Final Report: Evaluating performance of California's MPA network through the lens of sandy beach and surf zone ecosystems

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Executive Summary

Project Description and Background

Sandy beaches and their surf zones make up a large proportion of the open coast of California and are significant components of many MPAs statewide. The rich and productive food webs of beaches, including fishes and birds, are closely linked to subsidies from rocky reefs and coastal waters. In MPA baseline studies, these subsidies were shown to strongly affect the diversity and abundance of prey resources available for surf zone fish and birds in recipient beach ecosystems. Thus, MPA protection can affect beaches and their surf zones in two ways: directly through harvest of surf zone fish, and indirectly through the influence of trophic cascades and other factors influencing the key donor ecosystems of kelp forests and rocky reefs and their subsidies to beaches. The strong connections of beaches to rocky habitats, especially kelp forests, are key ecological pathways through which direct and indirect effects of MPA protection can cascade, making sandy beaches and surf zones an important element of long-term monitoring and integrative analyses to assess the performance of MPAs and inform adaptive management of the State's MPA network.

Our study was designed to provide a quantitative evaluation of the responses of sandy beach and surf zone ecosystems to MPA management. We generated estimates of abundance, biomass, size and diversity of fish and abundance and diversity of birds and wrack on beaches and surf zones in MPAs and an equivalent number of carefully matched reference sites. Our study provided the **first statewide comparisons** of surf zone fish and evaluated direct responses to MPAs for these fish, representing a baseline study. Our study provides comparisons of fish, wrack inputs and birds for beaches and surf zones in MPA and reference sites and evaluates potential ecological indicators for these understudied ecosystems across the state. We used our observations of beaches and surf zones to evaluate direct (harvest) and indirect (connectivity and trophic cascades) responses to MPAs to address the goals and objectives of the MLPA and MPA Action Plan.

Due to the lack of regular monitoring of beach and surf zone ecosystems in California, our study primarily serves as an MPA baseline study. For this reason, although we address a number of the MPA Action Plan goals and the more recent Decadal Evaluation Working Group (DEWG) questions, we modified the DEWG questions to remove the aspect of "over time" for our comparisons. Our results for beaches and surf zone evaluate potential direct effects of MPA management on communities and populations that are harvested, namely surf zone fish and potential indirect effects on indicators are not harvested but may benefit from connectivity within MPA habitats, specifically wrack and kelp subsidies and birds that forage on beaches. We provide new insights and information on the range of responses of sandy beach and surf zone ecosystems to MPAs and on the presence of numerous indicator taxa and species not covered by any other MPA monitoring or evaluation efforts.

Methods

Our study of beaches and surf zones included quantitative repeated surveys of three major response variables in carefully matched pairs of MPAs and reference sites:

1. Ecologically, commercially and culturally important surf zone fishes including surfperch, silversides, flatfish, smelt, sharks, and rays using beach seines and Baited Remote Underwater Video (surf-BRUVs).
2. Subsidies of macrophyte wrack and kelp plants cast onto beaches from kelp forest and rocky reef ecosystems
3. Birds that forage and roost on sandy beaches and in adjacent surf zones, including shorebirds, snowy plovers, gulls, seabirds, aquatic and wading birds and terrestrial birds

We surveyed dynamic physical characteristics as well as human use of sandy beaches and their surf zones at our sites. All of our study sites were located on the mainland coast with 26 sites for surf zone fish (13 MPA/Ref pairs) and 36 sites for birds, wrack, people (18 MPA/Ref pairs). In six MPA/Ref pairs for surf zone fish, the reference beach was a SMCA type MPA where sport fishing from shore is allowed. Fish were surveyed three times a season using six beach seine and surf BRUVs per survey in 2019 and 2020. Birds and kelp were surveyed monthly for seven months, August 2019 to February 2020. Our analyses used both simple overall comparisons using ANOVA and tests of the differences in each response variable between each MPA and its reference site calculated as a Log Response Ratios that handled the large MPA to MPA differences we anticipated and found.

