthly surveys of the study beaches from June 2014 to June 2015. All other information as inFigure 7.

4.1.2 Beach Slope

Mean values of beach slope did not vary consistently with intertidal level (HTS vs. WTO) at the beaches, although the steepest slope was generally observed at the HTS line (Figure 10). Beach slope at the WTO varied more than two-fold among beaches and the HTS varied more than four-fold among beaches. Mean slopes at the water table outcrop varied from 1.8° to 4.8° among the 12 beaches. Slopes generally were steeper at the HTS where mean slopes varied from 1.2° to 5.1° among the 12 beaches. The lowest mean WTO slopes (< 2.5°) occurred on the long flat beaches of Mad River, Samoa, and Pyramid Point during the baseline study. Moderately steep mean WTO slopes (> 4°) were observed at Van Damme, Gold Bluffs, and Kellogg Beach. Beach slopes at the HTS and WTO were not significantly correlated (r = 0.277, p = 0.384) for the 12 study sites.

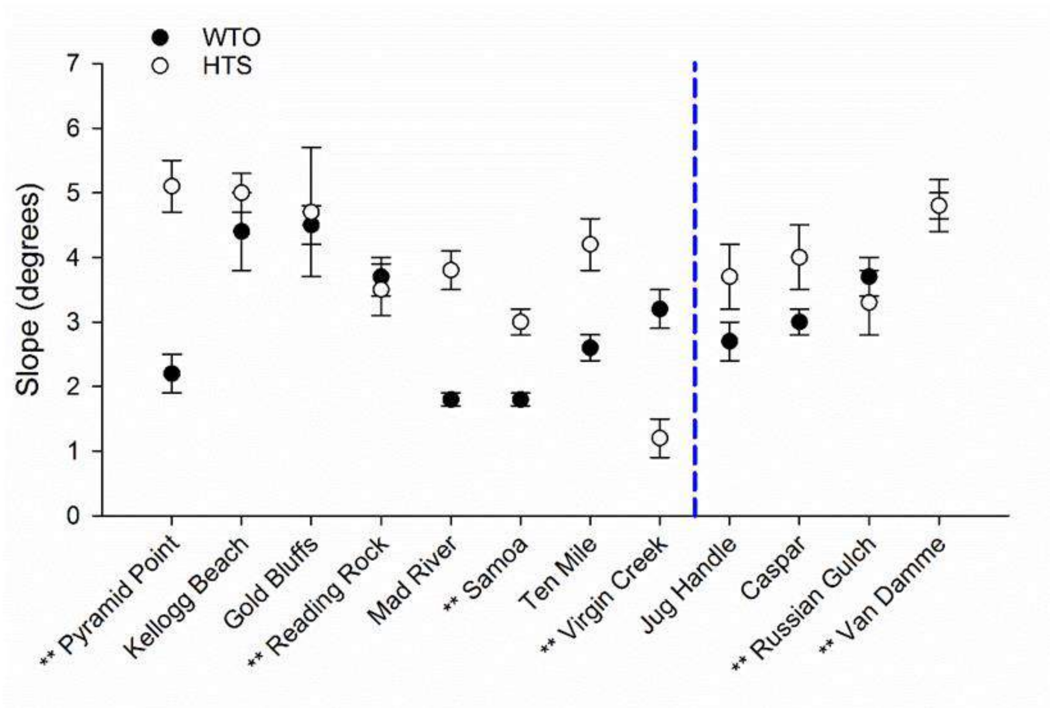

Figure 10. Beach slopes. Mean values of beach slope measured at the water table outcrop WTO (±SE) and at the high tide strand HTS (+ one standard error) of the study beaches in monthly surveys from September 2014 to June 2015 (Note that WTO and HTS mean slope were identical at Van Damme). All other information as inFigure 7.

4.1.3 Sediment grain size

The mean grain size of sediments from the WTO varied more than seven-fold among the 12 beaches, ranging from fine sand, 0.229 mm at Mad River, to very coarse sand, 1.618 mm at Kellogg Beach Figure 11). The mean grain size at the WTO was finer, < 0.400 mm, at the beaches located south of Reading Rock and north of Russian Gulch. Patterns across the sites were similar for mean grain size at the HTS line, although mean sand grain size was finer at the HTS level when compared to the WTO level (Figure 12). The mean grain size at the HTS was finer than 0.400 mm at all beaches except for Van Damme in the south and Kellogg Beach in the north. Mean grain size at the HTS was highly correlated with mean grain size at the WTO (r = 0.744, p = 0.0056).

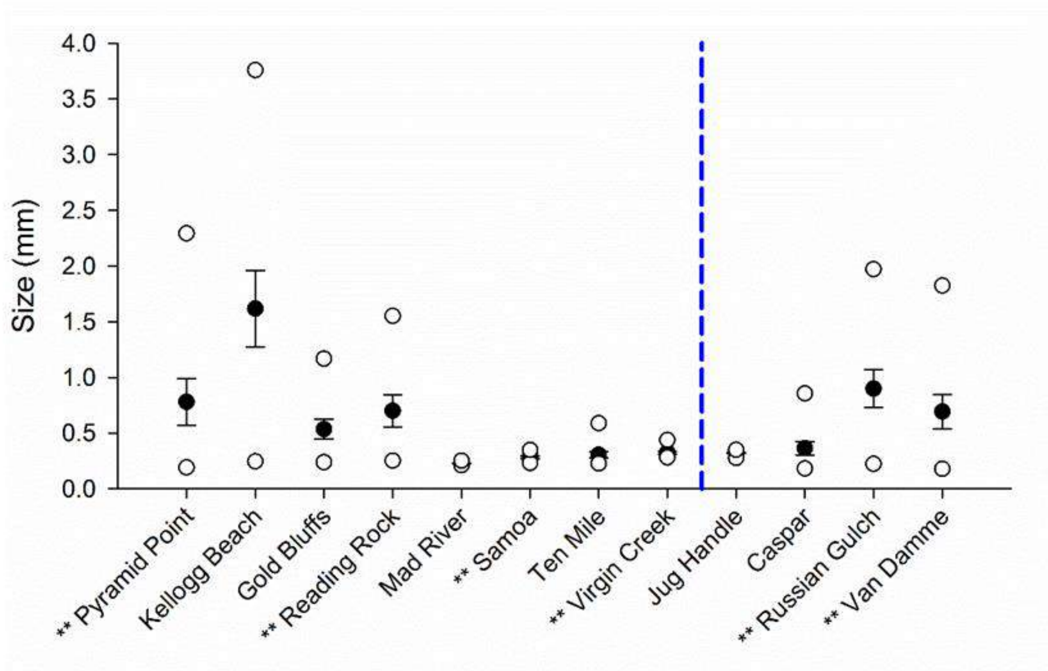

Figure 11. Sand grain size at the WTO. Overall mean (±SE) (●), maximum (o) and minimum (o) mean values for sediment grain size at the WTO level for monthly surveys of the study beaches from September 2014 to June 2015. All other information as in Figure 7.

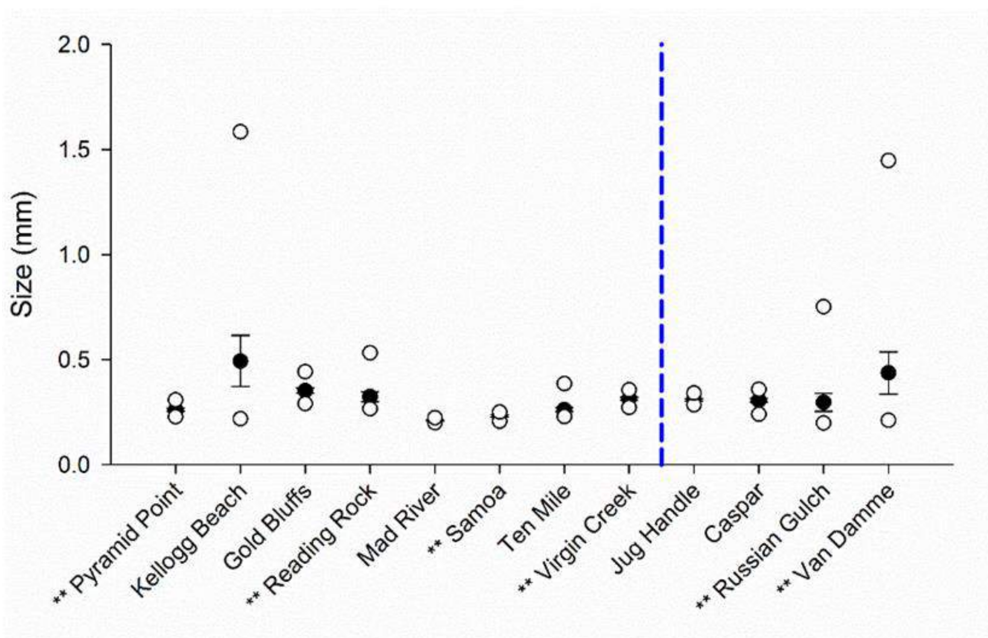

Figure 12.Sand Grain size at the HTS. Overall mean (±SE) (●), maximum (o) and minimum (o) mean values for sediment grain size at the HTS level for monthly surveys of the study beaches from September 2014 to June 2015. All other information as in Figure 7.

4.1.4 Significant breaker height and period

The mean values of significant breaker heights were only available for the six southernmost beaches, all located in Mendocino County. The breaker height varied almost an order of magnitude, with means ranging from 0.2 m to 1.9 m at the six southern beaches (Figure 13). Mean breaker heights > 1 m were observed on three of the six beaches, Ten Mile, Virgin Creek and Jug Handle, and mean breaker height decreased from north to south. Mean wave period varied more than two fold among sites, ranging from 5.7 to 15.4 seconds (Russian Gulch and Reading Rock, respectively) (Figure 14).

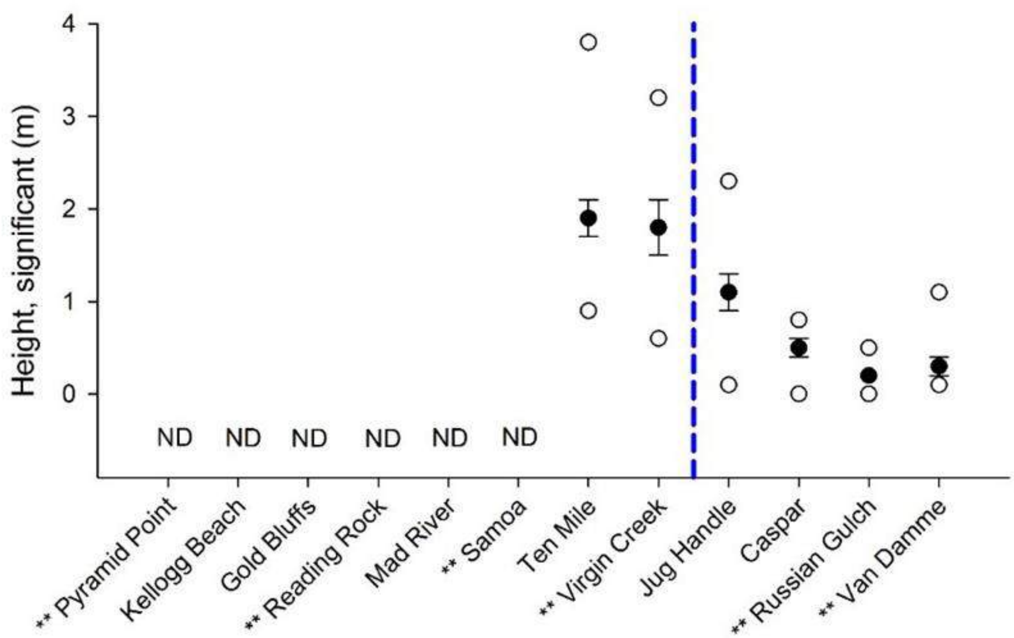

Figure 13. Breaker height. Mean (±SE) (●), maximum (o) and minimum (o) values of significant breaker height observed in monthly surveys of the study beaches from September 2014 to May 2015. All other information as inFigure 7.

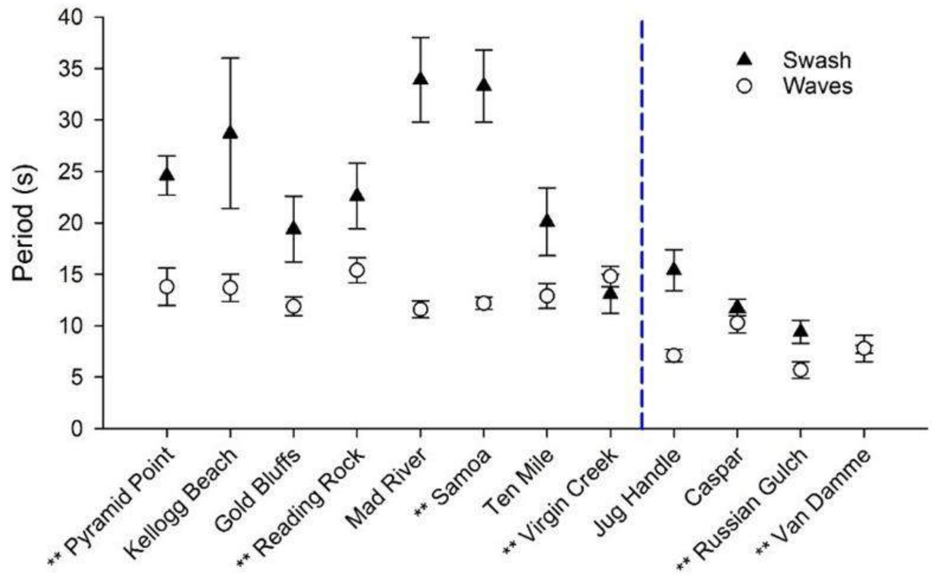

Figure 14. Wave and swash period. Mean values for wave and swash periods (seconds) observed in monthly surveys of the study beaches from September 2014 to June 2015. (Note that swash and wave period were nearly identical at Van Damme). All other information as in Figure 7.

4.1.5 Swash climate

Swash period represents the conversion of surf energy to intertidal swash, and depends upon significant breaker period, surf zone and swash zone slope and processes. Mean swash periods varied more than four-fold among the study beaches (7.7 to 33.9 seconds) in the monthly surveys (Figure 14). The comparison of mean wave and swash period (shown in Figure 14) gives a visual summary of the conversion of surf energy to swash on the study beaches. On beaches such as Virgin Creek, Caspar and Van Damme, where the mean swash period was very similar to the mean wave period, little conversion of surf energy occurred in the surf zone and waves broke almost directly on the beach face, creating harsh intertidal conditions. Where the mean swash period greatly exceeded the wave period as seen for Samoa, Mad River, and Kellogg Beach, surf energy was greatly transformed before reaching the intertidal swash zone, resulting in lower swash frequency and gentler intertidal conditions.

4.1.6 Beach morphodynamics – Dean’s parameter

The morphodynamic state of beaches as estimated by Dean’s parameter (Ω), which combines significant wave height and period with sand grain size in a dimensionless index, can range from reflective (Dean's < 1) to dissipative (Dean’s > 6) conditions (Figure 15). This index provides an estimate of the ability of the wave regime to suspend and move the sand at a particular beach. Reflective beaches are steep with coarse sand, narrow surf and swash zone and plunging breakers that break on the intertidal beach face. At the opposite end of the spectrum, dissipative beaches are wide and flat with fine sand and wide surf and swash zones where wave energy is dissipated before reaching the intertidal zone. Intermediate type beaches (Dean’s > 1 to < 6) are highly variable, responding strongly to wave conditions. They are also the most common type of beach on most continental coastlines.

Dean's parameter was only estimated for the six southernmost beaches, all located in Mendocino County, due to lack of wave height data from the northern beaches. Four of the six beaches were intermediate in morphodynamic type with mean values of Dean's parameter ranging from 1.1 to 3.7 (Figure 15). The lowest mean values of Dean's parameter were found on the two southernmost pocket beaches with means of < 1. However, 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.

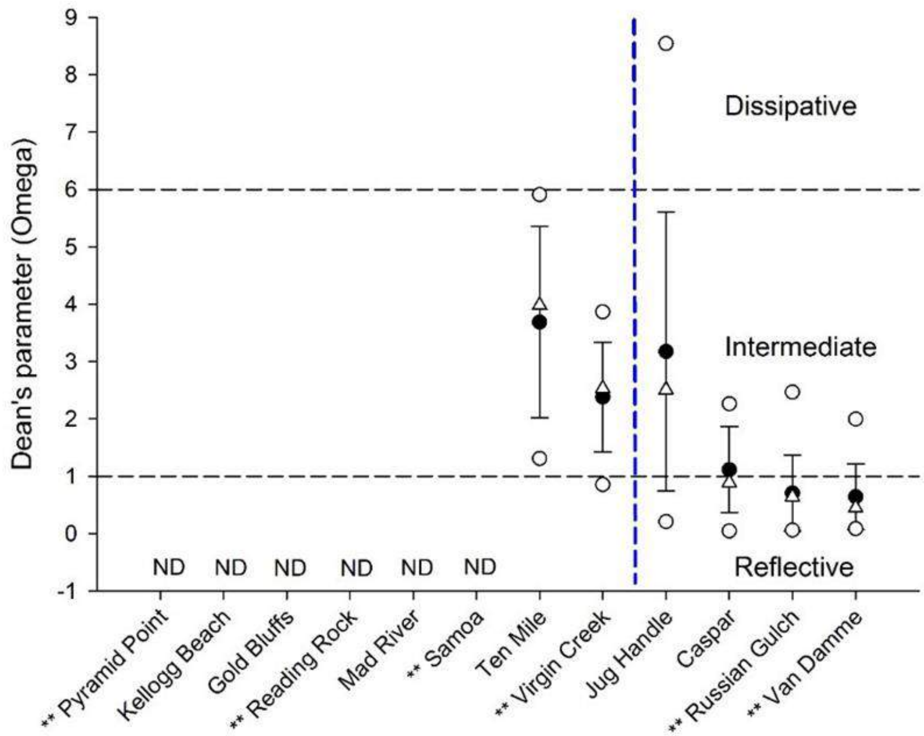

Figure 15. Dean's parameter. Overall mean (± 1 SD) (●), median (Δ), maximum (o) and minimum (o) values of Dean's parameter for monthly surveys of the study beaches from September 2014 to May 2015. Horizontal dotted lines represent values separating the major morphodynamic beach types: dissipative (> 6), intermediate (< 6 > 1) and reflective (< 1). All other information as in Figure 7.

4.1.7 Wind speed and air temperature

Mean values for average wind speeds during surveys varied more than two-fold among the beaches, ranging from 1.3 m s^{-1} to 3.1 m s^{-1} (Figure 16). Peak wind speeds observed ranged from 1.8 m s^{-1} to 4.3 m s^{-1}. The lowest average wind speeds were observed on two of the pocket beaches, Jug Handle and Caspar, and the three highest average and maximum wind speeds were observed on long beaches, Mad River, Kellogg Beach, and Samoa. Seasonally averaged wind speed varied more than two-fold among months with strongest overall average (3.2 m s^{-1}) and maximum winds (4.4 m s^{-1}) observed in September (followed by January and March), and the lightest winds (1.4 to 1.5 m s^{-1}) were observed in June and April (Figure 17).

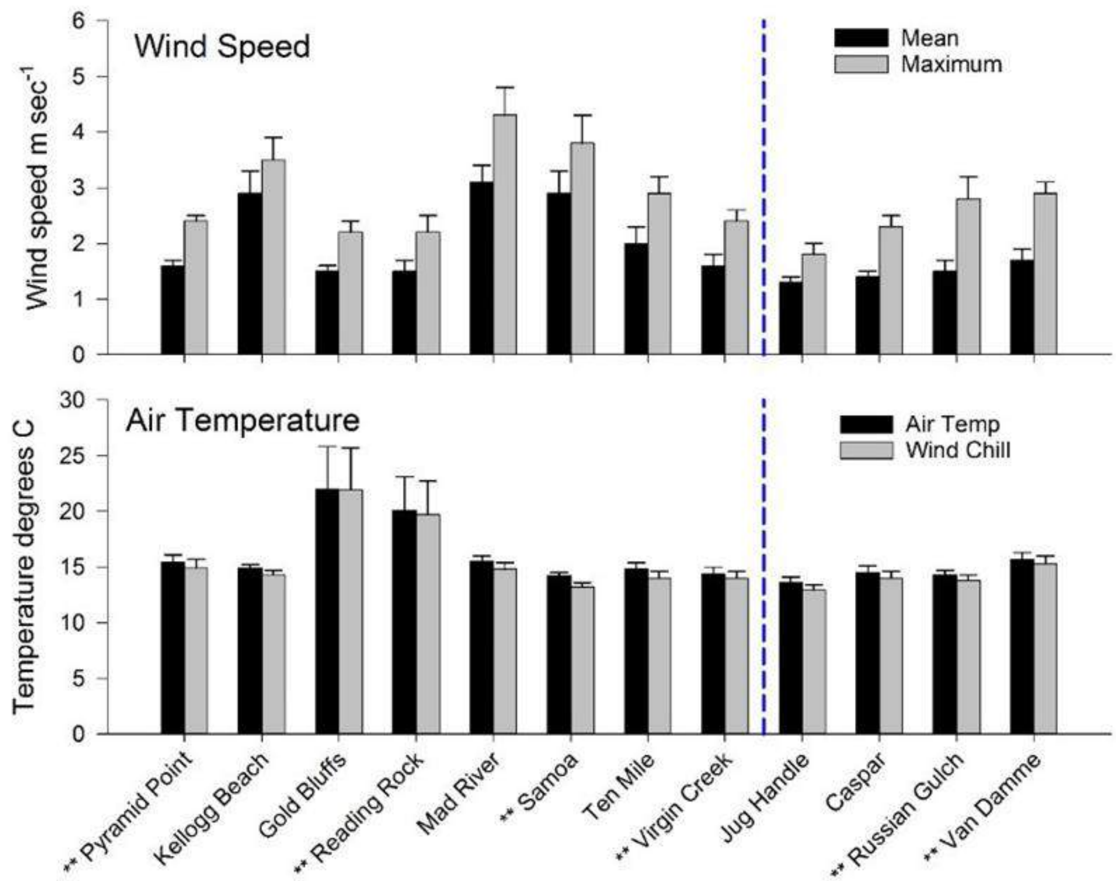

Figure 16. Site temperature and wind speed. Values of mean and maximum wind speeds and of mean air temperatures and wind chills observed for the study beaches in monthly surveys from September 2014 to June 2015. All other information as inFigure 7.

Spatial variation in mean values for air temperature among the beaches varied less than two-fold (13.6 to 22 °C) (Figure 16). Seasonal variation in overall mean air temperatures ranged from 12.7 °C in April to 25.5 °C in September during the baseline study (Figure 16). Wind chills varied two-fold from 12 °C to 24.6 °C during the study (Figure 17).

4.1.8 Regional Patterns

We found spatial gradients (south-to-north) in some of the physical characteristics of the study beaches when we examined correlations with coastline distance from Pyramid Point in the north to Van Damme in the south. Several measures of surf dynamics showed an increasing trend from south to north: wider surf zones ($r^2 = 0.58$, $p < 0.01$), taller breakers ($r^2 = 0.91$, $p < 0.01$), longer swash periods ($r^2 = 0.55$, $p < 0.01$) and longer breaker periods ($r^2 = 0.53$, $p < 0.01$) to the north. These patterns were also reflected in a geographic trend in the mean values of the beach morphodynamic index, Dean's parameter ($r^2 = 0.82$, $p = 0.013$). There were no simple geographic trends in measures of sand grain size, beach slope, or the widths of upper beach zones. Mean air temperature, wind chill and wind speeds did not vary spatially.

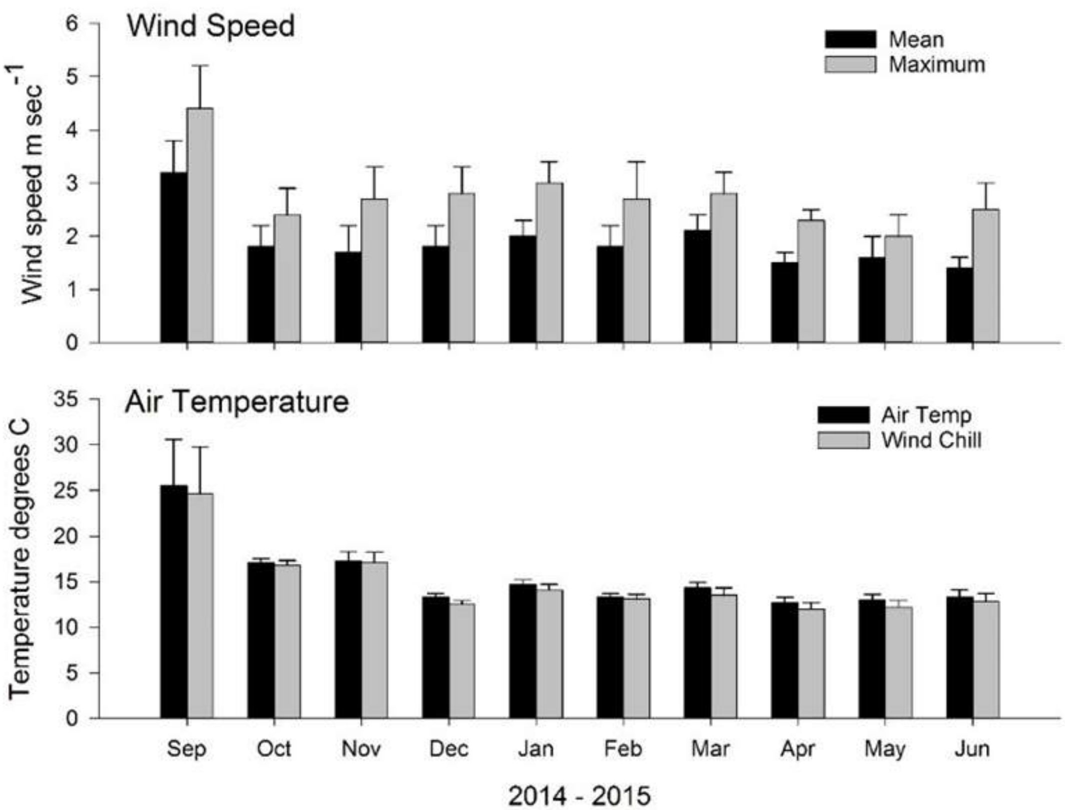

Figure 17. Seasonal temperature and wind speed. Monthly values of mean and maximum wind speeds and of mean air temperatures and wind chills observed for the 12 study beaches in surveys from September 2014 to June 2015.

Biological Characteristics of Beaches

4.1.9 Beach-cast wrack

Macrophyte wrack (=wrack) is an important trophic subsidy for invertebrates living on the beach, specifically wrack consumers (primarily talitrid amphipods, isopods and dipteran larvae) and their predators. These wrack-associated invertebrates are fed upon by birds, and by fishes when wrack piles are adrift in the water as tides and waves redistribute them. The cover of each identifiable macrophyte type (macroalgae, surfgrasses [*Phyllospadix* spp.] and eelgrasses [*Zostera* spp.]) was used to estimate the abundance ($m^2\ m^{-1}$) of each wrack type on the study beaches during the rapid monthly surveys. In the wrack we observed primarily 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), a diversity of red macroalgae, surfgrasses (*Phyllospadix* spp.) and eelgrasses (*Zostera* spp.). *Macrocystis pyrifera* was rarely observed.

The average cover of macrophyte wrack varied over two orders of magnitude among the beaches, ranging from 0.002 to 1.3 $m^2\ m^{-1}$ (Figure 18). The pocket beach, Russian Gulch, had the greatest average cover of wrack, more than double the amount seen at all other beaches except Van Damme. Low average wrack cover, < 0.5 $m^2\ m^{-1}$, occurred at all of the long beaches and at one of the pocket beaches, Caspar. The average cover of brown algal and kelp wrack varied from 0.0 to 0.55 $m^2\ m^{-1}$ and was < 0.05 $m^2\ m^{-1}$ at seven of the study beaches. The average cover of *Phyllospadix* wrack varied from 0.0003 $m^2\ m^{-1}$ to 0.64 $m^2\ m^{-1}$. Average cover of *Phyllospadix* was low, < 0.01 $m^2\ m^{-1}$ at six of the study beaches.

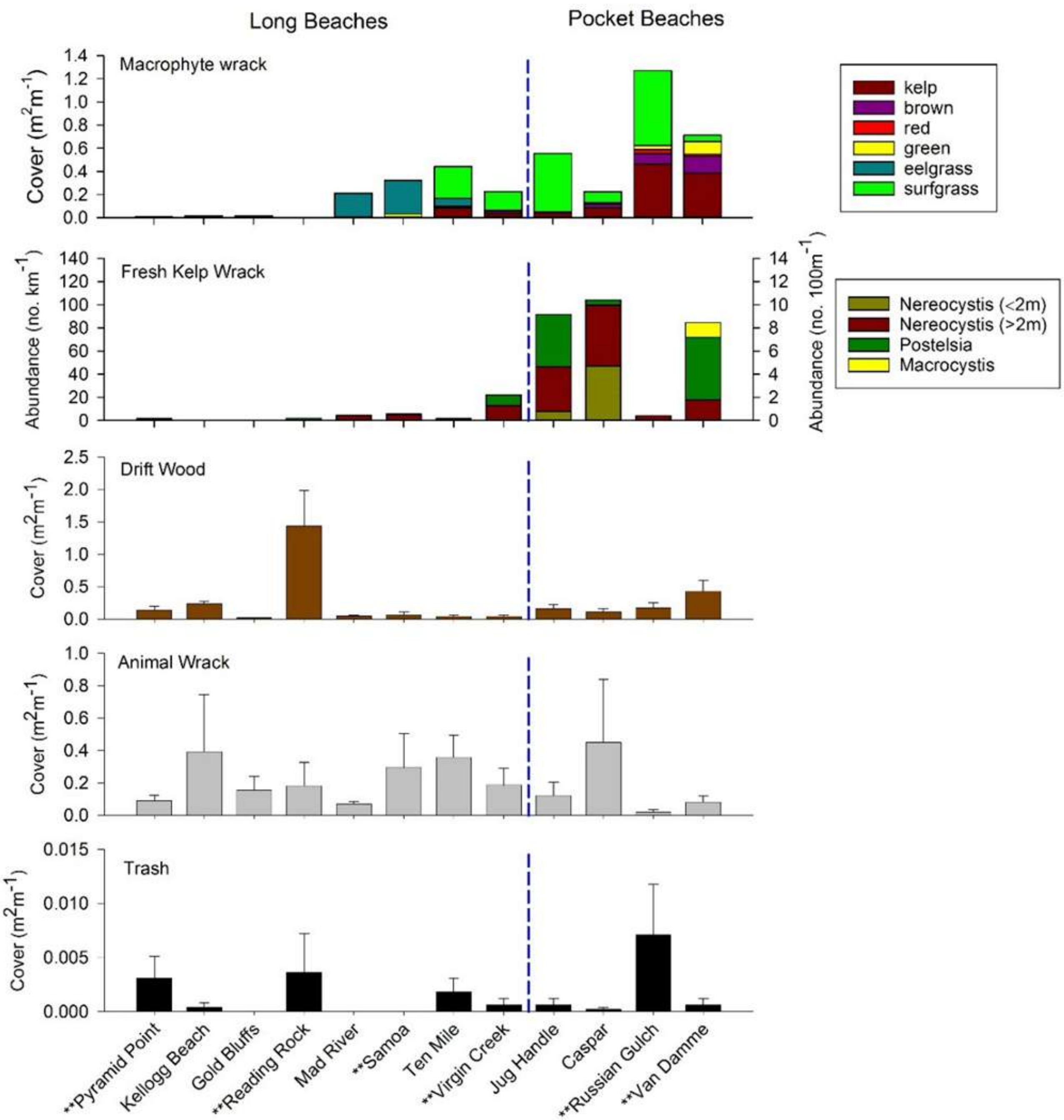

Figure 18. Cover of wrack, driftwood, animal wrack and trash and abundance of fresh kelp thalli. Mean cover and abundance (+ SE) from nine monthly surveys of 12 beaches between September 2014 and May 2015. Fresh kelp thalli were observed for 10 months at the six southernmost beaches. All other information as in Figure 7.

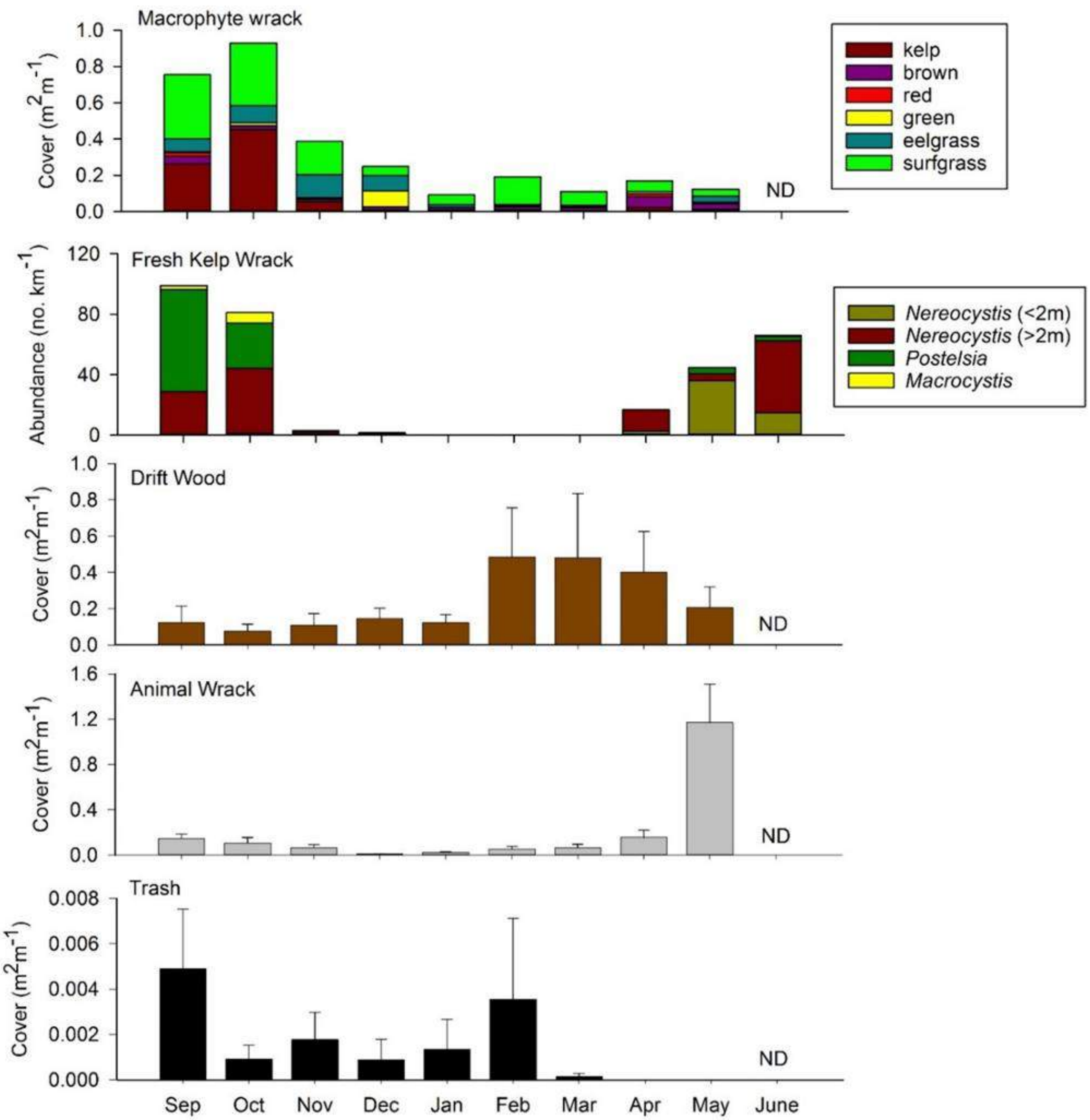

Figure 19. Seasonal cover of wrack, driftwood, animal wrack and trash and abundance of fresh kelp thalli. Data are means across sites (+ SE) for each month. During June, fresh kelp thalli were observed only at the six southernmost beaches. All else as in Figure 18.

Overall the monthly average cover of wrack was low in the NC study region, with mean values < 1 m^2 m^{-1} in every month (Figure 19). Seasonally, average wrack cover varied about an order of magnitude, ranging from 0.09 m^2 m^{-1} to 0.93 m^2 m^{-1} with peak values generally observed in the fall months. The cover of kelp wrack ranged from 0.002 to 0.45 m^2 m^{-1} and peaked in September and October. Kelp and other macroalgae annually senesce in the fall and therefore commonly wash up in the intertidal. Large winter storms may also rip up kelp and deposit it on the beach, although kelp abundance on the north coast was very low and wrack cover was minimal in the winter during our study. Between January and May, there was very little wrack on the beaches (< 0.2 m^2 m^{-1}).

Macrophyte wrack composition varied sharply among beaches. Kelp and other brown macroalgae made up 32% to 74% (and kelp alone 17% to 54%) of the wrack at four of the beaches (Gold Bluffs, Caspar, Russian Gulch and Van Damme) (Figure 18). Eelgrass, *Zostera*, made up 16% to 97% of the wrack at Ten Mile, Gold Bluffs, Samoa and Mad River, while surfgrass made up > 50% of the macrophyte wrack at seven of the 12 study beaches. The dominance of surfgrass at some beaches may be associated with the rapid turnover and processing of kelp and other more palatable wrack by beach consumers, such as talitrid amphipods, and lower rates of decomposition for surfgrass (Mews et al. 2006, Lastra et al. 2008).

The spatial distribution patterns of other non-macrophyte components of beach-cast matter (animal wrack, driftwood and trash) differed from that of macrophyte wrack (Figure 18). Driftwood cover was highest at Reading Rock (1.44 m^2 m^{-1}), but only 0.017 to 0.42 m^2 m^{-1} on the rest of the beaches. The average cover of animal wrack (consisting mostly of hydroids, bird feathers, mollusk shells, jellies, molts, etc.) ranged from 0.018 to 0.45 m^2 m^{-1}. Trash on the beach was very low overall ranging from 0.0 to 0.0036 m^2 m^{-1}. Animal wrack was most abundant in May, while the most trash was seen from September to February (Figure 19).

4.1.10 Fresh Kelp Wrack

The average total abundance of fresh beach-cast kelp thalli (*Nereocystis leatkeana*, *Postelsia palmaeformis* and *Macrocystis pyrifera* thalli) quantified in the alongshore surveys varied over two orders of magnitude (from 0.3 to 104 thalli km^{-1}) among sites (Figure 18). Van Damme, Jug Handle and Caspar all had > 80 thalli km^{-1}. *Nereocystis* made up more than 50% of the abundance of fresh kelp thalli at seven of the beaches (Kellogg, Mad River, Samoa, Ten Mile, Virgin Creek, Jug Handle and Caspar). *Macrocystis pyrifera* was only observed at Van Damme, the pocket beach that is southernmost of all the study sites, with an average abundance of 13 thalli km^{-1} and making up 15% of the fresh kelp abundance at that site. *Postelsia palmaeformis* was observed at all sites except Kellogg and Russian Gulch and made up over 50% of the fresh kelp thalli at four beaches (Pyramid Point, Gold Bluffs, Reading Rock and Van Damme).

The average abundances of fresh *Postelsia* and *Nereocystis thalli* were strongly correlated on long beaches ($r^2 = 0.80$, $p = 0.002$), but not on pocket beaches ($r^2 = 0.06$, $p = 0.75$) or across all beaches ($r^2 = 0.07$, $p = 0.4017$). Similarly, the average cover of kelp wrack across the entire width of the beach is correlated with fresh kelp abundance on long beaches ($r^2 = 0.65$, $p = 0.0281$), but not on pocket beaches ($r^2 = 0.62$, $p = 0.4217$) or across all beaches overall ($r^2 = 0.07$, $p = 0.4222$). These results suggest, fresh kelp surveys are a good predictor of kelp wrack on long beaches, but not on pocket beaches. The average abundance of fresh kelp thalli tended to be greater on pocket beaches than long beaches, but there was substantial variation among sites (Figure 18).

Macrophyte wrack cover and especially kelp cover was surprisingly low on NC beaches, and much lower than observed on north central coast beaches when surveyed as part of that region's baseline study in 2010 and 2011. Kelp forests are not as common, especially in the northern bioregion and this may be part of the reason kelp wrack is less abundant (Leibowitz et al. 2016). However, ocean conditions were also anomalously warm during the baseline study period and this likely had a negative impact on kelp productivity overall.

There was no evident difference in the abundance of fresh kelp thalli among MPA and reference sites, with the exception of *Nereocystis* on reference pocket beaches, which was over six fold more abundant than on MPA pocket beaches, and *Macrocystis*, which was only observed on one MPA pocket beach (Van Damme SMCA) (Figure 20).

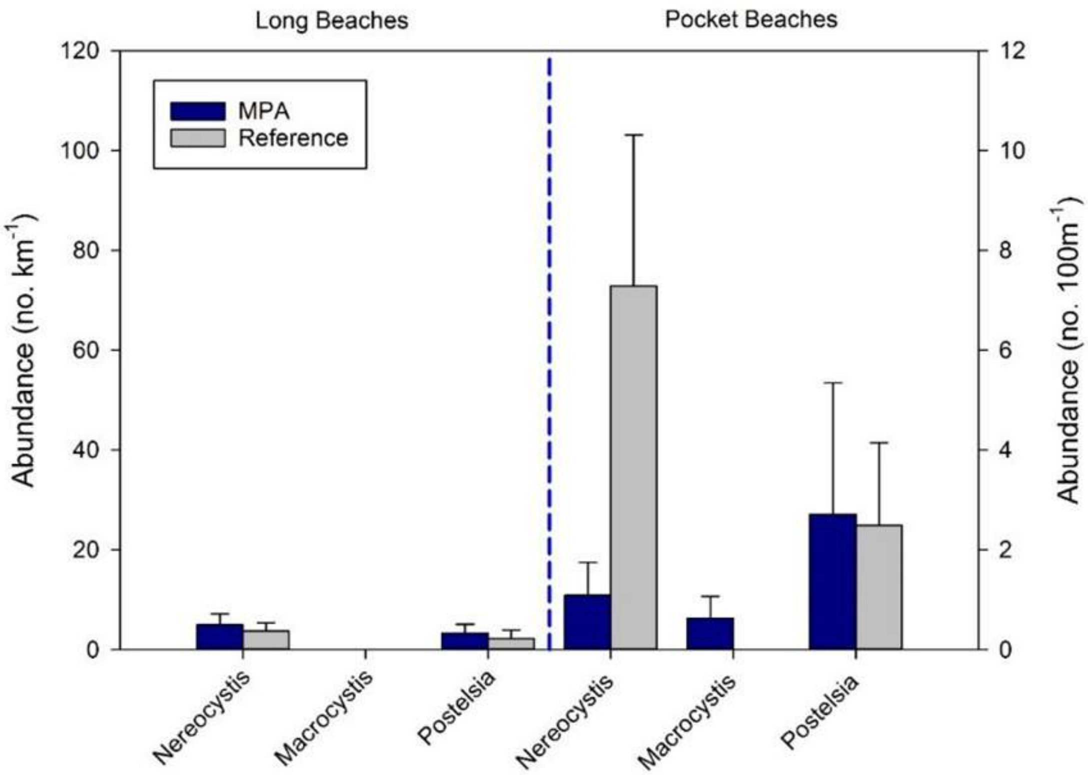

Figure 20. Abundance of fresh kelp thalli at MPA and reference beaches, by beach type. Data are means across sites (+ SE).

The large spatial differences observed in macrophyte wrack accumulation and composition among the beaches are most likely related to the proximity of rocky reefs and prevailing current and wind patterns (Leibowitz et al. 2016). The abundance of primary consumers of macrophytes, such as talitrid amphipods, may also influence the turnover rates and thus the standing stock of macrophyte wrack observed among beaches as well.

The abundance of fresh kelp thalli in the monthly alongshore counts peaked strongly in September and October (> 80 thalli km^{-1}) coinciding with the peak cover of kelps on the cross shore transects. Very low counts of fresh kelp thalli were observed on the beaches from November through April (< 20 thalli km^{-1}), after which fresh kelp began to appear in greater numbers during May and June (Figure 19). There was a strong correlation between average kelp wrack cover and average abundance of fresh kelp thalli over time (September 2014 – May 2015) on the study beaches ($r^2 = 0.72$, $p = 0.0075$).

Postelsia and young *Nereocystis* thalli (operationally defined as < 2 m from haptera to pneumatocyst) made up the greatest percentage of fresh kelp thalli in May (90%), presumably as fast growing and weakly attached thalli are pruned off by waves during the season with the strongest winds associated with upwelling (Figure 19). *Macrocystis* thalli were most abundant on the beaches in September and October (2.5 and 7 thalli km^{-1}).

4.1.11 Macroinvertebrates

Macroinvertebrate abundance and biomass of species endemic to beaches (from here on referred to as endemic species) varied sharply among the 12 focal beaches (Figure 21, Figure 22). Numerical abundance and total biomass are loosely correlated ($r^2 = 0.36$, $p = 0.039$). Total abundance varied over an order of magnitude from 8,838 individuals m^{-1} at Van Damme to 281,641 individuals m^{-1} at Mad River (Figure 21). Values of macroinvertebrate abundance >10,000 individuals 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).

Average wet biomass of macroinvertebrates also varied over an order of magnitude ranging from as little as 300 g m^{-1} at Jug Handle to as high as 15,334 g m^{-1} at Reading Rock (Figure 22). Macroinvertebrate biomass exceeded 5,000 g m^{-1} at seven out of eight long beaches. Mean macroinvertebrate biomass was generally high in the NC region relative to that reported for beaches elsewhere in the world (McLachlan et al. 1996; 1993). A dry biomass of >1,000 g m^{-1} is considered high and 5,000 g m^{-1} a ceiling value for macrofauna communities of exposed sandy beaches. Outside of California, dry biomass values exceeding 1000 g m^{-1} have been reported only for high intermediate to dissipative beach types (McLachlan et al. 1996). Using a conversion of 25 % of wet biomass as an estimate for dry biomass (McLachlan, personal communication), we estimated mean dry biomass values > 1000 g m^{-1} at seven of the 12 study beaches and a high value of 3,509 g m^{-1} at Mad River. The sand crab, *E. analoga,* biomass dominated the total macroinvertebrate biomass, averaging 53 % of the total biomass of all beaches. However, the proportion of community biomass composed of *E. analoga* varied among the study beaches and largely by beach type, ranging from 0.4 % to 2 % of the biomass on pocket beaches and from 44 % to 97 % on long beaches.

4.1.11.1 Biodiversity and species composition

Species occurrences and composition among sites were extremely heterogeneous (Table A- 1, Figure 21-Figure 25). Total species richness (equivalent to total species density as we sampled the same total area/volume of sand at each beach) ranged from 15 to 30 species. Across all 12 beaches in the NC MPA region, we observed 70 macroinvertebrate taxa, 66 identifiable to the species level plus an additional four taxa unique at the Genus or Family level (Table A- 1). This represents high (gamma) richness for open coast beaches compared to other parts of the world. Nine species of macroinvertebrates occurred in our samples at eight of the 12 focal beaches. Caspar stands out with respect to total species richness with 30 species of macroinvertebrates while Gold Bluffs had the lowest total richness with only 15 species.

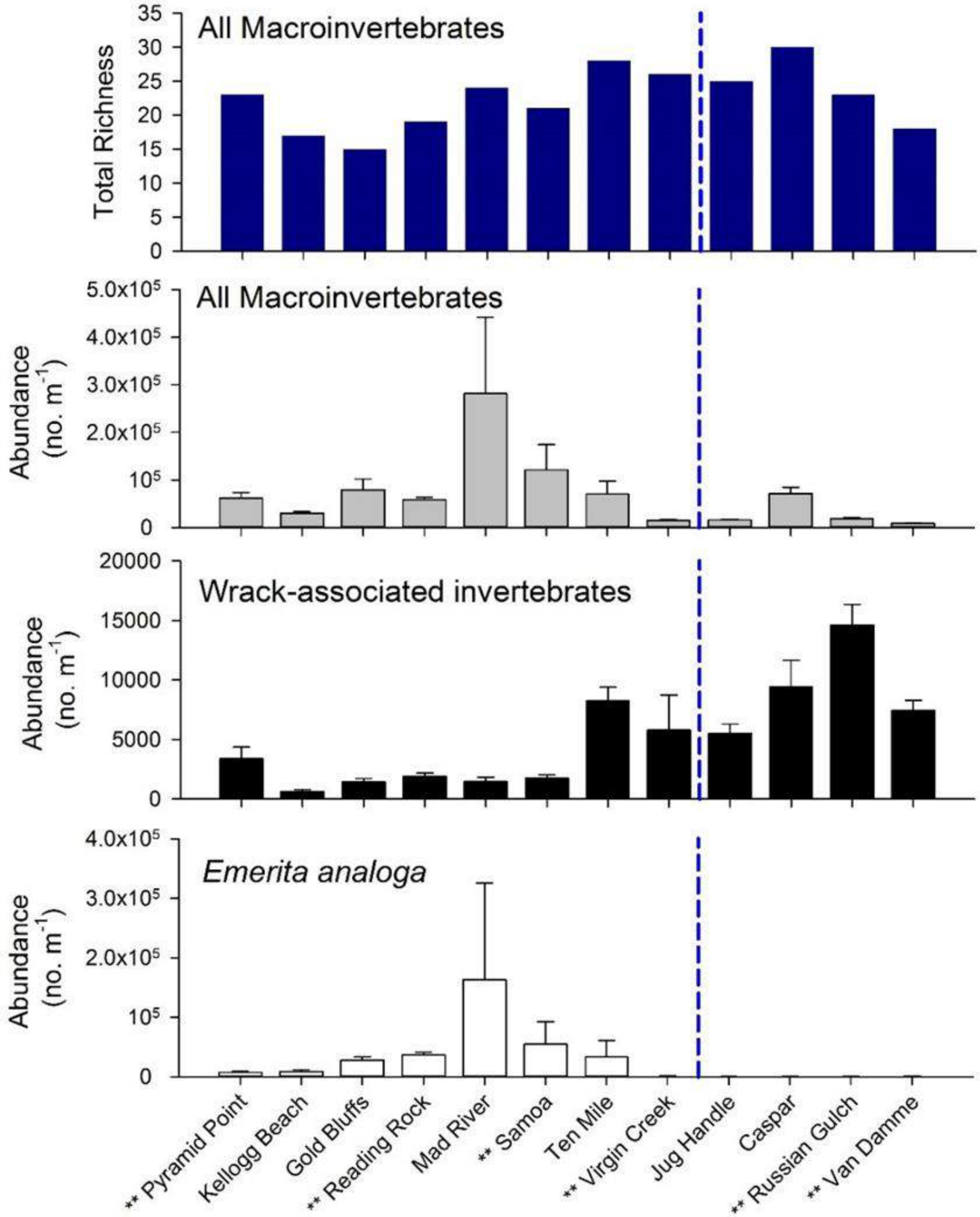

Figure 21. Average abundance (+ SE) and total richness of beach-endemic macroinvertebrates, wrack-associated invertebrates, and sand crabs. Beaches are arranged from south to north along the horizontal axis within beach type (dashed line separates long from pocket beaches).