Major findings

- **Direct effects of MPAs on surf zone fish were evident**
  - MPA responses in the abundance and species richness of surf zone fish **differed between survey methods** (Figure 1)
  - In surf-BRUVs, **abundance was greater** for surf zone fish in MPAs (Figure 1A) while in beach seines, abundance **did not differ** between MPAs and reference sites *(*Figure 1A*)*
  - **Biomass was significantly higher in MPAs** for all fish or targeted fish using LRR analysis of MPA/Ref site pairs but not with a simple ANOVA (Figure 1B).
  - In surf-BRUVs, **species richness was greater** for surf zone fish in MPAs (Figure 1C) while in beach seines, species richness **did not differ** between MPAs and reference sites (Figure 1C)
  - The strength of direct responses of surf zone fish to MPAs **varied with region**, **with greatest differences** in the South region
  - Responses of abundance of surf zone fish to MPAs **varied with fish group,** with positive effects observed in sharks and rays but not in croakers and surfperch
  - **Body size of the largest adult fish was greater in MPAs** for targeted surfperch species, including barred and silver surfperch
  - **Abundance of both large and small individuals** was greater in MPAs compared to reference beaches for live-bearing species, barred surfperch and silver surfperch, as well as for California corbina
- **Indirect effects of MPAs were not detected** e.g. via bottom up effects of inputs of kelps and other macrophytes from reefs to beaches (Figure 2)
  - Abundance of macrophyte wrack and of fresh kelp plants **did not differ** between MPA and reference sites (Figure 2A)
  - Wrack and kelp plant abundance **varied with region** and **was greatest** in the Central region where ranges of forest-forming kelps, *Nereocystis* and *Macrocystis*, overlap
  - Overall, the richness and abundance of all birds combined (shorebirds, gulls, seabirds and other birds) **did not differ** among MPA and reference beaches
  - Overall shorebird abundance **did not differ** between MPAs and reference sites but was 30% higher in MPAs overall (Figure 2B).
  - Within each region the **peak abundance of shorebirds was observed at an MPA site** suggesting beaches in those MPAs are important sites for shorebird conservation
  - Abundance and species richness of shorebirds were **positively correlated** with wrack abundance (Figure 2C) in agreement with previous and baseline studies
    - Where baseline information was available (21 sites), **major declines in abundance** of shorebirds were evident at five MPA and four reference beaches

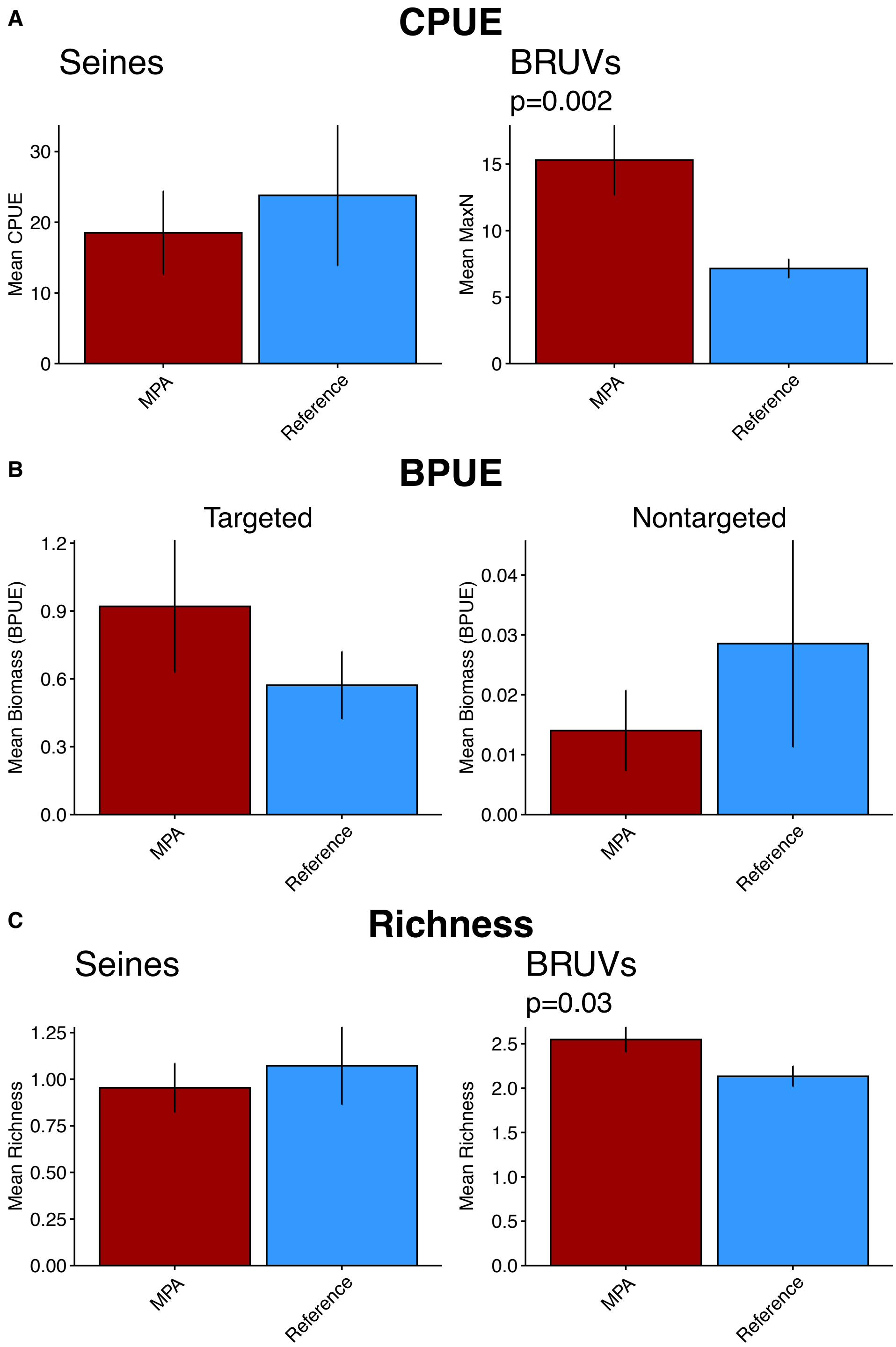

Figure 1. Direct effects of MPAs for surf zone fish as statewide mean values (±1 std error) in MPA and Reference sites A) CPUE (abundance) in seines and BRUVs, B) BPUE (biomass) of targeted and non-targeted species in seines, note for log response ratio (LRR) test on biomass of targeted species, p = 0.02 indicating a significant effect of MPAs (C) Species richness in seines and BRUVs. Insets of p values indicate overall significant differences between MPA and reference sites in ANOVAs. BRUV results based on 699 surveys, seine results based on 900 seine hauls at 26 sites.