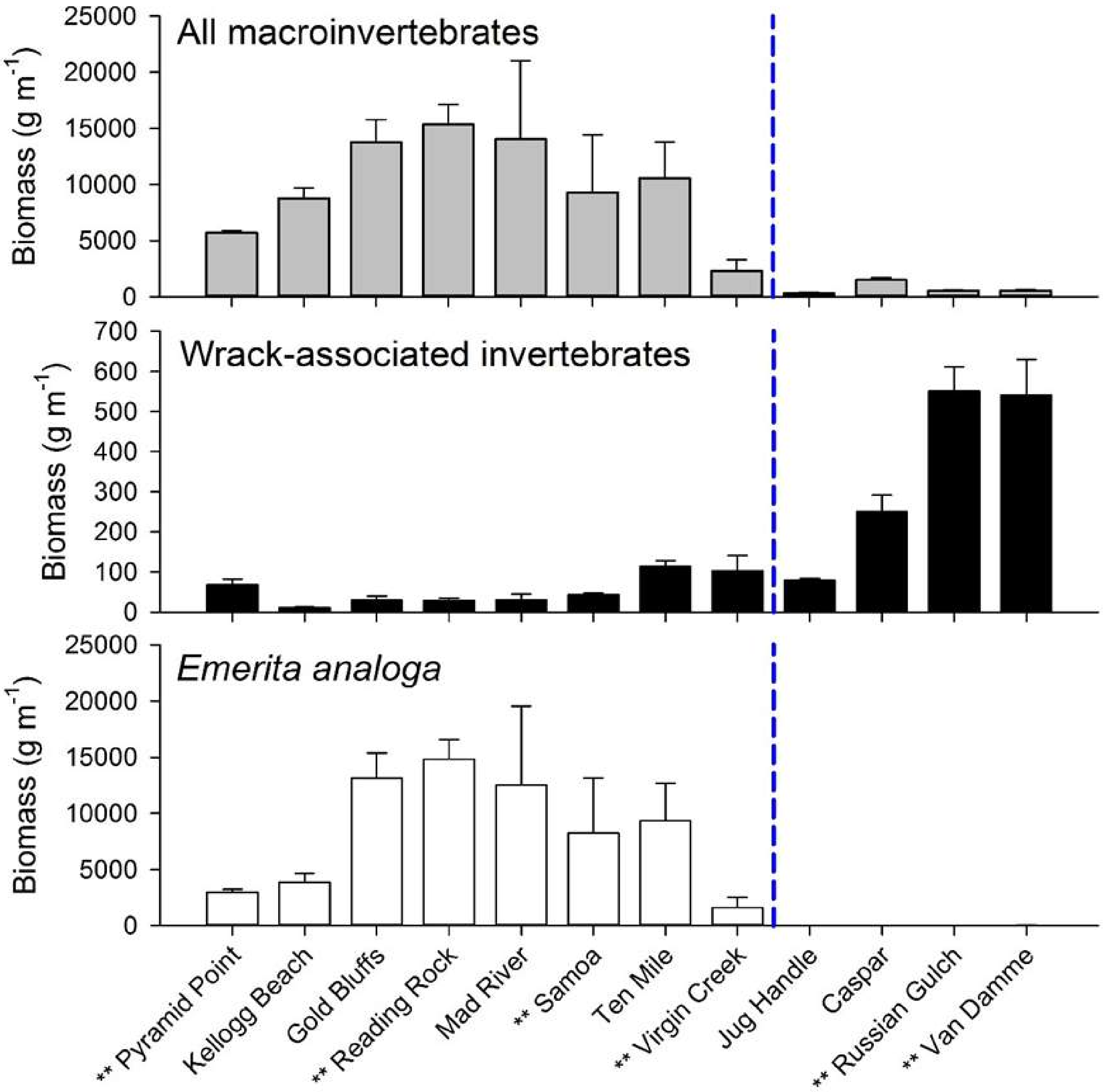

Figure 22. Average biomass (+ SE) of beach-endemic macroinvertebrates, wrack-associated invertebrates and sand crabs. All other information as in Figure 21.

Wrack-associated invertebrate species, (talitrid amphipods, isopods, insects and arachnids) (Table A- 1), which depend on subsidies of drift macroalgae from nearshore kelp forests and reefs, comprised an important component of intertidal community diversity on the beaches. A total of 15 wrack-associated invertebrate taxa were found in our surveys, making up 21 % of the total invertebrate species observed. The number of wrack-associated species on a single beach varied over four fold, ranging from two species at Pyramid Point, Kellogg and Reading Rock to nine species at Ten Mile. The proportion of wrack-associated species relative to total invertebrate richness varied almost four fold among beaches, ranging from 9 % at Pyramid Point to a high of 35 % at Russian Gulch. Wrack-associated species made up 25 % or more of the species at six of the 12 study beaches.

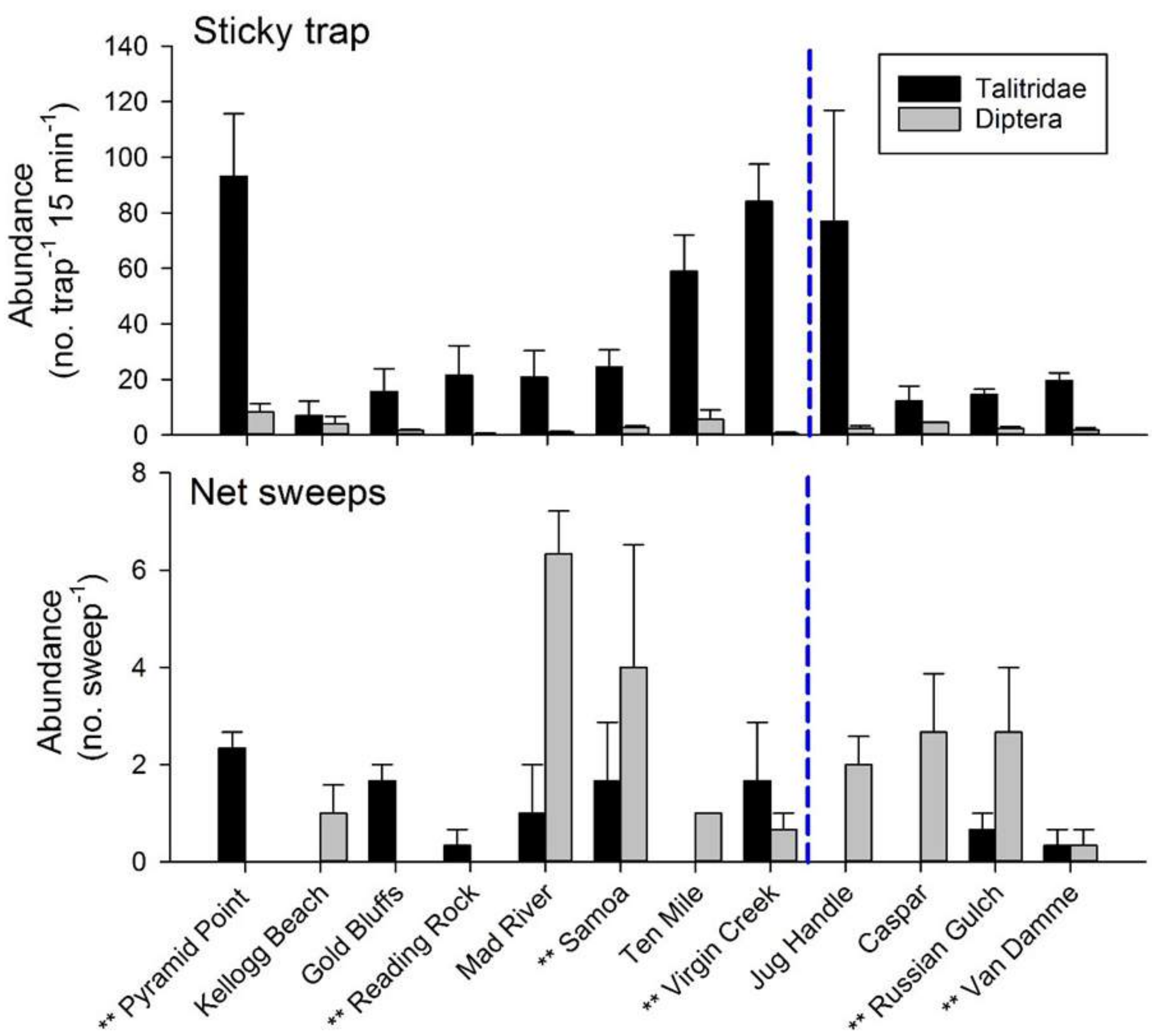

Figure 23. Abundance of talitrid amphipods and flies caught on sticky traps and in net sweeps during summer 2014 biodiversity sampling. Data are presented as averages (+SE) of three transects per beach. Abundances from the two sticky traps collected on each transect were averaged before calculating site averages and standard errors. All other information as in Figure 21.

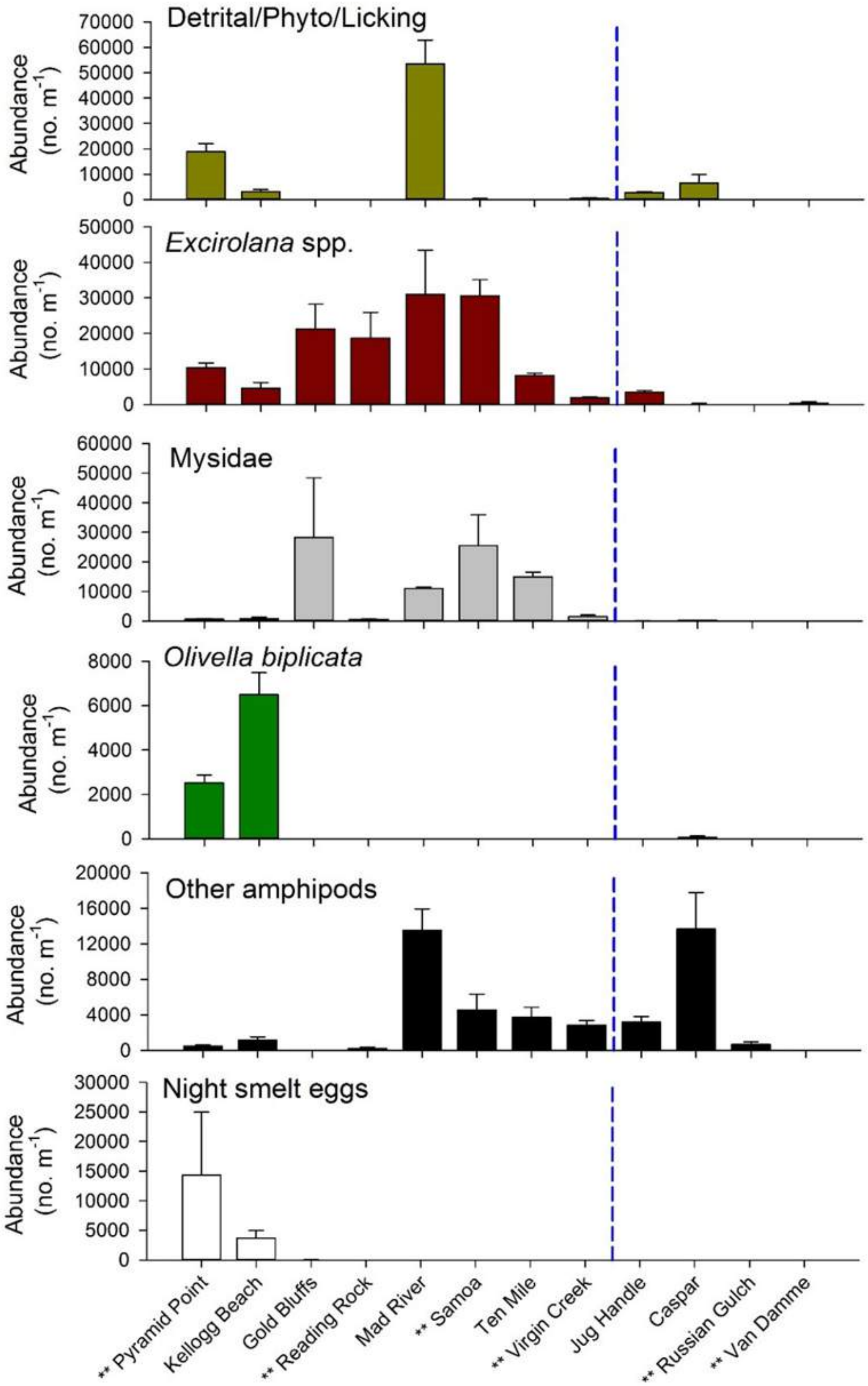

Figure 24. Average abundance (+ SE) of beach-endemic phytoplankton, detritus feeding and sand-licking invertebrates, Excirolana *spp., mysids,* Olivella biplicata*, other amphipods and night smelt eggs. All other information as in Figure 21.*

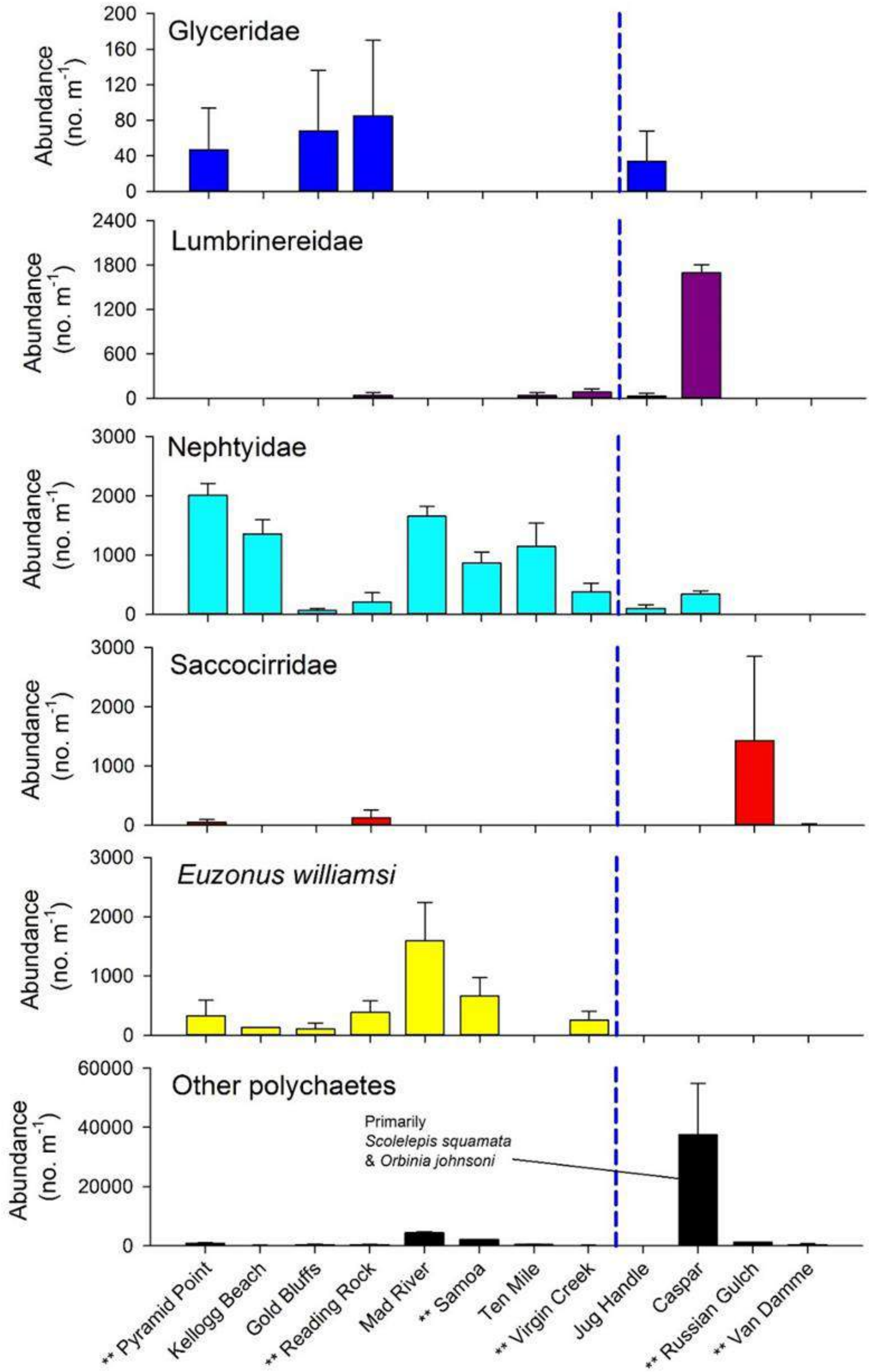

Figure 25. Average abundance (+ SE) of beach-endemic glycerid, lumbrineirid, nephytid, saccoccird, Euzonus williamsi *and other polychaete worms. All other information as in Figure 21.*

The only two invertebrate taxa observed across all 12 sites were *Megalorchestia* and *E. analoga*, and the upper beach isopod *Alloniscus perconvexus* occurred in samples from eleven of the study beaches (Table A- 1). The taxon *Megalorchestia* included five species: *M. benedicti, M. californiana, M. columbiana, M. corniculata* and *M. pugettensis*. Four additional taxa of macrofauna occurred in samples from ten of the study beaches: the polychaete *Nephtys californiensis,* the mysid *Archaeomysis grebnitzkii,* and the cirolanid isopods *Excirolana chiltoni and Excirolana linguifrons.* Two macroinvertebrate species occurred at eight of the beaches, the gammarid amphipods *Eohaustorius washingtonianus* and *Grandifoxus grandis*. Three macroinvertebrate species occurred at seven of the beaches, the polychaetes *Eteone dilatae* and *Euzonus williamsi,* and the talitrid amphipod *Megalorchestia benedictii* (Table A- 1)*.* The olive snail *Olivella biplicata,* a culturally important species, and was only abundant at two sites near Point St George (Pyramid Point and Kellogg) (Figure 24, Figure 26, Table A- 1).

4.1.11.2 Sand crabs and wrack-associated invertebrates

The two ecologically important taxa we are evaluating as potential indicators of the ecological state of sandy beaches (*E. analoga* and talitrid amphipods) were present on all 12 of the study beaches. They varied substantially among beaches in both their numerical abundance and biomass (Figure 21, Figure 22). *Megalorchestia* spp. dominated the abundance of all wrack-associated macroinvertebrates both numerically and by weight. Talitrids made up between 71 % and 99 % (average [SD] = 88 [9] %) of the numerical abundance and between 60 % and 100 % of the biomass (average [SD] = 89 [12] %) of all wrack-associated macroinvertebrates sampled.

The average abundance of *E. analoga* was much higher than wrack-associated invertebrates across all 12 beaches (average [SD] = 27,672 [46,424] no. m^{-1} and average = 5,131 [4,217] no. m^{-1}, respectively). The variation in the range of abundances was also much greater for *E. analoga* with three orders of magnitude variation (64 to 163,102 no. m^{-1}) than for wrack-associated invertebrates with one order of magnitude variation (637 to 14,604 no. m^{-1}) across the beaches. As expected, the average total biomass across all beaches also varied substantially (average [SD] = 5,542 [5,729] g m^{-1} and average = 154 [194] g m^{-1}, for *E. analoga* and wrack-associated invertebrates, respectively), as well as among sites ranging from 2.3 to 14,801 g m^{-1} for *E. analoga* and 11 to 551 g m^{-1} for wrack-associated invertebrates (Figure 23). *E. analoga* was the most abundant species observed at any site with an average of 163,102 individuals m^{-1} recorded at Mad River.

E. analoga was much less abundant on pocket beaches than long beaches (Figure 21, Figure 22). It was less than 4 % of the numerical abundance and biomass of macroinvertebrates at the pocket beaches. In contrast, at five of the eight long beaches, *E. analoga* made between 35 % and 61 % of the numerical abundance of macroinvertebrates, and between 44 % and 97 % of the macroinvertebrate biomass.

The percent of the average abundance of all macroinvertebrates made up by wrack-associated invertebrates was extremely wide, ranging from 0.5 % (Mad River) to 84 % (Van Damme) of the total. Wrack-associated invertebrates made up 79 % and 84 % of the numerical abundance of macroinvertebrates at two pocket beaches (Russian Gulch and Van Damme, respectively). A wide range in variation among sites was similarly found for wrack-associated invertebrate biomass, which made up less than 5 % of the biomass at eight of the 12 beaches, but was more than 90 % of the biomass at two sites (Russian Gulch and Van Damme) (Figure 22). Wrack-associated invertebrates made up only a small fraction of the total macroinvertebrate biomass at all long beaches (0.12 % to 4.5 %), but were important components of biomass at the pocket beaches: Jug Handle (26 %), Caspar (17 %), Van Damme (93 %) and Russian Gulch where this group peaked at 96 %.

4.1.11.3 Talitrid amphipods and diptera

4.1.11.3.1 Sticky Traps

To quantify the abundance of diptera 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. The sticky traps also captured talitrid amphipods that are active on the sand surface and other crawling and hopping insects, such as beetles. Small flies were often collected on the sticky traps but the adhesive used in the collection technique limits identification of the smaller species. Several species of beetles were collected on the sticky traps, including *Phyconomous marinus* (Monotomidae), *Aleochara sulcicollis* (Staphylinidae), *Cafius luteipennis* (Staphylinidae), *Tarphiota* spp. (Staphylinidae), *Bledius* spp (Staphylinidae), *Phaleromela* spp. (Tenbrionidae), and *Cercyon* spp. (Hydrophyllidae).

The abundance of flies and talitrids measured from sticky traps are presented in Figure 23. The average numbers of both flies and talitrid amphipods per trap were greatest at Pyramid Point (8.3 individuals trap^{-1} and 93.2 individuals trap^{-1}, respectively) (Figure 23). This was a surprising result for a site with such low wrack cover throughout the year (Figure 18). Other sites with relatively high talitrid abundance, Ten Mile (59 individuals trap^{-1}), Virgin Creek (84.2 individuals trap^{-1}), and Jug Handle (77 individuals trap^{-1}) had high kelp and brown macroalgal cover at the time of sampling.

4.1.11.3.2 Net Sweeps

The catch of flies using net sweeps varied more than six fold among the study beaches, ranging from 0.0 to 6.3 flies sweep^{-1} (Figure 23). Flies from nine different families were collected in the net sweeps, the most common from Chloropidae and Ephydridae. Talitrid amphipods and beetles (primarily Staphylinidae) were also collected. Talitrid amphipods caught in the net sweeps varied more than twofold among the study beaches, ranging from 0.0 to 2.3 amphipods sweep^{-1}. Kelp fly larvae feed on kelp and require ~ 2 weeks to develop and metamorphose into flies, a cycle apparently linked to the spring/neap tide cycles of moist aging deposits of kelp. Where kelp is scarce, dries too quickly or is consumed rapidly by other consumers, such as talitrid amphipods, kelp fly populations may be depressed.

4.1.11.4 Polychaete worms

The abundance, biomass, diversity, occurrence and species composition of polychaete worms varied tremendously among beaches and between long and pocket beaches (Figure 25, Figure 27, Table A- 1). Reading Rock stands out with respect to the number of different polychaete species observed (10), although the overall abundance and biomass of polychaetes was higher on other beaches. The deposit-feeding ophelid polychaete, *Euzonus williamsi*, only occurred on long beaches, whereas lumbrineirid and saccocirrid worms were notably absent or occurred in very low numbers on long beaches, but were each highly abundant on one of the pocket beaches (Figure 25). The predatory glycerid polychaetes only occurred on three long beaches and one pocket beach.

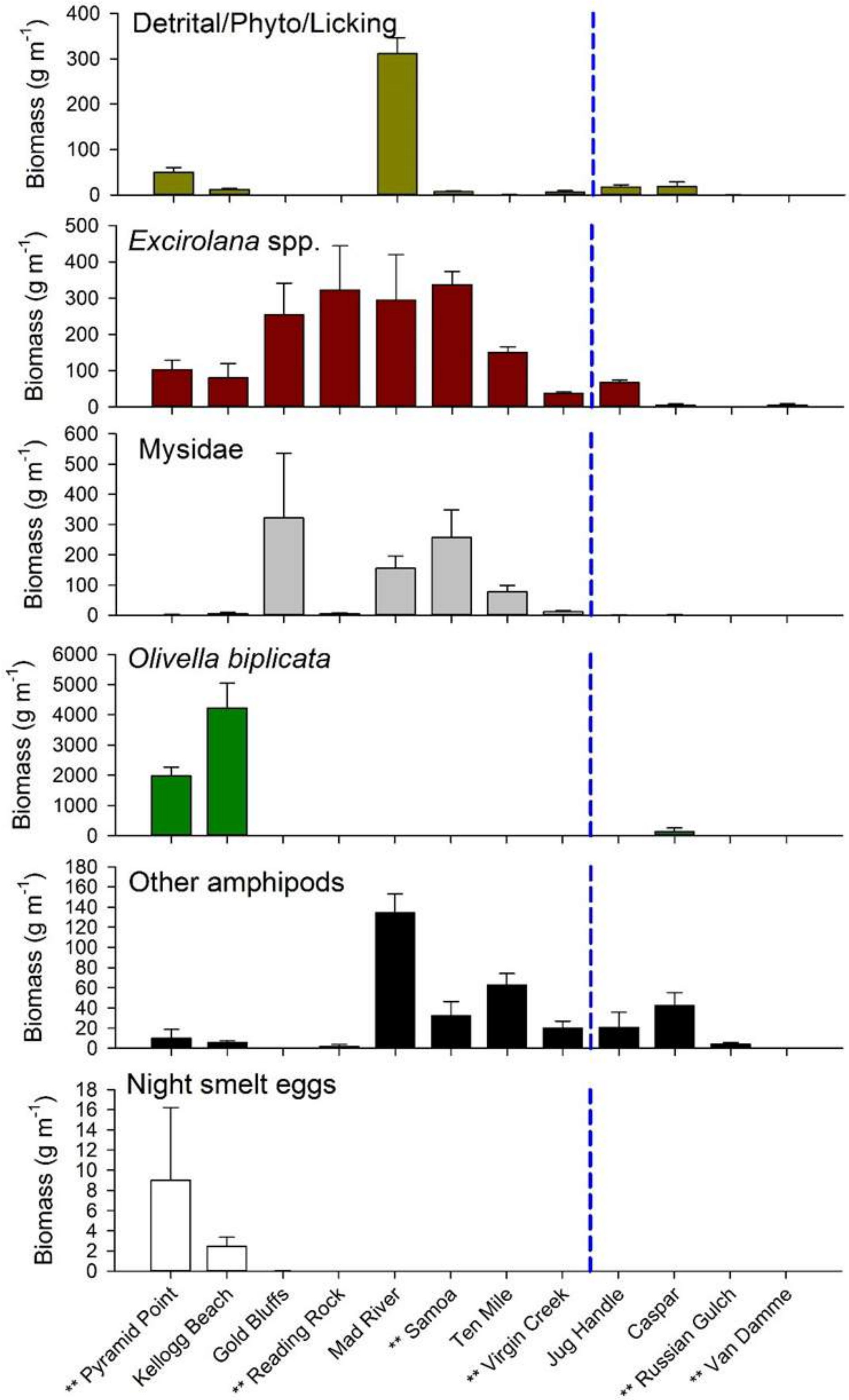

Figure 26. Average site biomass (+ SE) of beach-endemic detritus feeding and sand-licking invertebrates, Excirolana *spp., mysids,* Olivella biplicata*, other amphipods and night smelt fish eggs. All other information as in Figure 21.*

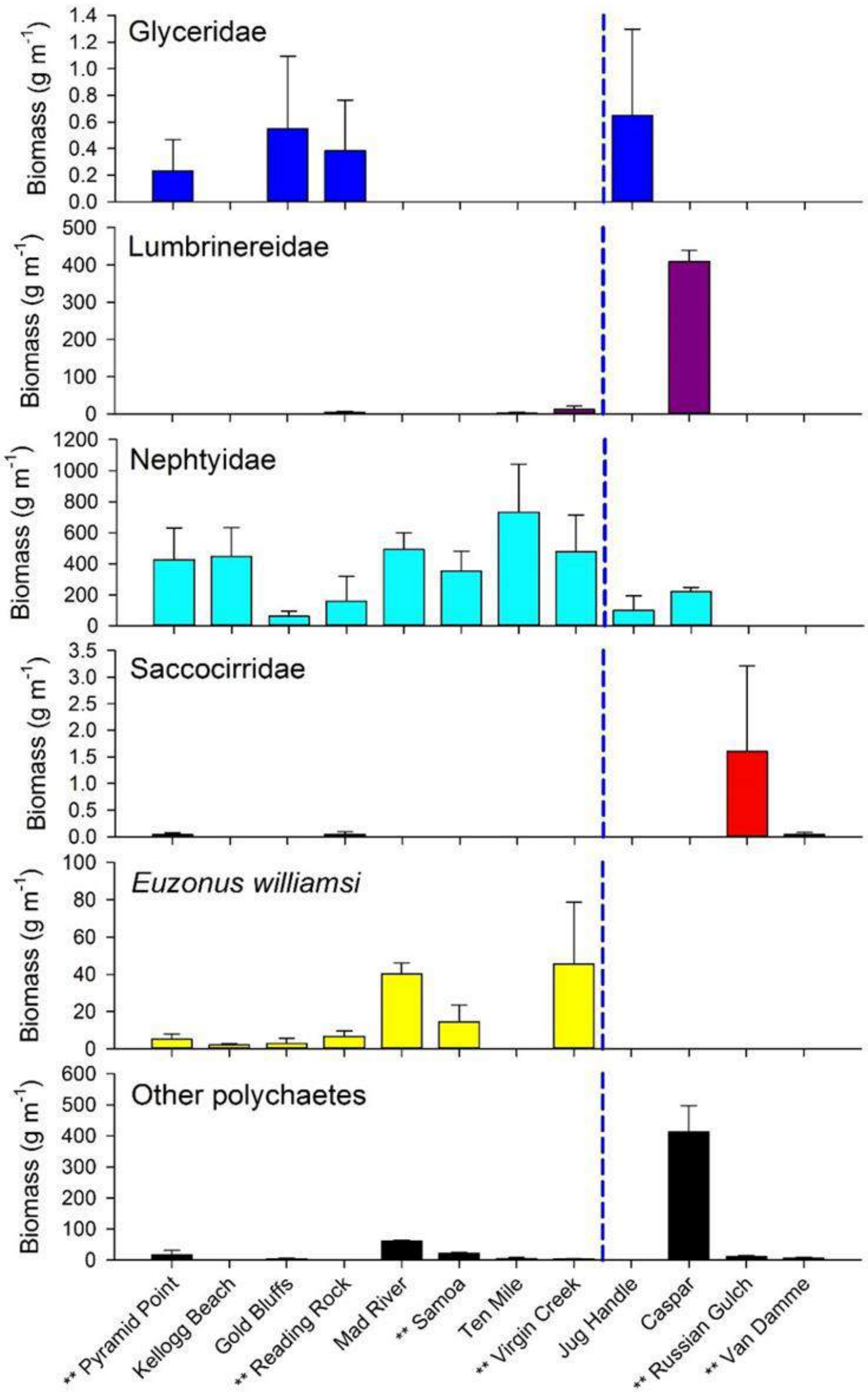

Figure 27. Average site biomass (+ SE) of beach-endemic glycerid, lumbrineirid, nephytid, saccoccird, Euzonus williamsi *and other polychaete worms. All other information as in Figure 21.*

4.1.11.5 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, with the exception of Caspar, a pocket beach where their abundance was very high (Figure 24). Other than the sand crab *E. analoga*, the haustoriid amphipod *Eohaustorius washingtonianus* was the most abundant single species observed at any site with 46,219 individuals m^{-1} recorded at Mad River, where we also observed the peak abundance of *E. analoga* from the biodiversity surveys.

4.1.11.6 Non-endemic macroinvertebrates

The biodiversity surveys on NC beaches revealed a surprising abundance and diversity of macroinvertebrate species (total = 19) not endemic to sandy beach ecosystems (Table A- 2). These species are likely transported from the habitats where they live (rocky intertidal and subtidal, kelp forest, estuary, etc.) by hitchhiking on macrophyte wrack or by currents that deposit them on the beach. The overwhelming majority of these species were found at Caspar (Figure 28, Figure 29), where the dexaminid amphipod, *Atylus tridens*, was the most abundant non-endemic single species observed at any site with 31,661 individuals m^{-1}. Non-endemic amphipods and isopods were found on all beaches in Mendocino County. These beaches all have nearby rocky habitat, estuaries or freshwater inputs that probably facilitate the movement of non-endemic species onto these beaches. However, these are not especially unique characteristics for beaches in northern California, or elsewhere. These non-endemic invertebrates may be a trophic resource (subsidy) for birds, if they arrive to the beach alive, or more likely they are a resource for scavengers, if they are dead on arrival.

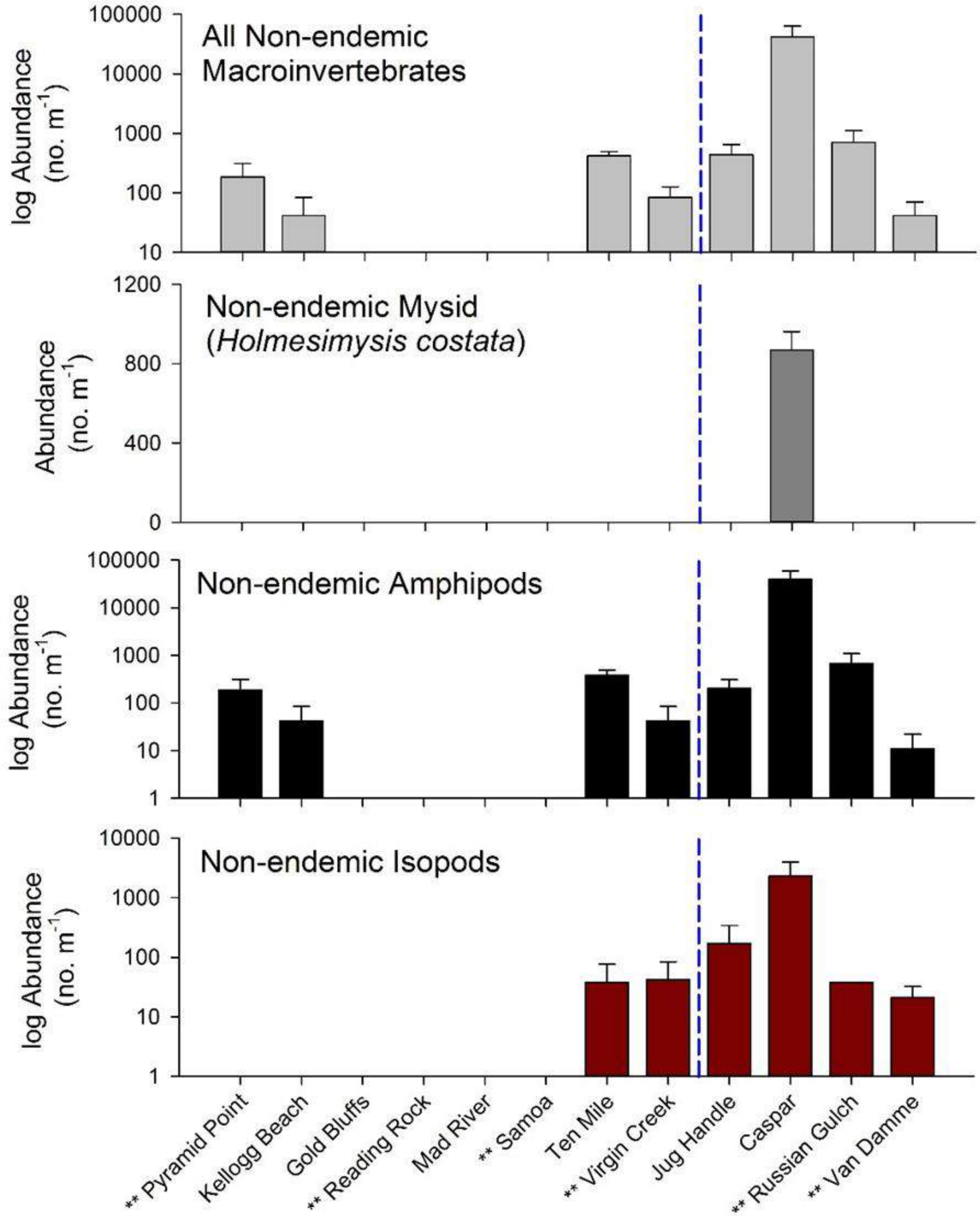

Figure 28. Average site abundance (+ SE) of macroinvertebrates, mysids, amphipods and isopods that are "incidental" to sandy beach habitat (transported to the beach from adjacent habitats such as rocky intertidal, kelp forests or estuaries). Note all data except the mysid H. costata *plotted on a log scale. All other information as in Figure 21.*

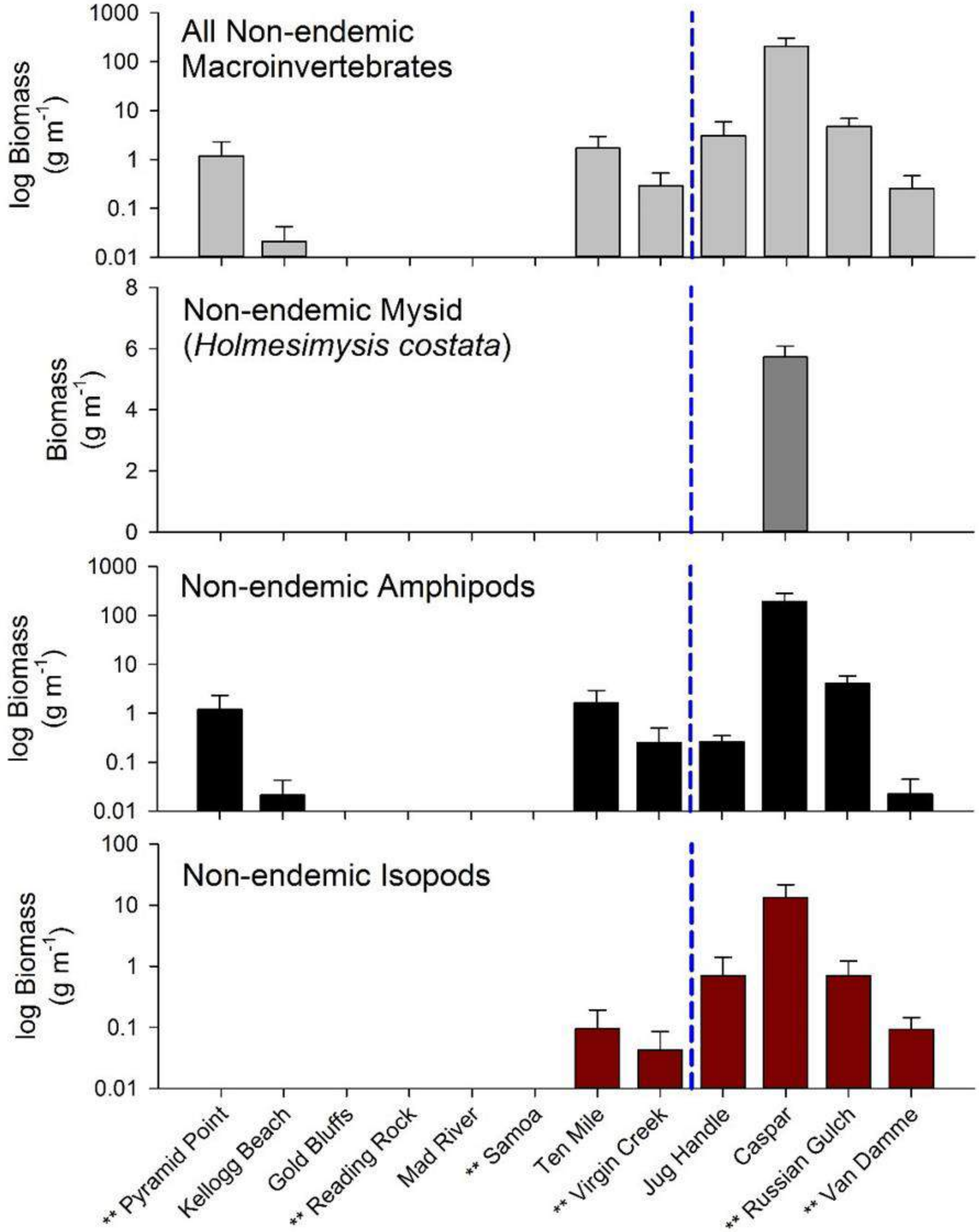

Figure 29. Average site biomass (+ SE) of macroinvertebrates, mysids, amphipods and isopods that are "incidental" to sandy beach habitat (transported to the beach from adjacent habitats such as rocky intertidal, kelp forests or estuaries). Note all data except the mysid H. costata *plotted on a log scale. All other information as in Figure 21.*

4.1.12 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 more than threefold higher on pocket beaches than long beaches (average [SD] on pocket beaches: 9,238 [3,919] no. m^{-1} vs. long beaches: 3,078 [2,628] no. m^{-1}). Wrack-associated invertebrates made up 32 % of the total invertebrate abundance and 48 % of the total invertebrate biomass on pocket beaches versus only 3 % of the abundance and 0.5 % of the biomass on long beaches.

There was no apparent difference in numerical abundance between MPA and reference sites (average [SD] on MPA beaches: 5,801 [4,854] no. m^{-1} vs. reference beaches: 4,461 [3,807] no. m^{-1}). However, wrack-associated invertebrates made up a greater percentage of total invertebrate abundance on MPA beaches (4% of the numerical abundance and 12 % of the biomass) than on reference beaches (1% of the numerical abundance and 5 % of the biomass).

In contrast, *E. analoga* was over two orders of magnitude more abundant on long beaches compared to pocket beaches (average [SD]: 41,445 [52,314] no. m^{-1} and 137 [135] no. m^{-1}, respectively), but there was high variability among beaches of both types. Similarly, sand crab biomass on long beaches was more than two orders of magnitude greater than on pocket beaches (average [SD]: 8,308 [5,036] g m^{-1} and 11 [12] g m^{-1}, respectively). Sand crabs were 83 % of the total invertebrate biomass on long beaches compared to only 2 % on pocket beaches. Reference beaches also had just over twice the abundance of *E. analoga* compared to MPA beaches (average [SD]: 38,750 [62,502] no. m^{-1} and 16,602 [23,253] no. m^{-1}, respectively), although the variation among beaches was extremely high. Total sand crab abundance made up 79 % and 81 % of total macroinvertebrate abundance on MPA and reference beaches, respectively.

4.1.13 Targeted sampling of sand crabs

We sampled sand crabs monthly at three sites (Gold Bluffs, Mad River, and Samoa SMCA) during the months of May through July 2015, concurrently with fishing surveys for surfperch (results reported below). The highest abundance of sand crabs from this sampling effort in 2015 was at Gold Bluffs, whereas Samoa SMCA had the lowest (Figure 30. Mean abundance of sand crabs in the swash zone). Except for Mad River, there was a decrease in mean abundance from May to June, followed by a large increase in July (Figure 30. Mean abundance of sand crabs in the swash zone), suggesting there may have been at least two major recruitment pulses between May and July. The large increase of sand crabs across sites in July was due to the arrival of many small, young recruits (Figure 30, Figure 31).

To determine the biomass of sand crabs, a weight-length relationship was determined (Figure A- 2). Biomass was greater at Gold Bluffs during the month of May (Figure 33) as crabs were more abundant (Figure 30Figure 31). Total biomass remained stable at Mad River across the entire season (Figure 33). However, there were changes in the size distribution over the same time. Medium and large sand crabs were abundant at Mad River during May and June, but not in July, while small crabs were very abundant in July (Figure 31).

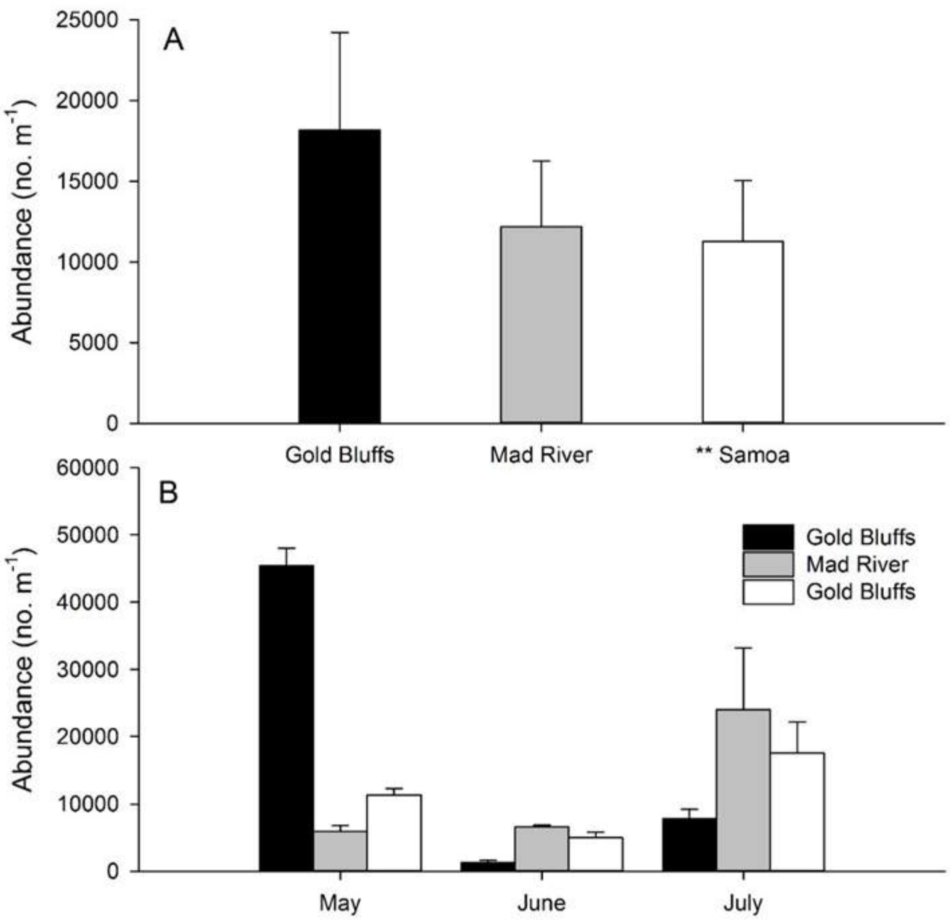

Figure 30. Mean abundance of sand crabs in the swash zone at three sampling sites: A) overall (May-July 2015) and B) by month. Data are averages (+SE).

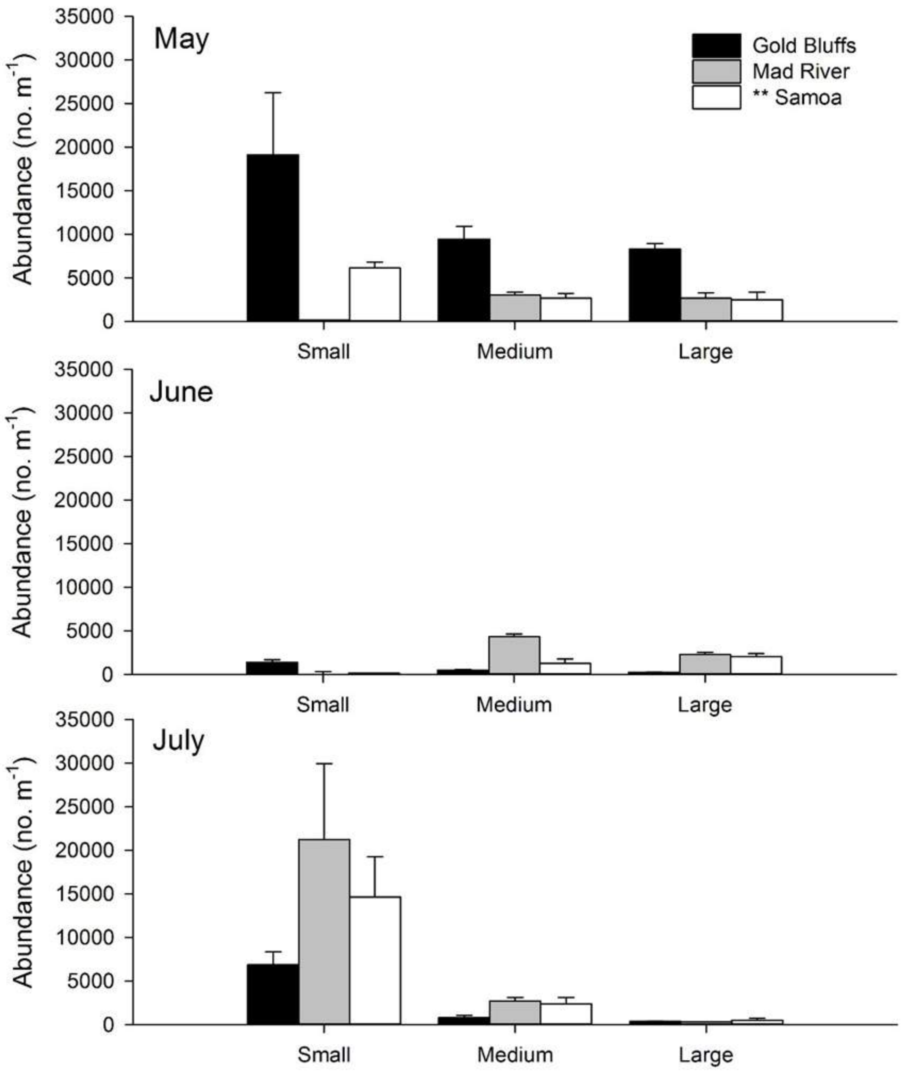

Figure 31. Average abundance of swash zone sand crabs by size class (small <10mm; 10mm< medium <15mm; large >15mm). All else as inFigure 30.