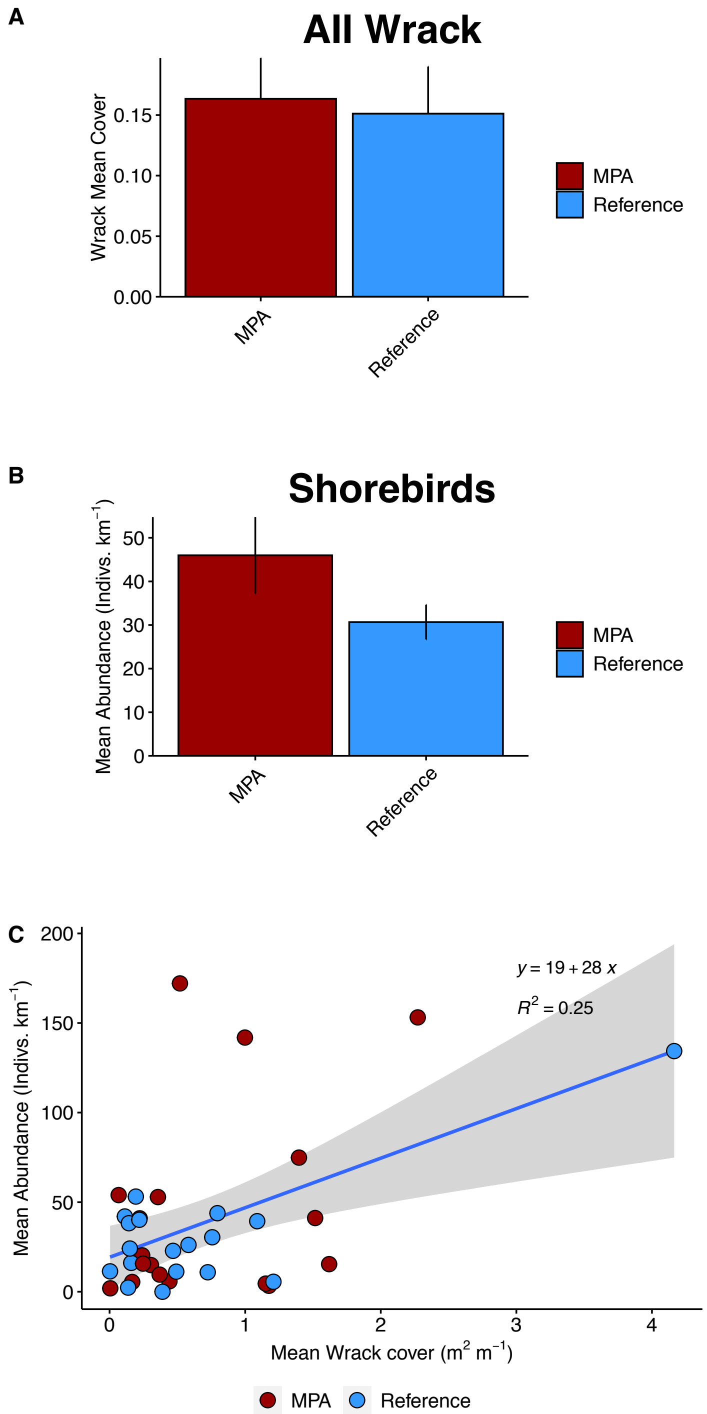

Figure 2 Indirect effects of MPAs on beaches A) Abundance of macrophyte wrack as statewide mean values (±1 std error) in MPA and reference sites B) Abundance of shorebirds as statewide mean values (±1 std error) in MPA and reference sites C) Mean abundance of shorebirds as a function of kelp wrack abundance. Results based on 252 surveys at 36 sites, August 2019-February 2020.

Conclusions

- Our results highlight the importance of California's beaches and surf zones in MPAs for surf zone fish and birds
- The positive responses of surf zone fish, biomass (LRR of seines), abundance (MaxN, BRUVs) and species richness (BRUVs) to MPAs are consistent with hypothesized direct effects of MPAs as a result of reduced fishing pressure

- Some species and groups of surf zone fish appear to respond more strongly to MPAs in abundance, biomass and population size structure
- We found support for the mechanism of indirect MPA effects with shorebird abundance and richness being significantly correlated with wrack cover; however, there was no difference in wrack across MPAs and reference sites. Our study occurs after a significant *Nereocystis* die off which likely influenced wrack abundance on the study beaches
- A number of beaches in MPAs appear to be hotspots of abundance and diversity for indicator taxa and metrics (surf zone fish, wrack and shorebirds)

Recommendations

- Initiate and establish long term monitoring programs for beaches and surf zones for metrics, including surf zone fish, shorebirds, invertebrates, wrack and beach characteristics, in MPA and reference sites, that will
    - Provide the data for analyses needed to address the “over time” element of DEWG MPA questions
    - Track long term trends in these indicators across state and regional scales
    - Provide context that allows analysis of responses of beach and surf zone indicators and habitat to climate change that can inform MPA management
- Leverage the MPA network to encourage managers to provide greater protection to sandy beach ecosystems above the mean high tide line and for ecologically important features including wrack, upper beach zones, surf zones, dunes, and sediment budgets, as well as linked features like lagoon, river and stream mouths.

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Introduction

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

Sandy beach and surf zone ecosystems are important components of the California shoreline that form a significant component of many of the state's MPAs, yet these ecosystems are infrequently studied or monitored statewide or globally. Although not generally the primary habitat used in MPA design and siting, the majority of coastal MPAs were designed to include sandy beach habitats. By region sandy beaches make up 36% of the South Coast region's shoreline (including the Channel Islands), 84% of the Central Coast region, 51% of the North Central coast region and 35% of the North Coast region (California Marine Life Protection Act Science Advisory Team 2009, Central Coast Regional Profile 2005, North Central Coast regional profile 2010, North Coast Regional Profile 2014). The establishment of the statewide network of marine protected areas (MPAs) along the coast of California thus provided outstanding opportunities to develop the first comprehensive description of the biodiversity of sandy beaches for all but the central region of the state as part of the MPA Baseline Studies Program. Sandy beach and surf zone ecosystems contain critical ecological and socioeconomic features through which direct and indirect effects of MPA implementation can cascade, making them an important target for long-term monitoring to assess ecosystem condition and functioning of California's MPA network. In this report we evaluate responses of the biota of sandy beach and surf zone ecosystems to MPA management and expand the ecological understanding of the biodiversity in California MPAs to include surf zone fish, wrack, and beach and surf zone birds.

Open coast surf zones can support diverse communities that include ecologically, culturally, and economically important fish species (reviewed in Olds et al. 2018). The abundance, composition and diet of these fish communities can be influenced by nearby habitats, including subsidies of drift kelp from kelp forests that provide macroinvertebrates enhancing foraging opportunities (Robertson & Lenanton 1984, Marin Jarrin and Shanks 2011, Olds et al. 2018). A number of surf zone fishes are important target species for recreational fisheries and abundance, biomass and size structure of their populations are expected to respond positively to MPA establishment. Many species of surf zone fish are harvested, primarily by recreational/sport fishing activities, but information on the responses of these species to MPAs is largely lacking. Importantly, MPA baseline characterization studies of beaches and surf zones did not include the majority of MPAs in the Central Coast region and surf zone fish were not surveyed in MPA baseline studies for the South Coast or the Central Coast regions. In the few regions where MPA baseline studies of surf zone fish occurred; they were limited in scope. On the North coast region, hook and line and A-frame net surveys for selected species (surfperch species and night smelt) were conducted at a few MPA/Ref pair sites for the MPA baseline study (Nielsen et al. 2017). For the North Central Region, hook and line surveys for surfperch were conducted at two MPA/ref site pairs during the MPA baseline study (Nielsen et al. 2013). Our Phase 2 MPA (current) study greatly expanded and enhanced the current geographic scope of monitoring for metrics of selected priority species and groups for sandy beach and surf zone ecosystems statewide. It also collected the first temporally comparable data across the entire state for these ecosystems.

Cross ecosystem connectivity represents a vital link for many ecosystems, providing energy, organic matter, nutrients, larvae and propagules. Connectivity can be reciprocal or more uni-directional, such as that among donor and recipient ecosystems. On the California coast and elsewhere, highly productive kelp forests are key donor ecosystems for recipient sandy beach ecosystems where in situ primary production is very low and food webs depend on allochthonous marine inputs (Dugan et al. 2003, Leibowitz et al. 2016). This connectivity means the influence of MPA protection on kelp forest ecosystems could cascade through sandy beaches that receive and utilize much of the abundant drift kelp exported by healthy kelp forests (Rodriguez et al. 2016) as an indirect MPA effect. The majority of drift kelp beaches within 5-10 km of its source kelp forest (Olhmann et al. in prep) so MPAs could potentially have a broader influence on adjacent ecosystem. Indirect responses to the protection of rocky reef habitats in MPAs could be manifested via the input of drift kelp to sandy beaches located inside and adjacent to MPAs. Those inputs of drift kelp or wrack to beaches support highly productive and rich intertidal invertebrate communities. These beach invertebrates provide important prey resources for migrating and wintering shorebirds, an indicator group in which many species are experiencing population declines (Brown et al. 2001). Beaches may represent more important foraging resources for shorebirds in regions where wetlands have been degraded, such as Southern California. We hypothesized that the wrack inputs from kelp forests to beaches could be greater in MPAs compared to reference sites. As a response to greater wrack inputs and resulting higher prey availability, we hypothesized that the richness and abundance of migrating and wintering shorebirds using beaches would be greater in MPAs than in reference sites.