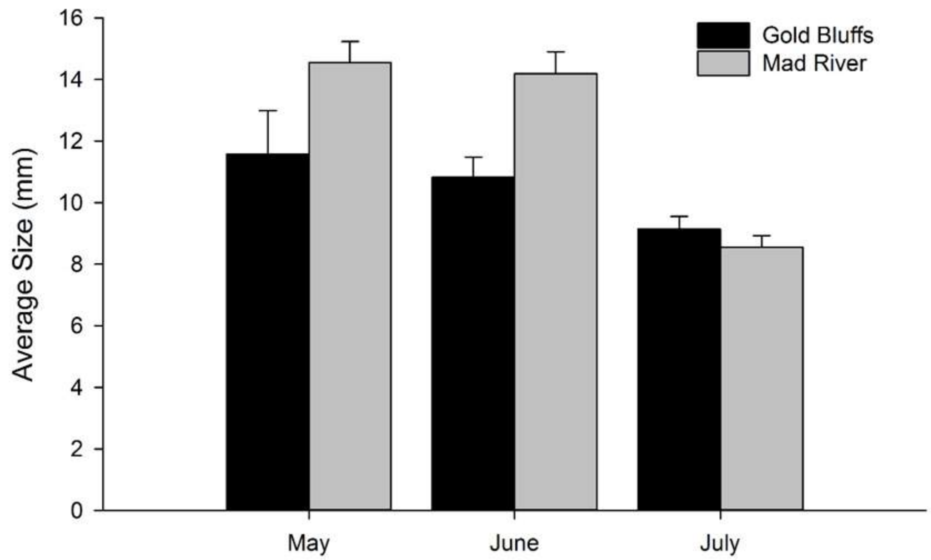

Figure 32. Average sizes of swash zone sand crabs from two beaches. All else as in Figure 30.

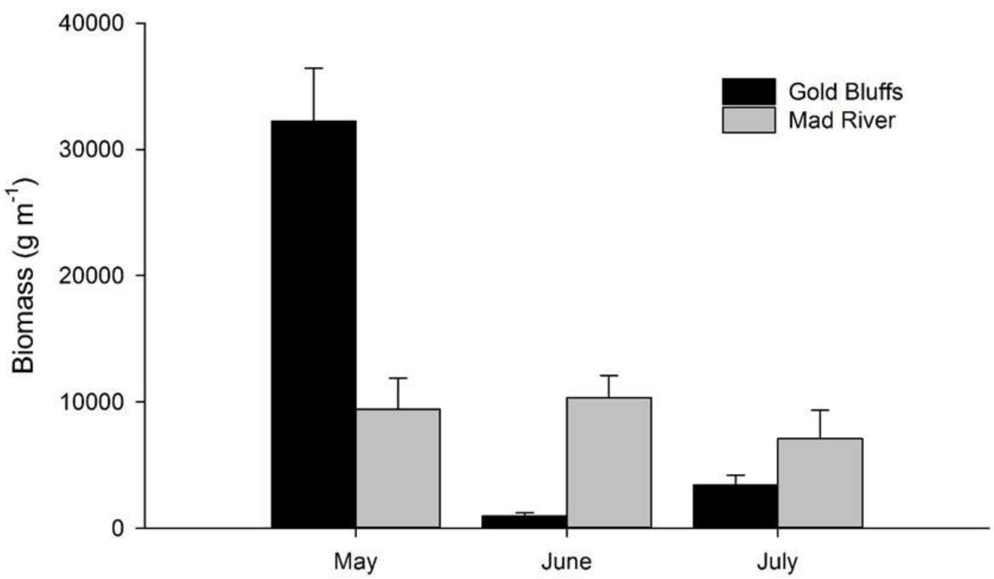

Figure 33. Mean biomass of swash zone sand crabs from two beaches. All else as in. Figure 30

4.2 Surf zone fishes

4.2.1 Redtail Surfperch

During the two sampling years, just two species of surfperch were caught: silver (*Hyperprosopon ellipticum*) and redtail (*Amphistichus rhodoterus*). A total of 885 redtail surfperch were collected. Silver surfperch were rarely caught (24 combined in years 1 and 2) therefore we did not include them in any further analyses.

Of the 885 redtail surfperch, 504 were tagged, yielding a return of five tags by local recreational anglers. Two of the returned tags were deployed at Pyramid Point SMCA and captured at the mouth of the Smith River after 13 and 14 days at liberty, each having traveled approximately 3 km. One of the returned tags was deployed at Reading Rock SMCA and captured again at Gold Bluffs Beach after 311 days at liberty, approximately 8 km away. The two remaining tag returns were deployed at Samoa SMCA and captured after 30 and 316 days at liberty, at distances of approximately 12 and 18 km, at the North Jetty entrance to Humboldt Bay and Hilfiker Beach within Humboldt Bay, respectively.

Despite deployment of more than 500 tags, only five tags were returned by recreational anglers. Low numbers of tag returns could be due to multiple factors: poor tag retention, fish death, and/or possible lack of angler participation in reporting recovered tags. A tag retention study determined that redtail surfperch are mostly unaffected by the plastic T-bar anchor tags used in our study (Marine Resources Program, Oregon Department of Fish & Wildlife, 2000), therefore, it is unlikely that premature death due to tagging was a likely cause of our low tag returns. Although limited (total of 5 tag returns), our tag returns may indicate that redtail surfperch in Northern California remain relatively local, with all returns yielding less than a 20 km movement along the open coast. In contrast, a study in southern Oregon indicated that redtail surfperch move considerable distances along open coastline, but may be limited by barriers that obstruct natural movement (Marine Resources Program, Oregon Department of Fish & Wildlife, 2000). Increased future tagging will be required to confirm these initial findings.

We examined the total number of redtail surfperch caught during each year. The beaches that had the greatest number of redtail combined over both years were Mad River and Samoa SMCA, however, catch varied dramatically across years (Figure 34). For most sites, total catch was greater during year 2 due to increased fishing effort. To account for differences in fishing effort and to estimate relative abundance of redtail surfperch, we calculated catch per unit effort (CPUE) by dividing the total catch by total angler hours. CPUE was not found to be significantly different across all MPAs and paired reference sites for the overall sampling effort [$F_{(8,50)} = 0.3525$, $p = 0.94$] or between sampling years [$F_{(8,49)} = 0.3148$, $p = 0.97$]. Combined CPUE of redtail surfperch across both years was greatest at Samoa SMCA and Kellogg Beach, however, CPUE also varied across the two sampling years (Figure 35). MPAs did not have greater CPUE than their paired reference sites (combined, or within single sampling years), with few exceptions. South Samoa Dunes had a lower CPUE than Samoa SMCA, although this difference was not significant. In addition, Samoa SMCA had a greater CPUE than Mad River in the first sampling year, however, this relationship was reversed in the second year. CPUE for Reading Rock SMCA in year 1 was greater than Gold Bluffs Beach, however, we believe that this was due to limited beach access at Gold Bluffs in 2014

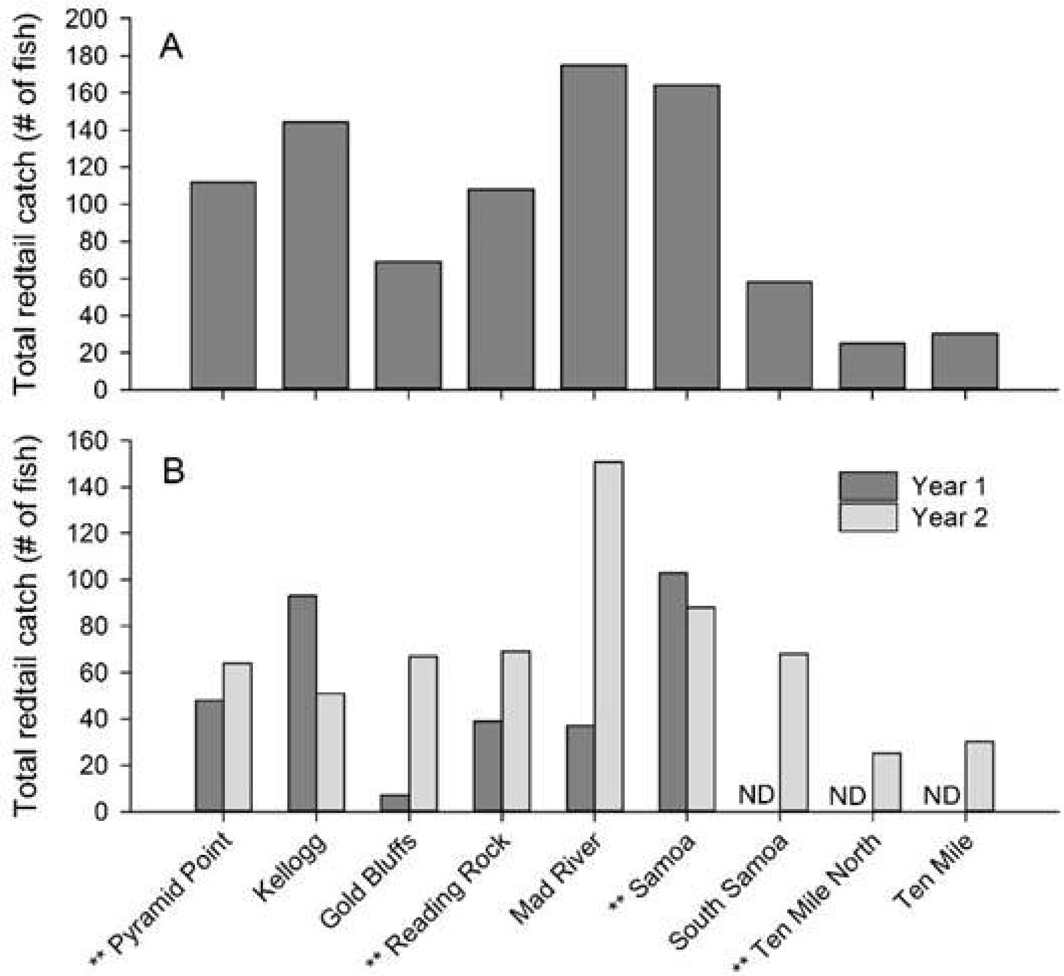

*Figure 34. Total catch of redtail surfperch at MPAs and reference sites A) combined over years 1 and 2 (2014, 2015) and B) separated by year 1 and 2.). No data (ND) for South Samoa, Ten Mile North, and Ten Mile during year 1. Beaches arranged from north to south along the horizontal axis. ** indicates MPAs.*

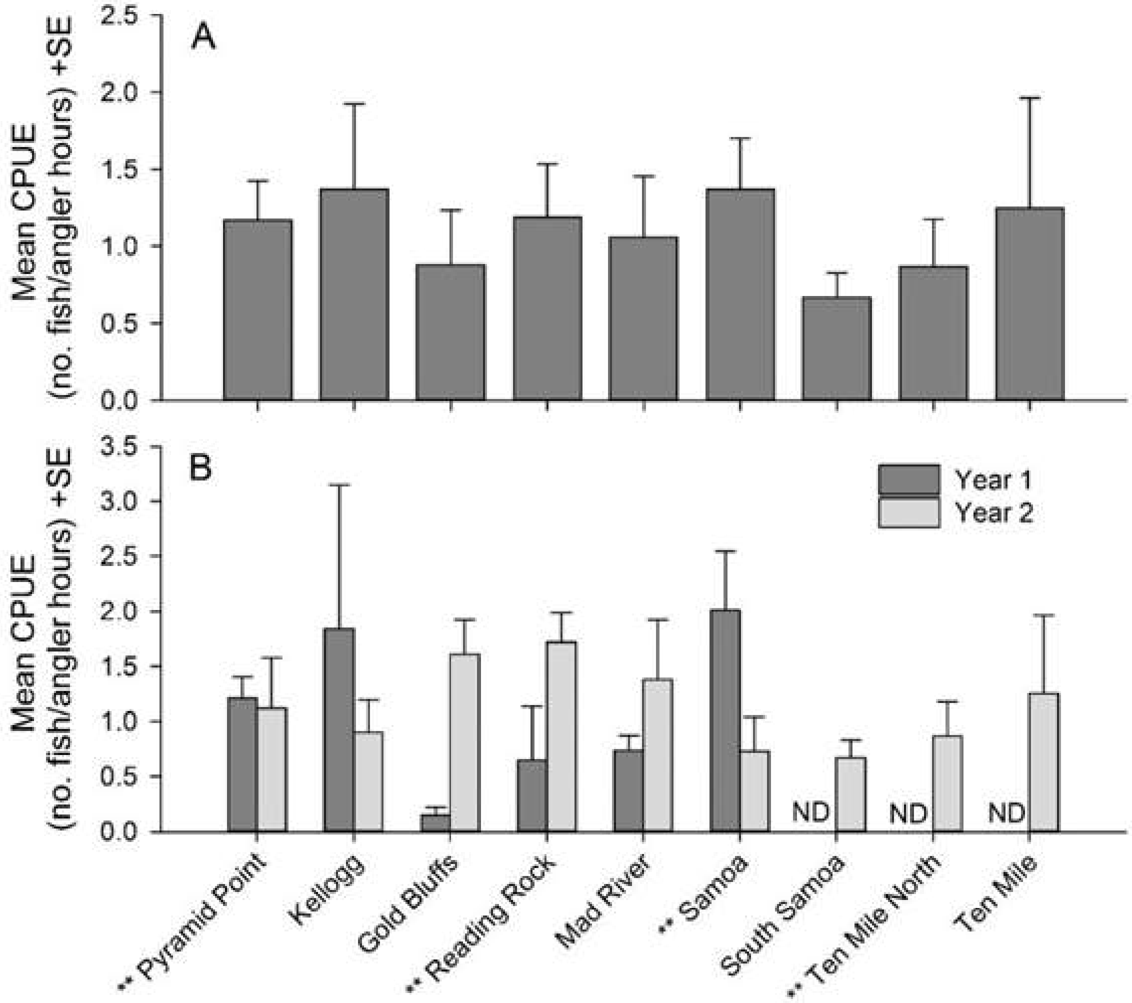

Figure 35. Mean relative abundance (CPUE) of redtail surfperch caught at North Coast MPAs and reference sites A) combined over years 1 and 2 (2014, 2015) and B) separated by year 1 and 2. All data are averages (+SE). No data (ND) for South Samoa, Ten Mile North, and Ten Mile during year 1. Beaches arranged from north to south along the horizontal axis. ** indicates MPAs.

Redtail surfperch ranged from 130 to 430 mm in total length (Figure 37), with an average size of 250 to 300 mm (Figure 37, Figure 36). Mean total length of redtail surfperch did not vary across sites when the data were examined with both years combined, or separated by sampling years (Figure 36). Fish at the more northern beaches (Pyramid Point SMCA, Kellogg Beach, Gold Bluffs, and Reading Rock SMCA), were larger in 2014 than 2015, however, this relationship may have been an artifact of less sampling effort in 2014.

The sex ratios of redtail surfperch, over the entire sampling effort, were nearly balanced. Sex ratios did not differ across paired sites, with few exceptions (Figure 38). Kellogg Beach, Mad River and Reading Rock SMCA had fewer males than females when compared to their paired sites (Kellogg: $F_{[8,875]} = 3.124$, $p = 0.0192$; Mad River: $F_{[8,875]} = 3.124$, $p = 0.0114$; Reading Rock SMCA: $F_{[8,875]} = 3.124$, $p < 0.05$), whereas Ten Mile North had (nearly significant) fewer males than its paired reference site ($F_{[8,875]} = 3.124$, $p = 0.0653$). Sampling year did not affect the likelihood of catching either sex. Males were caught more often than females during year 1 at Gold Bluffs, however, this result may be an artifact of the limited sampling access and/or small sample size.

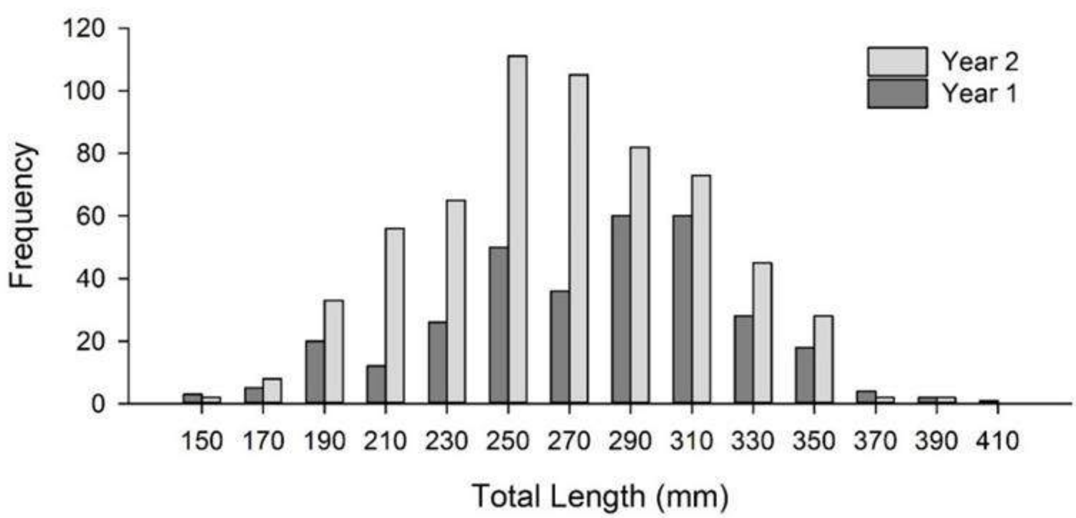

Figure 36. Total lengths of redtail surfperch caught over all North Coast sampling sites during years 1 and 2 (2014, 2015).

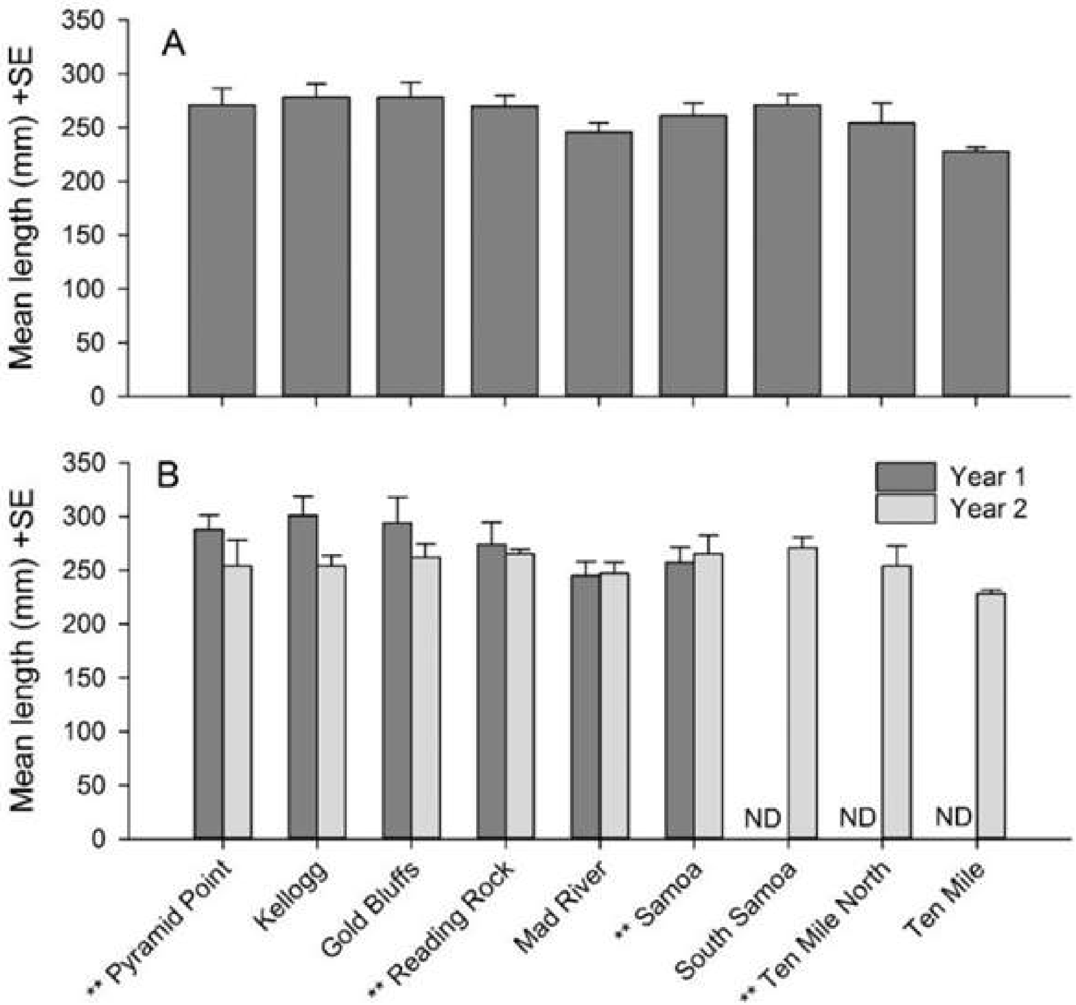

*Figure 37. Mean total length (mm) of redtail surfperch caught at North Coast MPAs and reference sites A) combined over years 1 and 2 (2014, 2015) and B) separated by year 1 and 2. All data are averages (+SE). No data (ND) for South Samoa, Ten Mile North, and Ten Mile during year 1. Beaches arranged from north to south along the horizontal axis. ** indicates MPAs*

Relative abundance of redtail surfperch was variable among sampling sites and years. However, within a year, their relative abundances at reference sites were mostly similar to their respective MPAs. Mean total length was similar across all MPAs and paired reference sites across both sampling years. Mean total length of redtail surfperch in the Northern Bioregion was less in 2015 than in 2014, with an average decrease of 30 mm in size. Sex ratios were nearly balanced with few exceptions. More male redtail surfperch were caught than females at Gold Bluffs Beach in 2014. However, this result is likely due to the small sample size (n = 7) and limited beach access during that year.

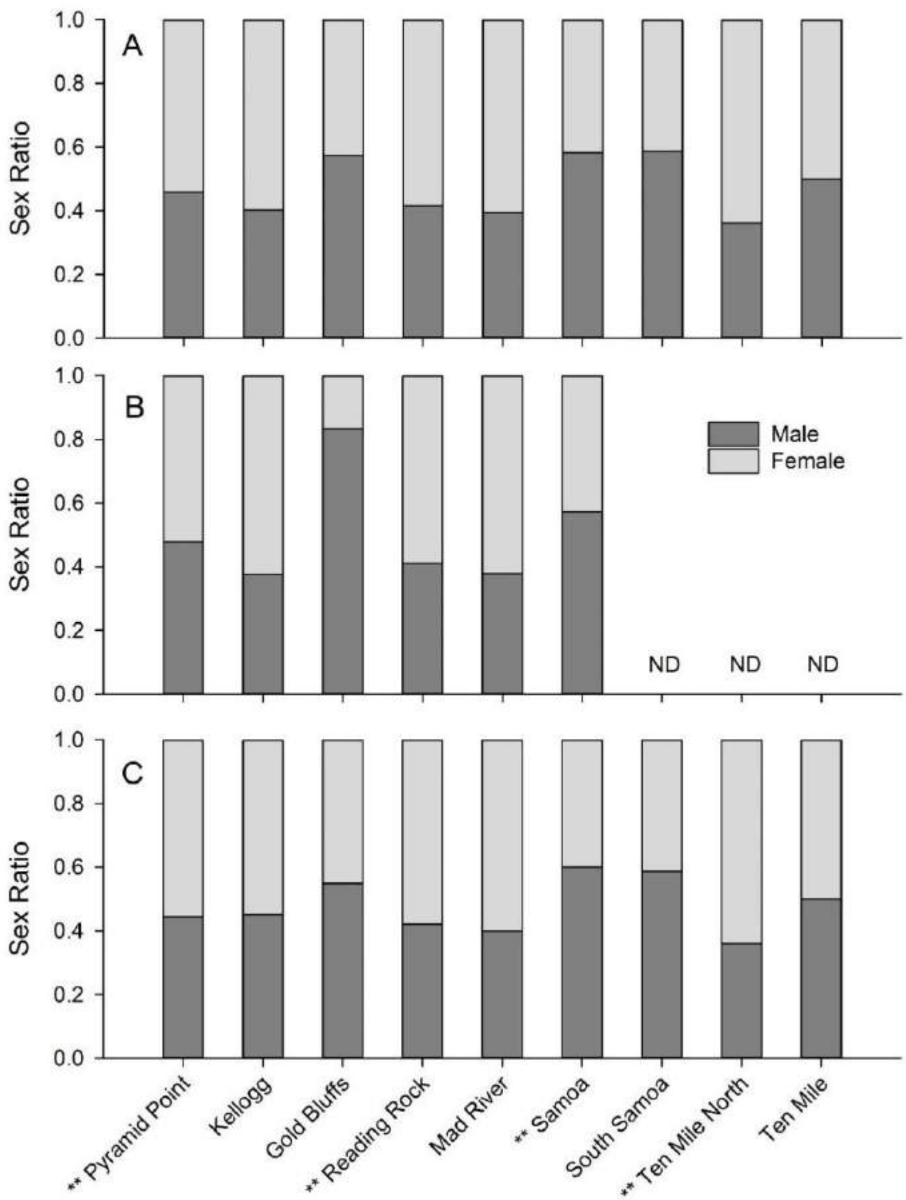

Figure 38. Sex ratios of redtail surfperch caught at North Coast MPAs and reference sites for A) combined years 1 and 2 (2014, 2015), B) year 1 and C) year 2. No data (ND) for South Samoa, Ten Mile North, and Ten Mile during year 1. Beaches arranged from north to south along the horizontal axis. ** indicates MPAs.

Interannual variability in relative abundance may partially be due to changes in our team's beach access across sampling years, exemplified by the differences in Gold Bluffs relative abundance between sampling years. Due to restricted beach access during year 1 (no beach-driving privileges), Gold Bluffs did not include the entire stretch of beach as compared to sampling at other sites, or during year 2 at Gold Bluffs, consequently impacting our results (Table 7).

Table 7. Comparison of year 1 and 2 (2014, 2015) sampling effort and mean catch-per-unit-effort (CPUE) at Gold Bluffs. Year 1 sampling had limited (no vehicle access) beach access, whereas year 2 sampling had greatly increased access due to beach driving permits. Sampling effort is total angler hours and CPUE is total catch divided by total angler hours.

Sampling year	Sampling effort	Mean CPUE
Year 1	43	0.15
Year 2	40	1.61

These results, as well as our sampling methods that mimic the gear and techniques used by local anglers in the Northern Bioregion, are reflective of the redtail surfperch-dominated catch of the Northern California surfperch recreational and commercial fisheries.

4.2.2 Diet analysis

A total of 261 redtail surfperch were sampled for diet analysis. Of these, 15 had empty guts; therefore, the diet analysis is based on 246 guts containing prey items. The sample was comprised of 65 fish from Kellogg Beach (KB), 55 from Gold Bluffs Beach (GBB), 104 from Mad River Beach (MR) and 22 from Ten Mile (TM) collected in 2014 and 2015. Twenty-one of the fish from TM were collected in one sample, in June 2015. Samples from both years were pooled for analysis. Because redtail surfperch grind food with their pharyngeal teeth, prey items are usually fragmented and mixed. To facilitate identification and enumeration, the contents of short sections of gut were processed separately.

Four basic measures of dietary composition for all food item categories are presented in Table 8- Table 12. When all sites are combined (Table 8), sand crabs (*E. analoga*) account for 67.9 percent by weight of the total dietary intake for redtail surfperch. They are the most dominant prey by weight at each of the four sites (Table 9 - Table 12). At MR, sand crabs were the most dominant prey item both numerically and by weight (60.8 % and 80.3 %, respectively). A small number of unidentifiable exogenous items are not included in the tables. The category of 'Crustacean Exoskeleton' includes exoskeletal fragments that could not be reliably categorized further; most are probably isolated fragments of sand crabs and shrimp.

The most abundant item overall was fish eggs, almost all of which were smelt eggs. Fish egg was the numerically dominant category at the two northern sites, KB and GBB. When large numbers of fish eggs were ingested, large amounts of fine gravel usually co-occurred in the gut. No fish eggs were found in the guts of fish at the two southern sites, MR and TM.

Invertebrate eggs numerically ranked third overall and second at MR. This ranking is due to ingestion of a relatively small number of egg masses, rather than large numbers of individual eggs. Shrimp and annelid worms were found in stomachs from all sites. Large numbers of female shrimp and sand crabs, which were carrying masses of eggs, were found in stomachs during the study. These eggs were weighed with the adults and their presence was noted but they were not enumerated.

Table 8. Abundance and weight of major dietary groups for redtail surfperch caught at four northern California reference sites: Kellogg, Gold Bluffs, Mad River and Ten Mile, collected in 2014 and 2015 (n=246).

Prey item	Number	% Number	Weight (g)	% Weight
Fish Egg	3440	48.87	4.5783	0.50
Sand Crab	1866	26.51	617.5288	67.93
Invertebrate Egg	591	8.40	3.0455	0.34
Amphipod	307	4.36	5.1703	0.57
Barnacle, Acorn	303	4.30	45.0788	4.96
Worm	153	2.17	14.5019	1.60
Crus. Exoskeleton	89	1.26	20.8528	2.29
Shrimp	77	1.09	61.5419	6.77
Microcrustacea	54	0.77	1.1268	0.12
Barnacle, Stalked	37	0.53	2.2292	0.25
Fish	27	0.38	65.8019	7.24
Unidentified	25	0.36	5.6836	0.63
Echinoderm	21	0.30	37.1261	4.08
Crab	17	0.24	20.4135	2.25
Isopod	11	0.16	0.1841	0.02
Mussel	11	0.16	0.2487	0.03
Salp	5	0.07	3.8563	0.42
Nematode	2	0.03	0.0048	0.00
Snail	2	0.03	0.0042	0.00
Spider	1	0.01	0.0421	0.00

Table 9. Abundance and weight of major dietary groups for redtail surfperch caught at Kellogg Beach, collected in 2014 and 2015 (n = 65).

Prey item	Number	% Number	Weight (g)	% Weight
Fish Egg	2643	71.57	3.4224	1.79
Sand Crab	444	12.02	83.8587	43.93
Barnacle, Acorn	269	7.28	40.7560	21.35
Invertebrate Egg	101	2.73	0.0431	0.02
Worm	72	1.95	2.2925	1.20
Microcrustacea	42	1.14	1.0729	0.56
Shrimp	26	0.70	19.9870	10.47
Crus. Exoskeleton	26	0.70	4.0791	2.14
Amphipod	24	0.65	0.0643	0.03
Unidentified	14	0.38	2.5980	1.36
Echinoderm	8	0.22	14.4981	7.59
Fish	7	0.19	12.0340	6.30
Mussel	6	0.16	0.0317	0.02
Crab	5	0.14	6.0697	3.18
Isopod	2	0.05	0.0419	0.02
Snail	2	0.05	0.0042	0.00
Spider	1	0.03	0.0421	0.02
Nematode	1	0.03	0.0022	0.00

Table 10. Abundance and weight of major dietary groups for redtail surfperch caught at Gold Bluffs Beach, collected in 2014 and 2015 (n = 55).

Prey item	Number	% Number	Weight (g)	% Weight
Fish Egg	797	67.20	1.1559	0.57
Sand Crab	226	19.06	117.5022	58.15
Barnacle, Stalked	37	3.12	2.2292	1.10
Shrimp	31	2.61	24.8830	12.31
Barnacle, Acorn	31	2.61	4.1275	2.04
Amphipod	22	1.85	0.1777	0.09
Fish	18	1.52	49.7352	24.61
Crus. Exoskeleton	8	0.67	0.8066	0.40
Worm	8	0.67	0.5875	0.29
Unidentified	3	0.25	0.4841	0.24
Crab	1	0.08	0.3633	0.18
Mussel	1	0.08	0.0177	0.01
Nematode	1	0.08	0.0026	0.00
Invertebrate Egg	1	0.08	0.0001	0.00
Microcrustacea	1	0.08	0.0001	0.00

Table 11. Abundance and weight of major dietary groups for redtail surfperch caught at Mad River, collected in 2014 and 2015 (n = 104).

Prey item	Number	% Number	Weight (g)	% Weight
Sand Crab	1071	60.82	366.0076	80.29
Invertebrate Egg	401	22.77	2.9951	0.66
Amphipod	118	6.70	0.2193	0.05
Worm	72	4.09	11.6099	2.55
Crus. Exoskeleton	46	2.61	13.5899	2.98
Echinoderm	12	0.68	22.6240	4.96
Shrimp	11	0.62	14.2576	3.13
Crab	11	0.62	13.9805	3.07
Salp	5	0.28	3.8563	0.85
Unidentified	5	0.28	2.4898	0.55
Barnacle, Acorn	3	0.17	0.1953	0.04
Isopod	3	0.17	0.0145	0.00
Fish	2	0.11	4.0327	0.88
Microcrustacea	1	0.06	0.0030	0.00

Table 12. Abundance and weight of major dietary groups for redtail surfperch caught at Ten Mile, collected in 2015 (n = 22).

Prey item	Number	% Number	Weight (g)	% Weight
Amphipod	143	35.93	4.7090	7.83
Sand Crab	125	31.41	50.1603	83.36
Invertebrate Egg	88	22.11	0.0072	0.01
Microcrustacea	10	2.51	0.0508	0.08
Shrimp	9	2.26	2.4143	4.01
Crus. Exoskeleton	9	2.26	2.3772	3.95
Isopod	6	1.51	0.1277	0.21
Mussel	4	1.01	0.1993	0.33
Unidentified	3	0.75	0.1117	0.19
Worm	1	0.25	0.0120	0.02

Two additional measures of dietary importance, percent frequency of occurrence and index of relative importance, were calculated for all sites combined (Table 13) and for each site separately (Table 14 - Table 17, Figure 39). Overall, sand crabs were found most often (75.2 % of 246 stomachs) and had an IRI of 7102, compared to the next highest IRI item, fish eggs (IRI = 502), which were found in only 10 % of stomachs. Shrimp was the only other taxon with an overall IRI of greater than 100. Sand crabs were the only important prey item at MR (IRI = 12,075) with unidentified 'Crustacean Exoskeletons' being the only other category with an IRI over 100 at that site. At the two northern sites, sand crabs were the dominant prey item (KB, IRI = 3185; GBB, IRI = 5615) and fish eggs were the next most important (KB, IRI = 1806; GBB, IRI = 1109). At both of these northern sites, barnacles were an important prey item on a sporadic basis. Sand crabs were again the most important prey category at TM (IRI = 9912), while amphipods were the second most dominant item, occurring in 63.6% of stomachs (IRI = 2784).

Table 13. Number of stomachs containing a specific dietary item, % Frequency of Occurrence, and Index of Relative Importance (IRI) values for major dietary groups for redtail surfperch caught at four northern California reference sites: Kellogg, Gold Bluffs, Mad River and Ten Mile, collected in 2014 and 2015 (n = 246).

Prey item	Number stomach	% Frequency of	Index of relative
Sand Crab	185	75.203	7102.4165
Fish Egg	25	10.163	501.7706
Shrimp	57	23.171	182.2157
Amphipod	37	15.041	74.1533
Crus. Exoskeleton	49	19.919	70.8781
Fish	20	8.130	61.9704
Worm	24	9.756	36.7701
Barnacle, Acorn	9	3.659	33.8914
Echinoderm	18	7.317	32.0673
Invertebrate Egg	7	2.846	24.8446
Crab	14	5.691	14.1546
Microcrustacea	6	2.439	2.1734
Barnacle, Stalked	6	2.439	1.8802
Isopod	8	3.252	0.5741
Salp	2	0.813	0.4026
Mussel	3	1.220	0.2239
Nematode	2	0.813	0.0235
Snail	1	0.407	0.0117
Spider	1	0.407	0.0077

Table 14. Number of stomachs containing a specific dietary item, % Frequency of Occurrence, and Index of Relative Importance (IRI) values for major dietary groups for redtail surfperch caught at Kellogg, collected in 2014 and 2015 (n = 65).

Prey item	Number stomach	% Frequency of	Index of relative
Sand Crab	37	56.923	3184.9205
Fish Egg	16	24.615	1805.7999
Shrimp	22	33.846	378.1979
Barnacle, Acorn	4	6.154	176.2073
Echinoderm	8	12.308	96.1393
Fish	7	10.769	69.9294
Crus. Exoskeleton	13	20.000	56.8166
Worm	8	12.308	38.7759
Crab	4	6.154	20.3997
Invertebrate Egg	2	3.077	8.4846
Amphipod	8	12.308	8.4131
Microcrustacea	3	4.615	7.8430
Mussel	1	1.538	0.2755
Isopod	2	3.077	0.2342
Snail	1	1.538	0.0867
Spider	1	1.538	0.0756
Nematode	1	1.538	0.0434

Table 15. Number of stomachs containing a specific dietary item, % Frequency of Occurrence, and Index of Relative Importance (IRI) values for major dietary groups for redtail surfperch caught at Gold Bluffs, collected in 2014 and 2015 (n = 55).

Prey item	Number stomach	% Frequency of	Index of relative
Sand Crab	40	72.727	5614.8456
Fish Egg	9	16.364	1109.0078
Shrimp	20	36.364	542.8259
Fish	11	20.000	522.6047
Barnacle, Stalked	6	10.909	46.0680
Amphipod	8	14.545	28.2606
Barnacle, Acorn	3	5.455	25.3986
Crus. Exoskeleton	6	10.909	11.7131
Worm	5	9.091	8.7752
Crab	1	1.818	0.4802
Mussel	1	1.818	0.1692
Nematode	1	1.818	0.1556
Invertebrate Egg	1	1.818	0.1534
Microcrustacea	1	1.818	0.1534

Table 16. Number of stomachs containing a specific dietary item, % Frequency of Occurrence, and Index of Relative Importance (IRI) values for major dietary groups for redtail surfperch caught at Mad River, collected in 2014 and 2015 (n = 104).

Prey item	Number stomach	% Frequency of	Index of relative
Sand Crab	89	85.577	12075.2857
Crus. Exoskeleton	23	22.115	123.6959
Invertebrate Egg	3	2.885	67.5812
Worm	10	9.615	63.8011
Echinoderm	10	9.615	54.2711
Amphipod	7	6.731	45.4249
Shrimp	10	9.615	36.0785
Crab	9	8.654	31.9446
Salp	2	1.923	2.1728
Fish	2	1.923	1.9196
Isopod	3	2.885	0.5006
Barnacle, Acorn	2	1.923	0.4100
Microcrustacea	1	0.962	0.0552

Table 17. Number of stomachs containing a specific dietary item, % Frequency of Occurrence, and Index of Relative Importance (IRI) values for major dietary groups for redtail surfperch caught at Ten Mile, collected in 2015 (n = 22).

Prey item	Number stomach	% Frequency of	Index of relative
Sand Crab	19	86.364	9912.1298
Amphipod	14	63.636	2784.4646
Crus. Exoskeleton	7	31.818	197.6592
Shrimp	5	22.727	142.5865
Invertebrate Egg	1	4.545	100.5569
Isopod	3	13.636	23.4514
Microcrustacea	1	4.545	11.8045
Mussel	1	4.545	6.0739
Worm	1	4.545	1.2327

When IRI was compared among size classes of fish, sand crabs were the dominant prey item among all size classes of fish at all sites (Figure 40, Figure 41). At KB, fish eggs were important to small and medium sized fish while barnacles were important in the diet of larger fish. For medium sized fish at KB, fish eggs were nearly as important as sand crabs (fish eggs, % IRI = 43; sand crabs, % IRI = 45). At GBB, fish eggs were again important among small and medium fish while fish were an important prey item for larger redtails. All sizes of fish at MR fed almost exclusively on sand crabs. At TM, the only important prey item other than sand crabs, among all three size classes of fish, were amphipods.

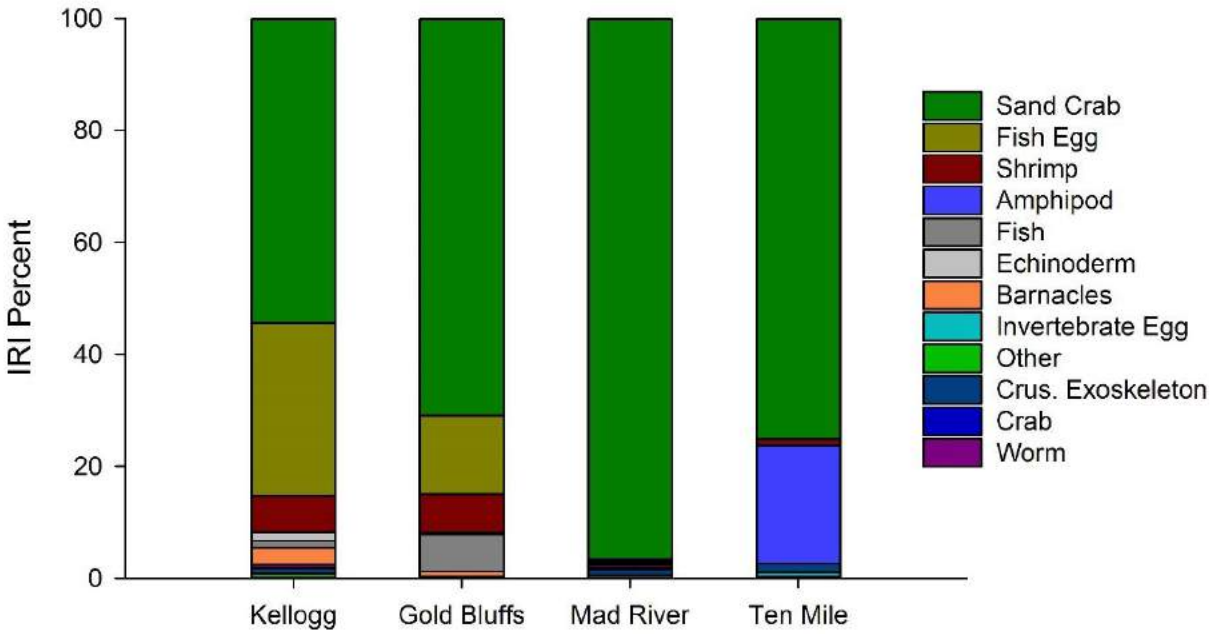

Figure 39. Index of relative importance (IRI) values of major dietary groups for redtail surfperch caught at four northern California reference sites collected in 2014 and 2015 (n = 246). IRI values are normalized to 100% for each site. Diet categories with IRI < 25 at a site were reclassified as 'Other'.

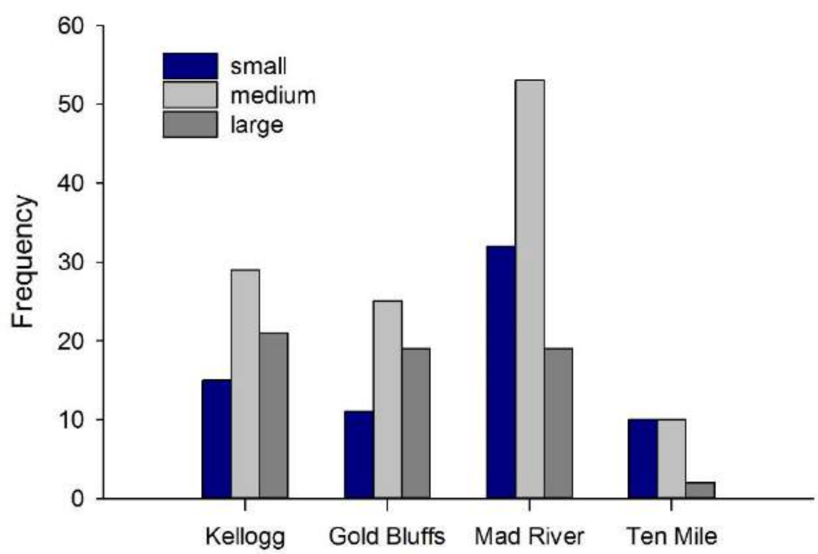

Figure 40. Standard length frequencies of redtail surfperch used in diet analysis. Fish were caught at four northern California reference sites in 2014 and 2015. Size classes are: small (<170 mm SL), medium (170 mm ≤ SL ≤ 220mm) and large (>220 mm SL) (n = 246).

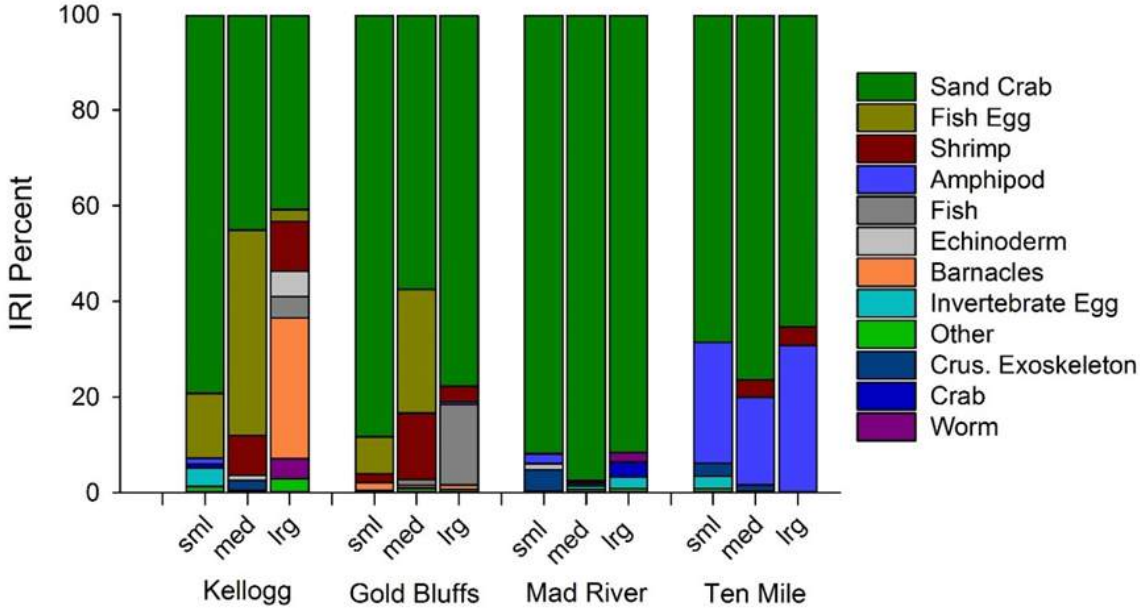

Figure 41. Index of relative importance (IRI) values of major dietary groups for redtail surfperch caught at four northern California reference sites collected in 2014 and 2015. Size classes are: small (<170 mm SL), medium (170 mm ≤ SL ≤ 220mm) and large (>220 mm SL). IRI values are normalized to 100% for each site / size class combination. Diet categories with IRI<50 within a site/size class combination were reclassified as Other (n = 246).

When all sites are combined (Table 8), sand crabs were the most dominant prey taxon, accounting for 67.9 % by weight of the total dietary intake and 26.5 % of the total number of prey items. They were found in 75 % of the 246 stomachs sampled (Table 13). The Index of Relative Importance (IRI), which helps balance the relative contributions of size and abundance of dietary items, reflects this importance; the overall IRI for sand crabs is more than an order of magnitude larger that the next most dominant dietary group, fish eggs.

Based on IRI values, sand crabs were the dominant prey items at all four sites, with fish at MR feeding almost exclusively on them (Table 14-Table 17, Figure 39). At all sites, fish in all three size classes fed predominantly on sand crabs (Figure 40). Small fish ate smaller sand crabs, while large fish consumed larger sand crabs, often females with egg masses. However, during times when small sand crabs were present, bigger fish often consumed large numbers of smaller individuals.

While many baits including sand crabs, marine worms, night crawlers, shrimp, mussels, clams and artificial "gulp worms" have been suggested for catching redtail surfperch, few studies have specifically addressed their feeding habits. Although previous studies have reported that they feed on small crustaceans and finfish, including sand lances, (Bennett and Wydoski 1977, CDFW 2013) none have indicated the overwhelming preference for sand crabs noted in our study. Bennett (1971) also reported redtail surfperch feeding on *E. analoga* along the Oregon Coast. However, he categorized them with crabs and shrimp as unspecified decapods, so their relative importance in that study is unknown. While it appears that many local fishers prefer artificial worms as bait for redtail surfperch, because of their relative convenience, many argue that large sand crabs are a preferred bait, especially for catching the larger fish.

Fish eggs were the most abundant food item overall (Table 8). The IRI possibly overestimates the importance of these very small (~1.0 mm) eggs due to their extreme abundance; conversely, the energy density of the fish eggs is relatively high. Virtually all of the fish eggs appeared to be smelt eggs, many with early embryos. Fish eggs were the numerically dominant category at the two northern sites, KB and GBB, but were not found in fish from MR and TM (Table 9 - Table 12).

GBB is locally recognized as the most important beach for commercial smelt fishing due to consistent spawning activity. As noted in the benthic invertebrate studies presented in this report, fish eggs were found in benthic cores from KB and GBB, but not from the two more southern sites (Figure 24, Figure 26). When guts contained large numbers of fish eggs, they also contained large amounts of small gravel indicating that the fish ingested both eggs and spawning substrate. Similarly at all sites, when worm remains were found, the fish had often taken in large amounts of sand, also indicating benthic feeding.

The two northern sites also showed the most diversity in diet (Table 14, Table 17, Figure 39). Both Kellogg Beach and Gold Bluffs Beach are more diverse habitats, with patchy rocky reefs occurring in the surf zone. Fish at KB and GBB sporadically ingested large numbers of barnacles. Overall, shrimp were found in almost 25% of stomachs (Table 13) and were fairly common at all sites. Their dietary importance is probably underestimated because they are relatively fragile and are broken down and digested rapidly, leaving little but exoskeleton in most cases.

Fish were found in KB and GBB stomachs (11 and 20 % Frequency of Occurrence, respectively) while two occurred in MR guts and none were found in TM guts. Most fish were found in the guts of large fish. Fish are an energy rich dietary item and their importance is probably somewhat underestimated because they are also easily digested. In many cases, skeletal elements were the major remnant of ingested fish. Some small fish were eaten and these, when identifiable, were smelt. Interestingly, in many cases, the fish remnants were definitely pieces of cut bait.

Amphipods ranked fourth in overall IRI, but were a relatively minor dietary component at all sites other than TM (Table 13, Table 17, Figure 39). At KB and GBB, small amphipods were infrequently taken, apparently often adventitiously, by fish feeding on larger prey. At MB, one small fish (100 mm SL) contained 100 of the 118 amphipods recorded from that site. The importance of amphipods in the diet of the TM fish may be due, at least in part, to the restricted sample from TM. Not only were 21 of the 22 fish collected in a single sample (June 2015), but 20 of the 22 specimens were small or medium fish. At TM, amphipods were an important prey item for redtail in all three size classes, although only one of the two large fish contained amphipods. The other large fish, which had not fed on amphipods, was collected September 2015. This fact suggests that temporal variation may exist in the degree to which TM fish prey upon amphipods. The lack of large redtail in the TM sample may also account for the complete absence of fish in guts from this site.

The ‘crab’ category is somewhat misleading. Only one small crab, which was ingested whole, was found. Interestingly, two fish had ingested several, fresh, energy-rich, egg-bearing pleiopods from large crabs. The rest of the crab category consists mainly of leg pieces and occasional carapace fragments from large crabs. Most of these appeared so old and degraded, that it is most probable that they were scavenged on the beach. Frequently, items such as gravel, wood fragments, degraded vegetation and other types of debris had also been ingested by fish from all locations.

In summary, sand crabs were clearly the most dominant dietary component for redtail surfperch collected at the four northern California beaches. Fish from more heterogeneous environments appeared to have more diverse diets. Although these fish prefer sand crabs when they are available, they appear to be somewhat opportunistic at other times. They definitely forage on the bottom and appear to capture or scavenge both infaunal and epifaunal prey.

4.2.3 Night Smelt

Spawning aggregations of night smelt were observed on four of the five beaches surveyed in 2014 and on four of the nine beaches surveyed in 2015 (Table 18, Table 19). Relative abundance in 2014 was low at most sites, except for Gold Bluffs and during occasional sampling events at Kellogg Beach and Samoa SMCA (Table 18), where we encountered multiple Walker Scale level 5 spawning events (Figure 6), which consist of many thousands of fish completely covering stretches of beach over a 100-meter distance for an hour or more. No night smelt were seen at Mad River during this sampling year. During 2015, relative abundance was low across all sites (Table 19) with the largest recorded spawning events measuring three on the Walker Scale, which consists of hundreds of fish in one or more distinct locations scattered along the wave slope for short periods of time. Spawning aggregations of night smelt were absent from Pyramid Point SMCA, Mad River Beach, Ten Mile SMR, Ten Mile SMCA, and Ten Mile during all nights in which surveys took place.

*Table 18. Night smelt relative abundance, 2014. Values determined using the Walker Scale, ranging from zero (no fish on beach) to five (fish covering the beach). ** indicates MPAs.*

Sample Site	March	April	May	June	July	Aug
Kellogg	1	2	5	1	2	5
Gold Bluffs	5	4	5	4	4	4
Reading Rock **	1	1	2	1	2	1
Mad River	0	0	0	0	0	0
Samoa Dunes **	0	0	0	0	0	5

*Table 19. Night smelt relative abundance, 2015. Values determined using the Walker Scale, ranging from zero (no fish on beach) to five (fish covering the beach). ** indicates MPAs.*

Sample Site	May	June	July	Aug
Pyramid Point	-	0	0	0
Kellogg	2	-	0	0
Gold Bluffs	-	-	3	2, 2
Reading Rock **	-	-	1	0, 0
Mad River	0	0, 0	-	-
Samoa Dunes **	0	0, 3	-	-
Ten Mile North **	0	0	0	-
Ten Mile	0	0	0	-

Mean total length of male night smelt was greater than females ($F_{[1,1511]}=397.6$, $p < 0.01$) (Figure 42). Male mean length was greater at Kellogg Beach and Gold Bluffs than at Reading Rock ($F_{[3,1364]}=27.02$, $p < 0.01$) and Samoa Dunes ($F_{[3,1364]} = 27.02$, $p = 0.0126$) (Figure 43). This trend was also true for female night smelt, however the difference at Reading Rock was not quite significant (RR: $F_{[3,141]}$ =5.541, p = 0.06 ; SMD: $F_{[3,141]}$ = 5.541, p = 0.0129) (Figure 44). Male night smelt were larger in the 2014 sampling year than in 2015 ($F_{[1,1366]}$ = 33.49, p < 0.01) (Figure 43), however, this annual difference was not significant in females. Both the longest (144 mm) and shortest (103 mm) male night smelt specimens collected over the course of the entire project were collected at Reading Rock SMCA in 2014 (Table 20). Similarly, both the longest (130 mm) and shortest (95 mm) female night smelt specimens collected over the course of the entire project were collected at Gold Bluffs Beach in 2014 (Table 21).

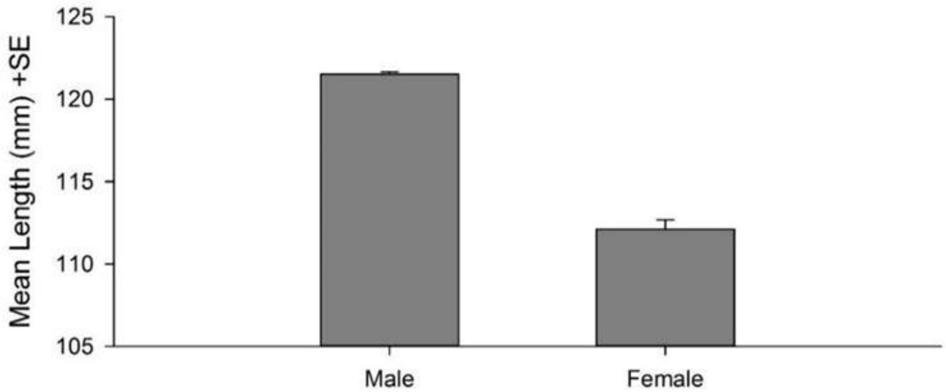

Figure 42. Mean total length of night smelt caught at North Coast MPAs and reference sites, 2014 and 2015. All data are averages (+SE).

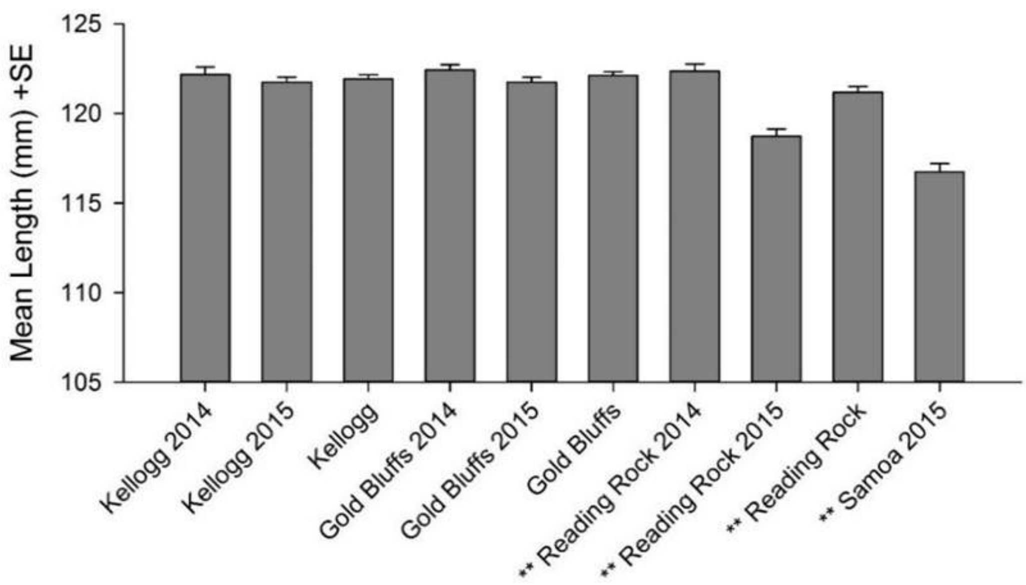

*Figure 43. Mean total length of male night smelt caught at North Coast MPAs and reference sites (2014, 2015). All data are averages (+SE). No data for Samoa during year 1. ** indicates MPAs.*

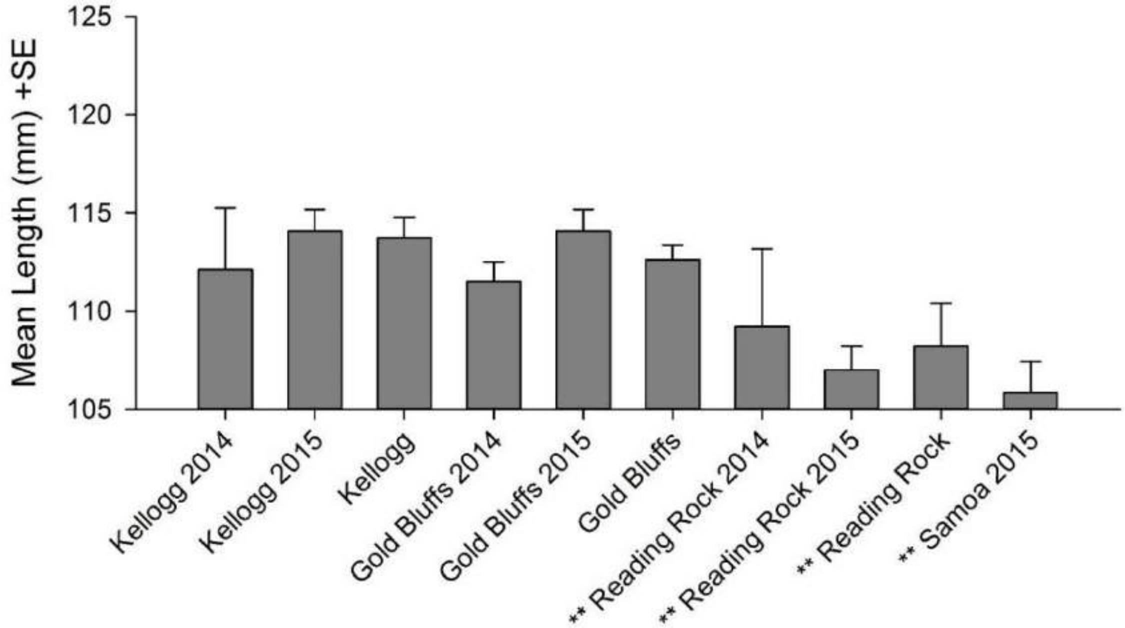

*Figure 44. Mean total length of female night smelt caught at North Coast MPAs and reference sites. All data are averages (+SE). No data for Samoa during year 1. ** indicates MPAs.*

*Table 20. Length characteristics of male night smelt collected in the North Coast region during years 1 (2014) and 2 (2015). ** indicates MPAs.*

Sample Site	Year	Min Length	Max Length	Mean Length	Standard Error	Sample Size (n)
Kellogg	2014	110	133	122.2	0.422	116
Kellogg	2015	110	138	121.7	0.275	265
Kellogg	Combined	110	138	121.8	0.230	381
Gold Bluffs	2014	106	140	122.4	0.305	302
Gold Bluffs	2015	110	138	121.7	0.275	265
Gold Bluffs	Combined	106	140	122.1	0.208	567
Reading Rock	2014	103	144	122.4	0.408	236
Reading Rock	2015	108	130	118.8	0.415	105
Reading Rock	Combined	103	144	121.2	0.323	341
Samoa **	2015	108	125	116.7	0.472	79

*Table 21. Length characteristics of female night smelt collected in the North Coast region during years 1 (2014) and 2 (2015). ** indicates MPAs.*

Sample Site	Year	Min Length (mm)	Max Length (mm)	Mean Length (mm)	Standard Error	Sample Size (n)
Kellogg	2014	100	127	112.1	3.125	8
Kellogg	2015	101	128	114.1	1.091	35
Kellogg	Combined	100	128	113.7	1.049	43
Gold Bluffs	2014	95	130	111.5	1.000	46
Gold Bluffs	2015	101	128	114.1	1.091	35
Gold Bluffs	Combined	95	130	112.6	0.748	81
Reading Rock **	2014	100	119	109.2	3.967	5
Reading Rock **	2015	104	110	107.0	1.225	4
Reading Rock **	Combined	100	119	108.2	2.184	9
Samoa **	2015	102	120	105.8	1.590	12

Male night smelt had a greater mean weight than female night smelt ($F_{[1,705]}$ = 183.1, $p < 0.01$) (Figure 45). In 2014, mean male weights were different across sampling sites ($F_{[2,645]}$ = 10.8, $p < 0.01$); mean weight of male night smelt collected at Gold Bluffs was significantly higher than those collected at either Kellogg Beach or Reading Rock SMCA (Table 22). Mean female weights did not differ across sites (Figure 46, Table 23). Both males and females tended to be larger at Gold Bluffs than at the other sites.

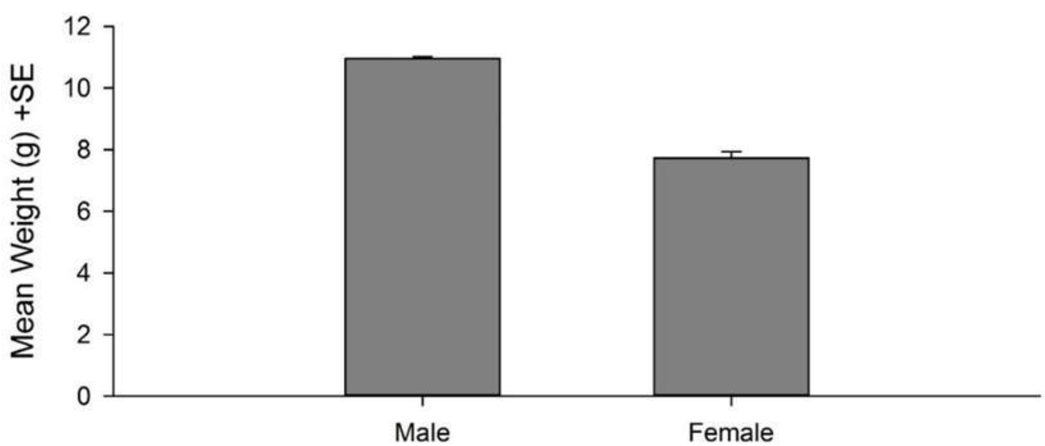

Figure 45. Mean weight of night smelt caught at North Coast MPAs and reference sites, 2014 and 2015. All data are averages (+SE).

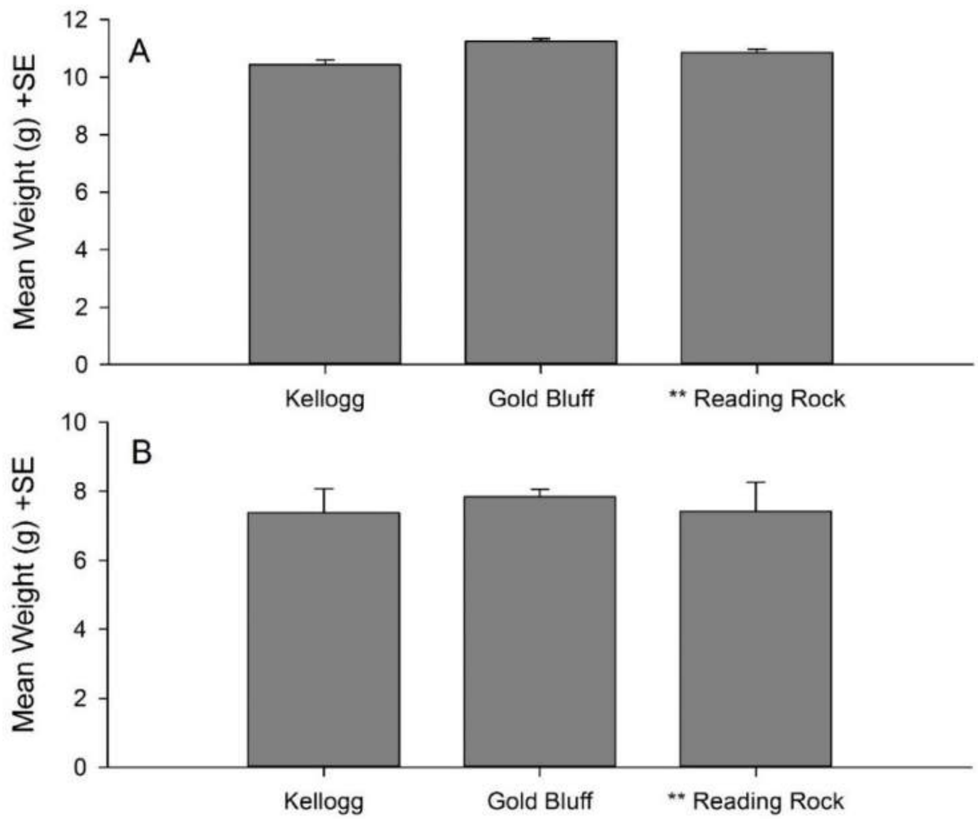

*Figure 46. Mean weight of A) male and B) female night smelt caught at North Coast MPAs and reference sites. All data are averages (+SE). ** indicates MPAs.*

*Table 22. Weight characteristics of male night smelt collected in the North Coast region during year 1 (2014). ** indicates MPAs.*

Sample Site	Min Weight (g)	Max Weight (g)	Mean Weight (g)	Standard Error	Sample Size (n)
Kellogg	6.3	15.2	10.4	0.174	131
Gold Bluffs	5.9	15.3	11.4	0.095	300
Reading Rock **	5.6	15.4	10.8	0.114	217

*Table 23. Weight characteristics of female night smelt collected in the North Coast region during year 1 (2014). ** indicates MPAs.*

Sample Site	Min Weight (g)	Max Weight (g)	Mean Weight (g)	Standard Error	Sample Size (n)
Kellogg	4.7	11.1	7.4	0.705	8
Gold Bluffs	5.2	12.2	7.8	0.230	46
Reading Rock **	5.7	9.5	7.4	0.838	5

Male fish heavily dominated all spawning populations of night smelt encountered (Table 24). The percentage of female night smelt in all samples collected varied between 4 % and 14 % with an average of 9 %. The highest percentage of females was present in August samples collected on Gold Bluffs Beach, though no clear seasonal trend or site-specific differences in sex ratio are evident.

Table 24. Sex ratio (Male : Female) of night smelt per 100 (male) fish collected in the North Coast region during year 2 (2015).

Sample Site	May	June	July	August
Kellogg	100 : 5	-	-	-
Gold Bluffs	-	-	100 : 7	100 : 14; 100 : 12
Reading Rock **	-	-	100 : 4	-
Samoa **	-	100 : 12	-	-

Relative abundance of spawning night smelt was variable among sample sites and years. We did not observe a single spawning event in the southern bioregion but did receive anecdotal reports from fisherman of multiple spawning events occurring on nearby beaches that we did not sample. The most spawning activity was observed on Gold Bluffs Beach. This beach was the only sample site where spawning fish were observed on all of the sampling trips and had the highest relative abundance of spawning night smelt both between and within years.

The distribution of spawning night smelt was extremely patchy on all beaches where night smelt were present, with only one or several dense aggregations of spawning fish nestled within vast stretches of beach on which fish were completely absent. Conspicuous annual variability in both presence/absence and relative abundance was observed over the course of the project, with significantly more spawning activity taking place in 2014. This observation is consistent with previous work that showed that spawning populations of night smelt consist primarily of 2-year old fish (Slama 1994) and that populations of short lived forage species respond rapidly to environmental variability (Pikitch et al. 2012). Both spawning site fidelity to a limited number of specific beaches and known annual fluctuations in abundance in response to environmental variability outside of marine reserves needs to be considered when determining the utility of night smelt abundance as a metric for long term monitoring of marine protected area performance.

Although this study does provide some basic baseline information on the length and weight of spawning populations of night smelt over a representative distribution of marine protected areas and reference sites in the North Coast MPA Study Region, the majority of sample sites produced a limited amount of data. This is particularly true with regard to female fish due to the limited number of sampling trips, low number of spawning events encountered at some sample sites, and highly skewed ratio of male to female fish. The sample sizes of females used for this baseline characterization was low throughout the study. This disparity in the number of females to males observed is consistent with previous studies showing that male fish largely dominate the spawning population (Slama 1994, Sweetnam et al. 2001). It also speaks to the potential need for more frequent sampling on beaches without reliably consistent spawning activity if length and weight characterization of the female portion of the population is desired for long term MPA monitoring. Recent work, however, has shown little indication that differences in size structure exist among beaches in northern California and alternatively show that fish lengths vary more over the course of the spawning season than across sampling sites (Collaborative Fisheries Research-West 2015).

Several features of the data collected during the course of this project are consistent with historical knowledge provided by local commercial night smelt fishermen. Fishermen reported observing a high degree of spatial and temporal variability in the relative abundance of spawning night smelt over the geographic range of our study area with some particular beaches being far more consistent than others as was demonstrated by our data. However, major changes in the abundance and distribution of spawning populations of night smelt have been observed on semi-decadal timescales. Spawning aggregations of night smelt of the frequency and magnitude now only found on Gold Bluffs Beach was common on Kellogg and Mad River Beaches in the early 1990's. During this time there were far more participants in the commercial fishery and landings were documented from a greater variety of beaches. Fishermen also reported observing little variability in the size of night smelt across beaches and years as well as relatively few females present in spawning aggregations. The latter observations are consistent with the data collected during this project. Due to the temporal and spatial variability in the data mentioned above, we recommend that this species is no longer be considered as an indicator for north coast sandy beach MPAs.

4.3 Birds

4.3.1 Species richness, composition and abundance

During the baseline study, 108 surveys were conducted on 12 beaches between September 2014 and May 2015. The eight long beaches (8 km total) and four pocket beaches (1.18 km total) were surveyed once a month for 9 months (Table 2, Table 3, Table 4). A total of 17,891 birds of 68 species were observed in the surveys, including 8,714 individuals of 20 species of shorebirds, 4,984 individuals of seven species of gulls and 3,559 individuals of 19 species of seabirds (Table A- 3). We also recorded 398 terrestrial birds of 11 species and 236 aquatic/wading birds of 11 species in our monthly surveys. On average we observed 217 birds km^{-1} mo^{-1} with averages of 106 shorebirds km^{-1} mo^{-1}, 60 gulls km^{-1} mo^{-1}, 43 seabirds km^{-1} mo^{-1}, 5 terrestrial birds km^{-1} mo^{-1}, and 3 aquatic/wading birds km^{-1} mo^{-1}.

Shorebirds and gulls were the most important groups, making up 76.6% of birds observed in the study. Overall composition of the birds observed in our surveys was 48.7% shorebirds, 27.9% gulls, 19.9% seabirds, 2.2% terrestrial birds, and 1.3% aquatic/wading birds. The mean number of species observed was nine species km^{-1} with two shorebird species km^{-1}, three gull species km^{-1}, two seabird species km^{-1}, one terrestrial species km^{-1} and one aquatic/wading species km^{-1}. Terrestrial and aquatic/wading birds were diverse (22 out of 70 species) but low in abundance (< 700 individuals observed out of 17,891 total observations).

There are limited prior peer-reviewed studies of shorebirds on the North coast; however, the abundance and richness of shorebirds during this study were considerably higher than that reported by Colwell and Sundeen (2000). During 160 surveys of 40 Humboldt and Del Norte beaches, Colwell and Sundeen (2000) found 12 shorebird species, a maximum richness of nine species, and an average abundance of 12 birds per 0.5 km. Their mean species richness was higher than those found during our surveys, with three species per 0.5 km, but they also had considerable variation (± 2 species). A potentially confounding factor is the difference in timing of the surveys between the two studies with respect to tidal cycles that affect the availability of some intertidal prey species to shorebirds. We constrained our surveys to low tide periods when shorebirds are actively foraging on beaches, while Colwell and Sundeen (2000) surveyed at a variety of different times during the tidal cycle

4.3.2 Temporal patterns

4.3.2.1 Shorebirds

Shorebird abundance exhibited a strong seasonal pattern (Figure 47). With the exception of three key locally breeding species, Black Oystercatcher, Western Snowy Plover, and Killdeer, most shorebirds observed in the study were species that nest in other regions during the summer. Peak shorebird abundance on long beaches occurred at Mad River in March 2015 with 3,000 individuals km^{-1} observed, and later peaks were seen at Samoa (April, 780 individuals km^{-1}) and Ten Mile (May, 603 individuals km^{-1}). Shorebirds were not common on pocket beaches, but similar to long beaches, we observed peak abundances during October and November and March through May, coinciding with fall and spring migration periods. The lowest number of shorebirds observed at the beaches in June corresponded to the breeding season for many species of shorebirds.

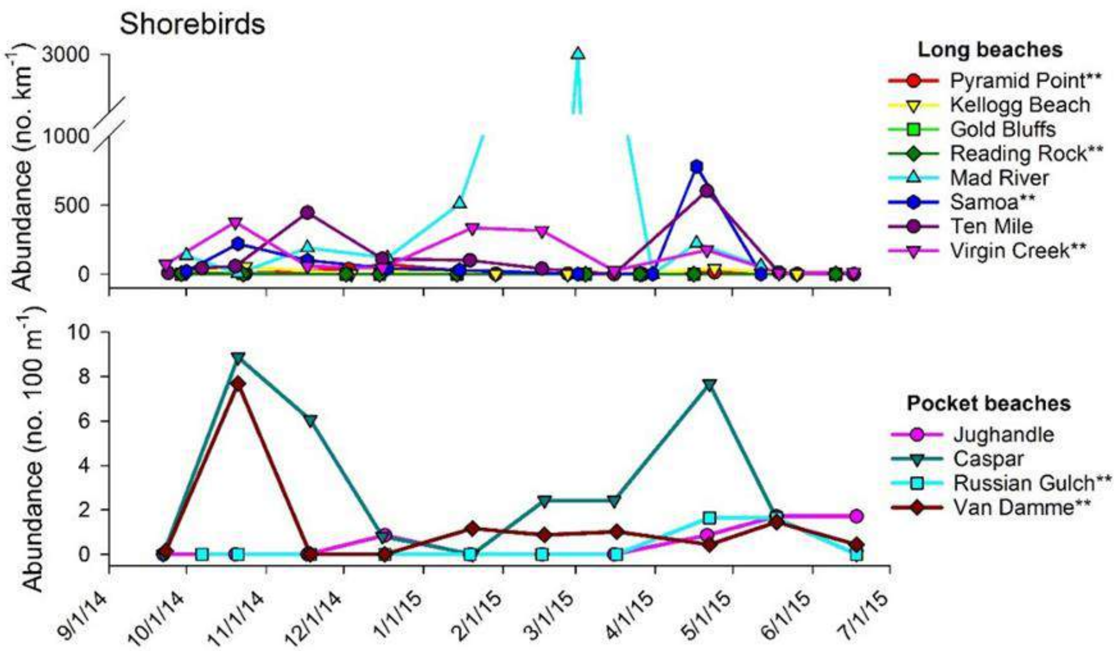

Figure 47. Seasonal variation in total abundance of shorebirds. All observations were made along a standard 1 km transect except at four pocket beaches where transect lengths ranged from 0.12 to 0.69 km (note difference in scale between the plots). Abundances were normalized to 100 m for all pocket beaches. Six of the 12 beaches surveyed were within MPAs (indicated by **).

4.3.2.2 Gulls

Gulls were the second most abundant type of bird observed in our surveys and their presence throughout the year was common, with the lowest abundances in April and May (Figure 48). Gull abundance on long beaches peaked in December 2014 at Reading Rock with 271 individuals km^{-1} observed. Other peaks were seen at Virgin Creek (September, 254 individuals km^{-1}), Samoa (January, 223 individuals km^{-1}) and Mad River (January, 236 individuals km^{-1}). It was common to see at least one to two gulls per pocket beach on any given month with the exception of Russian Gulch, which had no gulls during the November, January and February surveys. We observed an unusually large group of gulls at Caspar in February 2015 with 46 individuals per 100 m).

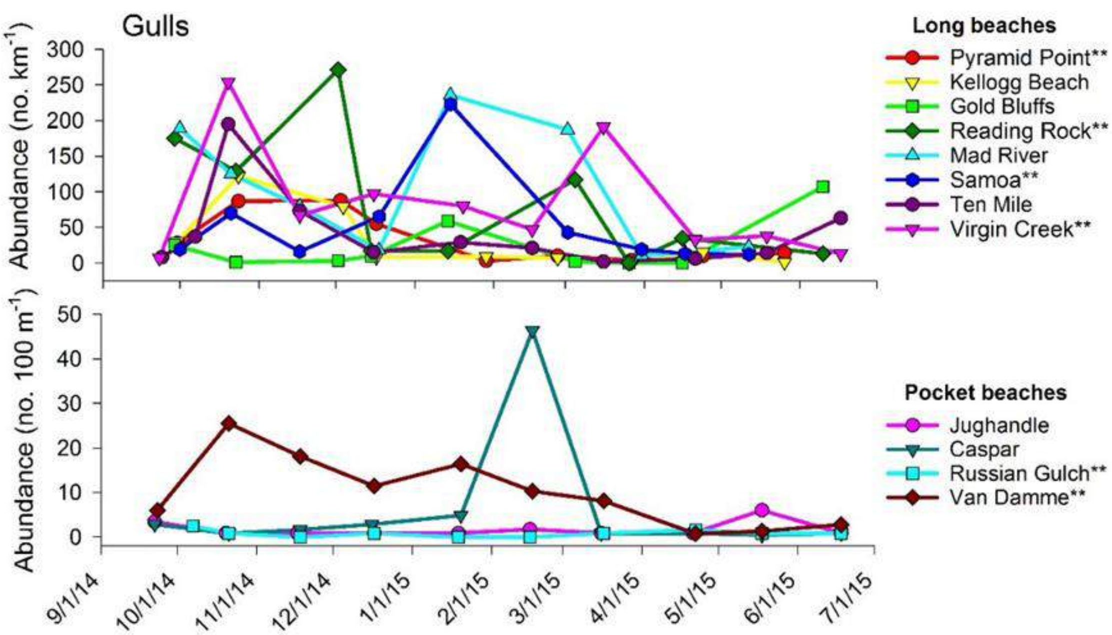

Figure 48. Seasonal variation in total gull abundance. All other information as in Figure 47.

4.3.2.3 Seabirds

Seabirds (operational defined here to include Surf Scoter, technically a sea duck, as they are commonly observed in the surf zone) were the third most abundant type of bird observed in the study. The abundance of seabirds observed in the nearshore waters of long beaches varied seasonally with a distinct peak in the fall months of September and October and lower numbers in the spring and summer (Figure 49). Seabird abundance observed from long beaches peaked in September 2014 at Reading Rock with 1,619 individuals km^{-1} observed. A second large peak was seen at Gold Bluffs in October with 488

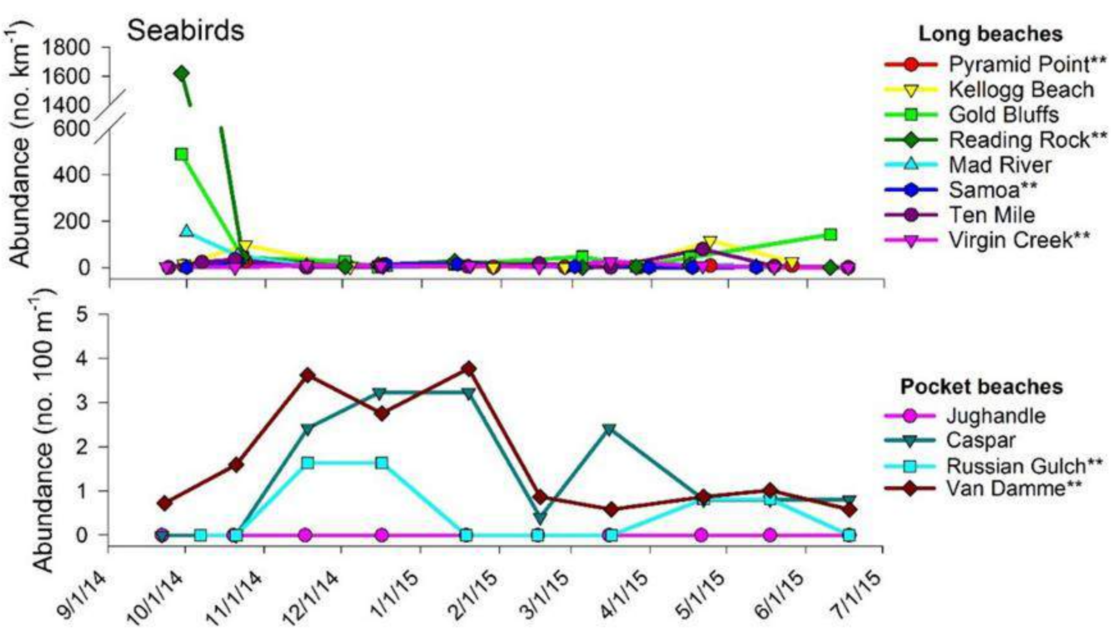

Figure 49. Seasonal variation in total seabird abundance. All other information as in Figure 47.

individuals km^{-1}. Seabirds were most common at pocket beaches from November through February, with the exception of Jug Handle where we never saw any seabirds.

4.3.2.4 Other birds

Peak abundances of terrestrial birds on long beaches varied with guild and season (Figure 50). American Crows and Ravens made up the majority of observations on long beaches during February and March. Insectivorous species, such as swallows and flycatchers, peaked in the summer months of May and June on long beaches (Figure 50).The peaks in abundance on pocket beaches during the summer months were also largely composed of Insectivorous species. The increased use of intertidal beach habitats by insectivorous birds at this time likely coincides with the typical Mediterranean summer dry season and a corresponding lack of insect prey in adjacent terrestrial habitats. These birds were primarily observed fly-catching on and around wrack deposits and feeding on other wrack-associated invertebrates. This observed use of beaches for foraging by resident breeding birds, as an example of a marine subsidy to terrestrial ecosystems, was also noted in the north central coast region. This subsidy could potentially be influenced by management actions, including MPA protection of adjacent habitats (e.g., kelp forests) that may indirectly influence the abundance of macrophyte wrack on beaches.

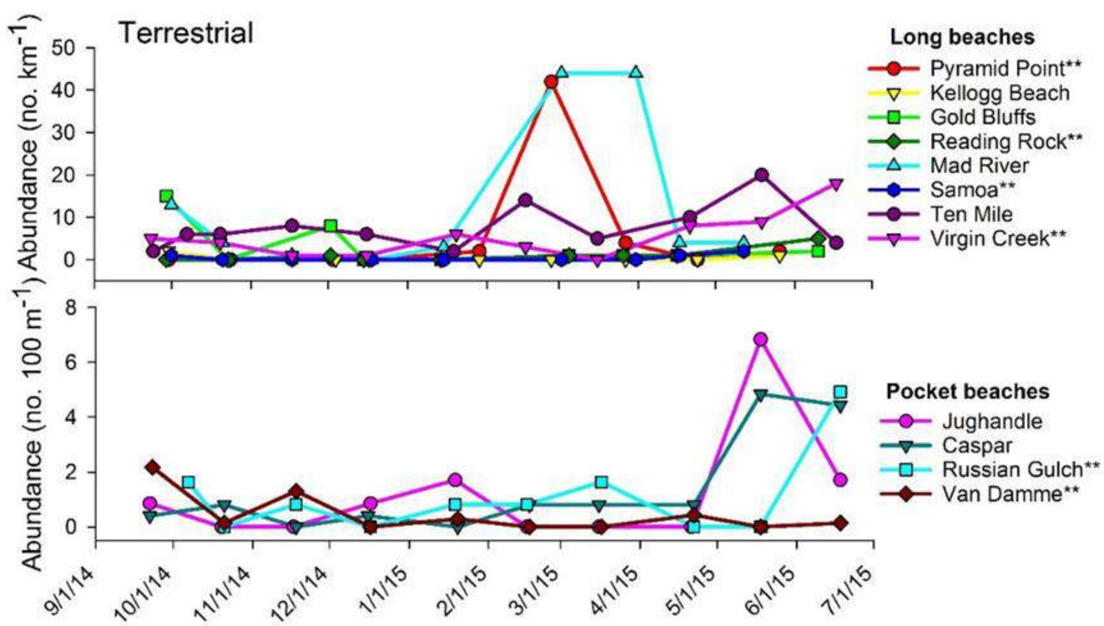

Figure 50. Seasonal variation in total abundance of terrestrial birds. All other information as in Figure 47.

Aquatic/wading birds and terrestrial birds were present year round but their abundance was much lower than shorebirds, gulls and seabirds in the baseline study (Figure 51). [Note however that Surf Scoter was assigned to the seabird grouping and could have been included here instead.] The abundance of aquatic/wading birds observed on the study beaches varied seasonally with the peak observation on a long beach at Kellogg with 40 individuals km^{-1} observed in May 2015, and the peak on a pocket beach at Caspar, with six individuals per 100 m observed in June 2015.

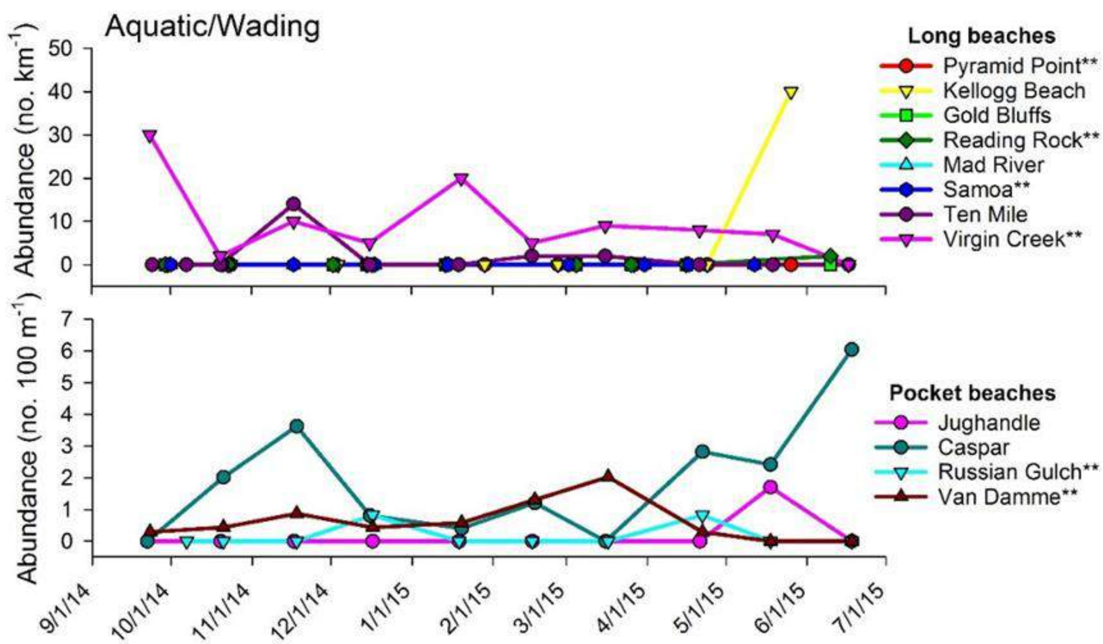

Figure 51. Seasonal variation in total abundance of aquatic/wading birds. All other information as in Figure 47.

4.3.3 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 eight northernmost beaches were long beaches (1 km or greater) that generally included more extensive back beach or dune habitat. This included the MPA sites of Pyramid Point, Reading Rock, Samoa and Virgin Creek and the reference sites of Kellogg Beach, Gold Bluffs, Mad River and Ten Mile. To the south of these beaches, we sampled four pocket beaches that varied from 0.12 km to 0.69 km in length and were embedded in rocky habitats. These beaches included the MPA sites of Russian Gulch and Van Damme and the reference sites of Jug Handle and Caspar.

4.3.3.1 Shorebirds

Spatial variation in shorebird abundance and distribution was evident within the two types of beaches (Figure 52). Mean abundance of shorebirds varied over three orders of magnitude among the eight long beaches, ranging from < 1 to 471 shorebirds km^{-1}). On the four pocket beaches the abundance of shorebirds was extremely low overall, ranging from < 1 to 3 birds per 100 m.

The highest mean number of shorebirds per beach (471 birds km^{-1}) was observed at Mad River (Figure 52). Mean numbers of shorebirds per beach also exceeded 100 birds km^{-1} at Samoa, Ten Mile and Virgin Creek. Very low mean numbers of shorebirds (< 1 bird km^{-1}) were observed at Reading Rock and Gold Bluffs. Similarly, the highest mean number of shorebirds observed at Caspar was three birds per 100 m. The four pocket beaches in our study supported relatively low numbers of shorebirds, with less than one per 100 m of shoreline.

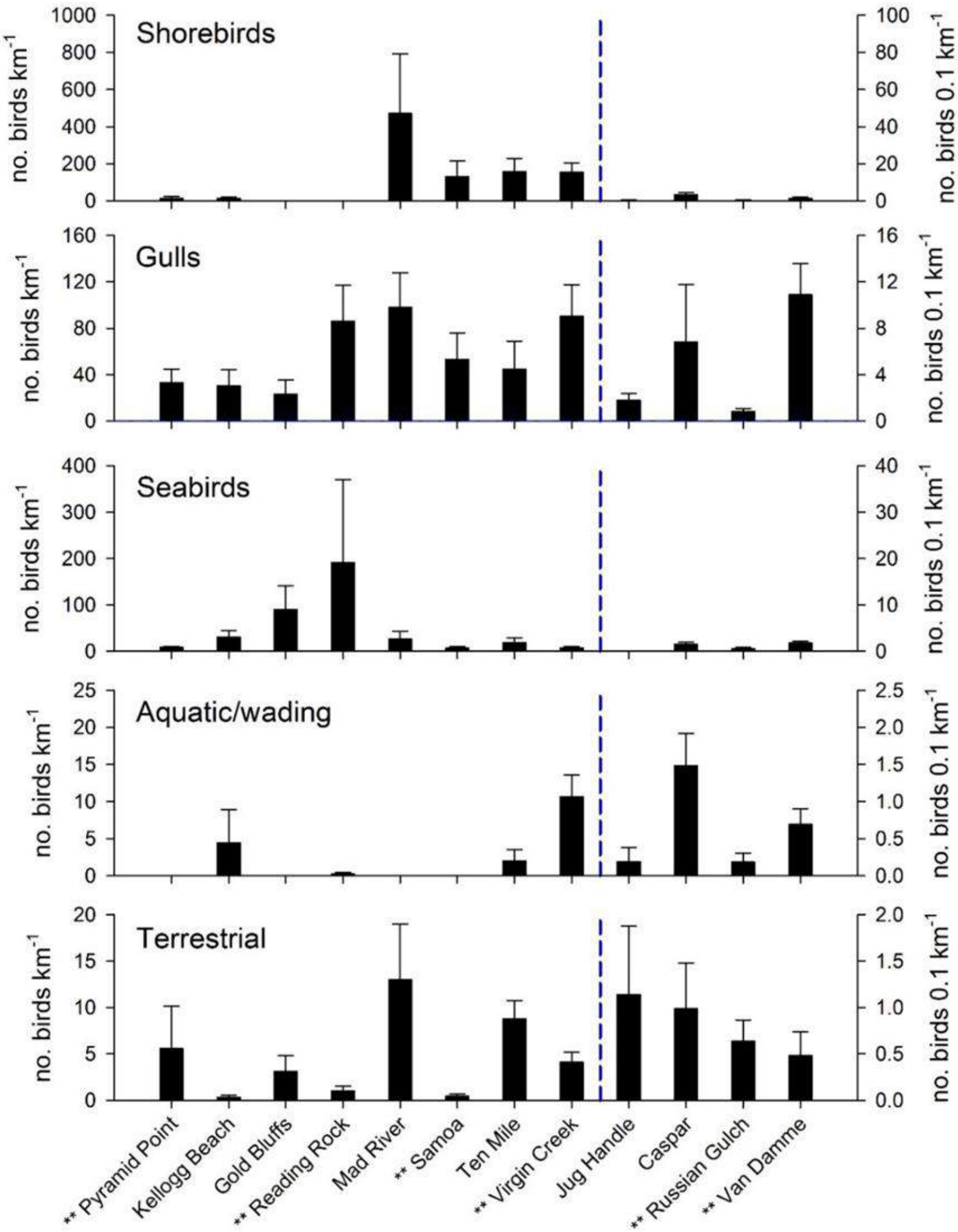

*Figure 52. Average abundance of shorebirds, gulls, seabirds, aquatic/wading birds and terrestrial birds observed at 12 beaches from 9 monthly surveys between September 2014 and May 2015. All observations were made along a standard 1 km transect except on pocket beaches where transect lengths were truncated to the length of the shoreline present (Jug Handle =0.12 km, Caspar = 0.25 km, Russian Gulch = 0.12 km & Van Damme = 0.69 km). Abundances were normalized to 0.1 km for all pocket beaches. Beaches are arranged from north to south along the horizontal axis within beach type (dashed line separates long from pocket beaches; note difference in axis scaling). Six of 12 the beaches surveyed were within MPAs (indicated by **). Six sites were surveyed in each of the two bioregions on either side of Cape Mendocino, with a large spatial gap of approximately 175 km between Ten Mile and Samoa.*

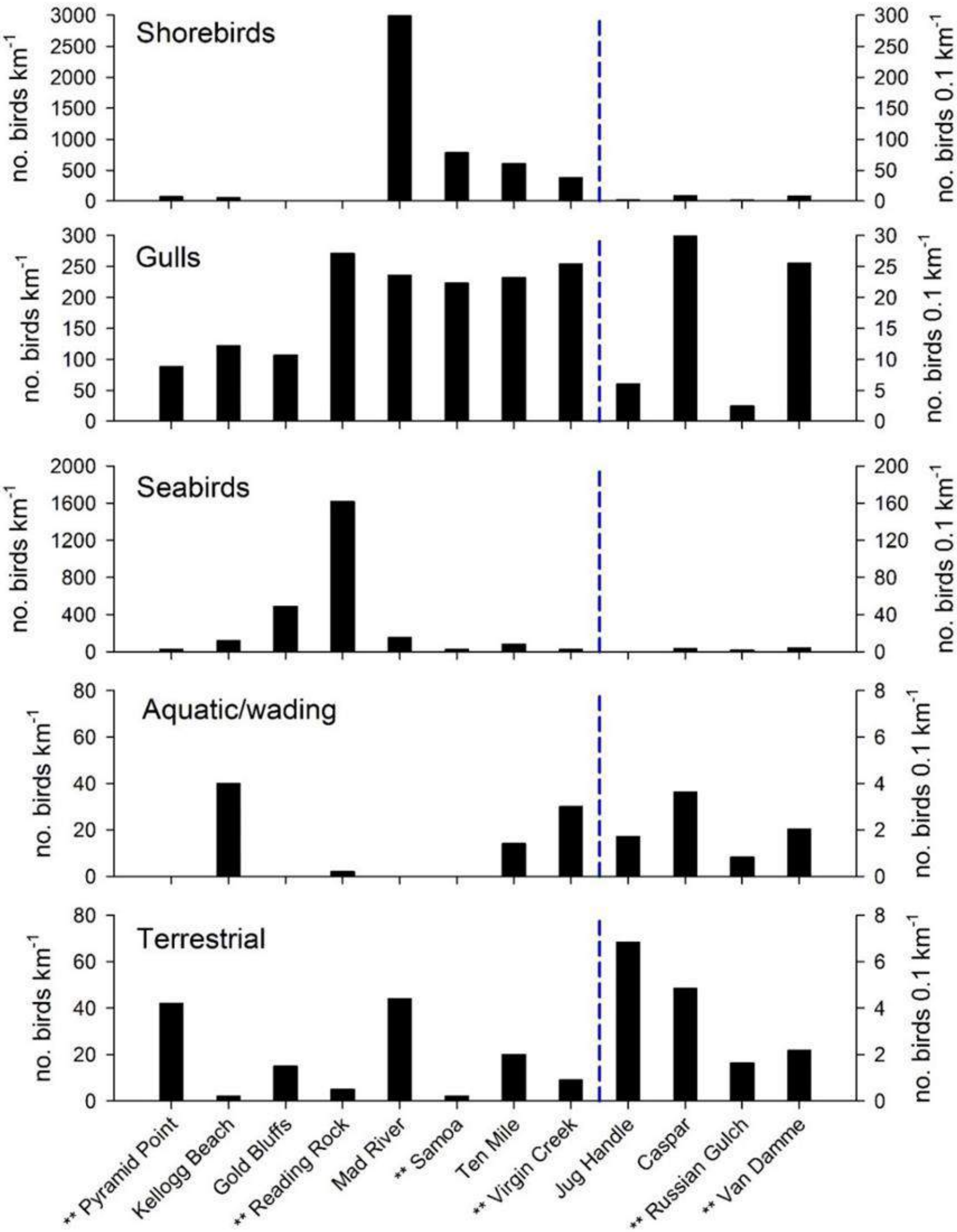

Figure 53. Peak abundances of shorebirds, gulls, seabirds, aquatic/wading birds and terrestrial birds observed at 12 beaches from 9 monthly surveys between September 2014 and May 2015. All other information as in Figure 53.

For the eight long beaches, the greatest peak abundance of shorebirds observed in a single survey was 3,000 birds km^{-1} at Mad River and the lowest peak abundance of shorebirds, two bird km^{-1}, was observed at Gold Bluffs (Figure 53). For the pocket beaches, the highest peak abundance of shorebirds, nine birds per 100 m, was observed at Caspar and the lowest peak abundance, two birds per 100 m, was observed at Russian Gulch.

Shorebirds were more abundant on reference beaches than MPA beaches for both long and pocket beaches, although variation was very high (Figure 54).