Some benefits of MPA protection may occur quickly after MPAs are established, while other changes can take decades to respond (Grorud -Colvert et al. 2021). Individual species, families, and trophic groups will respond to these protections at different rates depending on life history characteristics, behavior, numbers at time of protection, and other human activities that may be allowed in the MPA (Claudet et al. 2008). The magnitude of the effect of protection will also depend on historical fishing pressure (Claudet et al. 2008). Taken together these insights lead us to expect variable responses to MPAs in California for different groups of organisms, especially among those that may have received a direct effect of MPAs, such as protection from harvest, compared with potential indirect effects of MPAs via trophic connectivity.

In 2019 we initiated a suite of statewide studies aimed at 1) assessing ecosystem indicators that could be used for long-term monitoring for use in a synthetic evaluation of the effectiveness and changes over time in the state's MPA network of MPAs and 2) providing an evaluation of the direct and indirect responses of sandy beaches and surf zones to MPA management (Table 1). The majority of the data collection relied on use of a range of standard ecological surveys by a scientific research team. Our 45 study sites included 26 beaches located within MPAs and 19 reference beaches that were outside the boundaries of MPAs. We surveyed at least one beach inside an MPA and one reference beach in Santa Barbara, Los Angeles, Orange and San Diego Counties in the south coast, in Santa Barbara, Monterey, Santa Cruz, San Mateo on Central Coast and in Marin, Sonoma, Mendocino, and Humboldt on the North Coast (Figure 1, Table 3).

Table 1 Metrics and Key Attributes for Ecosystem Assessment investigated on sandy beaches and surf zones in the Phase 2 Monitoring of California's MPA network.

Level	**Metrics and Key Attributes**		**Indicator/Focal Species or Taxa**
Direct effects	Diversity	Surf Zone Fish	Species richness, abundance, biomass and size structure of targeted and untargeted fish and elasmobranchs
Indirect effects	Diversity	Predatory Birds	Species richness, abundance Shorebirds, Seabirds, Gulls, Aquatic & Wading and Terrestrial birds. Includes threatened species, Western Snowy Plover and Belding's Savannah Sparrow
	Productivity & connectivity	Beach wrack	Macrophyte wrack composition and abundance, abundance of wavecast kelp plants
Non-consumptive Use	Human Use	Visitors	People and dogs
Consumptive Uses	Fishing	Sport	Surf fishing

The first ecological component evaluated direct effects of MPAs on surf zone fish. We conducted surveys of surf zone fish at 28 beaches, 14 MPA and 14 reference beaches, statewide. Most of these beaches were also surveyed for birds (excluding Whalers Cove, Stillwater Cove, Laguna Beach and Strands Beach). This quantitative sampling used standard beach seining and Surf BRUVs to quantify surf zone fish and invertebrates. We surveyed surf zone fish at our 28 beaches three times per season in summer-early fall of 2019 and 2020.

The second ecological component for our phase 2 studies evaluated a number of indirect effects of MPAs including birds, macrophyte wrack, kelp plants and visitors as well as physical characteristics of 36 study beaches, in 7 consecutive months of surveys August 2019 – February 2020. These surveys allowed us to characterize the Fall/Winter season for the dynamics of wrack deposition and the occurrence and diversity of birds and humans uses on the study beaches. The 36 study beaches in this component included 18 pairs of beaches, these pairs consisted of one beach located within an MPA and a matched reference beach outside the MPA. Twelve beaches (6 MPA/Ref Pairs) were surveyed on the mainland coast of each of the three regions. Importantly, because of the ecological impacts of common management practices previously shown for beaches in the SC region (e.g. Dugan et al. 2003, 2008, Dugan and Hubbard 2010, Hubbard et al. 2013, Viola et al. 2013) our study site selection purposely excluded both MPA and reference beaches that were known to be groomed, manipulated with heavy equipment or subject to direct beach filling in the region with only one exception. However, at least 4 of the study beaches in the SC region were subject to regular vehicle use by lifeguards and/or park rangers.