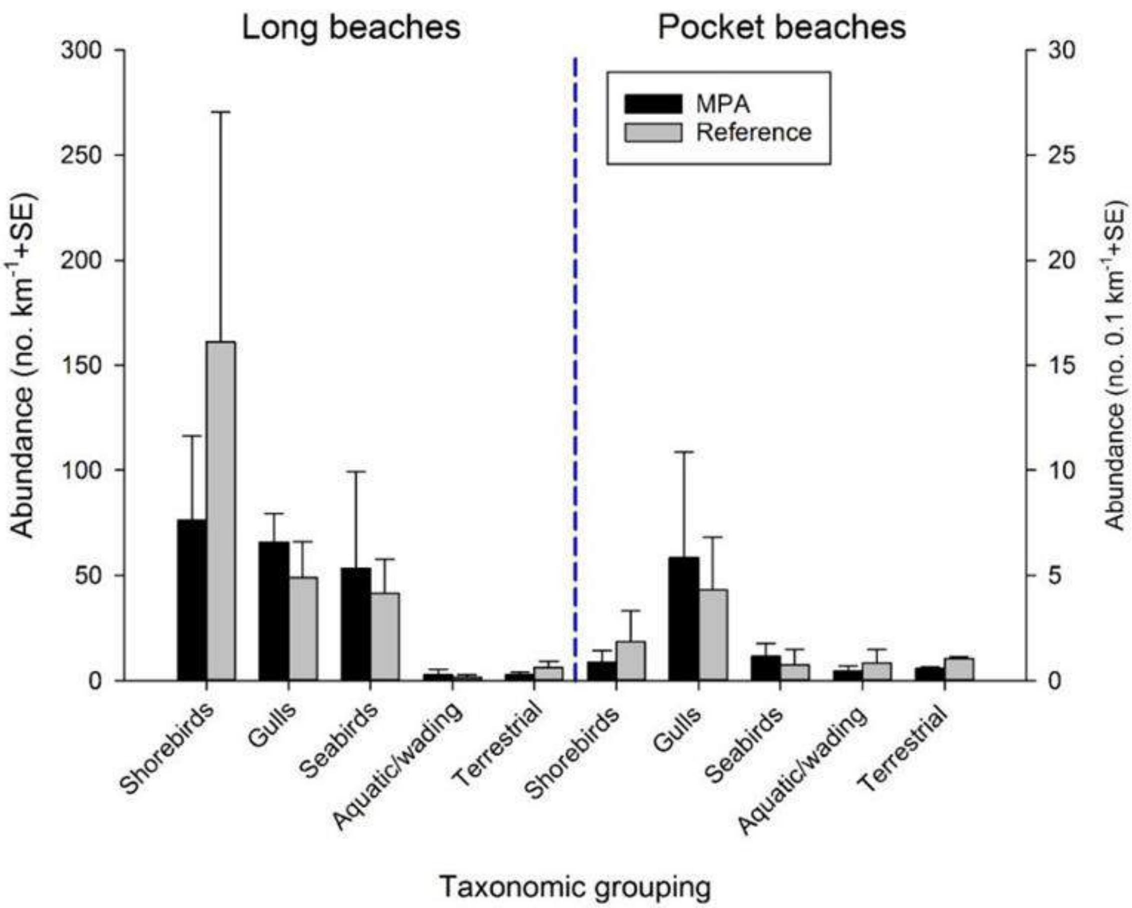

Figure 54. Average abundance of shorebirds, gulls, seabirds, aquatic/wading birds, and terrestrial birds observed in MPA and reference beaches by beach type. Data are from 9 monthly surveys at 12 sites between September 2014 and May 2015 (dashed line separates long from pocket beaches; note difference in axis scaling).

4.3.3.2 Gulls

Spatial variation was also evident in gulls among the beaches. Mean abundance of gulls varied more than four-fold among the eight long beaches ranging from 23 to 98 birds km^{-1} (Figure 52). On the four pocket beaches, the abundance of gulls ranged from one to 11 birds per 100 m. Mean abundance of gulls per month exceeded 90 birds km^{-1} at two of the long beaches, Mad River and Virgin Creek.

The highest peak abundance of gulls observed in a single survey was 271 birds km^{-1} at Reading Rock (Figure 53). Peak abundance of gulls in single surveys exceeded 250 birds km^{-1} at Reading Rock and Virgin Creek. On the four pocket beaches, the highest peak abundance of gulls, 46 birds per 100 m, was observed at Caspar and the lowest peak abundance, three birds per 100 m, was recorded at Russian Gulch.

During the baseline study, gulls were more abundant at MPA beaches than reference beaches on both long and pocket beaches (Figure 54).

4.3.3.3 Seabirds

The mean abundance of seabirds (including Surf Scoters, see operational definition in Methods section 3.1.3, Rapid Surveys) also varied considerably among the beaches (Figure 52). Mean seabird abundance varied more than an order of magnitude ranging from 7 birds km^{-1} to 191 birds km^{-1} at Samoa and Reading Rock, respectively. On the four pocket beaches, the abundance of seabirds ranged from 0 birds per 100 m at Jug Handle to 2 birds per 100 m at Van Damme. Mean abundance of seabirds per month exceeded 85 birds km^{-1} at two of the long beaches, Gold Bluffs and Reading Rock. For the eight long beaches, the highest peak abundance of seabirds observed in a single survey was 1,619 birds km^{-1} at Reading Rock and the lowest peak abundance was 25 birds km^{-1} observed at Samoa (Figure 53). We observed the highest peak abundance of seabirds, 4 birds per 100 m, at Van Damme and the lowest peak abundance, 0 birds per 100 m at Jug Handle.

4.3.3.4 Other birds

Spatial variation in the abundance of aquatic and wading birds appeared to be strongly regional with greatest abundance observed on the study beaches located in Mendocino County and zero to very few of these birds observed on five of the six study beaches to the north of cape Mendocino (Figure 52). This may be related to regional variation in habitat heterogeneity such as the presence of rocky habitat suitable for roosting near the survey transects. The mean abundance of aquatic and wading birds on long beaches varied from 0 to 11 birds km^{-1} and on pocket beaches from < 1 to 2 birds per 100 m (Figure 52).

Terrestrial birds were observed on all 12 study beaches, with abundances ranging from < 1 to 13 birds km^{-1} on long beaches and zero to one bird per 100 m on pocket beaches.

4.3.4 Species Richness

4.3.4.1 Shorebirds

Twenty species of shorebirds were observed in the 108 surveys of the study beaches (Table A- 3). Besides the federally listed Western Snowy Plover, many of the shorebird species observed on the 12 study beaches in the baseline study (Table A- 3) are listed on the Yellow Watch List in the 2014 State of the Birds Report (http://www.stateofthebirds.org/2014/extinctions/watchlist.pdf). These include Black Oystercatcher, Willet, Whimbrel, Long-billed Curlew, Marbled Godwit, Black Turnstone, Short-billed Dowitcher, and Dunlin (Figure A- 5, Figure A- 6). Species on the Yellow Watch List are either range restricted (small range and population), or are more widespread but with troubling declines and high threats. This indicates the potential importance of sandy beaches and MPAs in shorebird conservation efforts.

Strong spatial variation among the study beaches was evident in the species richness of shorebirds in the baseline study. The average number of shorebird species observed varied over an order of magnitude among beaches, ranging from < 1 species at Gold Bluffs to five species at Virgin Creek (Figure 55). The total number of species observed during the study also varied fourteen fold among the beaches, ranging from one shorebird species at Russian Gulch, Jug Handle and Gold Bluffs to 14 species at Virgin Creek with an average of five species per study beach (Figure 56). Another beach with high total species richness (> 10 species) for shorebirds included Ten Mile.

The maximum number of species of shorebirds observed on a single survey date was eight species, which occurred at Virgin Creek in September 2014, October 2014, and April 2015, and at Ten Mile in April 2015. The average species richness of shorebirds was strongly correlated with the average abundance of shorebirds across the study beaches, if the one clear outlier, Mad River Beach, is not included (Figure 58). Mad River Beach had exceptionally high abundance of small sand crabs during summer (Figure 21) that may have made the beach an especially attractive foraging area for shorebirds. Transect length was not correlated with either average species richness of shorebirds ($R^2 = 0.09$, $p = 0.33$) or average abundance of shorebirds ($R^2 = 0.13$, $p = 0.26$).

Virgin Creek and Ten Mile, which both had high numbers (> 10) of total shorebird species, also have high habitat heterogeneity and contain some rocky outcrops. Relatively low total species richness (< 4) occurred on beaches with high cliffs at Jug Handle, Russian Gulch and Van Damme (Figure 56). These beaches have creek mouths and rocky habitat but also have tall cliffs overlooking the beach. These landscape features can provide perches for raptors that prey on shorebirds and likely influence bird distributions on beaches.

Peak average species richness of shorebirds occurred in the fall of 2014 and April 2015 and lowest average richness was observed in January through March 2015 on the study beaches (Figure 57). Total species richness also varied among months ranging from five to 18 species observed in a month on the 12 study beaches. The average total number of shorebird species observed was 10 species per month in the nine-month study.

4.3.4.2 Gulls

Gulls had the highest average species richness on Van Damme and the lowest on Russian Gulch beach, both pocket beaches (Figure 55), while total species richness of gulls was highest (7 species) on Ten Mile and Virgin Creek, both long beaches, and the lowest was on Russian Gulch also a pocket beach (Figure 58). The lowest species richness of gulls was observed in spring 2015 (March-May) (Figure 57).

4.3.4.3 Seabirds

Seabirds, like gulls, had the highest average species richness on Van Damme and the lowest on Russian Gulch beach (Figure 55), but total species richness of seabirds was highest (13 species) on Van Damme. , and the lowest was on Ten Mile (Figure 58). The highest species richness of seabirds was observed in December and the lowest in February (Figure 57).

4.3.4.4 Aquatic/wading birds

The average and peak species richness of aquatic and wading birds were low overall (Figure 55, Figure 56). The highest average and peak species richness was observed on Van Damme, Caspar and Virgin Creek Beaches, in the southern bioregion.

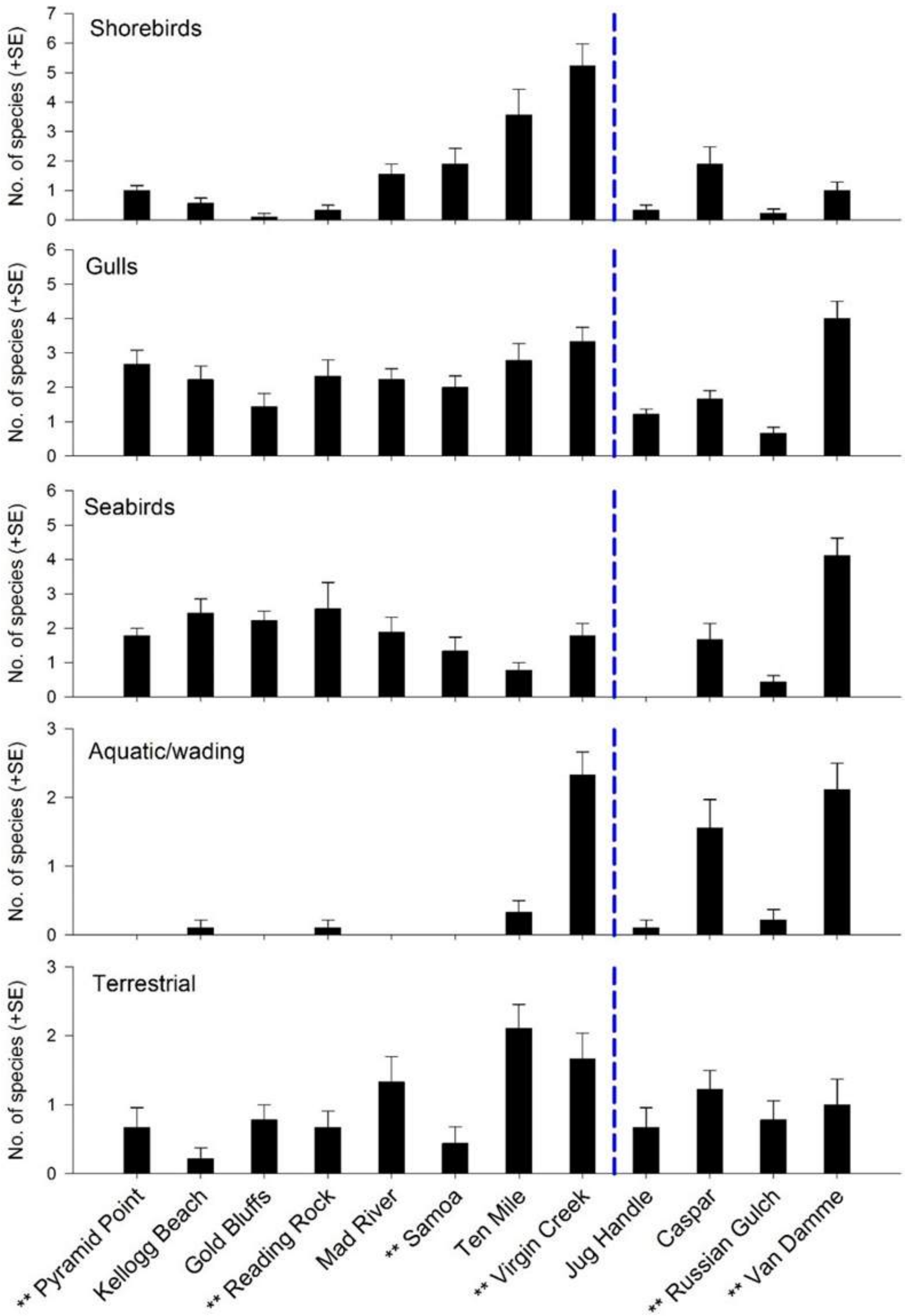

Figure 55. Average species richness of shorebirds, gulls, seabirds, aquatic/wading birds and terrestrial birds observed at 12 beaches from 9 monthly surveys between September 2014 and May 2015. All other information as in Figure 52.

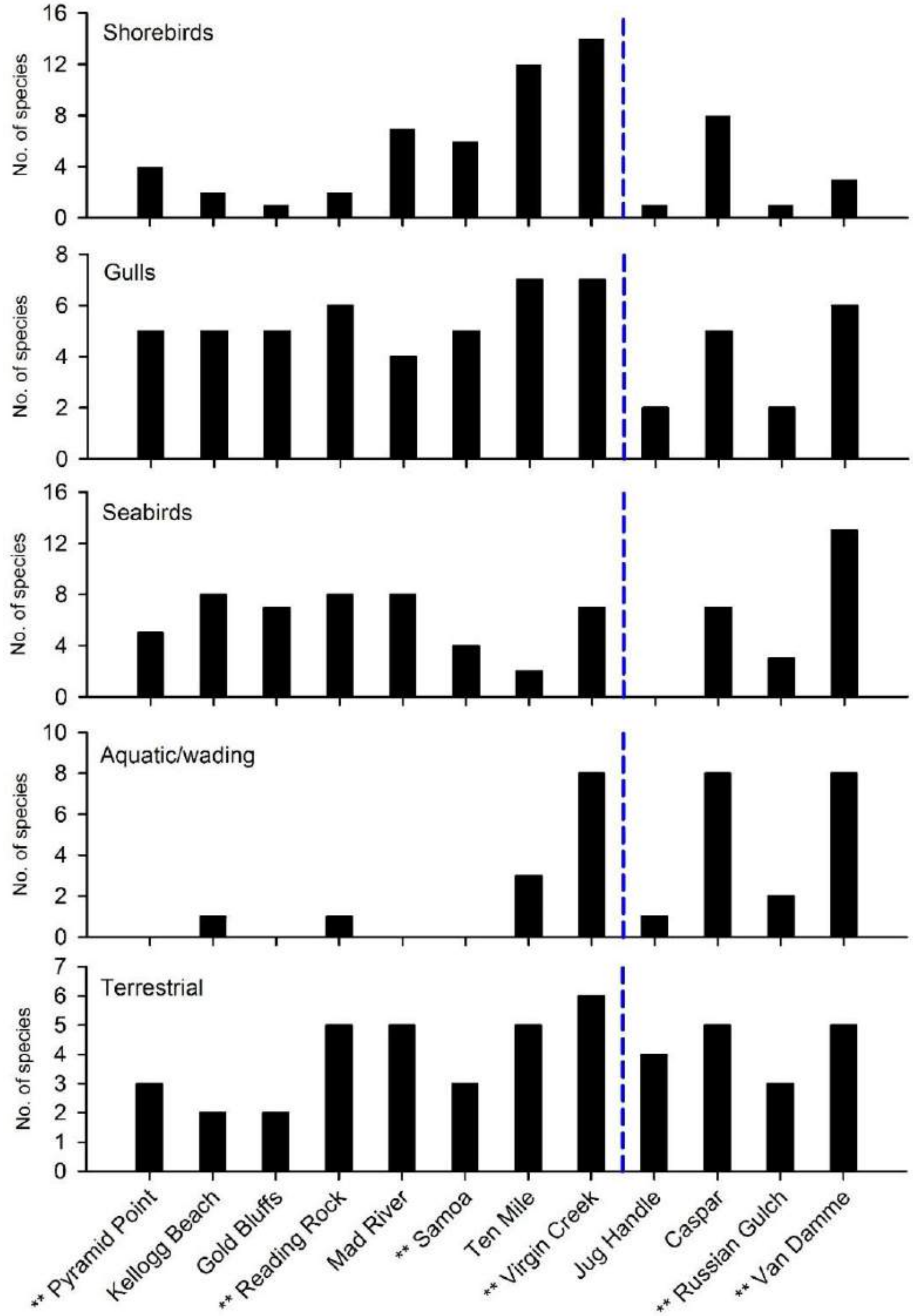

Figure 56. Total species richness of shorebirds, gulls, seabirds, aquatic/wading birds and terrestrial birds observed at 12 beaches from 9 monthly surveys between September 2014 and May 2015. All other information as in Figure 52.

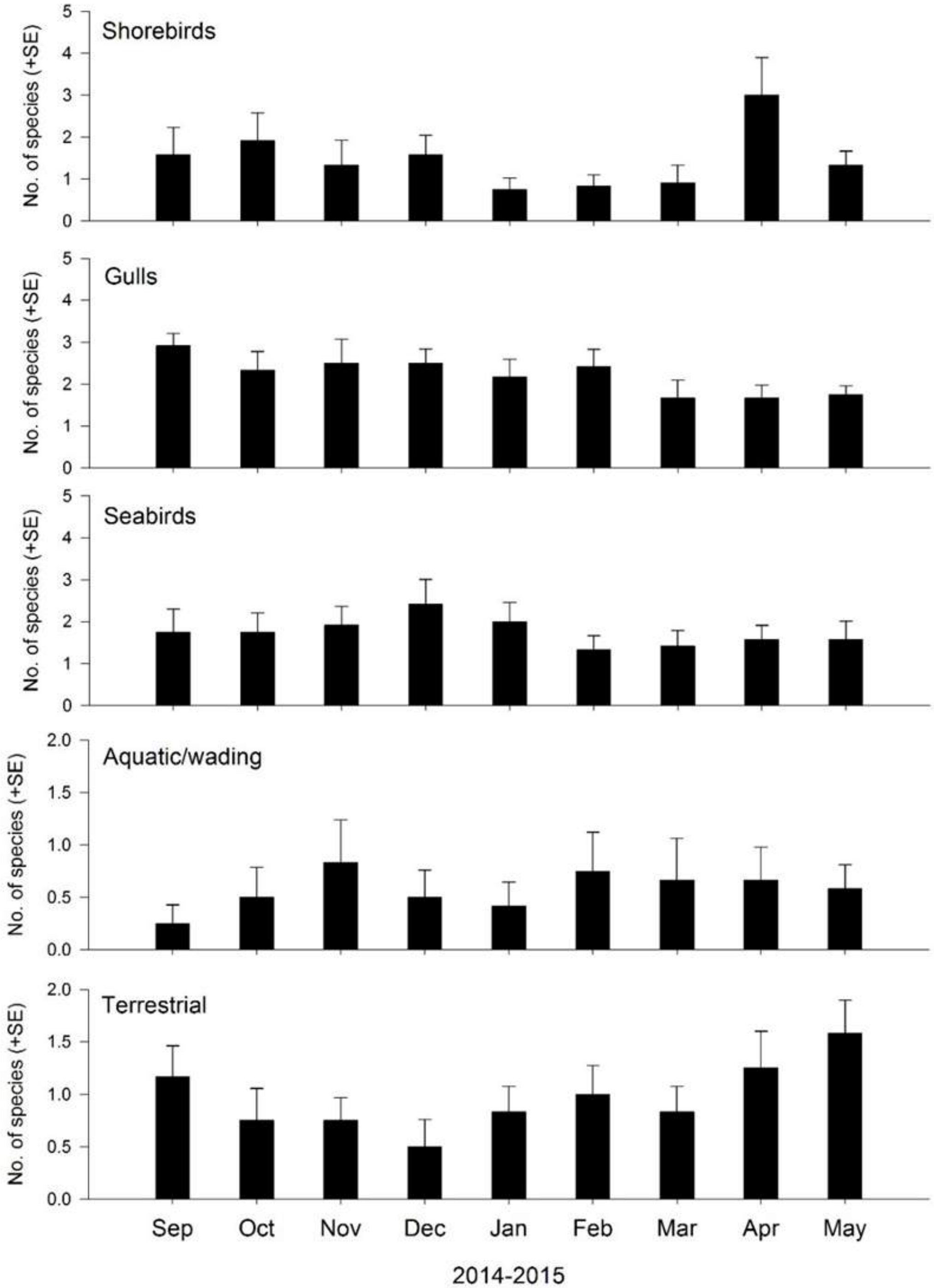

Figure 57. Average monthly species richness of shorebirds, gulls, seabirds, aquatic/wading birds and terrestrial birds observed at 12 NC beaches. Surveys were conducted once a month from September 2014 to May 2015.All other information as in Figure 52.

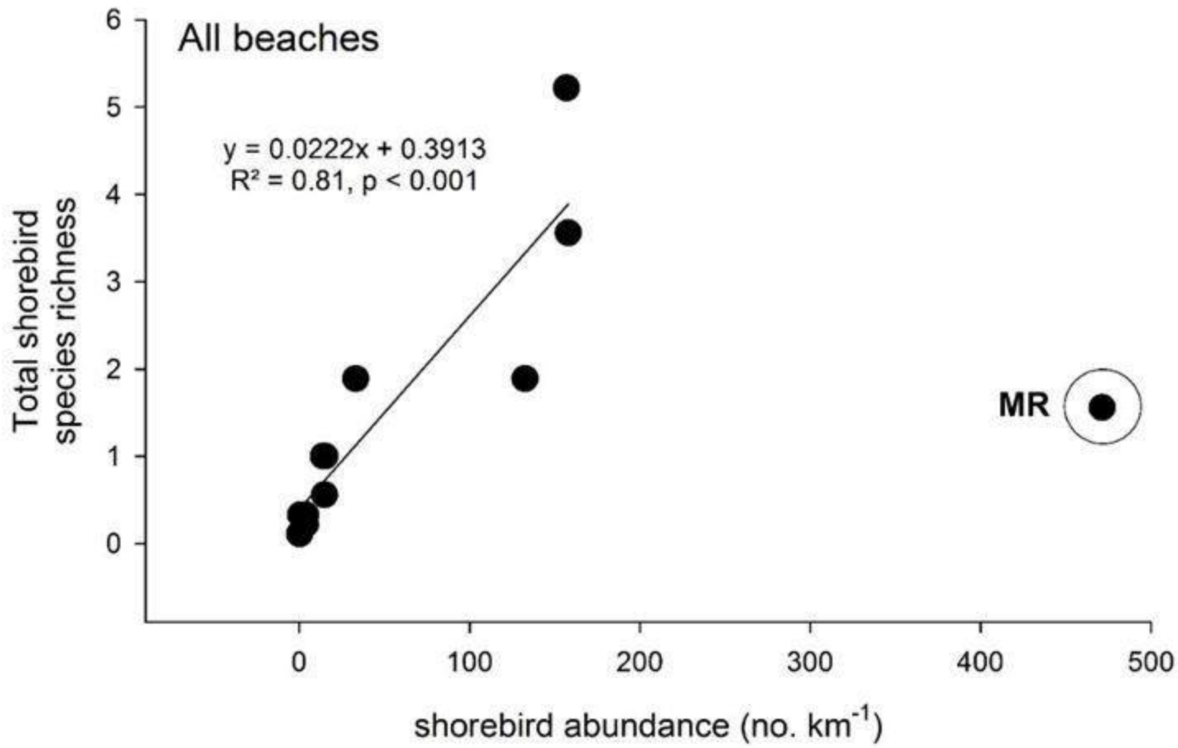

Figure 58. Total shorebird species richness as a function of average shorebird abundance excluding the outlier Mad River (MR).

4.3.4.5 Terrestrial birds

The average species richness of terrestrial birds was greatest at Ten Mile and total species richness was greatest at nearby Virgin Creek (Figure 55, Figure 56). Kellogg beach had both the lowest average and total species richness. Gold Bluffs beach was as low in specie richness of terrestrial birds as Kellogg beach. Average monthly species richness for this group was highest in May and lowest in December (Figure 57).

4.4 Human use & activities

We observed 562 people in the 108 surveys of the 12 study beaches. The average number of people observed on the beaches (including the surf zones) was 14 km^{-1} (Figure 59). The peak number of visitors observed during a single survey was 43 people at Van Damme in March 2015. The mean number of visitors per month across all the beaches in the region varied from two to 28 people km^{-1} in December and February, respectively (Figure 60). The February samples for the six southernmost beaches were collected during the President's Day holiday and the following day, resulting in higher than expected human activity on the beaches despite it being winter and a weekday. The average number of people observed among beaches varied by an order of magnitude, ranging from one person km^{-1} at Gold Bluffs to 50 people km^{-1} at Jug Handle (Figure 59).

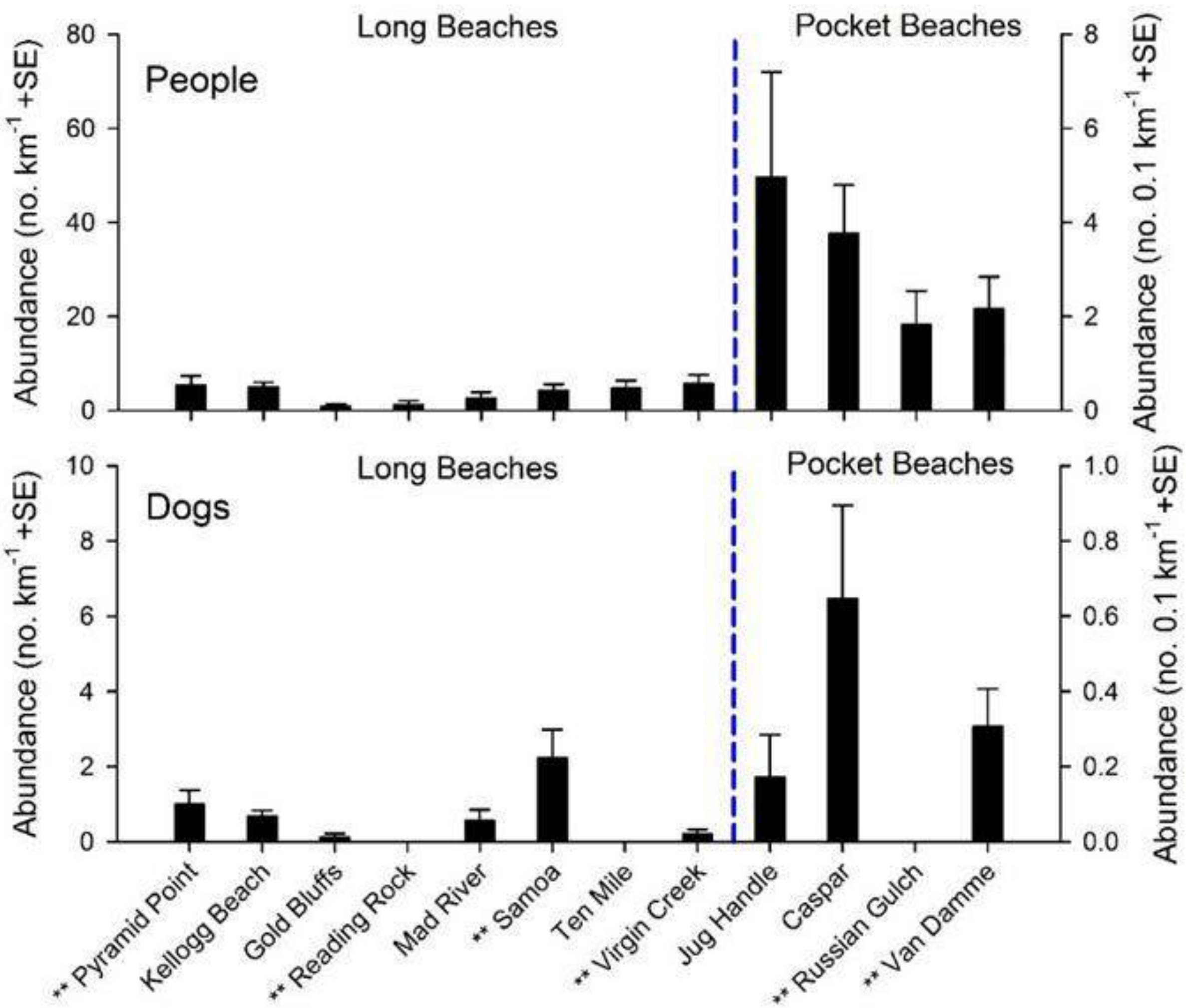

Figure 59. Average site abundance of people and dogs across the 12 beaches surveyed in the NC region between September 2014 and May 2015. Beaches are arranged from north to south along the horizontal axis within beach type (dashed line separates long from pocket beaches). Additional information as in Figure 52.

We observed 80 dogs in the 108 surveys of the 12 study beaches. The overall average number of dogs observed on the beaches was one km^{-1} (Figure 59). The peak number of dogs observed during a survey was six (Van Damme, April 2015). The mean number of dogs observed across months varied from less than one to two km^{-1} (October and September, respectively; Figure 60). The average number of dogs varied by an order of magnitude among beaches, ranging from zero at Reading Rock, Ten Mile and Russian Gulch, to seven km^{-1} at Caspar.

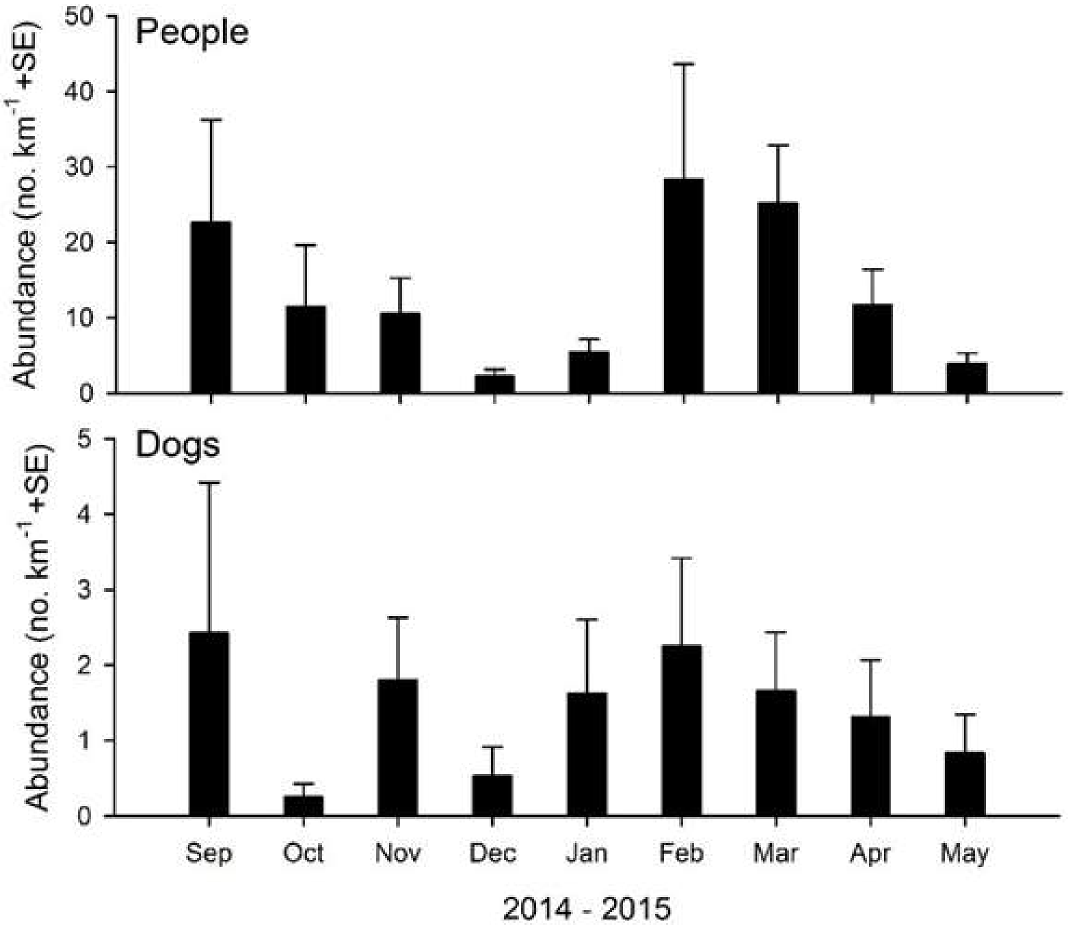

Figure 60. Seasonal average abundance of people and dogs across the 12 beaches surveyed in the NC region between September 2014 and May 2015. All other information as in *Figure 52*.

Visitors used beaches in a wide variety of ways that we categorized into four broad groups in decreasing order of occurrence: nature walks, resting (i.e., sitting, standing or sunbathing) or socializing (picnicking), water sports and beach sports (Table 25). In the nature walk category, most people were walking on the beach, occurring 62 times by 347 people. Nature walk activities were more common at MPA sites (32 times, 186 people) than reference sites (30 times, 161 people). Resting/socializing was observed 36 times for 118 people. Kayaking and surfing were the most common water sports. Kayaking occurred six times by 18 people, and surfing occurred four times by 15 people. Water sports were more common at MPA sites (12 times, 37 people) than reference sites (10 times, 27 people) and more prevalent at pocket beaches (16 times, 48 people) than long beaches (six times, 16 people). Jogging and Frisbee were the most popular beach sport activities, occurring ten times by 29 people. Beach sports were also more common at MPA sites (ten times, 28 people) than reference sites (three times, five people), but more common at long beaches (nine times, 24 people) than pocket beaches (four times, nine people).

Table 25. Frequency of occurrence and number of people engaging in human activities during paired monthly surveys of six beaches in MPAs and six neighboring reference beaches in the North Coast Region from September 2014 to May 2015. Eight 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 0.69 km (total length of shoreline surveyed each month = 9.18 km).

Activity	Frequency					Number				
	MPA	Reference	Long	Pocket	Total	MPA	Reference	Long	Pocket	Total
Nature walk										
Photography	1	0	0	1	1	1	0	0	1	1
Walking	31	30	37	24	61	185	161	169	177	346
Total	**32**	**30**	**37**	**25**	**62**	**186**	**161**	**169**	**178**	**347**
Resting/socializing										
Picnic	3	0	1	2	3	11	0	5	6	11
Sitting	1	1	0	2	2	1	4	0	5	5
Standing	13	14	17	10	27	36	53	49	40	89
Sunbathing	1	3	1	3	4	3	10	3	10	13
Total	**18**	**18**	**19**	**17**	**36**	**51**	**67**	**57**	**61**	**118**
Water sports										
Abalone Diving	0	1	0	1	1	0	2	0	2	2
Boating	0	0	0	0	0	0	0	0	0	0
Diving	4	0	0	4	4	13	0	0	13	13
Fishing	2	3	4	1	5	4	7	10	1	11
Kayaking	4	2	0	6	6	14	4	0	18	18
Paddleboard	0	2	0	2	2	0	5	0	5	5
Surfing	2	2	2	2	4	6	9	6	9	15
Total	**12**	**10**	**6**	**16**	**22**	**37**	**27**	**16**	**48**	**64**
Beach sports										
Digging	0	1	0	1	1	0	2	0	2	2
Frisbee	2	0	1	1	2	8	0	4	4	8
Horseback riding	1	0	1	0	1	1	0	1	0	1
Jogging	7	1	7	1	8	19	2	19	2	21
Metal detecting	0	1	0	1	1	0	1	0	1	1
Total	**10**	**3**	**9**	**4**	**13**	**28**	**5**	**24**	**9**	**33**

People were most abundant on pocket beaches, especially Jug Handle and Caspar (Figure 59). The most popular long beaches were Virgin Creek, Pyramid Point and Kellogg. Dogs were also most abundant on pocket beaches, with the highest average abundance at Caspar and Van Damme (Figure 59). The most popular long beaches for dogs were Samoa and Pyramid Point.

People and dogs were more abundant at MPA sites than reference sites on long beaches, but the opposite was found on pocket beaches, where people and dogs were twice as abundant on reference beaches than MPA beaches (Figure 60).

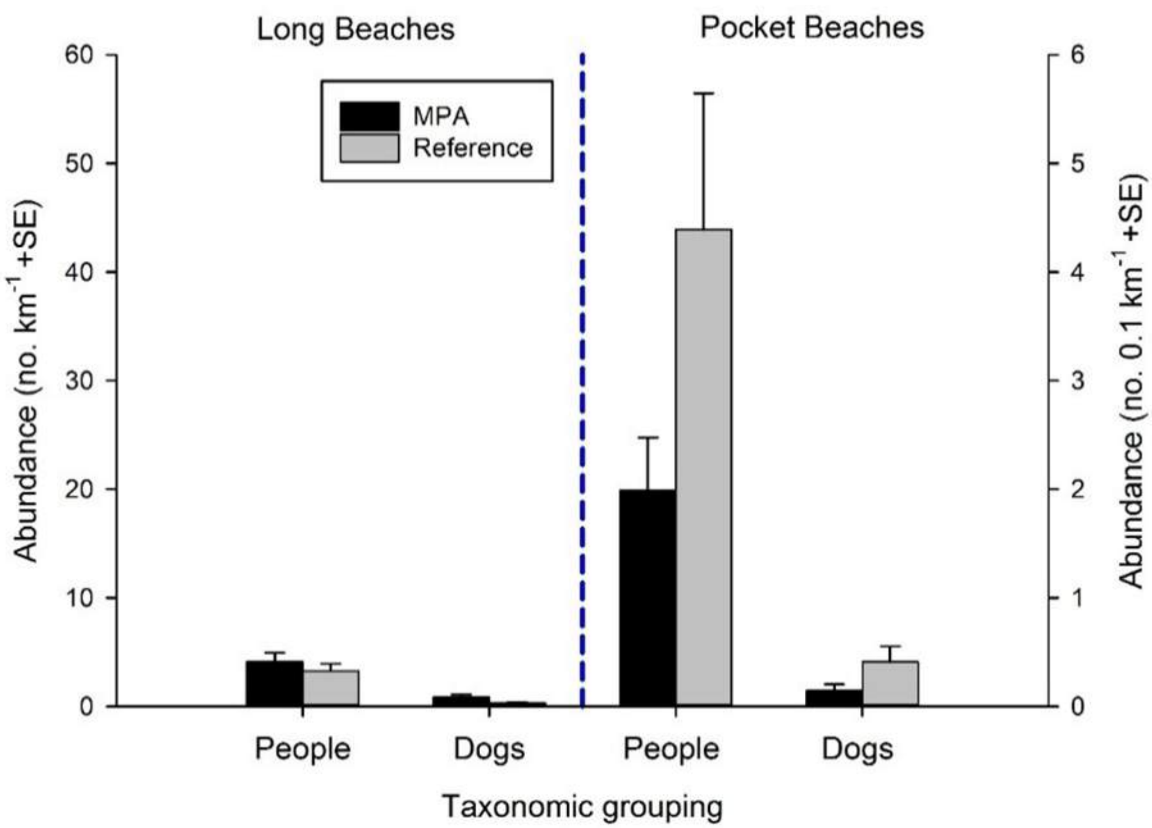

Figure 61. Average abundance of people and dogs observed in MPA and reference beaches by beach type (dashed line separates long from pocket beaches). Data are from 9 monthly surveys at 12 sites between September 2014 and May 2015.

4.5 Community ecology and trophic relationships

Based on prior research and MPA baseline studies in the NCC and SC MPA regions (Dugan et al 2003, Nielsen et al. 2013, Dugan et al. 2015, Liebowitz et al. 2016), we had a priori expectations for how a specific set of ecological processes, mostly trophic relationships and subsidies from adjacent ecosystems, could influence the ecological structure of NC beaches. The main relationships are summarized in Figure 2.

Beaches are closely linked with other coastal ecosystems, such as kelp forests, reefs and the nearshore ocean. The press and pulse of environmental drivers and human activities can strongly influence this critical connectivity and the structure and function of beach ecosystems (Dugan et al 2008, McLachlan & Brown 2006, Revell *et al*. 2011). Below, we evaluate our hypothesized functional relationships by examining the relationships between key drivers and predicted ecological responses (see **3.1.6 Data analyses** page 33 for details).

4.5.1 Macroinvertebrate communities and beach characteristics

The relationships among physical beach characteristics, wrack, macroinvertebrates and shorebirds were not always consistent across beach types (long vs. pocket), therefore we present results by beach type when overarching relationships did not emerge as statistically significant and interactions were evident from visual inspection.

Macroinvertebrate species richness and macrofauna community structure responded to physical characteristics of the beach. Macroinvertebrate species richness was negatively correlated with beach slope at the WTO (Figure 62). Beach slopes are generally correlated with grain size (Bascom 1980), with coarser sand able to repose at steeper angles than fine sand. This suggests that beaches with flatter shore slopes, and by extension finer sand, can support greater biodiversity. Species richness of the macroinvertebrate community was also negatively correlated with sand grain size at the WTO (Figure 62), although the relationship was weaker. These results reflect the influence grain size can exert on the diversity of burrowing animals. More infaunal species are able to inhabit beaches with fine sand compared to those with coarse sand. Sand grain size can also be affected by sediment sources, erosion/accretion dynamics and human activities.

Macroinvertebrate species richness on long beaches was strongly positively correlated with the active intertidal width (Figure 63) and the width of the saturated sand zone (Figure 63), exhibited a positive trend with overall beach width ($r^2 = 0.44$, $p = 0.07$), consistent with well-established species-area relationships. However, other mechanisms related to the physical environment may also influence these communities. For example, when pocket beaches were included the relationships were weaker.

When plotted separately, the four pocket beaches seemed to exhibit similar relationships between macroinvertebrate species richness and beach widths but the number of beaches is low and none of the relationships were statistically significant (active intertidal width: $r^2 = 0.36$, $p = 0.4$; saturated sand zone: $r^2 = 0.62$, $p = 0.21$; overall beach width $r^2 = 0.45$, $p = 0.33$).

The abundance and biomass of the swash-riding sand crab, *E. analoga*, were positively correlated with swash period across all beaches ($r^2 = 0.48$, $p = 0.01$ and $r^2 = 0.39$, $p = 0.03$, respectively), as were overall macroinvertebrate abundance and biomass ($r^2 = 0.49$, $p = 0.01$ and $r^2 = 0.53$, $p < 0.01$, respectively). Swash periods that exceed wave periods represent greater transformation and reduction of wave energy across the surf zone, creating favorable conditions for intertidal animals (Figure 14). Since sand crabs are suspension feeders, longer swash periods might translate into a more efficient feeding environment and reduced wave impacts. In contrast, talitrid amphipod abundance and biomass were negatively correlated with swash period on all beaches ($r^2 = 0.60$, $p < 0.01$ and $r^2 = 0.53$, $p = 0.01$, respectively). Further investigation is needed to understand what might be driving this strong relationship.

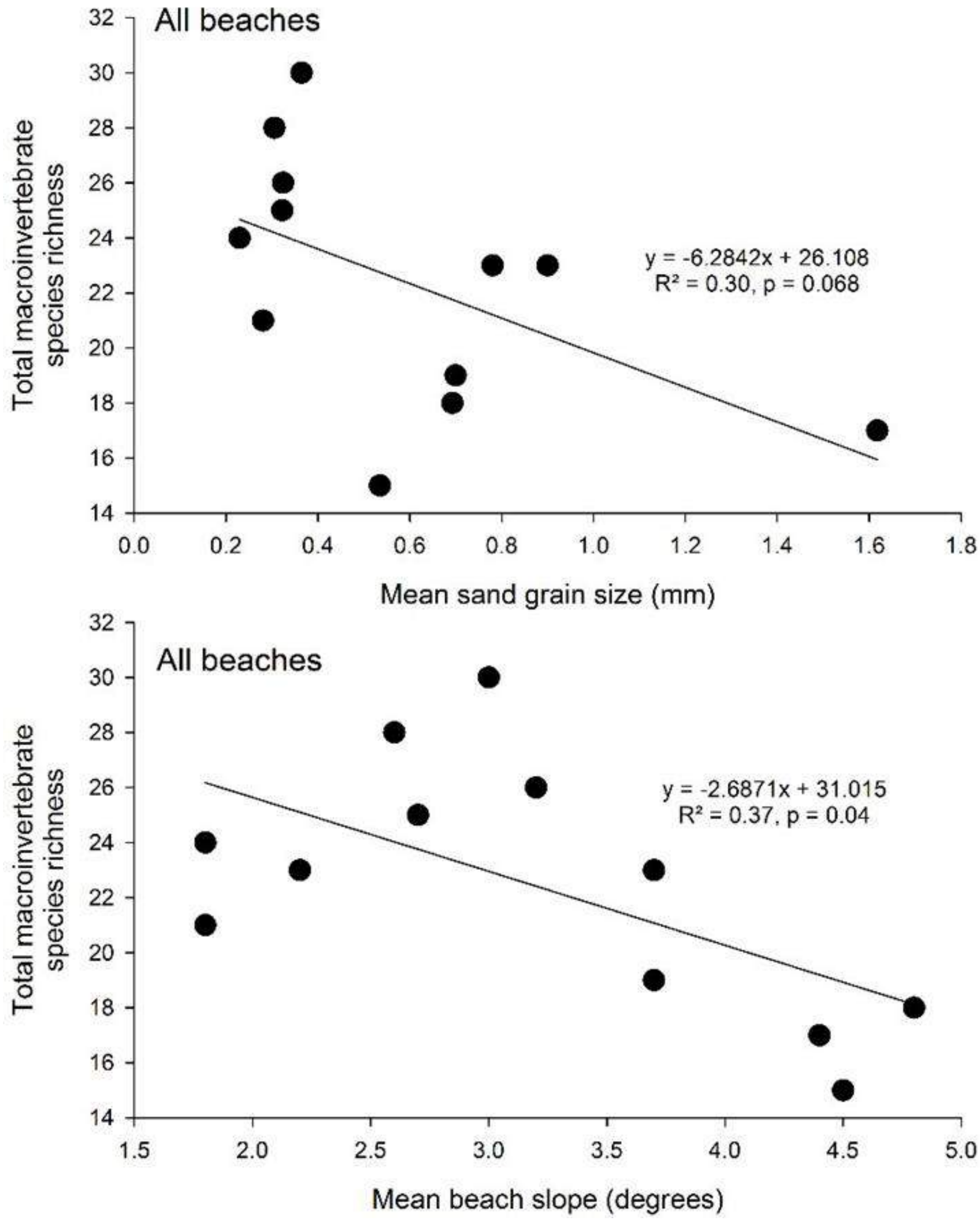

Figure 62. Total macroinvertebrate species richness (endemic species only) as a function of mean sand grain size and slope at the WTO at all 12 study beaches.

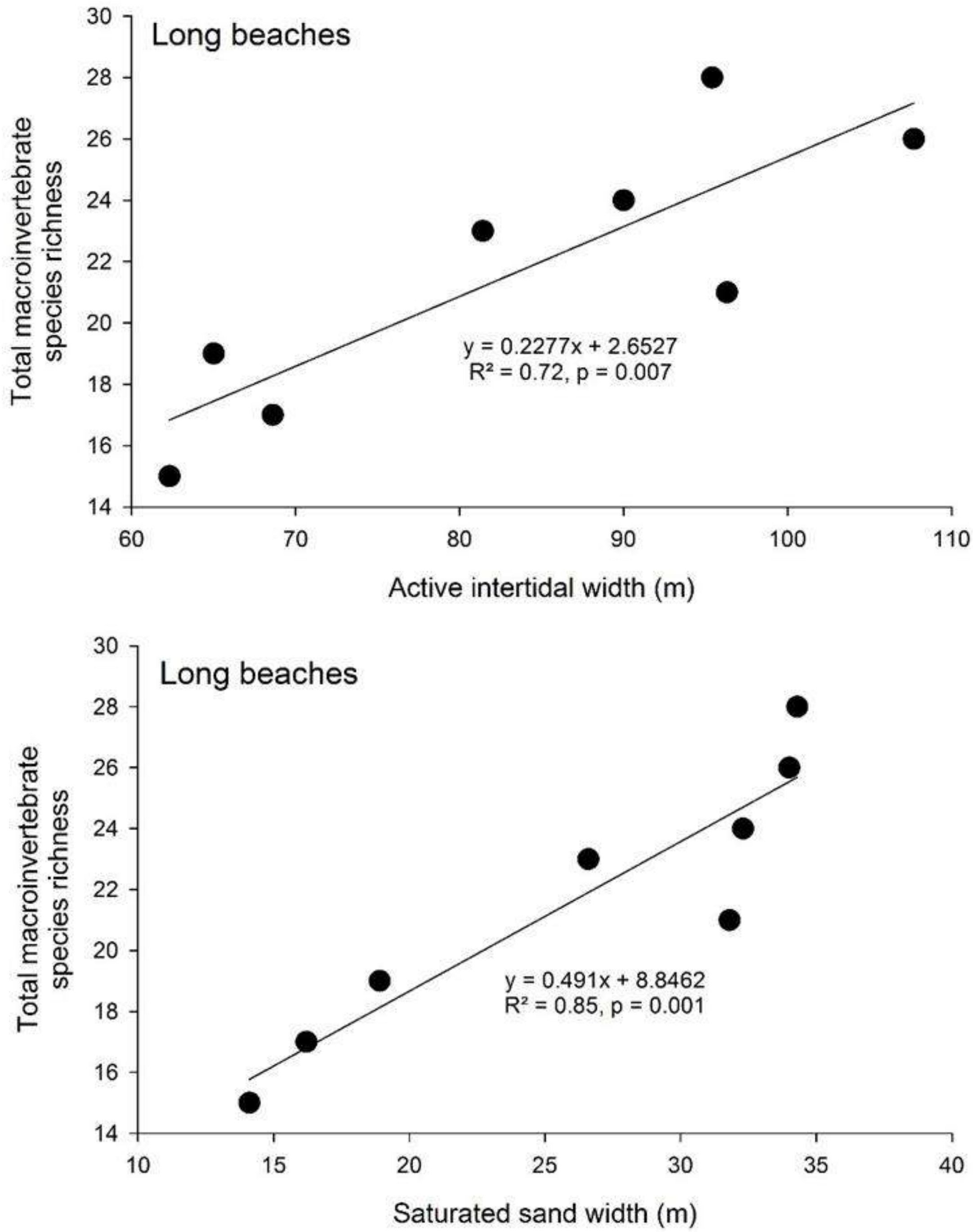

Figure 63. Total invertebrate species richness as a function of active intertidal beach width and saturated sand width for long study beaches only.

4.5.2 Fresh kelp abundance and macrophyte wrack

The numerical abundance of fresh kelp thalli (from the along shore transect) was a good indicator of both brown macroalgal wrack cover and kelp wrack cover on long study beaches (Figure 64). The abundance of fresh kelp thalli was also positively correlated with marine wrack cover overall (includes all kelp, red, green, brown, surfgrass and eelgrass wrack) on long beaches ($r^2 = 0.50$, $p = 0.05$), but the relationship was weaker, probably reflecting the differences in proximity to the various types of donor ecosystems (Leibowitz et al. 2016). In contrast, on pocket beaches marine wrack cover was strongly correlated with fresh kelp abundance ($r^2 = 0.91$, $p = 0.046$) but not with either brown wrack cover or kelp wrack cover. This result suggests that on pocket beaches fresh kelp may be a stronger indicator of

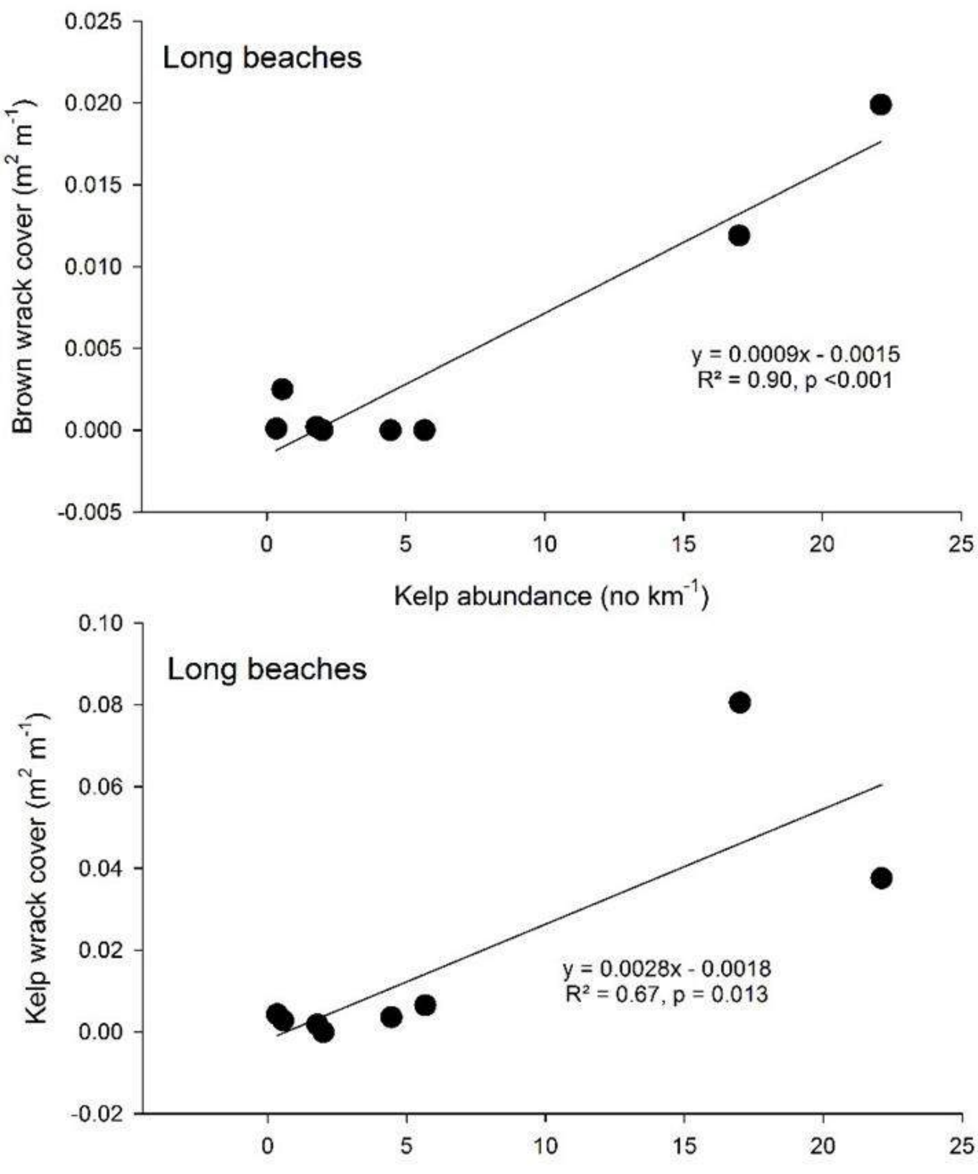

Figure 64. Average cover of brown and kelp wrack as a function of average kelp abundance on long study beaches only.

wrack supply and transport processes overall and/or that consumers process and remove fresh kelp quickly.

4.5.3 Macroinvertebrates and Macrophyte Wrack

Macroinvertebrate communities on long beaches were strongly related to macrophyte wrack in the north coast region. Overall species richness of the endemic macrofaunal community was positively correlated with the mean cover of wrack and with the number of stranded kelp thalli (individuals) on long beaches (Figure 65). No relationship between these factors was evident on pocket beaches, but sample size was low (n=4). Our results for long beach results are consistent with earlier findings from studies on southern California beaches (Dugan et al. 2003, Dugan et al. 2000, 2004, Dugan 1999), and baseline results from the South Coast region (Dugan et al. 2015) and the North Central Coast region (Nielsen et al. 2013). This strong and consistent result appears to be related to the presence of a number of species of insects and crustaceans that are functionally associated with stranded macrophyte wrack. The importance of insects endemic to beaches to overall intertidal biodiversity is an important result of this study that is consistent with prior work.

Wrack-associated beetles were a diverse group with more than 24 species recorded in our samples in the North Coast region (Table A- 1). These included two carabids, *Akephorus marinus* and *Akephorus obesus*, two tenebrionids, *Coelus ciliatus* and *Phaleromela globosa*, two hydrophilids, *Cercyon fimbriatus* and *Cercyon luniger*, a curculionid, *Emphyastes fucicola*, three species of histeriids, *Hypocaccus gaudens*, *Neopachylopus aeneipunctatus*, and *Neopachylopus sulcifrons*, six genera and ten species of staphylinids, including *Aleochara sulcicollis*, *Bledius monstratus*, *Cafius* spp., *Hadrotes crassus*, *Tarphiota* spp., and *Thinopinus pictus*. Diptera were also widespread, occurring at all twelve of the study beaches. Five species of wrack-consuming talitrid amphipods, genus *Megalorchestia* spp., and the wrack- feeding isopod, *Alloniscus perconvexus*, were often abundant on study beaches with accumulated macrophyte wrack. All of these wrack-associated species are potential prey for invertebrate predators and for birds at all stages of the tidal cycle.

The cover of marine macrophyte wrack was an excellent predictor of wrack-associated taxa and of talitrid amphipods on the study beaches. The mean abundance, biomass and total species richness of wrack-associated invertebrates were positively correlated with mean wrack cover across all study beaches (Figure 66). The mean abundance and biomass of talitrid amphipods (*Megalorchestia* spp.) were also significantly and positively correlated with the mean cover of wrack on all study beaches ($r^2 = 0.74$, $p < 0.001$ and $r^2 = 0.71$, $p < 0.001$, respectively). This is not surprising because talitrid amphipods make up the majority of the wrack-associated species on the study beaches. The abundance of kelp thalli was also a very strong predictor of wrack-associated invertebrate abundance and biomass (Figure 67), and of the abundance and biomass talitrid amphipods ($r^2 = 0.76$, $p < 0.01$ and $r^2 = 0.83$, $p < 0.01$, respectively) on long beaches.

The overall abundance of macroinvertebrates was not correlated with the standing crop of marine macrophyte wrack or the abundance of stranded kelp thalli. However the mean biomass (g m^{-1}) of macroinvertebrates had a negative relationship with both marine macrophyte wrack ($r^2 = 0.37$, $p = 0.04$) and stranded kelp abundance ($r^2 = 0.45$, $p = 0.018$), a result that likely reflects the dominance of suspension feeding species, such as sand crabs, on the long beaches.

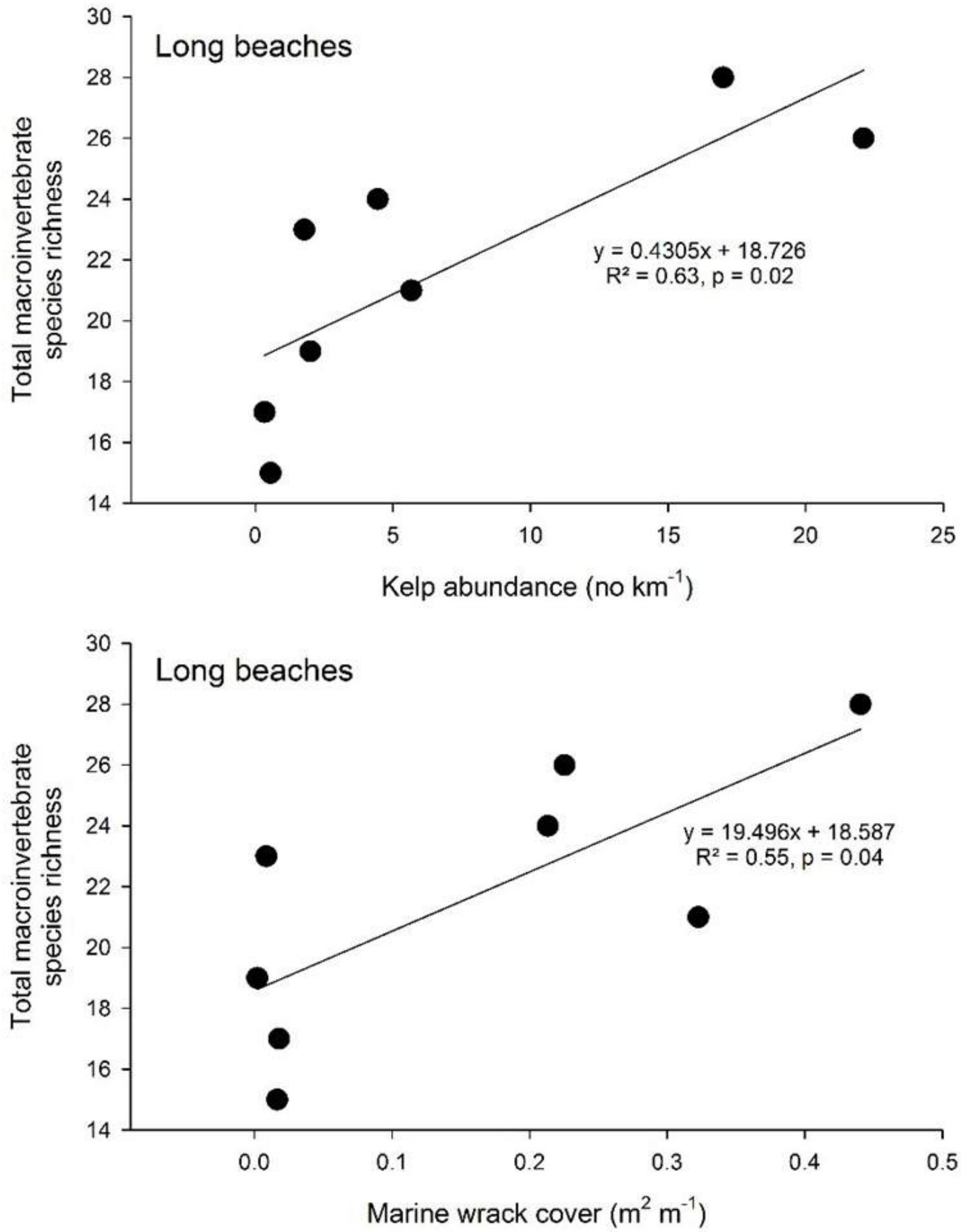

Figure 65. Total macroinvertebrate species richness (endemic species only) as a function of average fresh kelp abundance and average marine wrack cover. Marine wrack includes all kelp, red, green, brown, surfgrass and eelgrass wrack.

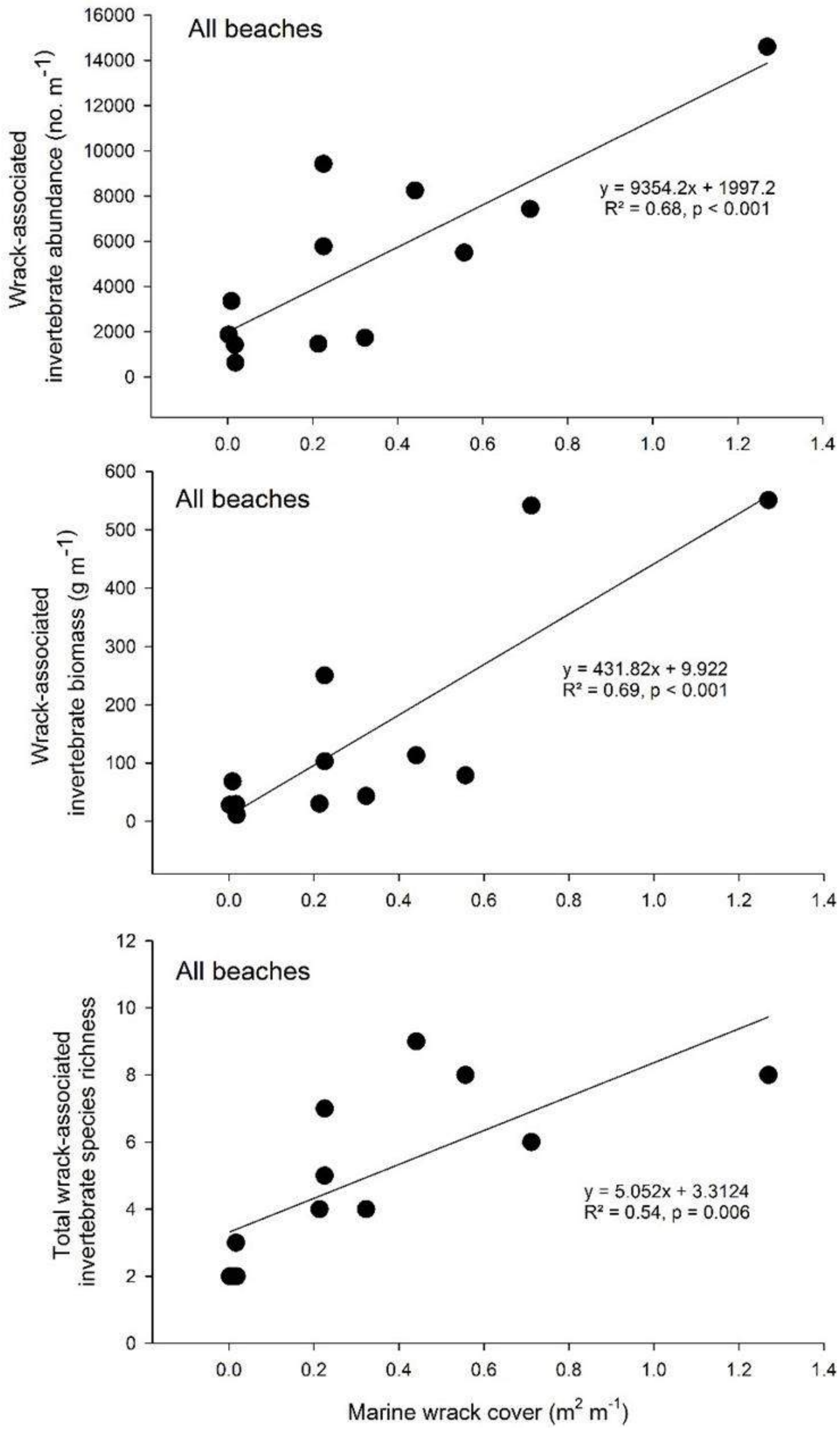

Figure 66. Average abundance and biomass and total species richness of wrack-associated invertebrates as a function of marine wrack cover.

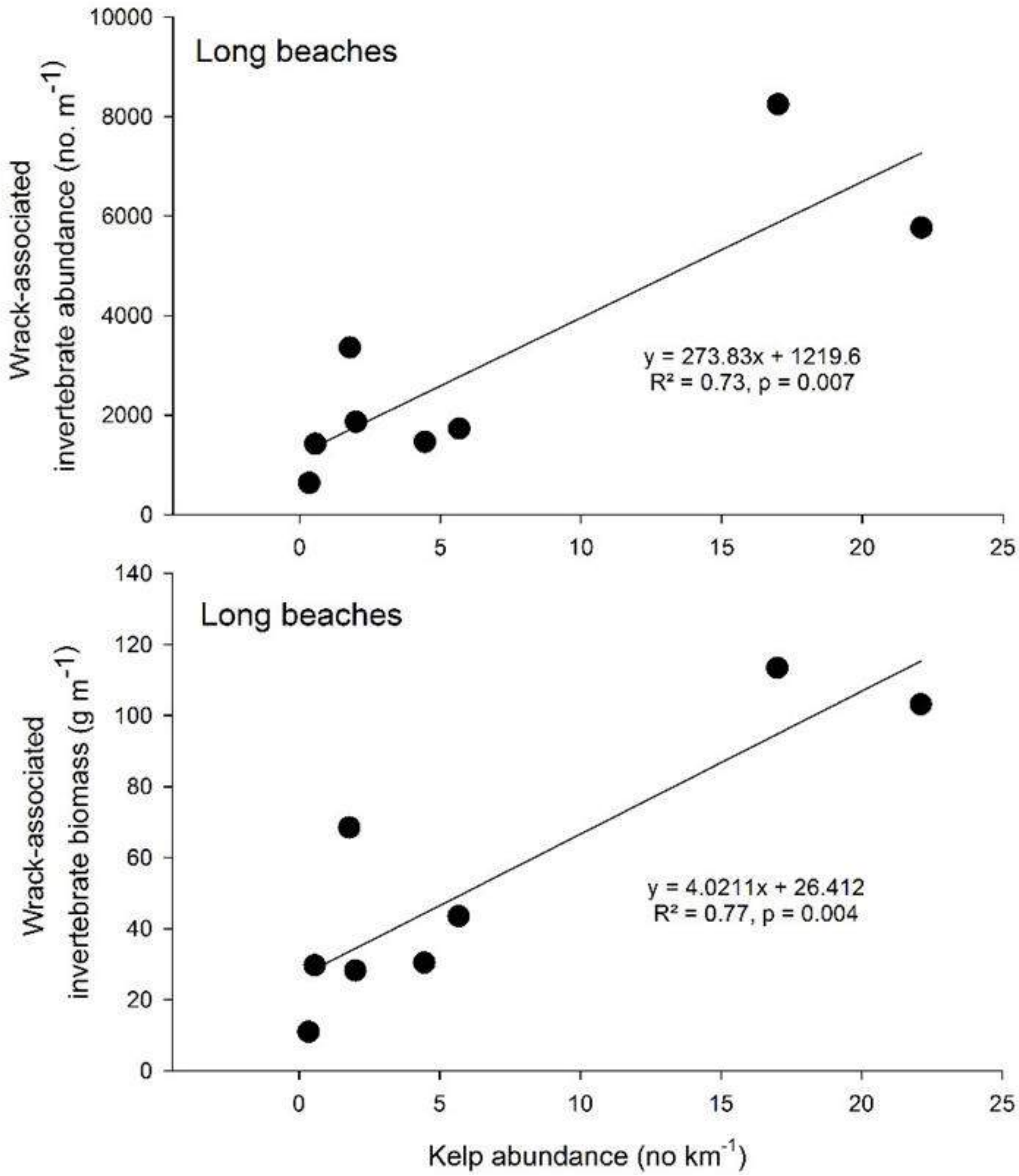

Figure 67. Average abundance and biomass of wrack-associated invertebrates as a function of mean fresh kelp abundance.

4.5.4 Shorebirds and macroinvertebrate communities

We found very strong relationships between the distribution and abundance of shorebirds on beaches in the NC region and characteristics of the intertidal macroinvertebrate community. The mean species richness of shorebirds was positively correlated with species richness of the macroinvertebrate community across all study beaches, and the relationship is especially striking on the long beaches (Figure 68). This result is consistent with results from the SCMPA baseline study of beaches (Dugan et al. 2015).

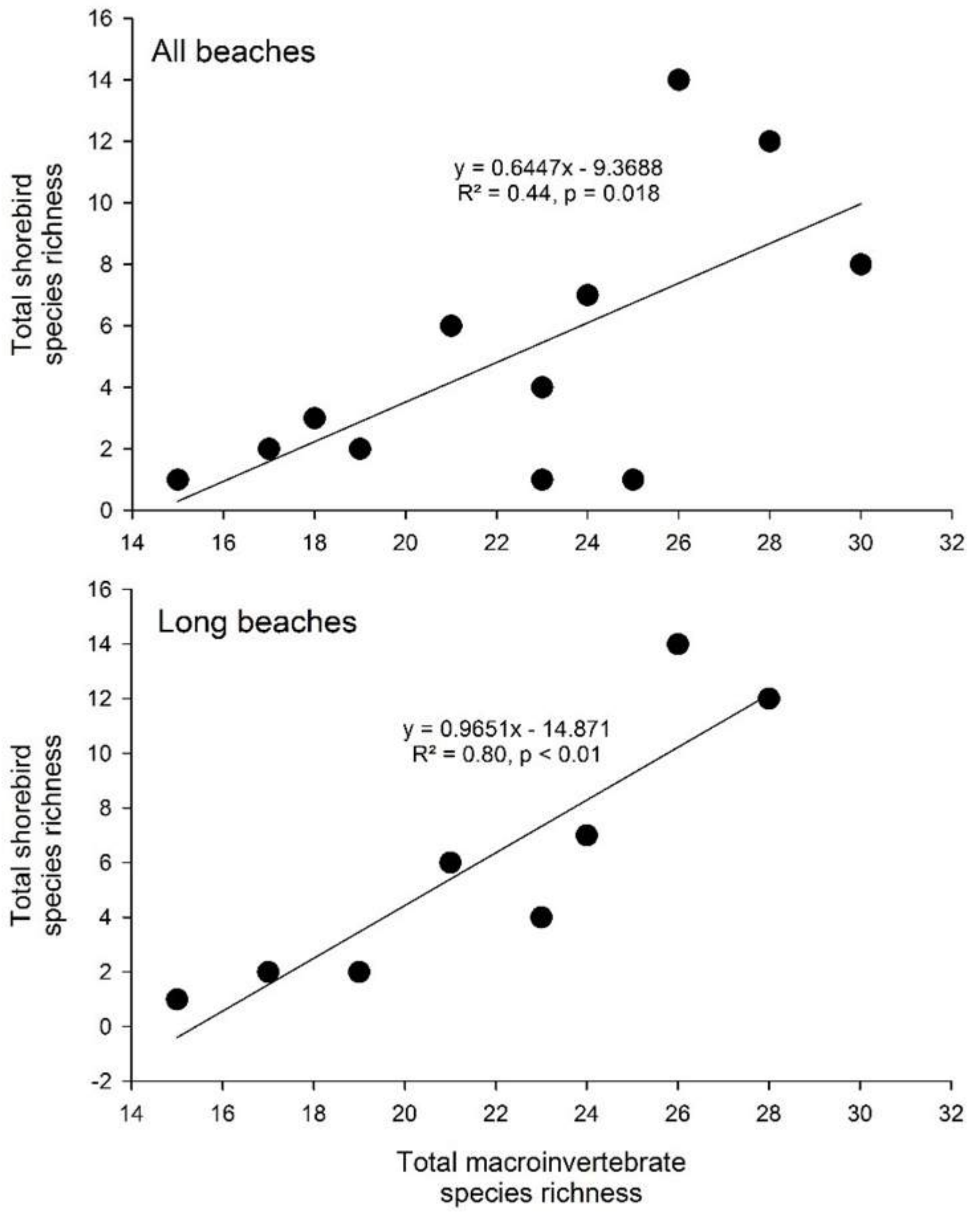

Figure 68. Total endemic macroinvertebrate species richness as a function of total shorebird species richness.

The mean abundance of shorebirds on all beaches was also correlated with endemic macroinvertebrate abundance ($r^2 = 0.73$, $p < 0.001$) but not with their mean biomass. Interestingly, shorebird abundance on pocket beaches was also positively correlated with the abundance of non-endemic macroinvertebrate species ($r^2 = 0.87$, $p = 0.07$), although the relationship was probably driven mostly by one beach. Non-endemic macroinvertebrates were most common on pocket beaches (Table A- 2, Figure 28, Figure 29). Caspar (a pocket beach) had very high non-endemic macroinvertebrate abundance and the highest shorebird abundance at any pocket beach. We believe this beach was especially attractive to shorebirds because of the diversity of habitats present in a small area. We regularly observed many shorebirds by the stream and small freshwater lagoon on the back beach.

4.5.5 Shorebirds and selected taxa of macroinvertebrates

Relationships between the species richness and abundance of shorebirds and the abundance and biomass of selected prey species/taxa, particularly the proposed indicator taxa, *E. analoga* and *Megalorchestia* spp., were not entirely consistent. Shorebird abundance was positively correlated with the abundance of sand crabs, but the results for Mad River is clearly driving the entire relationship (Figure 69). At this beach there was very high recruitment of sand crabs and it had the highest average abundance of shorebirds (more than two fold higher) during the nine months of the study.

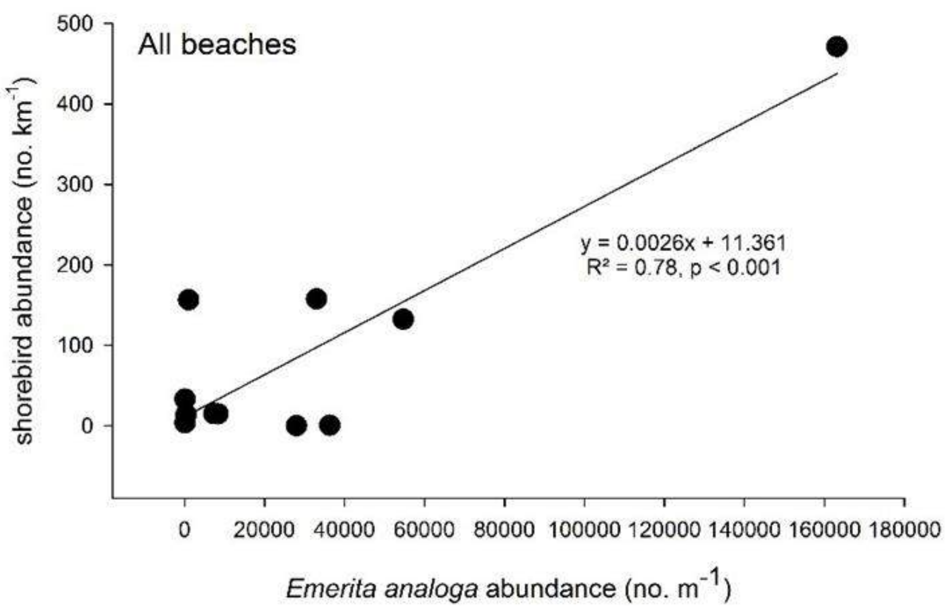

Figure 69. Average shorebird abundance as a function of Emerita analoga *abundance.*

In contrast, the relationship between shorebird abundance and talitrid amphipod biomass on long beaches (only), is only statistically significant when Mad River, a clear outlier, is removed (Figure 70). That pattern is similar for the abundance of talitrid amphipods ($r^2 = 0.54$, $p = 0.06$, excluding Mad River). The results for sand crabs suggest that shorebirds may be attracted to dense aggregations of prey, such as the young of the year sand crabs we observed at Mad River in 2014. Redtail surfperch also appeared to respond to the high availability of sand crab prey on NC beaches. Sand crabs were the dominant food type by weight, abundance and frequency (Table 11, Table 16), and were the only important prey type (index of relative importance) for redtail surfperch from Mad River (Figure 39). However, shorebirds also responded to the availability of alternative prey resources, such as talitrid amphipods on long beaches (Figure 70).

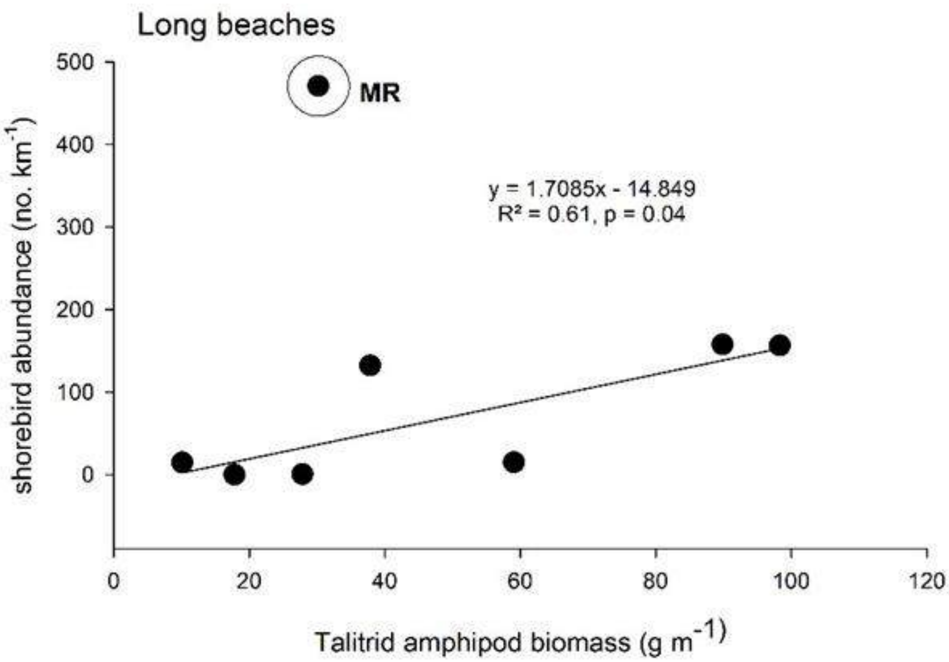

Figure 70. Average shorebird abundance as a function of talitrid amphipod biomass [excluding Mad River (MR)].

4.5.6 Redtail surfperch and sand crabs

Based on the analysis of their diet, redtail surfperch appeared to feed preferentially on sand crabs at sites where they were abundant, (see section 4.2.2, Diet analysis). We hypothesized redtail surfperch would also be more abundant (or attracted to) beaches when and/or where sand crabs were more locally abundant. We were able to test this hypothesis by comparing the mean CPUE for redtail surfperch from the fishing surveys in summer 2015 to the estimated abundances of sand crab in the swash zone during the same months and on the same beaches where the targeted sand crab surveys were done. Our results provide evidence that suggests mean CPUE was greater where/when sand crabs were more abundant (Figure 71).

A limitation of this analysis is that although the sand crab surveys were conducted on the same beaches during the same months the redtail surfperch fishing study was being conducted, the studies were not tightly linked in time and space. Tides, sea state, coastal morphology, and other factors strongly influence the physical habitat on both short and long time scales. However, the local abundance of these two trophically linked, mobile species likely reflects an integrated response to both current and recent conditions at the site.

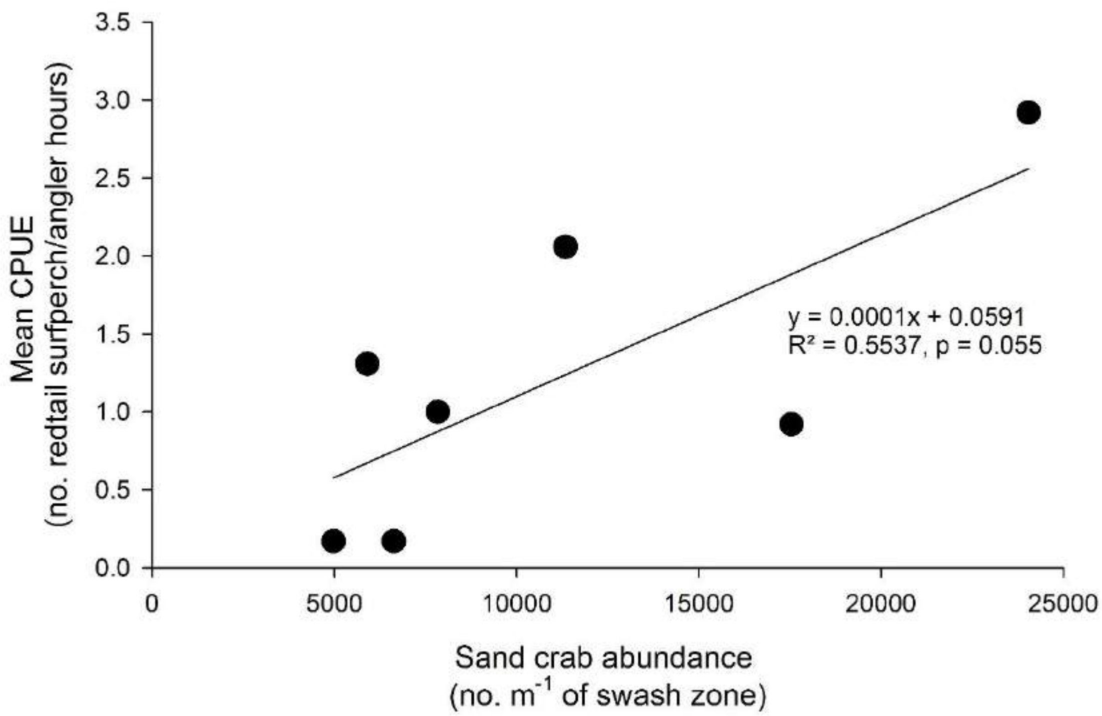

Figure 71. Mean catch per unit effort as a function of swash zone sand crab abundance.

Abundance of redtail surfperch, as estimated through CPUE, show a clear linear relationship to the abundance of sand crab prey, although there is still a fair amount of unexplained variation in the relationship (Figure 71). Some of this might be accounted for by the differences in the timing and precise locations of sampling and fishing effort across the beaches, and should be addressed in a follow-up study. This relationship coupled with the results of the diet analyses warrants further investigation. Clearly redtail surfperch are opportunistic feeders, but our data suggest there may be a tighter link between sand crab abundance and redtail surfperch abundance than previously appreciated.

4.5.7 Pocket beaches are different

In prior work monitoring sandy beaches on the north central coast MPA region we found that bird assemblages were substantially different between pocket and long beaches (results of a PERMANOVA analysis; Nielsen et al. 2013). We therefore hypothesized we would see similar differences in this study between the beach types. However, in this study we were also spanning two different bioregions (north and south of Cape Mendocino) and all the pocket beaches we surveyed are located in the southern bioregion, so this is a potentially confounding factor. However, we observed many of the same ecological differences between pocket and long beaches in this study as those we observed on north central coast beaches in 2010 and 2011.

On the pocket beaches we surveyed in the north central coast (NCC) region there were fewer shorebirds and more non-marine birds (= terrestrial and aquatic/wading birds from this study) than along the longer beaches. We also noted greater cover and abundance of kelp wrack, greater abundance and biomass of wrack-associated invertebrates, and lower abundance and biomass of sand crabs on pocket beaches compared to long beaches. These ecological patterns are strikingly similar to those we observed and reported in the sections above for this study region further north.

On the NC pocket beaches we studied, shorebirds were scarce (Figure 52, Figure 53), most likely because of the constrained beach area offering little refuge from predatory birds in the wooded areas on the bluffs, and/or the greater density of people and dogs. The abundance of terrestrial birds and aquatic/wading birds was not strikingly different between long and pocket beaches, however the composition of terrestrial birds did differ between beach types (Figure 73). Corvids dominated the species composition of terrestrial birds on long beaches while the assemblage on pocket beaches was more diverse and included more fly-catching birds, such as swallows and black phoebes, and fish-eating birds such as ospreys and kingfishers. Interestingly, on pocket beaches, although their availability was much higher than on long beaches, neither the abundance nor the biomass of talitrid amphipods seemed to attract shorebirds; there was no relationship with shorebird abundance or richness.

In contrast, on the eight long study beaches, species richness of shorebirds was positively correlated with both the abundance and biomass of talitrid amphipods (Figure 72) and with the abundance and biomass of wrack-associated invertebrates overall ($r^2 = 0.68$, $p = 0.01$ and $r^2 = 0.74$, $p < 0.01$, respectively). These results provide further evidence of the strong trophic links, at least on long beaches, between shorebirds and the macroinvertebrates that depend on macrophyte wrack-subsidies from adjacent ecosystem, which have been observed frequently in southern California (Dugan et al 2003, 2015, Schooler et al. in press) and in north central California as well.

To further explore the potential differences between the ecology of pocket and long beaches in northern California we conducted multivariate analyses of the bird community, the macroinvertebrate community and the composition of the beach-cast wrack cover. We used MDS analyses coupled with PERMANOVA to test for *a priori* hypothesized differences between beach types, while also testing for potential differences between the northern and southern bioregion and MPA status (see section 3.1.6, Data analyses, page 33 for methodological details). We expected to see differences between beach types, but were not sure if these might just be confounded by differences between bioregions. We did not expect to see differences associated with MPA status at this time.

We found striking differences in the assemblages of birds observed on pocket beaches versus long beaches (Figure 74, Table 26), even after accounting for any potential differences between bioregions. There were no differences associated with either bioregion or MPA status (Table 26). This result is consistent with our analyses of study beaches in the NCC region done in prior years, increasing the robustness of this finding for the manner in which different types of birds interact with these two different beach types.

There were also strong differences in the composition and abundance of macroinvertebrates both between bioregions and between beach types (Figure 75, Table 26). There was no difference based on MPA status, as expected (Table 26). This result differs somewhat from what we observed in the NCC coast, where the same type of multivariate analysis yielded no statistically significant difference between the invertebrate assemblages on pocket versus long beaches. Although we did observe similar differences in the abundances and biomass of two key groups, sand crabs and wrack-associated macroinverterbates between beach types in both MPA study regions, macroinvertebrate community structure and composition was highly variable among NCC beaches (Nielsen et al. 2013).

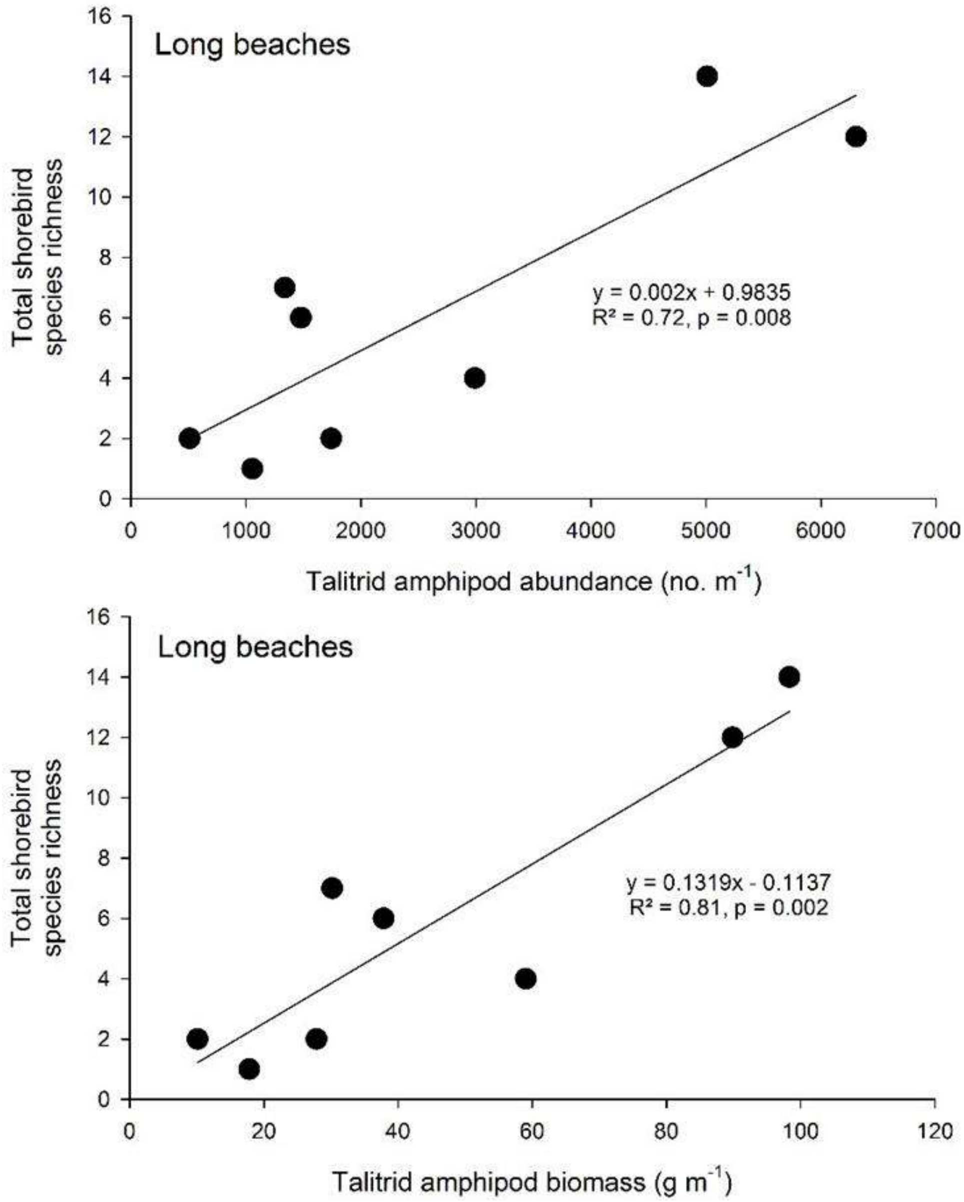

Figure 72. Total shorebird species richness as a function of average talitrid amphipod abundance and biomass.

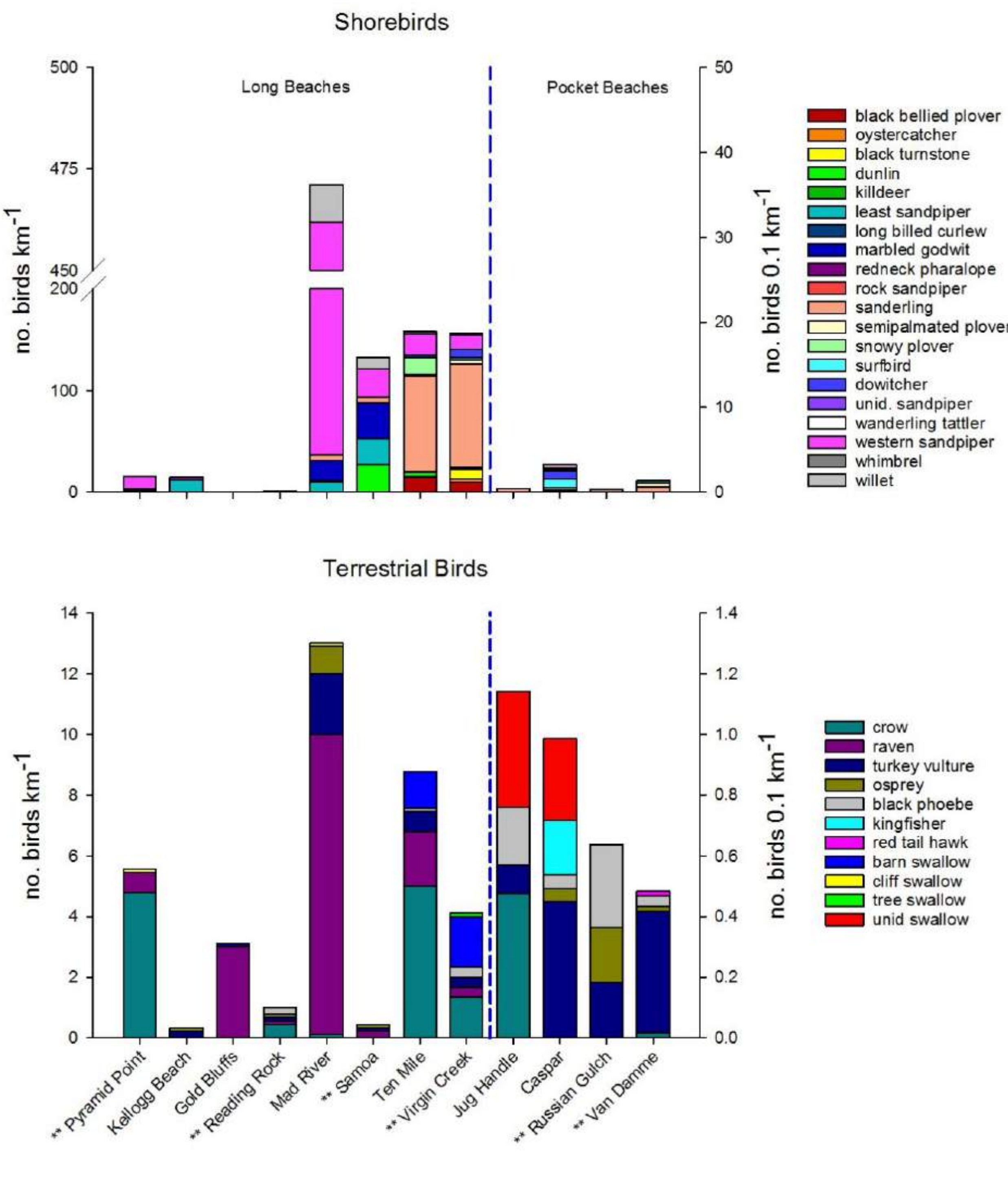

Figure 73. Average abundance of species of shorebirds and terrestrial birds observed at 12 beaches from 9 monthly surveys between September 2014 and May 2015. All other information as in Figure 52.

Table 26. PERMANOVA analyses of birds, macroinvertebrates and wrack. Data were fourth root transformed prior to calculation of Bray-Curtis similarity matrix. Analysis was conducted on the similarity matrix using 5000 permutations of the reduced model residuals. Bold indicates $p < 0.05$. Region= North or South of Cape Mendocino; MPA status = MPA or reference beach; Beach type= pocket beach or long beach.

Bird community structure (average abundance)						
Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Region	1	4419.2	4419.2	0.94733	0.6595	3
MPA status	1	563.18	563.18	1.3326	0.3231	64
Beach type (Region)	1	3465	3465	2.5667	**0.0342**	4937
Region x MPA	1	806.82	806.82	1.5718	0.2396	64
MPA x type (Region)	1	641.29	641.29	0.47504	0.8372	4981
Residual	6	8099.9	1350			
Total	11	18557				
Macroinvertebrate community structure (average abundance)						
Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Region	1	6442.5	6442.5	1.7633	**0.0002**	3
MPA status	1	880.12	880.12	0.70294	0.5424	64
Beach type (Region)	1	2569.1	2569.1	2.009	**0.0468**	4915
Region x MPA	1	653.77	653.77	0.60547	0.5555	64
MPA x type (Region)	1	1462.1	1462.1	1.1434	0.3515	4959
Residual	6	7672.5	1278.7			
Total	11	21584				
Wrack composition (average cover)						
Source	df	SS	MS	Pseudo-F	P(perm)	Unique perms
Region	1	3546.4	3546.4	10.7	**0.0002**	3
MPA status	1	263.58	263.58	1.8571	0.2447	64
Beach type (Region)	1	223.03	223.03	0.53838	0.7177	4941
Region x MPA	1	120.18	120.18	1.3321	0.2117	64
MPA x type (Region)	1	171.98	171.98	0.41515	0.7896	4977
Residual	6	2485.6	414.26			
Total	11	7457.4				

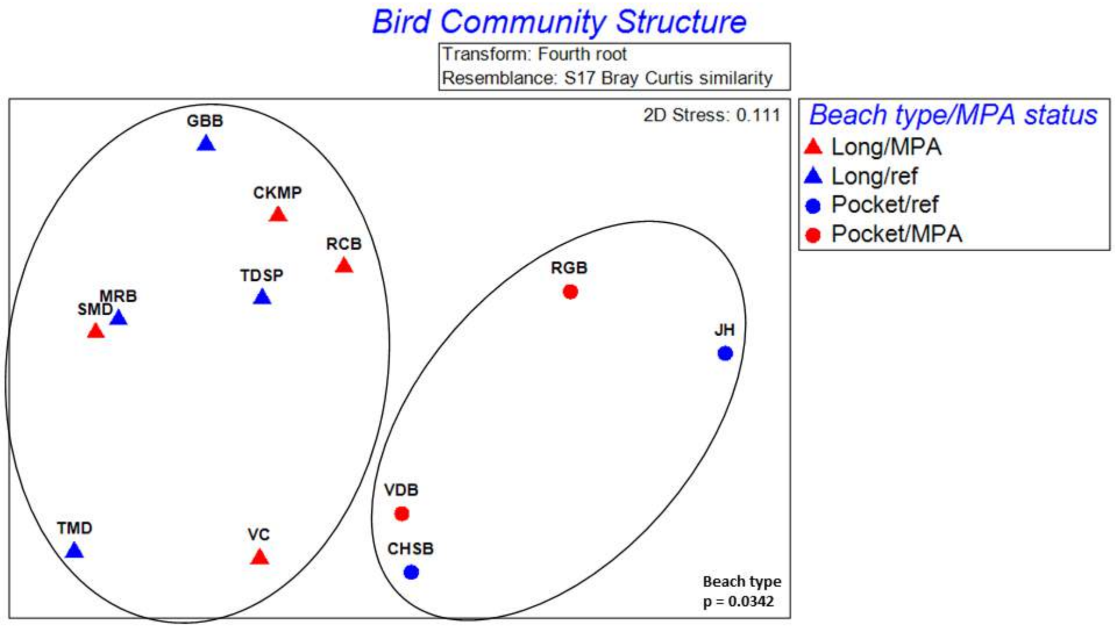

Figure 74. MDS plot of bird abundances from 12 study beaches in Northern California. The assemblage of birds on pocket beaches is substantially different from the assemblage observed on long beaches, but there were no differences with MPA status or between beaches north and south of Cape Mendocino (bioregions) (Table 26).

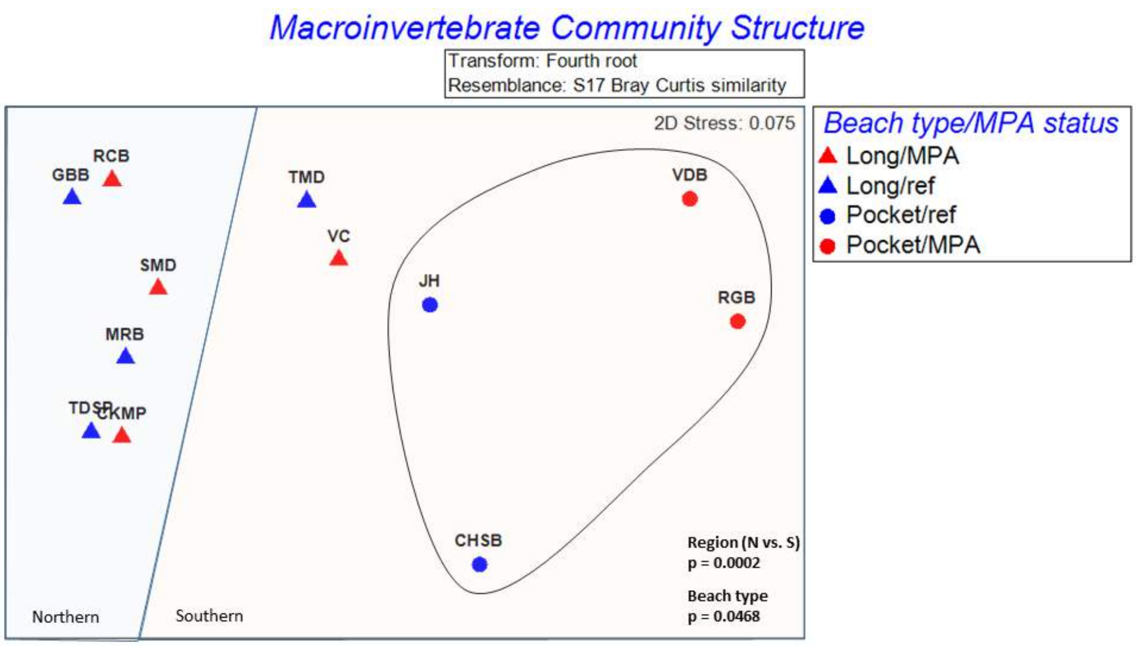

Figure 75. MDS plot of macroinvertebrate abundances from 12 study beaches in Northern California. The macroinvertebrate assemblages on northern beaches differs from southern beaches, and pocket beaches are different from long beaches; there were no differences based on MPA status (Table 26).

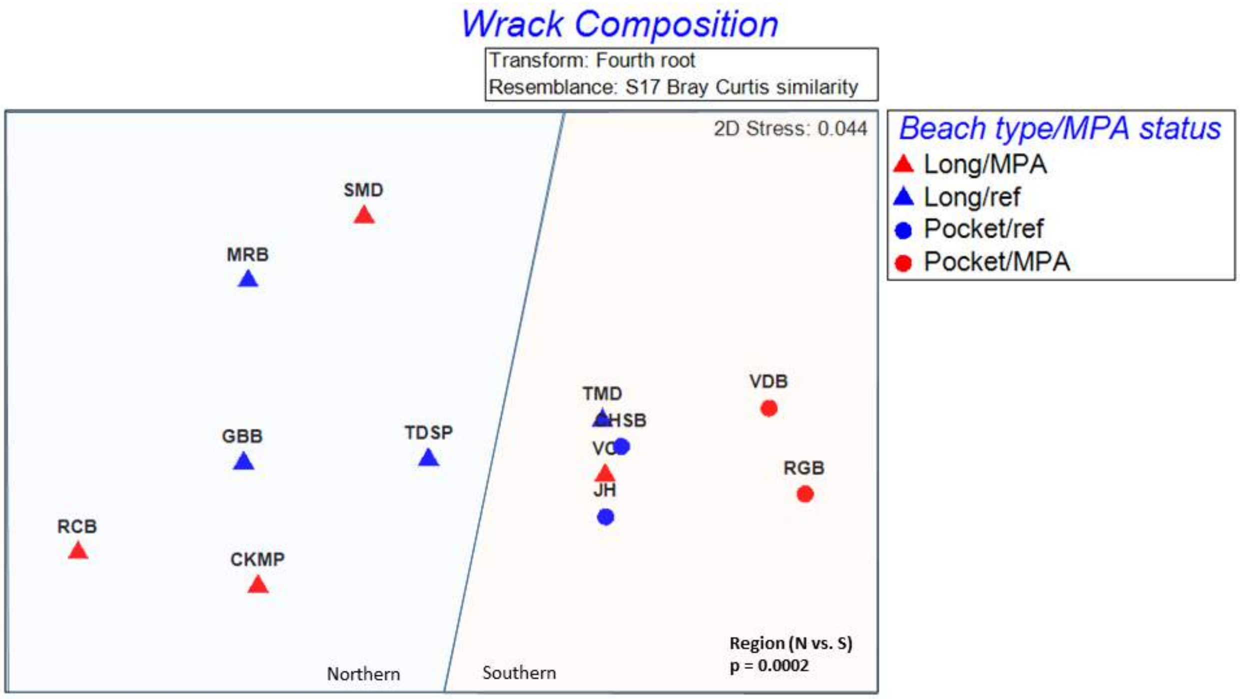

Figure 76. MDS plot of marine macrophyte wrack cover from 12 study beaches in Northern California. Beaches north and south Cape Mendocino differed substantially in the abundance and composition of wrack, but there were no differences between beaches based on either beach type or MPA status (Table 26).

Interestingly, the beaches from north of Cape Mendocino differed sharply from those south of Cape Mendocino with respect to wrack cover, but there are no differences in wrack cover among beach types or beaches with different MPA status (Figure 76, Table 26). In the NCC coast region no differences in wrack cover were detected among beach types either (Nielsen et al. 2013). However, we did see strong links between wrack cover and the proximity and abundance of adjacent wrack source habitats, such as kelp forests, estuaries and macroalgal beds on rocky habitats (Liebowitz et al. 2016). Within California, kelp forests are known to be more abundant south of Cape Mendocino than north of it, and this pattern was noted during the MPA planning process (*pers. comm.* Karina Nielsen). During this study we also observed more kelp wrack cover and higher abundance of fresh kelp on the study beaches south of Cape Mendocino (Figure 18). This may be a result of the overall scarcity of kelp forests in the northern MPA bioregion of California.

Our understanding of the ecology of sandy beaches in California has been improved and refined as a result of baseline monitoring for MPAs. Our results from the NC and NCC regions suggest that long and pocket beaches are ecologically distinct and deserve separate consideration in future coastal conservation planning as they do not support the same suite of organisms and ecosystem functions. We propse a new conceptual understanding depicting the key ecological differences between pocket and long beaches (Figure 77) based on our results from both the NC study presented here and prior work on the NCC (Nielsen et al. 2013). While our understanding of the key processes and trophic pathways for long beaches was further supported, pocket beaches clearly provide a different set of ecological functions and resources for wildlife than long beaches. However, many questions remain. This distinction is not meant to offer any value judgement on the relative socio-ecological value of pocket versus long beaches, but rather offers an initial illustration of how they differ. Specifically, pocket beaches offer a different suite of habitat and trophic resources that are apparently less appealing to many shorebirds. We speculate this is the result of the reduced availability (abundance and biomass) of invertebrates and increased exposure to predators, and possibly disturbances from the higher density of people and dogs on pocket beaches. Unfortunately we were not able to study the fishes associated with

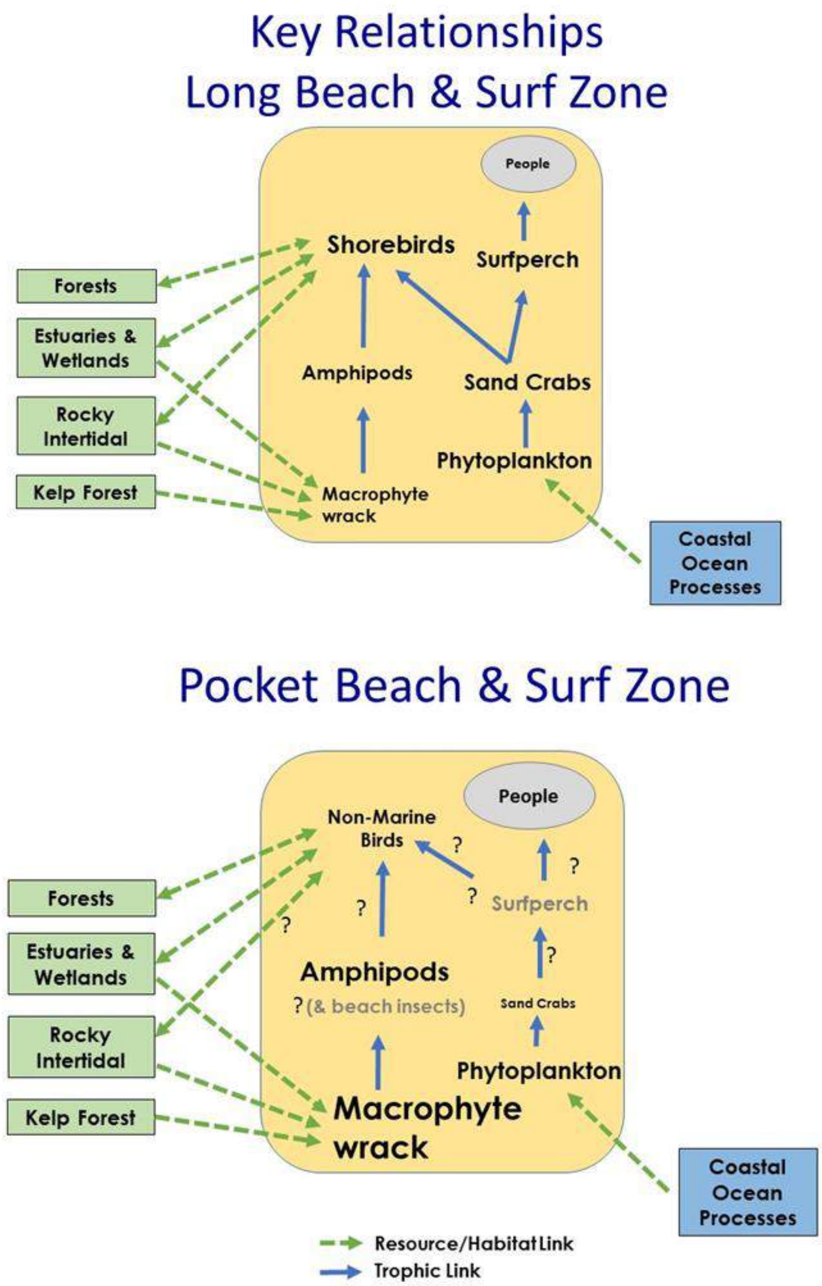

Figure 77. Key differences in energy pathways and trophic links between long and pocket beaches.

pocket beaches, but we suggest further study is warranted. At the same time, pocket beaches support a higher diversity and abundance of insectivorous terrestrial birds and thus may contribute to the food webs of adjacent habitats.

4.5.8 Indicators of community structure and trophic resources for long-term monitoring

We examined how three potential biotic indictors of trophic resources and subsidies to beach ecosystems (the abundance of sand crabs, talitrid amphipods and fresh kelp thalli) correlated with the MDS representations of bird and macroinvertebrate assemblages and wrack composition. We calculated the Spearman correlations between these three variables and the two MDS axes in each analysis (Table 27) and superimposed them as vector bi-plots onto the ordination graphs (Figure 78, Figure 79, Figure 80**Error! Reference source not found.**).

Table 27. Relationship between MDS analyses and three prospective biotic indictor variables proposed as long-term monitoring. Values are the Spearman rank correlations between MDS axis values (from wrack composition, macroinvertebrate and bird assemblage analyses) and fresh kelp, talitrid amphipod and sand crab abundances. See text and Figure 78, Figure 79, Figure 80 for additional details.

Biotic Indicator	**Horizontal MDS Axis**			**Vertical MDS Axis**		
	Wrack	***Inverts***	***Birds***	***Wrack***	***Inverts***	***Birds***
Fresh Kelp Thalli	0.3	0.8	0.3	0.6	0.0	-0.9
Talitrid Amphipods	-0.1	0.9	0.5	0.8	0.0	-0.5
Sand Crabs	0.4	-0.7	-0.8	-0.8	0.3	0.4

Interestingly, for all three assemblages, the sand crab abundance vectors were almost opposed in orientation to fresh kelp thalli and talitrid amphipod abundance vectors (Figure 78, Figure 79, Figure 80), reflecting the importance of sand crabs on long beaches, and the greater abundance and biomass of talitrid amphipods and kelp thalli on pocket beaches. These vectors aligned well with the major axes of variation distinguishing among beach types and bioregions (Figure 75, Figure 74, Figure 76), demonstrating how these indicators might serve to distinguish among beaches with different community structures. All three of the prospective indicators were also strongly correlated with different aspects of the two dimensions (axes) of the MDS plots (Table 27). These consistent relationships provide evidence of the usefulness of these in representing important aspects of community structure. This is in addition to their representation of the availability of key trophic resources, an important functional metric for sandy beach ecosystems. .

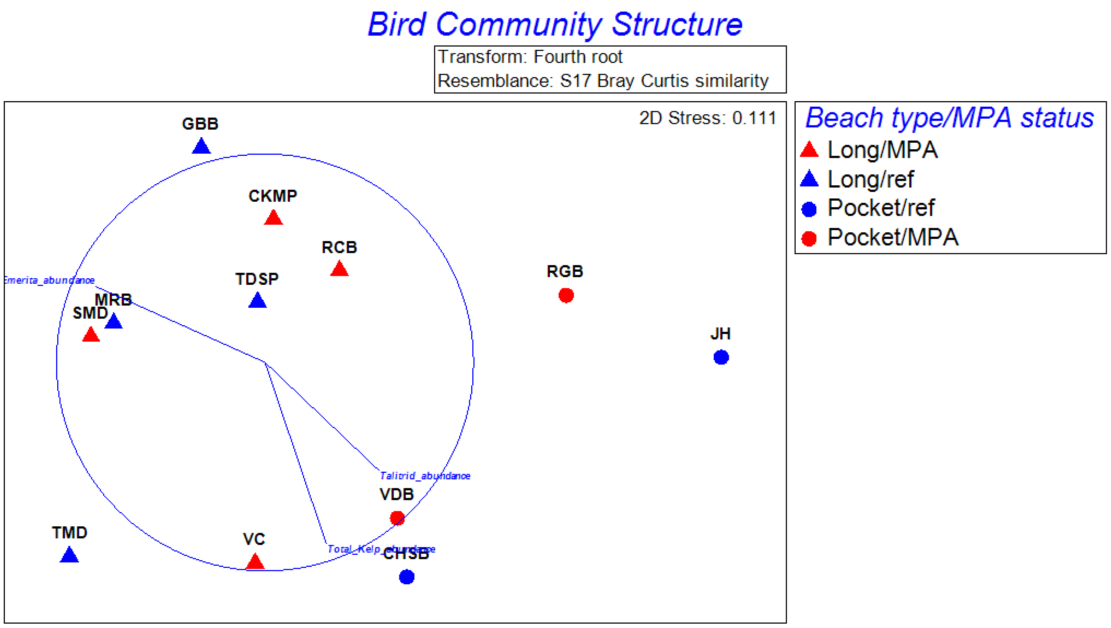

Figure 78. MDS plot of bird abundances from 12 study beaches in Northern California with correlation vectors of proposed indicator variables superimposed. Spearman rank correlation vectors between the MDS axes and kelp, sand crab and talitrid amphipod abundances. Vectors ending closer to the perimeter of the circle represent r values closer to 1, while those closer to the center of the circle approach 0. Vectors that are completely parallel to an axis (e.g. the vertical axis) are correlated with that axis and not the other (horizontal) one, thus the angle represents the degree of correlation with both axes simultaneously. See text for additional details.

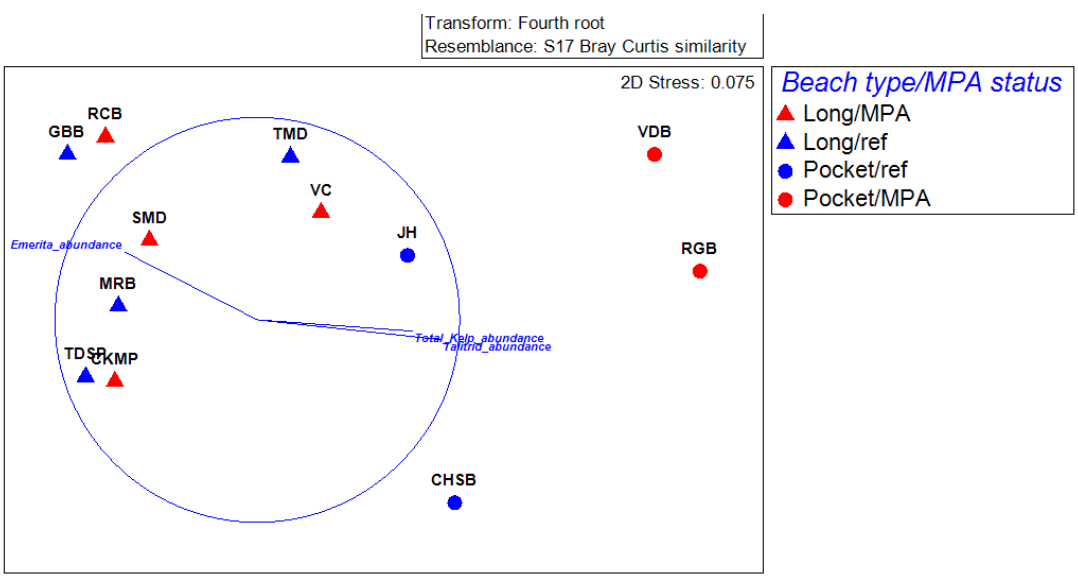

Figure 79. MDS plot of macroinvertebrate abundances from 12 study beaches in Northern California with correlation vectors of proposed indicator variables superimposed. All else as in Figure 78.

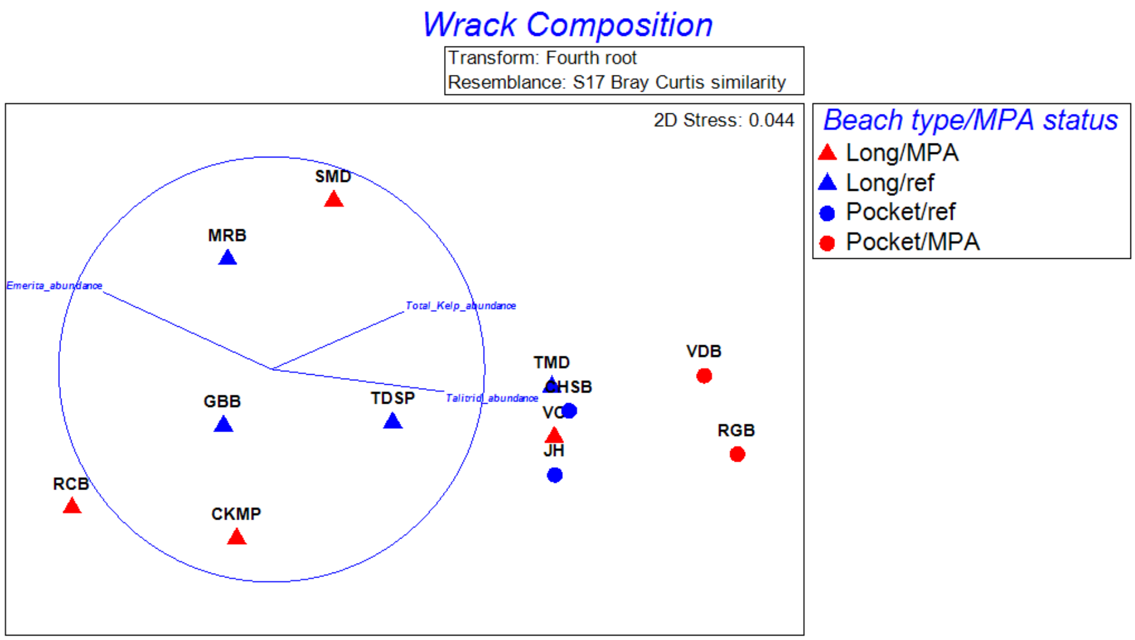

Figure 80. MDS plot of wrack composition from 12 study beaches in Northern California with correlation vectors of proposed indicator variables superimposed. All else as in Figure 78.

4.5.9 Limitations

Our results represent a major advance in understanding sandy beaches ecosystems of the northern California. However, we also had to make tradeoffs between tractability and comprehensiveness given the limits of available personnel, time and funding, and also weather. We would have preferred to be able to conduct monthly beach surveys for a full year, for example. However, based on prior experience we think we captured the most variable and ecologically important times of the year for most variables. In addition, winter storms stymied our ability to do concurrent monthly surveys, within the same week, in both bioregions in some months. This was simply not possible given local conditions. Ideally we would have sampled sand crabs and talitrid amphipods twice over the summer to better estimate both recruitment of juveniles and adult population sizes. Furthermore, the low abundance of kelp wrack compared to our observations on the NCC is confounded with the strong differences in ocean conditions between the two periods, making it impossible to know whether or not this representative of the bioregion, the conditions of this year, or both.

In contrast, the many qualified and dedicated volunteers willing to participate in the fishing surveys and the collaboration with CDFW staff, allowed for more integrated sampling over time. However, pocket beaches were not represented in this effort. Surf zone fish sampling was restricted to long beaches, in the north coast study region due to budgetary and logistical considerations. Pocket beaches are relatively few in Humboldt and Del Norte counties as compared to Mendocino County. In comparison to long beaches, pocket beaches require more sampling effort (increased personnel) and are therefore relatively more expensive to sample. Despite these drawbacks, it would be informative to sample pocket beaches for surf zone fishes in future monitoring. Compared to long beaches, pocket beaches show an increased diversity of fishes (surfperch, flatfishes, rockfish, sculpins, smelt, silversides, etc.). Pocket beaches are known to serve as nursery habitat to a wide variety of species due to the drift algal and debris mats and associated invertebrate prey fauna found in/on these more protected beaches (Lenanton et al. 1982).

Additional limitations of the study include the lack of data collection in the Cape Mendocino region and studies focused on razor clam populations or the role of scavengers and meso-carnivores (e.g., terrestrial mammals) on beaches and beach-nesting birds.

Nonetheless we think we captured a representative range of variability for the study period on these beaches for the variables we reported, allowing us to discern major seasonal patterns, gain insights into important trophic connections and make comparisons among the beaches studied.

4.5.10 Summary

Our work represents the first surveys of surfperch and night smelt performed on the north coast. It is also the first comprehensive biodiversity survey of macroinvertebrates, birds and marine wrack on sandy beaches for the NC region. The ecology of coastal marine habitats from northern California is under-represented in the peer-reviewed scientific literature. This is somewhat surprising as the region is home to a major public institution of higher education, Humboldt State University (HSU), with a focus on marine science and a dedicated marine laboratory, Telonicher Marine Laboratory. To some extent, this may be because the California State University (CSU) system is constrained by historical legacy, budget, legislative mandates and institutional culture to emphasize classroom instruction over research and academic leadership.

Our baseline study found compelling evidence supporting hypotheses concerning connectivity with other coastal ecosystems through wrack subsidies and functional relationships affecting sandy beach ecosystems and food webs, consistent with the results from other regions (Dugan et al. 2003, 2008, Nielsen et al. 2013, Dugan et al. 2015, Leibowitz et al. 2016, Schooler et al. in press; Figure 2). Macroinvertebrate communities on beaches responded to factors associated with sediments and swash climate. Birds and surfperch were associated with the presence of key trophic resources, including both suspension feeding and wrack-associated macroinvertebrates. The strong influence of subsidies of drift macrophytes on community structure and resulting responses in the abundance and distribution of higher trophic levels as indicated by shorebirds represents some of the critical linkages among coastal ecosystems through which the direct and indirect effects of MPAs may be realized. Additionally we documented new findings regarding the differences between the ecological characteristics of pocket and long beaches, extending the findings of North Central Coast baseline studies of beach ecosystems.

In agreement with results from the North Central Coast and South Coast regions (Nielsen et al. 2013; Dugan et al. 2015), shorebirds appear to be sensitive indicators of ecosystem conditions on beaches in the North Coast region. This strong result agrees with the suggestion that shorebirds (sandpipers, plovers, etc.) could be sentinels of coastal ecosystems that integrate environmental conditions on a hemispheric scale (Piersma & Lindstrom 2004). The loss of migration staging, foraging, and wintering habitats has been implicated in the declines of populations of many species of shorebirds in North America and is a major concern for shorebird conservation planning and management (Howe et al. 1989, Brown et al. 2001, Bart et al. 2007; Morrison et al. 2001, 2006), as are the effects of climate change (e.g. Kendall et al. 2004). The north coast of California represents a very important area for shorebirds during migration.

The diversity of surfperch caught on the North Coast differed from the North Central Coast. While redtail surfperch dominated the catch on the North Coast, while both redtail and silver surfperch were common on the North Central Coast. Catch per unit of angler effort was similar in both regions. From our diet analysis we learned that sand crabs are an important part of the diet of redtail surfperch, as are fish eggs. Spawning aggregations of night smelt were spatially and temporally variable, and more consistently on some beaches than others.

4.6 Local and Traditional Ecological Knowledge and Participant Perspectives

The infusion of research funding into the North Coast region helped build new capacity and leverage existing capacity. Limited investment in the research mission of the CSU by the State reduces some of the benefits and resources that might otherwise be available to support local community information and planning needs. For example, the MPA baseline program funding supporting our collaboration with the California Department of Fish and Wildlife (CDFW) and greatly enhanced the 2013 fishery independent study on north coast redtail surfperch. The collaborative nature of our study also greatly expanded, geographically and temporally, a one-year project recently awarded to the California Commercial Beach Fishermen's Association (CCBFA), CDFW and H.T. Harvey & Associates, by Collaborative Fisheries Research-West, which examined spawning populations of night smelt in Humboldt and Del Norte counties.

Many local community members, including tribal members, fishers and university scientists, found the MPA planning process for this region challenging and problematic. Although virtually everyone involved shared a strong appreciation for the value of a healthy marine ecosystem, and supported the concept of sustainable management of natural resources, some disagreed with the scientific premises, applicability of scientific evidence from elsewhere, and the overall philosophical approach of using no-take marine reserves as a conservation and management tool. Some questioned the need for formal protections and restrictions given the remoteness of the region, low population size and the cultural norms and identity of the region. North coast tribes and politicians struggled to resolve the legal and ethical issues surrounding the sovereignty of the tribes and their human rights.

However, the stakeholder-engaged planning process, including all its challenges, created new channels of communication in the region among different communities. Additionally, the MPA baseline monitoring program and associated funding emphasized collaboration among different entities, institutions and local community members. Our project team reflects these priorities and included partnerships with academic scientists, government scientists, an environmental consulting business, a local tribe, commercial and recreational fishers and university students. The research funding allowed our team to synthesize many different types of information, work collaboratively, train students and community members in scientific methods, teach university students how to fish, engage in informal cultural exchange and develop a deeper collective understanding of the many facets of sandy beach ecosystems and coastal communities in northern California. Below we offer additional contextual information based on team members personal perspectives and interpretations of our research observations that integrate local and traditional ecological knowledge.

For the Tolowa Dee-ni', the implementation of the California Marine Life Protection Act (MLPA) Initiative on the North Coast, beginning in 2009, threatened their access to and the continued use of Tr'uu-luu-k'wvt. The entire area of Tr'uu-luu-k'wvt, also known as Pyramid Point, was selected for a marine protected area that would not have allowed any recreational or commercial fishing. Although the Tolowa Dee-ni' Nation maintains that the State does not have authority to regulate their subsistence, ceremonial, and customary fishing uses because the right to continue these uses has never been ceded or explicitly extinguished by Congress, the State maintained they had authority. Through a difficult and arduous three-year process, the Tribe was successful in ensuring that although a marine protected area would be designated at Pyramid Point, that it would continue to allow non-commercial "tribal take" by members of the Tolowa Dee-ni’ Nation. Thus, the Tribe prevailed and was successful in ensuring the continuance of the traditional surf smelt fish camps.

Through a commitment to the continuance of this important cultural and subsistence activity and the diligence to ensure that these practices continue, the Tribe has secured access, as well as political and regulatory recognition to support the continuance of fish camps. All of this, however, is meaningless, if the habitat is not protected and the resource is not healthy and available. Thus, there is a need to understand why we are seeing a decline in surf smelt returning to Tr'uu-luu-k'wvt*,* resulting in the current habitat assessments being conducted by Tribal biologists.

Traditional ecological knowledge gathered through ethnographic interviews and archival research by Tolowa Dee-ni’ Nation biologists (and this research team) shows that *dee-sri~k* (*Olivella spp.*) was/is present in abundant numbers around Point St. George. Tolowa Dee-ni’ utilized this area for the gathering of *dee- sri~k* shells for use on regalia. Shells are still collected today for the same purpose. *Ch’uy-xee-ni* (night smelt) was also found to be routinely caught on both Kellogg Beach and within Pyramid Point MPA, however Tribal anglers have noticed a severe decline in *lhvmsr* (surf smelt) and *ch’uy-xee-ni* in the last decade. Speculation as to the cause from Tribal citizens ranges from pollution from coastal developments and pesticides, to an increase of human activity, to warmer waters, to possibly just a fluctuation in forage fish life cycles. To help shed light on the causes for the decline, the Tribe has been conducting comparative smelt habitat assessments since 2013 to determine if suitable spawning habitat is available and what kind of influence water quality has on fresh water outlets to spawning areas. This work is ongoing and will be highly important information as smelt are a culturally keystone species to Tolowa Dee-ni’ and their way of life.

It is vital to Tolowa culture that marine stewardship practices, traditions and knowledge are passed down to future generations. Utilizing tribal youths during the summer to assist with data collection and participate in traditional fish camp has given them the opportunity to experience these practices first-hand. Summer Youth that participated in our summer sampling and tagging of *chii-la’-lhsrik* (surfperch) learned a great deal, both from HSU biologists and from Tribal biologists. Members of the Summer Youth program have been influenced by this experience and, as a result, some have decided to pursue an education in the natural sciences.

Historical catch data indicates that significant spawning activity has occurred on beaches for which our data show relatively little spawning activity. We believe this is due to the cyclic nature of night smelt abundance on semi-decadal timescales, and may be related to ocean conditions, but further research is needed to understand these relationships. Anecdotal information provided by local fisherman indicates that the geographic distribution of night smelt spawning activity expands during periods of high relative abundance and contracts during periods of low relative abundance. A period of high relative abundance occurred during the late 1990’s and early 2000’s with periods of lower abundance occurring in the 1980’s and 2010’s. Long-term monitoring efforts must be careful to evaluate all new data collected within the context of the cyclic nature in abundance of the species.

The fishery for night smelt is fairly unique in that it is almost exclusively a commercial fishery, there is no limit on the number of participants, the fishery is open 365 days per year, there are no restrictions on the amount of fish each fisherman can catch, and access to the wave slope with a four wheel drive vehicle is required. Limitations on fishing effort are functionally regulated only by vehicle access restrictions onto beaches where night smelt spawn. Gold Bluffs Beach, within Prairie Creek State Park, is host to nearly the entire commercial fishery and there are only seven active vehicle use permits for the purpose of commercial fishing on the beach. These permits are non-transferable and will cease to exist when the current permit holders stop fishing. It is expected that commercial fishing effort will decline in proportion to the decline in vehicle access on beaches in the region and that all beaches that prohibit vehicle use will become de facto marine reserves for night smelt. When fishery induced mortality is eliminated the abundance of night smelt will fluctuate only in response to environmental forcing and the species may serve as a unique indicator of ecosystem condition unaffected by human interactions. However, based on the above and reinterred in the following section on long-term monitoring, at present we do not recommend night smelt as an indicator species for future MPA beach monitoring.

During the implementation of sandy beach MPAs, along the north coast, there was much discussion and controversy as to whether or not surfperch (i.e. redtail surfperch) should be considered as an “indicator species” due to their relatively low recreational and commercial economic value and because populations were assumed to be relatively stable. Our results from studying redtail surfperch from Ten Mile in southern Mendocino County to Pyramid Point in northern Del Norte County suggest that redtail surfperch populations are stable, as we noted little variation in CPUE, sizes, or sex ratios among the nine beaches (MPAs and reference sites) that we studied. In addition, although based only on a few tag returns, they appear to show little migratory behavior, meaning changes in vital rates (e.g., mortality) on a single beach due to any cause have the potential to impact local populations. It should also be noted that of the nearly 300 km of sandy beach habitat along the north coast, tens of kilometers are not accessible to fishing nor are these areas subjected to most land-based anthropogenic disturbances. Consequently, we argue, based on their stable population levels, coupled with the fact that many beaches already serve as refuges from fishing mortality due to inaccessibility at the current time, redtail surfperch do serve as a logical indicator species for monitoring MPA beach habitats. Future changes to their population structure, in specific areas, could quickly serve as a signal of natural or human induced environmental perturbations.

The importance of beach vehicle-use when monitoring for surf zone fishes should also be considered for future research conducted within this region.

5 Long Term Monitoring

The beaches we studied in the NC region were physically and ecologically diverse. Comprehensive biodiversity surveys are essential for creating a baseline inventory and periodic assessments of MPA performance with respect to meeting diversity related conservation goals. In addition, we extended and strengthened conclusions from the NCC baseline monitoring that pocket beaches have unique ecological characteristics clearly distinguishing them from long beaches. Unlike the cacophony of seaweeds and invertebrates on full display on rocky shores and in tidepools at low tide, to appreciate the biodiversity of beaches, you need to dig for buried treasure, taking your lead from the birds, so to speak.

The biodiversity of beaches consists of the many invertebrates that live in the sand, and the insects and crustaceans associated with piles of decomposing seaweeds, and other marine wrack along with the many birds and surf zone fishes that feed on these resources. The diversity and abundance of invertebrates reflect the quality of the energetic resources available to support a variety of coastal and marine organisms. Understanding the ecological processes that support this provisioning function, and how management actions and environmental changes impact them, is critical for understanding how MPA networks contribute to the resilience of coastal ecosystems.

Beaches rely on primary production supplied from adjacent marine ecosystems in the form of macrophyte wrack from kelp forests, rocky shores and estuaries, to fuel a food web important to birds and a diverse assemblage of insects endemic to beaches. Changes influencing adjacent habitats and their connectivity to beaches may have strong impacts on beach ecosystems. Microscopic, single-celled algae (phytoplankton) that live in coastal waters sustain sand crabs, bivalves and other suspension-feeding fauna that comprise the bulk of intertidal biomass on beaches. Redtail surfperch, shorebirds and seabirds feed extensively on these fauna. Changes in ocean conditions related to climate change and climate cycles can influence both the productivity of the surf zone food web, and the dispersal of larval stages. Migrating shorebirds feed on the macroinvertebrates buried in the sand and in the surf zone to fuel their flight to and from distant breeding and nesting areas. Surfperch and seabirds also feed on these invertebrates, thus beaches are part of the network of critical habitats that support these species.

The physical habitat of a beach can be compromised through management actions that do not account for the valuable ecological functions beaches provide. Beaches also hold great cultural importance to people for a variety of reasons and uses, including recreational activities (including fishing), commercial and subsistence fishing, and traditional or ceremonial practices.

5.1 Ecological indicators for sandy beaches

Comprehensive baseline surveys are labor and time intensive and require specialized expertise. However, they also provide guidance on key ecological indicators or proxies that if tracked over time would be very informative regarding ecosystem condition. Some of these may be amenable to monitoring by dedicated and trained volunteers or university students. Based on results from this baseline study for the NC region, prior MPA baseline studies in California, and expert judgement on sandy beach metrics from the scientific literature (Schlacher et al. 2014), we recommend a suite of indicators that are clearly linked to beach biodiversity, trophic support and habitat suitability (Table 28). In addition, we recommend observations of the numbers of people who visit the beach and the kinds of activities they engage in to provide additional context.

While we are confident the indicators we describe below are very good ones, based in part on their consistency with results from other regions, we think more scientific study is required to design a long-term monitoring plan.

Many of the indicators we recommend can be measured from structured observations using simple tools and walking on the beach (birds, fresh kelp, beach and surf zone characteristics, etc.). The relationships we describe below hold up very well on long beaches. For example, we recommend some simple observations of the location of important zones on the beach and their slope. The width of the saturated sand zone at low tide was a strong predictor of invertebrate richness in the NC region (Figure 63, $r^2 = 0.85$). It is related to the potential for a beach to support a diverse assemblage of invertebrates. If small sand samples can be collected and quantified in a laboratory later on, and the slope of the beach measured, additional valuable information can be gained about the quality of the habitat.

Table 28. Recommended indicators for long-term monitoring of sandy beach ecosystems in the north coast MPA region.

Metrics and Key Attributes		**Indicator/Focal Species or Taxa**
Trophic Structure	Predatory Birds	Birds – abundance species richness **All birds**,
	Long Beach Fishes	Surf zone Fishes –abundance, size structure **Surfperch**
	Pocket Beach Fishes	Surf Zone Fishes – abundance, diversity, , size structure, diet **Resident adults/ juveniles using nursery areas**
	Suspension Feeders	Macroinvertebrates -– abundance, biomass **Sand crabs**
	Wrack consumers	Wrack Invertebrates -– abundance, biomass **Talitrid amphipods**
Productivity	Beach Wrack	Macrophyte Wrack -– composition, abundance **Fresh kelp**
Physical Habitat	Beach & surf zone	Beach Characteristics – simple profile (slope saturated sand zone width, sand grain size Surf zone Characteristics – swash period
Non-consumptive Use		Human use – abundance, recreational activities **People on the beach, activities**
Consumptive Use		Human use – fishing effort **People fishing, total catch, hours spent**

A simple monthly count of fresh kelp plants observed along a standard transect is a good predictor of overall invertebrate richness on the beach (Figure 65, $r^2 = 0.63$), and of wrack-associated invertebrate richness (Figure 66, $r^2 = 0.54$) as well as their abundance and biomass (Figure 66, $r^2=0.68$, $r^2=0.69$). Kelp provides both habitat and food for wrack-associated species.

Standardized bird counts along the same transect could be done on a monthly basis. Birds are more abundant on beaches where trophic resources are abundant. Both invertebrate richness and the abundance of talitrid amphipods are strongly correlated with the richness of shorebirds observed on the beach (Figure 68, $r^2 = 0.80$; Figure 70, r^2=0.61).

Sand crabs are clearly another important indicator species, and like talitrid amphipods, sand crabs were observed on every beach we studied in the NC region. They are both ubiquitous and important energetic resources for shorebirds and surf zone fish. Sea ducks, such as Surf Scoter, also feed on sand crabs. As a result of this study, we now know that sand crabs are enormously important to the diet of redtail surfperch (Figure 41). The second most important part of their diet at some beaches was fish eggs, mostly smelt eggs, on beaches where smelt spawning activity was also frequently observed (Table 18, Table 19). We thus recommend sand crab abundance as a key indicator variable of the trophic support available for birds and surf zone fish on sandy beach ecosystems of the North Coast region.

Talitrid amphipod abundance is also a good indicator for similar reasons. However, these animals must be sacrificed and require a basic laboratory facility to be quantified.

We strongly recommend follow up studies to identify the best time of year to sample for characterizing recruitment and established, mature populations of sand crabs. Our observations suggested sand crab recruitment occurs later in northern California than southern California. Prior work and observations suggests that sand crab recruitment in northern California and Oregon may also be intermittent (e.g., Sorte et al. 2001). We need to better understand seasonal and interannual variation, including the timing of recruitment, to recommend a specific long-term monitoring strategy. The year we sampled these beaches coincided with the large and anomalous warm water event that started in 2013 and persisted through late 2015, and a period of intense drought in California. The large numbers of small sand crabs we observed during the summer of 2014 may have been the result of unusually favorable conditions for northward larval transport. Sand crabs are also intolerant of low salinity conditions. The drought may have also reduced the exposure of juvenile sand crabs to rainfall events during low tides.

Additionally the wide, dissipative (long) beaches of the NC region present some new sampling challenges. These wide sand flats result in a more patchy distribution of sand crabs across the beach (separated by 10s of meters), instead of occurring in a zone that can be more reliably discerned. Patchiness also exists in the alongshore dimension with patches of sand crabs occurring 10s to > 100s of meters apart. A targeted study is needed to design an appropriate sampling approach as the methods we've recommended for sand crabs as an indicator species in other regions (Nielsen et al. 2013, Dugan et al. 2015) will not be appropriate for these beaches. These beaches will require a higher level of sampling effort in the design to adequately describe the abundance of sand crabs as an indicator species.

With a dedicated group of trained fishers, and repeated fishing trips to a beach, catch and release fishing coupled with some simple measurements can provide valuable information on the population status of redtail surfperch. CPUE values for all MPA and reference sites indicate that redtail surfperch populations are relatively similar along NC sandy beaches at this time. This coupled with the fact that they may show limited movements make this species a good candidate for long-term monitoring. However, we recommend additional tagging studies be done to better understand redtail surfperch movement among beaches before committing to a specific long-term monitoring strategy.

Likewise, with sufficient personnel, repeated sampling of fishes at a selection of pocket beaches would provide information on a greater diversity of surf zone fishes, including those that utilize pocket beaches as nursery habitat.

Despite being an important forage fish, a regionally valued commercial fishery and a culturally important species, night smelt populations exhibit great temporal and spatial variability in spawning activity. Consequently, considerable experience is needed to locate spawning aggregations. Due to these limitations, we recommend that night smelt not be used as an indicator.

Additional variables, some not formally evaluated as part of this study, should be considered for future studies. Given the cultural and recreational importance of razor clams in the region, a focused study of this species is warranted. Additionally, it would be worth investigating if including razor clam shells in the beach wrack surveys as specific category might shed light on the presence or abundance of razor clam populations. We observed many mysids and crangonids in the swash zone while collecting core samples, and some of these were incidentally captured in our samples, but new sampling techniques are required to evaluate the ecological importance of these potentially important trophic resource. Lastly, we did not address the role of scavengers and meso-carnivores (e.g., terrestrial mammals) on these beach ecosystems. Given the low level of development in the region compared to more populous and urbanized beaches in other parts of California, this functional group may be playing a more important ecological role in this region than is apparent in this study.

In summary, we think the metrics we have identified are tractable, appropriate and informative for long-term monitoring of the ecological status of beaches. They will be most useful if complemented by periodic studies that are more comprehensive. We also strongly suggest that additional focused studies be done to develop more specific recommendations for the design of a long-term monitoring program.

There are many opportunities to include motivated community members who are interested in natural history and willing to be trained in the required scientific approaches needed to collect useful observations, under the supervision of professional scientists. There are also many formal and informal benefits of engaging community members in the scientific process of conducting ecological studies. We endorse the approaches and recommendations made in Dugan et al. (2015) regarding developing a tiered training program, reflecting the successful training approach used by Reef Check California.

The value of long-term time series for understanding how ecosystems are faring and their responses to management actions and environmental changes are well known. However, we caution that the costs of training and managing volunteers, and conducting quality assurance and quality control of the data collections, and other administrative support and technical expertise required to maintain a reliable and useful long-term monitoring program, are substantial and require ongoing financial support. We suggest that collaborating with university programs with a focus on marine science and ecology, including marine laboratories, may be one mutually beneficial and cost-effect option for the State to consider. Regularly offered courses in marine ecology both within often incorporate field work and study of issues related to natural resource management and conservation issues. There is also increasing interest in and appreciation for the value of service-courses, internships and capstone research projects as part of undergraduate curricula across many majors beyond those with a focus on field biology. University science professors and researchers could provide much needed technical expertise and oversight of such a program. Collaborations with existing or growing tribal science programs in the region should also be given strong consideration. Engaging with local non-profit or community organizations such as local

Audubon chapters, recreational fishing clubs and the like, should also be explored. With adequate support, oversight, and tiered training, as recommended in the South Coast MPA baseline report (Dugan et al. 2015), citizen scientists might be able to extend the scope of a scientific long-term monitoring program. In addition, there would be invaluable soft-benefits to society such as broadening the reach of science-engagement with the extended communities of local and regional stakeholders.

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8 Appendices

8.1 Photographs of Study Beaches.

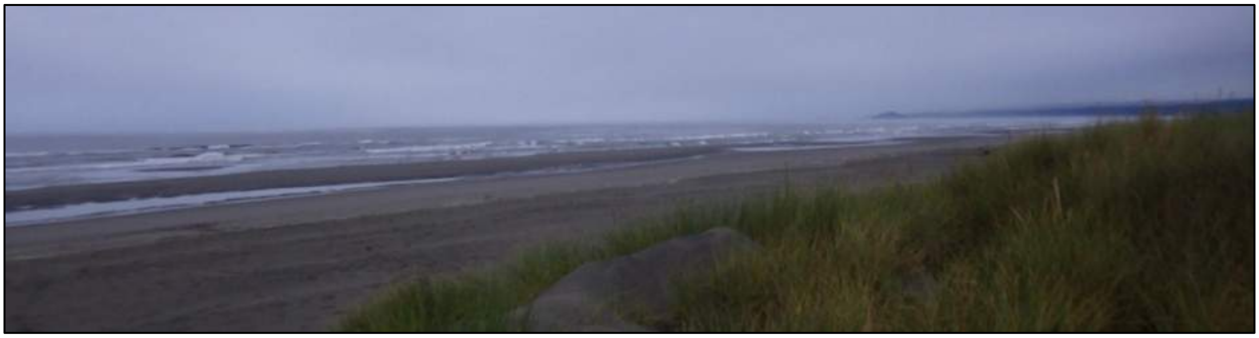
Long Beaches: (photographs arranged from North to South)

Pyramid Point SMCA

Kellogg Beach

Gold Bluffs

Reading Rock SMCA



Mad River

Samoa SMCA

South Samoa

Ten Mile North

Ten Mile

Virgin Creek SMCA

Pocket Beaches: (photographs arranged from North to South)

Jug Handle

Caspar


Russian Gulch SMCA


Van Damme SMCA

8.2 Wrack Survey Summer 2014

Summary level data of the mapped, one-time survey of wrack cover taken concurrently with biodiversity sampling in July and August 2014. Patterns were broadly similar to those reported for the rapid monthly surveys in the following year across these same sites, except that the cover of surfgrass on Virgin Creek and the overall cover of marine wrack at Van Damme was very high on the biodiversity sampling date. See methods for additional details.

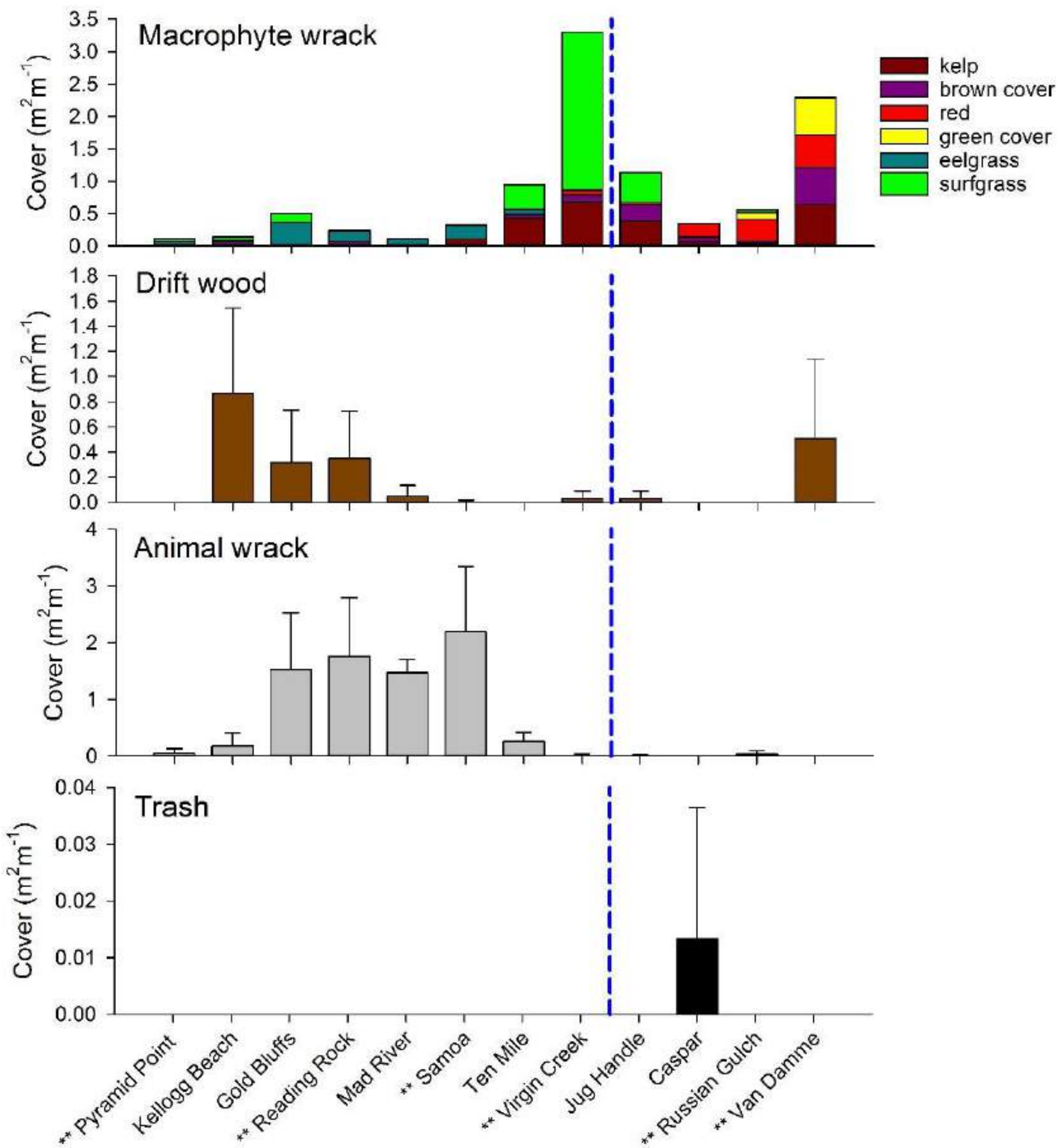


Figure A- 1. Cover of marine macrophyte wrack and other beach wrack during summer biodiversity surveys. All other information as in *Figure 18*.

8.3 Macroinvertebrate Species Richness

Comprehensive tables of beach endemic and non-endemic taxa of macroinvertebrates from macroinvertebrate biodiversity surveys in summer 2014 on 12 study beaches.

Table A- 1. Macroinvertebrate beach-endemic species collected in surveys of the 12 focal study beaches. Six of the 12 the beaches surveyed were within MPAs (indicated by **). 'X' indicates species that were found in biodiversity surveys, 'p' indicates species that were found only in other surveys at that site, '☨' indicates wrack-associated species found in the biodiversity surveys. A gray highlight indicates abundance > 10,000 individuals m^{-1} in the survey.

	Pyramid Point **	**Kellogg Beach**	**Gold Bluffs**	**Reading Rock ****	**Mad River**	**Samoa ****	**Ten Mile**	**Virgin Creek ****	**Jug Handle**	**Caspar**	**Russian Gulch ****	**Van Damme ****
NEMERTEA												
Unid. Nemertea		X				X				X		
Cerebratulus marginatus						X						
Carinoma mutabilis	X	X			X	X				X		
Paranemertes californica					X							
MOLLUSCA												
Olivella biplicata	X	X								X		
POLYCHAETA												
Unid. Polychaeta	X		X			X	X					
Lumbrineris zonata				X			X	X	X	X		
Nephtys californiensis	X	X	X	X	X	X	X	X	X	X		
Pisione hermansi	X	X	X	X								
Aphelochaeta elongata							X					
Saccocirrus sonomacus				X							X	X
Saccocirrus sp.	X			X								
Pygospio californica	X			X	X	X	X	X				
Pygospio elegans					X							
Scolelepis squamata	X				X	X				X		
Glycera dibranchia				X					X			
Hemipodia simplex	X		X	X								
Nereis vexillosa											X	X
Anaitides williamsi											X	
Eteone dilatae		X	X	X	X	X	X			X		
Capitella sp.										X		
Thoracophelia dillonensis										X		
Euzonus williamsi	X	X	X	X	X	X		X				
Orbinia johnsoni								X		X	X	X
Paraonella platybranchia	X	X			X	X	X			X		
ARTHROPODA (MYSIDA)												
Unid. Mysidae										X		

Archaeomysis grebnitzkii	X	X	X	X	X	X	X	X	X	X		
ARTHROPODA (AMPHIPODA)												
Unid. Amphipoda	X				X					X	X	X
Proboscinotus loquax					X							
Eohaustorius sawyeri	X	X			X				X	X		
Eohaustorius sp.	X	X			X				X		X	
Eohaustorius washingtonianus	X	X		X	X	X	X	X	X			
Allorchestes rickeri							X	X	X	X	X	
Allorchestes sp.										X	X	
Desdimelita californica										X		
Americhelidium micropleon	X						X	X		X		
Pacifoculodes spinipes	X	X			X	X				X		
Foxiphalus xiximeus									X	X	X	
Grandifoxus grandis				X	X	X	X	X	X	X	X	
Majoxiphalus major	X											
Mandibulophoxus gilesi					X	X	X	X	X			
Megalorchestia benedictii †					X		X	X	X	X	X	X
Megalorchestia californiana †						X	X	X	X	X	X	
Megalorchestia columbiana †	X	X	X	X	X	X	X	X		X	X	
Megalorchestia corniculata †											X	X
Megalorchestia pugettensis †									X		X	X
Megalorchestia sp.	X	X	X	X	X	X	X	X	X	X	X	X
ARTHROPODA (ISOPODA)												
Alloniscus perconvexus †	X	X	X	X	X	X	X	X	X	X		X
Excirolana chiltoni	X	X	X	X	X	X		X	X	X		X
Excirolana linguifrons	X	X	X	X	X	X	X	X	X			X
Excirolana sp.				X								
Porcellio scaber								X				X
ARTHROPODA (DECAPODA)												
Unid. Decapoda					X					X		
Lissocrangon stylirostris	X	X					X	X	X		X	
Emerita analoga	X	X	X	X	X	X	X	X	X	X	X	X
ARTHROPODA (CUMACEA)												
Lamprops tomalesi	X									X		
INSECTA (COLEOPTERA)												
Unid. Coleoptera				X		p						
Amblyderus sp.							X					
Amblyderus parviceps			X									
Unid. Carabidae	X											
Akephorus marinus								X				
Akephorus obesus				X			X	X				X
Diabrotica undecimpunctata							X			X	X	X
Unid. Curculionidae											X	

Emphyastes fucicola						X	X		X		X	X
Unid. Histeridae			X			X		X				X
Hypocaccus gaudens †					X		X					
Neopachylopus aeneipunctatus †									X			
Neopachylopus sulcifrons †							X	X	X			
Cercyon fimbriatus										X		X
Cercyon luniger												p
Cercyon sp.							p				p	
Phyconomous marinus							p					
Aleochara sulcicollis					p						p	
Aleochara sp.	p											
Unid. Staphylinidae			X	X			p			p		p
Bledius monstratus †							X	X	X	X	X	X
Bledius sp.	p											
Cafius canescens †							X	X	X		X	
Cafius lithocharinus †											X	
Cafius luteipennis											p	
Cafius seminitens †							X					X
Cafius sp.										X		X
Hadrotes crassus											X	
Tarphiota fucicola					X						X	
Tarphiota geniculata	p							X	p	p		
Tarphiota sp.									p			
Thinopinus pictus							X					
Unid. Tenebrionidae					X	X					X	X
Coelus ciliatus										X		
Coelus sp.										X		X
Phaleromela globosa									X	X	X	X
Phaleromela sp.	p											
Insecta (Diptera)												
Unid. Diptera	p	p	p	p	p	p	X	p	p	X	X	X
Acarthophthalmus nigrinus						p						
Fucellia separata									p		p	
Fucellia sp.							X			X	X	X
Unid. Stenoscinis					p							
Unid. Chloropidae					p	p				p		
Coelopa vanduzeei									X	p		
Parathalassius aldrichi					p							
Parathalassius sp.									p	p		
Unid. Dolichopodidae							X					
Drosophila melanogaster suzukii					p							
Unid. Empididae						p						
Ditricophora sp.					p							

Lamproscatella sibilans										p	p	
Paralimna sp.					p							
Unid. Ephydridae					p						X	X
Unid. Therevidae	X		X	X								
Thoracochaeta johnsoni							p					
INSECTA (HYMENOPTERA)												
Unid. Hymenoptera					p		X					
Hymenoptera A							X					
Hymenoptera B				X								
Unid. Formicidae											X	p
ARTHROPODA (ARACHNIDA)												
Unid. Arachnida			X	X								
Unid. Eutichuridae†			X									
FISH												
Night smelt embryos	X	X	X									
ECHINODERMATA												
Ophiuroidea		X										
Total Species Observed	**24**	**18**	**14**	**20**	**29**	**21**	**31**	**26**	**27**	**33**	**27**	**20**

*Table A- 2. Macroinvertebrate species not endemic to sandy beaches (transported from adjacent habitats via kelp wrack, etc.) collected in surveys of the study beaches. Six of 12 the beaches surveyed were within MPAs (indicated by **). 'X' indicates species that were found in biodiversity surveys, p indicates species that were found only in other surveys at that site. A gray highlight indicates abundance > 2,000 individuals m-1 in the survey.*

	Pyramid Point **	Kellogg Beach	Gold Bluffs	Reading Rock **	Mad River	Samoa **	Ten Mile	Virgin Creek **	Jug Handle	Caspar	Russian Gulch **	Van Damme **
MOLLUSCA												
Mytilus sp.									X			
Euspira lewisii												X
Collisella paradigitalis									X			
ARTHROPODA (MYSIDA)												
Holmesimysis costata										X		
ARTHROPODA (AMPHIPODA)												
Anisogammarus pugettensis										X	X	
Calliopius pacificus										X	X	
Caprella mendax											X	
Americorophium spinicorne										X		
Atylus tridens							X			X	X	
Allorchestes bellabella							X	X	X	X	X	
Photis brevipes												X
Jassa borowskyae	X	X										
Hartmanodes hartmanae	X						X		X	X	X	
ARTHROPODA (ISOPODA)												
Idotea fewkesi									X	X	X	
Idotea urotoma										X		
Exosphaeroma inornata							X	X	X	X	X	X
Gnorimosphaeroma oregonensis										X		
ARTHROPODA (DECAPODA)												
Pugettia richii										X		
ARTHROPODA (PYCNOGONIDA)												
Nymphopsis spinosissima									X			
Total Species Observed	**2**	**1**	**0**	**0**	**0**	**0**	**4**	**2**	**7**	**12**	**8**	**3**

8.4 Weight-length Model for Sand Crabs from Gold Bluffs Beach

Model used to estimate biomass of sand crabs in targeted study at three beaches May - July 2015.

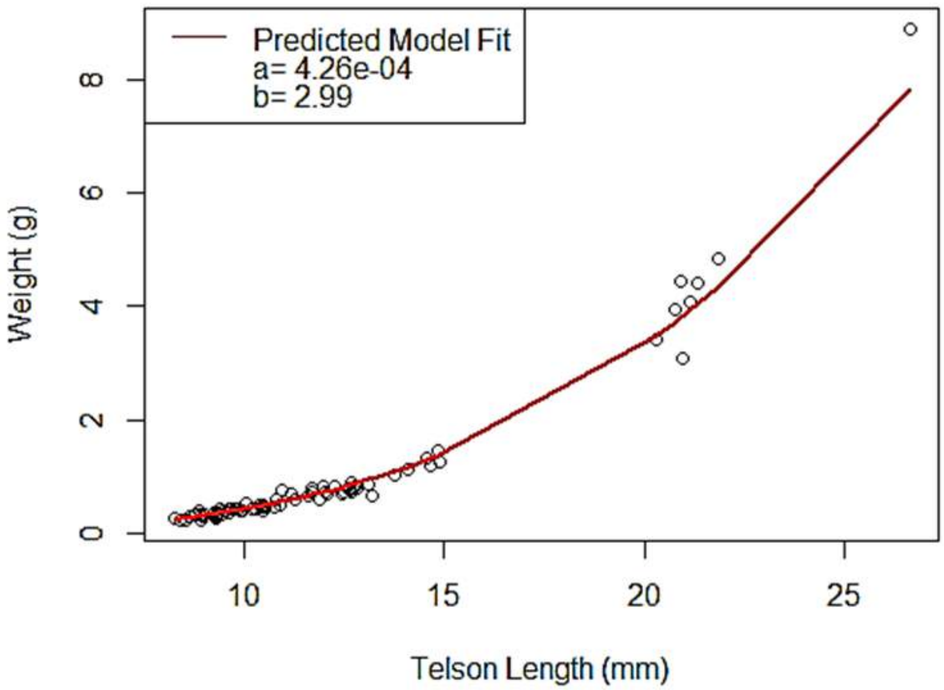


Figure A- 2. Weight-length model ($W=aL^b$) for 77 sand crabs collected from Gold Bluffs Beach in August 2015. See text for details.

8.5 Slope and Sand Grain Size: Targeted Sand Crab Study – Summer 2015

Physical data collected concurrently with the targeted sand crab study. Beach slopes at the water table outcrop were similar for all three sites during the month of May, but then greatly increased at Gold Bluffs beach during June and July, while the other sites remained relatively the same (Figure A- 3). The mean geometric sand size of Gold Bluffs beach varied greatly across months, whereas sand size remained relatively constant at Mad River and Samoa SMCA (Figure A- 4).

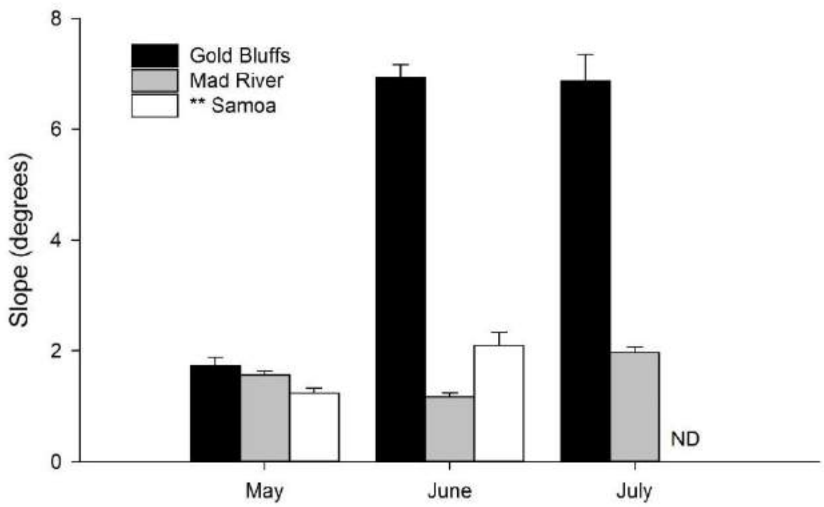


*Figure A- 4. Beach slope at the water table outcrop. ** No data for Samoa SMCA July sampling. All else as in All else as in Figure 30..*

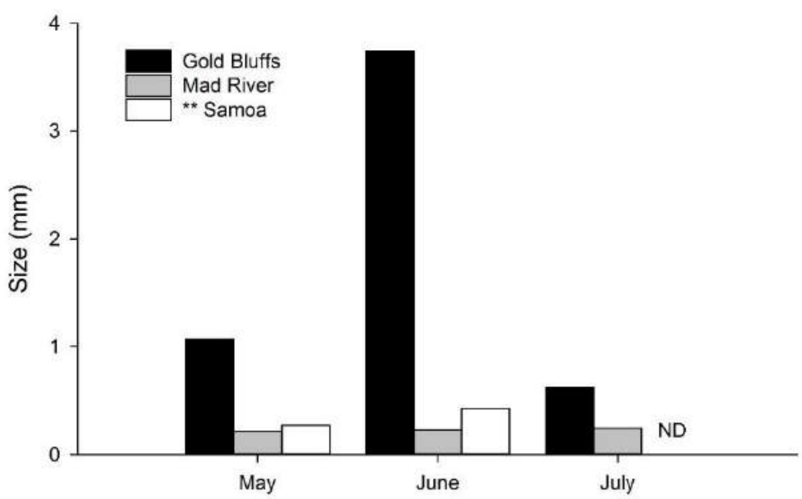


*Figure A- 3. Geometric mean size of sand samples taken at the water table outcrop. ** No data for Samoa SMCA July sampling. All else as in Figure 30.*

8.6 Bird Abundance, Peak Abundance and Occurrence by MPA Status

Table A- 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 = 6) and reference (n = 6) beaches from monthly surveys between September 2014 and May 2015. Counts were made along a standard 1 km transect at eight long beaches and four pocket beaches (two MPA and two reference) where transect lengths ranged from 0.12 to 0.69 km (total length of shoreline surveyed each month = 9.18 km). Boldface common name indicates species with mean abundance > 2 birds km^{-1}.

Common Name	**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										
Western Sandpiper	490	4048	4538	54.9	130	3000	3000	11	13	24
Sanderling	964	895	1859	22.5	322	463	463	7	5	12
Marbled Godwit	314	180	494	6	270	130	270	7	2	9
Least Sandpiper	232	225	457	5.5	130	90	130	3	10	13
Dunlin	250	36	286	3.5	250	36	250	1	1	2
Black Bellied Plover	88	132	220	2.7	25	54	54	6	6	12
Willet	103	84	187	2.3	100	84	100	2	1	3
Western Snowy Plover	0	151	151	1.8	0	60	60	0	6	6
Black Turnstone	117	10	127	1.5	29	6	29	9	3	12
Black Oyster Catcher	88	9	97	1.2	10	4	10	25	5	30
Dowitcher (unid'd)	72	25	97	1.2	72	23	72	1	2	3
Killdeer	19	34	53	0.6	8	13	13	5	9	14
Semipalmated Plover	32	12	44	0.5	32	12	32	1	1	2
Surfbird	39	3	42	0.5	21	2	21	3	2	5
Whimbrel	10	16	26	0.3	4	8	8	3	2	5
Long Billed Curlew	13	10	23	0.3	13	10	13	1	1	2
Rock Sandpiper	2	3	5	0.1	2	3	3	1	1	2
Sandpiper (unid'd)	5	0	5	0.1	5	0	5	1	0	1
Wandering Tattler	0	2	2	0	0	2	2	0	1	1
Redneck Pharalope	0	1	1	0	0	1	1	0	1	1
All shorebirds	**2838**	**5876**	**8714**	**105.5**						

Common Name	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										
Gull (unid'd)	1578	1234	2812	34	220	225	225	41	39	80
Western Gull	1070	477	1547	18.7	150	137	150	42	38	80
California Gull	176	53	229	2.8	49	32	49	19	10	29
Mew Gull	121	55	176	2.1	55	16	55	15	7	22
Heermann's Gull	22	104	126	1.5	10	77	77	7	6	13
Ring Billed Gull	68	8	76	0.9	30	7	30	10	2	12
Bonaparte's Gull	16	2	18	0.2	16	1	16	1	2	3
All Gulls	**3051**	**1933**	**4984**	**60.2**						
SEABIRDS										
Scoter (unid'd)	1352	3	1355	16.4	1350	3	1350	2	1	3
Surf Scoter	321	934	1255	15.2	158	400	400	22	24	46
Brown Pelican	105	262	367	4.4	32	88	88	17	14	31
Brandt'S Cormorant	104	215	319	3.9	71	112	112	16	12	28
Western Grebe	68	21	89	1.1	25	6	25	11	7	18
Pelagic Cormorant	45	16	61	0.7	7	4	7	18	8	26
Caspian Tern	0	55	55	0.7	0	55	55	0	1	1
Double Crested Cormorant	11	3	14	0.2	3	2	3	6	2	8
Common Loon	3	7	10	0.1	1	3	3	3	5	8
Red Breasted Merganser	7	2	9	0.1	3	1	3	4	2	6
Brant	5	1	6	0.1	5	1	5	1	1	2
Pigeon Guillemot	5	0	5	0.1	5	0	5	1	0	1
Cormorant (unid'd)	3	2	5	0.1	1	1	1	3	2	5
Tern (unid'd)	3	0	3	0	3	0	3	1	0	1
Loon (unid'd)	2	0	2	0	2	0	2	1	0	1
Common Tern	0	1	1	0	0	1	1	0	1	1
Pacific Loon	0	1	1	0	0	1	1	0	1	1
Merganser (unid'd)	1	0	1	0	1	0	1	1	0	1
Murrelet (unid'd)	1	0	1	0	1	0	1	1	0	1
All seabirds	**2036**	**1523**	**3559**	**43.1**						

Common Name	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										
Raven	12	132	144	1.7	4	44	44	8	17	25
American Crow	60	51	111	1.3	41	14	41	9	11	20
Turkey Vulture	32	38	70	0.8	15	16	16	10	13	23
Barn Swallow	15	11	26	0.3	9	7	9	2	2	4
Osprey	5	10	15	0.2	1	8	8	5	3	8
Black Phoebe	10	4	14	0.2	1	1	1	10	4	14
Swallow (unid'd)	0	10	10	0.1	0	6	6	0	2	2
Belted Kingfisher	0	4	4	0	0	1	1	0	4	4
Cliff Swallow	1	1	2	0	1	1	1	1	1	2
Red Tailed Hawk	1	0	1	0	1	0	1	1	0	1
Tree Swallow	1	0	1	0	1	0	1	1	0	1
All terrestrial	**137**	**261**	**398**	**4.6**						
AQUATIC/WADING										
Canadian Goose	46	44	90	1.1	30	40	40	8	3	11
Eared Grebe	27	4	31	0.4	5	2	5	12	3	15
Mallard	8	22	30	0.4	6	5	6	2	6	8
Harlequin Duck	23	0	23	0.3	7	0	7	7	0	7
Bufflehead	18	3	21	0.3	17	2	17	2	2	4
Great Egret	3	14	17	0.2	1	14	14	3	1	4
Common Goldeneye	13	1	14	0.2	4	1	4	5	1	6
American Coot	3	3	6	0.1	2	3	3	2	1	3
Great Blue Heron	1	1	2	0	1	1	1	1	1	2
Horned Grebe	1	0	1	0	1	0	1	1	0	1
Snowy Egret	0	1	1	0	0	1	1	0	1	1
All Aquatic/wading	**143**	**93**	**236**	**3**						

8.7 Species Accounts of Birds

8.7.1 Shorebirds

Overall, abundance varied greatly among individual species of shorebirds, ranging over three orders of magnitude from less than one bird km^{-1} to 55 birds km^{-1} for total monthly observations (Table A- 3). The average abundance of seven species of shorebirds exceeded two individuals km^{-1} during the baseline study.

Based on average observed abundance over the study, the most abundant shorebird species were Western Sandpiper (55 birds km^{-1}), Sanderling (23 birds km^{-1}), Marbled Godwit (6 birds km^{-1}), Least Sandpiper (6 birds km^{-1}) Dunlin (4 birds km^{-1}) and Black-bellied Plover (3 birds km^{-1}), all of which breed outside the study region. Other important species included Willet (2 birds km^{-1}), Western Snowy Plover (2 birds km^{-1}), and Black Turnstone (2 birds km^{-1}). Three species that nest in the study region, Western Snowy Plover, Black Oystercatchers (1 km^{-1}), and Killdeer (1 birds km^{-1}) were observed regularly on some of the beaches. Nine species of shorebirds were observed in five or more of the individual monthly surveys (Figure A- 5). Western Sandpipers, Sanderlings, and Marbled Godwits, which use NC beaches as migration and wintering habitat, were observed in 24, 12 and 9 of the individual surveys, respectively. Western Snowy Plovers, Black Oystercatchers, and Killdeer, which nest on beaches in the NC region, were observed in 6, 30, and 14 individual surveys, respectively.

8.7.2 Western Sandpiper

Western Sandpipers were the most abundant shorebird observed in the baseline study and accounted for 52% of the shorebirds observed. A total of 4,538 Western Sandpipers were observed in 108 surveys of study beaches. The average total abundance of Western Sandpipers was 55 birds km^{-1} (Table A- 3). Western Sandpipers were observed in 24 individual surveys and average abundance varied among months ranging from less than one to 250 birds km^{-1} (Figure A- 5). The abundance of Western Sandpipers showed strong seasonal patterns corresponding to fall migration and wintering with average abundance ranging from 19 to 250 birds km^{-1} from November thru February. Spring migration was also observed during April with a peak of 22 birds km^{-1} followed by a drop off in May to < 1 bird km^{-1}.

Although they were the most abundant shorebirds we observed, Western Sandpipers only occurred at seven of the eight long beaches and one of the four pocket beaches (Figure A- 6). Western Sandpipers were never observed on the transect at Reading Rock, Jug Handle, Russian Gulch, and Van Damme. The average abundance of Western Sandpipers varied over two orders of magnitude among beaches, ranging from zero to 425 birds km^{-1}. The study beach with the highest average numbers of Western Sandpipers (425 birds km^{-1}) was Mad River. The average abundance of Western Sandpipers also exceeded 10 birds km^{-1} at Samoa, Ten Mile, Virgin Creek and Pyramid Point (Figure A- 6). Western Sandpipers are gregarious and tend to occur in flocks. The abundance of Western Sandpipers observed exceeded 50 birds km^{-1} in ten individual surveys and the peak abundance observed during the study was 3000 individuals at Mad River in February 2015 (Table A- 3).

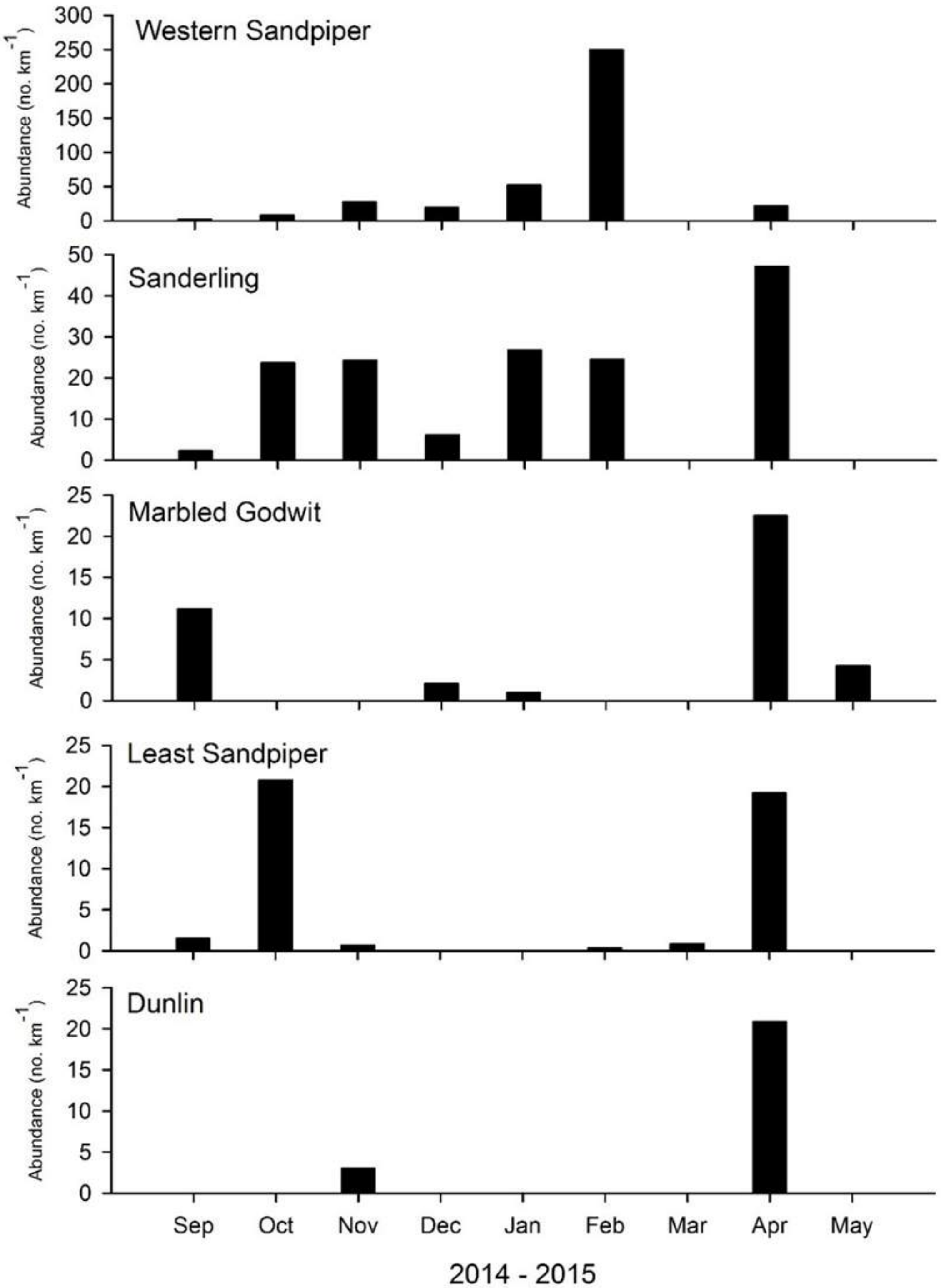


Figure A- 5. Average monthly abundance of the six most abundant shorebird species (non-breeding: Western Sandpiper, Sanderling, Marbled Godwit, Least Sandpiper, Dunlin, Black-bellied Plover) and three breeding species: Black Oystercatcher, Killdeer and Western Snowy Plover across the 12 beaches surveyed monthly in the NC region between September 2014 and May 2015. All other information as in Figure 47.

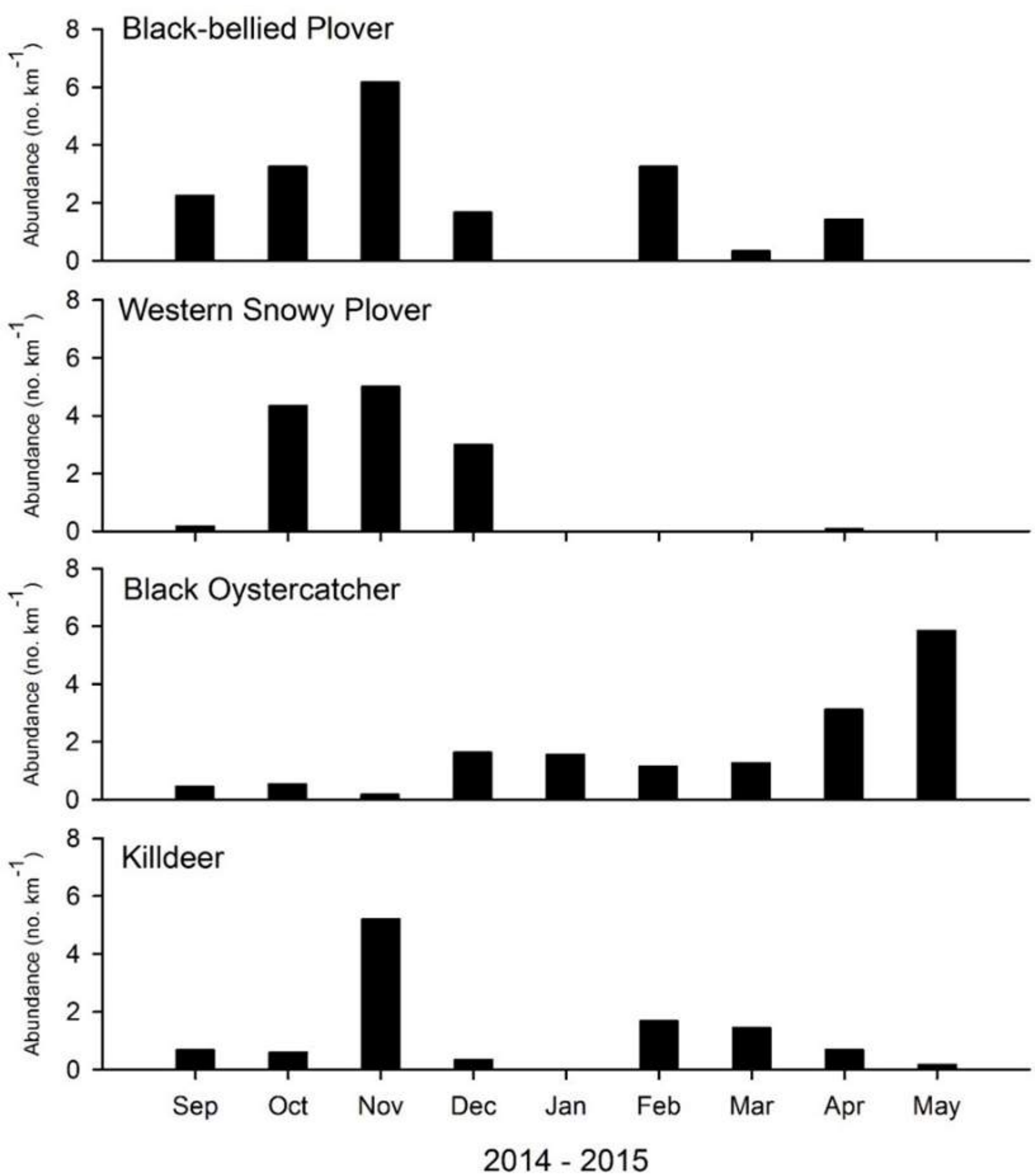


Figure A- 5. Con't.

8.7.3 Sanderling

A total of 1,859 Sanderlings occurred in the study (Table A- 3Table A- 3). Sanderlings accounted for 21% of the total shorebirds and were observed in 12 surveys. The overall average abundance of Sanderlings was 23 birds km^{-1}.

Sanderlings were observed on four of the 12 study beaches. The average abundance of Sanderlings varied two orders of magnitude among sites, ranging from 0 to 102 birds km^{-1}. The highest average abundance of Sanderlings (102 birds km^{-1}) occurred at Virgin Creek. The peak abundance of Sanderlings observed during our study was 463 individuals at Ten Mile in February 2015.Sanderlings were observed in eight of the ten months of the baseline surveys and average abundance varied among months, ranging from 0 to 47 birds km^{-1} (Figure A- 5). Sanderlings showed seasonal patterns corresponding to fall migration and wintering with average abundance exceeding 20 birds km^{-1} in October, November, January and February. Spring migration of Sanderlings was also observed in April with an average abundance of 47 birds km^{-1} during that survey.

8.7.4 Marbled Godwit

A total of 494 Marbled Godwits occurred in the study (Table A- 3). Marbled Godwits accounted for 6% of the total shorebirds and were observed in nine surveys. The overall average abundance of Marbled Godwits was six birds km^{-1}.

Although they were the third most abundant shorebirds we observed, Marbled Godwits occurred at only four of the eight long beaches and were never recorded on the four pocket beaches during our baseline study (Table A- 3, Figure A- 6). Average abundance of Marbled Godwits ranged from 0 to 34 birds km^{-1}. The study beach with the highest average numbers of Marbled Godwits (34 birds km^{-1}) was Samoa. The peak abundance of Marbled Godwits observed during our study was 270 individuals at Samoa in April 2015.

Marbled Godwits were observed during seven of the ten months of the baseline surveys and average abundance varied among months, ranging from 0 to 23 birds km^{-1}. Peaks in the average abundance of this species occurred during September (11 birds km^{-1}) and April (23 birds km^{-1}).

8.7.5 Least Sandpiper

A total of 457 Least Sandpipers occurred in the study (Table A- 3.). Least Sandpipers accounted for 5% of the total shorebirds and were observed in 13 surveys. The overall average abundance of Least Sandpipers was six birds km^{-1} (Table A- 3).

Least Sandpipers occurred on four of the eight long beaches and one of the pocket beaches (Figure A- 6). The average abundance of Least Sandpipers varied five-fold among the beaches, ranging from 0 to 26 birds km^{-1}. The highest average abundance of Least Sandpipers occurred at Samoa (26 birds km^{-1}).

Least Sandpipers were observed in eight of the ten months of the baseline surveys and the average abundance observed varied among months, ranging from 0 to 20 birds km^{-1} (Figure A- 5). The average abundance of Least Sandpipers peaked during October 2014 (20 birds km^{-1}) and April 2015 (19 birds km^{-1}). Average abundance of Least Sandpipers exceeded one bird km^{-1} in only two other months, December and May.

8.7.6 Dunlin

A total of 289 Dunlin occurred in the study (Table A- 3). Dunlin accounted for 3% of the total shorebirds and were observed in two surveys. The overall average abundance of Dunlin was 4 birds km^{-1}. Dunlin occurred on only two of the long beaches and none of the pocket beaches. The two beaches where Dunlin were observed were Samoa (28 birds km^{-1}) and Ten Mile (4 birds km^{-1}). Dunlin were observed in two of the ten months of the baseline surveys, November and April, with an average abundance of 3 and 21 birds km^{-1}, respectively (Figure A- 5).

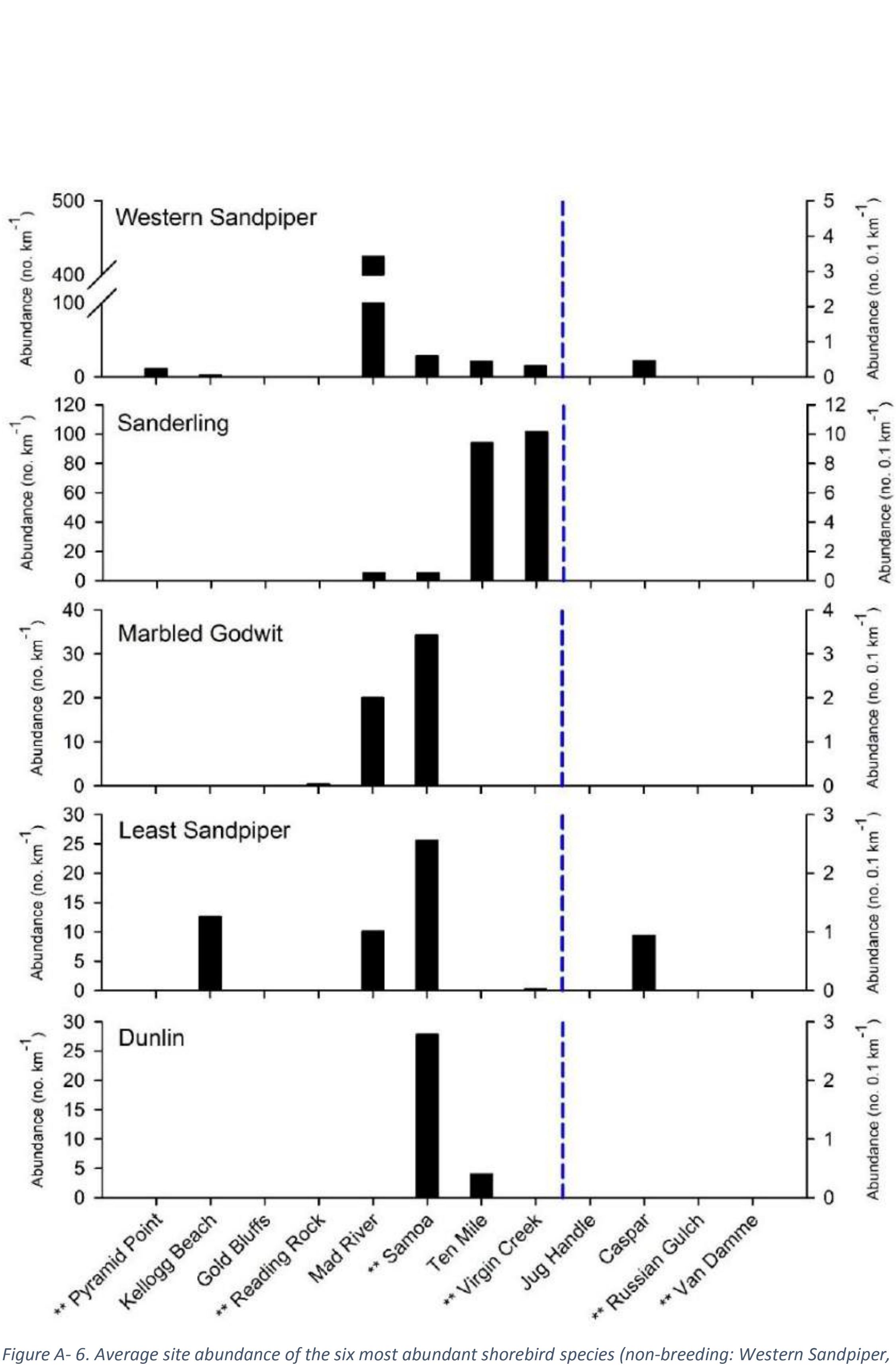


Figure A- 6. Average site abundance of the six most abundant shorebird species (non-breeding: Western Sandpiper, Sanderling, Marbled Godwit, Least Sandpiper, Dunlin, Black-bellied Plover) and three breeding species: Black Oystercatcher, Killdeer and Western Snowy Plover across the 12 beaches surveyed monthly in the NC region between September 2014 and May 2015. All other information as in Figure 52.

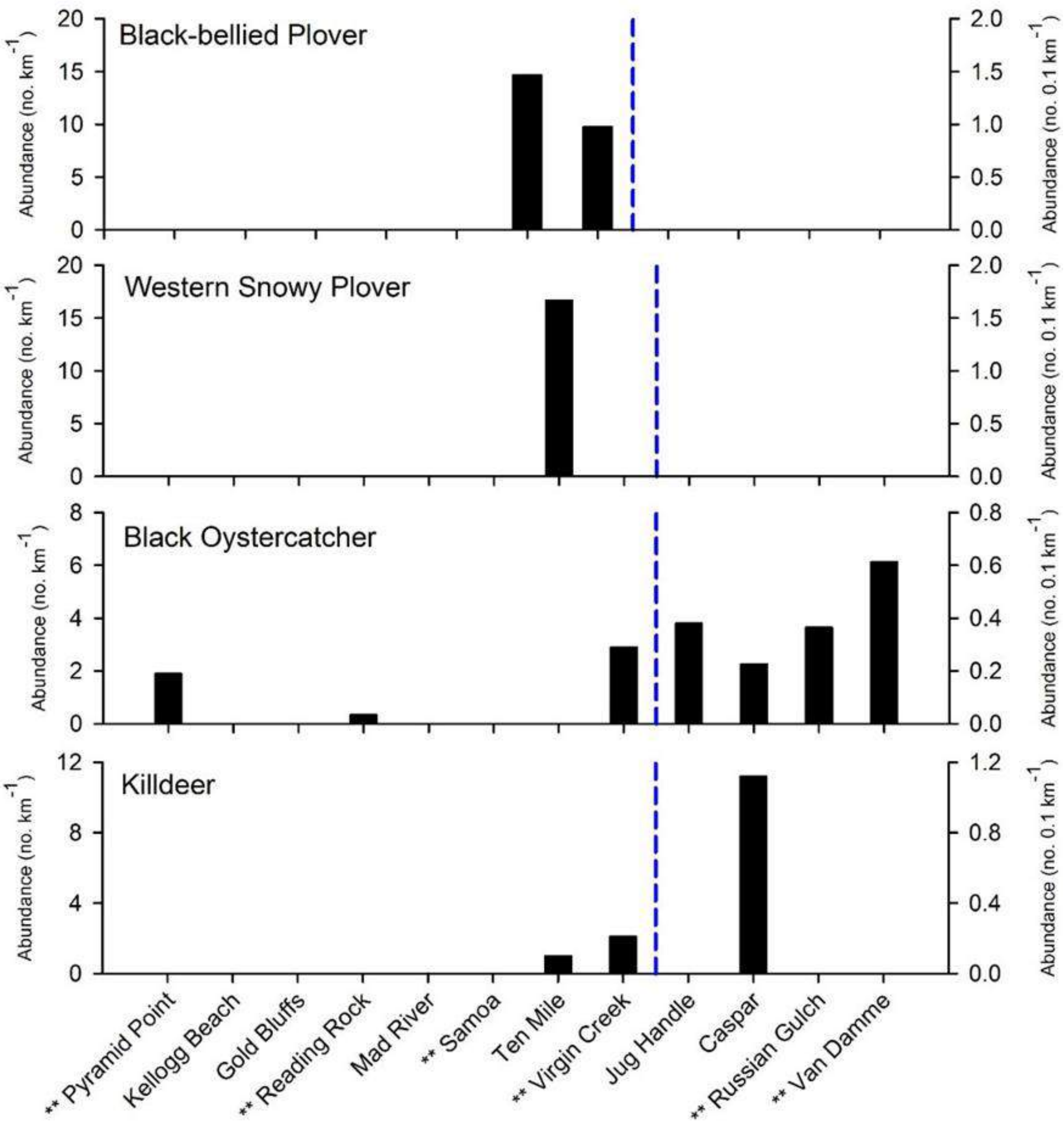


Figure A- 6. Con't.

8.7.7 Black-bellied Plover

A total of 220 Black-bellied Plover occurred in the study (Table A- 3). Black-bellied Plover accounted for 3% of the total shorebirds and were observed in 12 surveys. The overall average abundance of Black-bellied Plover was 3 birds km^{-1} (Table A- 3).

Black-bellied Plover occurred on only two of the long beaches and none of the pocket beaches (Table A-3). The two beaches where Black-bellied Plover were observed were Ten Mile (15 birds km^{-1}) and Virgin Creek (10 birds km^{-1}). Black-bellied Plover were observed in eight of the ten months of the baseline surveys and the average abundance observed varied among months, ranging from 0 to 6 birds km^{-1} (Table A- 3). Black-bellied Plover showed seasonal patterns corresponding to fall migration and wintering with average abundance exceeding three birds km^{-1} in October, November and February. Spring migration of Black-bellied Plover was weakly observed in April with an average abundance of one bird km^{-1} during that survey.

8.7.8 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 151 Western Snowy Plovers were observed in the baseline study (Table A- 3). Western Snowy Plovers accounted for 2 % of the total shorebirds and were observed in six surveys. The overall average abundance for Western Snowy Plovers was two birds km^{-1} (Table A- 3).

Western Snowy Plovers had a restricted spatial distribution, occurring at only two of the long beaches and none of the pocket during the baseline surveys (Table A- 3). The two beaches where Western Snowy Plovers were observed were Ten Mile (17 birds km^{-1}) and Mad River (< 1 bird km^{-1}).

Western Snowy Plovers were recorded in five months of the baseline surveys, and average abundance of this species peaked between October and December with a range of 3 to 5 birds km^{-1} (Table A- 3). The peak number of Snowy Plovers observed in a single survey, 60 birds, was in November 2014 at Ten Mile, where a roost site may occur during pre-breeding dispersal.

8.7.9 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 97 Black Oystercatchers occurred in the baseline study (Table A- 3). This species accounted for 1 % of the total shorebirds and were observed in 30 surveys. The overall average abundance of Black Oystercatchers was one bird km^{-1} (Table A- 3).

Black Oystercatchers were observed on only three of the eight long beaches, Pyramid Point, Reading Rock and Virgin Creek, and Black Oystercatchers were seen on all four pocket beaches, which are all bounded by either rocky cliffs or rocky outcrops (Figure A- 6). The average abundance of Black Oystercatchers ranged from < 1 to 3 birds km^{-1} at the long beaches, and zero to one bird per 100 m on the four pocket beaches (Figure A- 6).

Black Oystercatchers were observed in all ten months of the baseline study, and total abundance varied among months, ranging from < 1 to 6 birds km^{-1} (Figure A- 5). Average monthly abundance of this species was highest in April and May, with 3 and 6 birds km^{-1}, respectively. The months of December through March all showed an average abundance of Black Oystercatchers more than one bird km^{-1}.

8.7.10 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 53 Killdeer were observed in the baseline study with an average abundance of one bird km^{-1} (Table A- 3).

Killdeer were observed on only two of the long beaches, Ten Mile and Virgin Creek with an average abundance of 1 and 2 birds km^{-1}, respectively, and on one of the pocket beaches, Caspar with an average abundance of 1 birds 0.1 km^{-1} (Figure A- 6). A pair of Killdeer with two chicks were present during the breeding season at Virgin Creek indicating that nesting likely occurred at that site during the baseline study.

Killdeer were observed in nine of the ten months of the study with average abundance ranging from 0 to 5 birds km^{-1} (Figure A- 5). The largest numbers of Killdeer were recorded outside the nesting season in November (5 birds km^{-1}), and during the nesting season in February (2 birds km^{-1}) and March (1 bird km^{-1}).

8.7.11 Gulls

Overall, abundance varied greatly among individual species of gulls, ranging over two orders of magnitude from less than one bird km^{-1} to 19 birds km^{-1} for total monthly observations (Figure 52). The average abundance of four species of gulls and of unidentified gulls exceeded one individual km^{-1} during our study. Based on average abundance observed over the study, the most abundant gull species were Western Gull (19 birds km^{-1}), California Gull (3 birds km^{-1}), Mew Gull (2 birds km^{-1}) and Heerman's Gull (2 birds km^{-1}) (Table A- 3). Western Gulls comprised 31 %, California Gulls comprised 4.6 %, Mew Gulls comprised 4 %, and Heerman's Gulls comprised 3 % of the total gulls observed in the study. Unidentified gulls were generally immature individuals and were likely of the species recorded as adults in the surveys. Gulls were frequently observed on the study beaches, the three most abundant gull species as well as unidentified gulls were observed in 20 or more of the monthly surveys (Table A- 3).

8.7.12 Seabirds

Overall, abundance varied greatly among individual species of seabirds, ranging over two orders of magnitude from zero birds km^{-1} to 16 birds km^{-1} for total monthly observations (Figure 52). The average abundance of four species of seabirds exceeded 1 individual km^{-1} during our study. Based on average abundance observed over the study, the most abundant seabird species were Unidentified Scoter (16 birds km^{-1}), Surf Scoter (15 birds km^{-1}), Brown Pelican (4 birds km^{-1}), and Brandt's Cormorant (4 birds km^{-1}) (Table A- 3). Unidentified Scoters comprised 38 %, Surf Scoters comprised 35 %, Brown Pelicans comprised 10 %, and Brandt's Cormorants comprised 9 % of the total seabirds observed in the study. Seabirds were regularly observed on the study beaches, with five species of seabirds observed in 10 or more of the individual surveys (Table A- 3).

8.7.13 Other birds

Terrestrial and aquatic/wading birds contributed considerably to the total diversity of the bird surveys (22 out of 70 species, 31 %) but much less to the total abundance (634 individuals, 4 %) (Table A- 3).

However, monthly species richness of terrestrial birds was not high, varying from one to two species in the baseline study, and monthly species richness of aquatic/wading species varied from zero to one species (Figure 57) suggesting high turnover of these species.

Terrestrial birds included migratory and resident species who nest locally (e.g. Black Phoebe, American Crow). Terrestrial birds were commonly observed foraging on the study beaches and were generally recorded using upper shore habitats. The feeding modes of terrestrial birds using the beaches vary widely from aerial insect catchers (Black Phoebe, swallows, kingbirds), scavengers and carrion feeders (American Crow, Common Raven, Turkey Vulture), to birds of prey (Osprey, Red-tailed Hawk). The most common and widespread terrestrial bird species observed was the Raven (144 individuals, 2 birds km^{-1}), a scavenger and carrion feeder that was observed on 25 of the surveys. Barn Swallows (26 individuals, < 1 bird km^{-1}) were the most abundant fly-catching species and were observed foraging seasonally on some beaches but only recorded on four individual surveys. Average species richness of terrestrial birds peaked at Ten Mile, Virgin Creek, Mad River and Caspar (Figure 55). Corvids, including American Crows and Common Ravens, are known to prey upon nesting shorebirds and can cause decreased reproductive success in Western Snowy Plover, a beach nesting species listed as threatened. A total of 111 American Crows were observed in the baseline study and the overall average abundance was 1 bird km^{-1} (Table A-3). American Crow is a resident breeding species that accounted for 28 % of the terrestrial birds and was observed in 20 of the 108 surveys.

The most common and widespread aquatic/wading bird species was the Canada Goose (90 individuals, 38 %), which was observed on 11 of the surveys. The Eared Grebe was the second most abundant aquatic/wading species observed (31 individuals, 13%) but was the most commonly occurring aquatic/wading species, seen during 15 surveys (Table A- 3). Average species richness of aquatic/wading birds greater than two species km^{-1} was observed at Virgin Creek, Van Damme, and Caspar (Figure 55).

9 Financial Report

This is summary financial report of the project expenses as of the end of February 2017. Additional expenses and cost share for the project have been posted since this time.

	Budget		**Actual**		**Variance**	
	SEA GRANT FUNDS	GRANTEE SHARE	SEA GRANT FUNDS	GRANTEE SHARE	SEA GRANT FUNDS	GRANTEE SHARE
Total salaries & wages	$ 200,820	$ 45,998	$ 176,794	$ 36,579	$ (24,026.13)	$ (9,418.87)
Fringe	$ 67,945	$ 4,327	$ 56,284	$ 3,577	$ (11,660.74)	$ (749.95)
Total permanent equip	$ -	$ -	$ 5,564	$ -	$ 5,563.61	$ -
Expendable supplies and equip	$ 15,863	$ 500	$ 16,775	$ -	$ 912.23	$ (500.00)
Total (domestic) travel	$ 24,202	$ 7,200	$ 15,685	$ 14,800	$ (8,517.49)	$ 7,600.00
Pubs & Comms	$ 2,450	$ -	$ -	$ -	$ (2,450.00)	$ -
Total Other	$ 59,600	$ 2,000	$ 62,000	$ 2,000	$ 2,400.00	$ -
TOTAL DIRECT	$ 370,880	$ 60,025	$ 316,048	$ 56,956	$ (54,831.94)	$ (3,068.82)
IDC	$ 79,120	$ 8,130	$ 59,035	$ 19,051	$ (20,085.40)	$ 10,921.46
IDC (foregone) waived as match		$ 68,143	$ -	$ 30,646	$ -	$ (37,496.37)
TOTAL COSTS	$ 450,000	$ 128,167	$ 375,082	$ 90,605	$ (74,917.34)	$ (37,562.19)