The primary goal of this report is to provide an assessment of the ecological state of sandy beach and surf zone ecosystems with particular emphasis on the effects of protection and management related to the establishment of a statewide network marine protected areas (MPAs). The majority of refined MPA questions from the Decadal Evaluation Working Group (DEWG) needed to be modified to remove the phrase “over time” to be applicable to the majority of our results due to the lack of regular ecosystem monitoring for beaches and surf zones. However, our results provide new insights and information on the responses of sandy beach and surf zone ecosystems to MPAs and on the presence of numerous indicator taxa and species not covered by any other MPA monitoring efforts. The initiation of long-term monitoring programs and datasets on surf zone fish, as well as beach birds, wrack and characteristics, in MPAs and reference sites would make possible the types of analyses needed to address the “over time” element of the refined DEWG MPA questions.

Methods

MPA Baseline Studies

Our Phase 2 MPA monitoring study and site selection is linked to the regional MPA baseline studies of sandy beaches and surf zones conducted following the designation of the MPAs in the North-Central Coast (2010), the South Coast (2012) and the North Coast (2014) Regions (Table 2). For details on these studies, see final technical reports for Dugan et al. (2015), Nielsen et al. (2012, 2017). No baseline studies of beaches and surf zones were conducted in the majority of the MPAs of the Central Coast Region, designated in 2007. All of the MPA baseline studies of beaches and surf zones used the same methods to measure response variables of wrack abundance, kelp plants, bird abundance and diversity as well as recording use by humans and dogs on MPA/Ref site pairs. Importantly, surf zone fish were not uniformly or comprehensively surveyed in the regional MPA baseline studies. Hook

Table 2 List of the MPA baseline studies conducted for sandy beach and surf zone ecosystems by region, (Note: the former North Central region is now split between the North and Central regions).

Region	Years	Sites	Fish	Bird	Kelp	Invert.	Beach
North	2014-15	14 (7 MPA)	Y (4 MPA)	Y	Y	Y	Y
North Central	2010-12	10 (5 MPA)	Y (2 MPA)	Y	Y	Y	Y
Central	N/A	None	N	N	N	N	N
South	2011-13	12 (6 MPA)	N	Y	Y	Y	Y

and line surveys for surfperch were conducted at four sites in the North-Central coast, and nine sites on the North coast in the MPA baseline surveys (Nielsen et al. 2014, 2017).

Study Sites

We selected a total of 20 different MPAs as study sites based on the criteria in the MLPA Action Plan and the availability of baseline data (Table 2). Once the MPAs with suitable beach habitat were selected for our Phase 2 study, we carefully screened and selected a suitable reference site for each MPA site. For the 11 MPA sites used in the earlier baseline studies, we reviewed existing reference sites and selected new reference sites as needed, particularly for fish survey. For the nine new MPA sites, which included the majority of Central Coast sites, as well as sites in the other regions, we carefully selected matching reference sites. Thirteen of the MPA sites were surveyed for birds and fish, three were surveyed only for birds and four only for fish due to either a limited extent of beach habitat for bird surveys or surf zone characteristics that were not suitable for fish surveys. The location of the fish or bird surveys within an MPA depended on habitat suitability as well. Of our 21 MPA sites, shore fishing is allowed at five sites (MacKerricher SMCA, Carmel Bay SMCA, VAFB SMR, Swamis SMCA, and Dana Point SMCA). To expand the coverage of MPAs in our study, four of the five fished MPA sites were used as reference sites for surf zone fish and matched with a fully protected MPA as above (with the exception of the VAFB SMR). For the bird and wrack surveys, these sites were used as MPA sites, with the exception of the Dana Point SMCA where too much of the beach habitat was constrained by coastal armoring (Table 3).

Metrics

We surveyed and conducted analyses of the following metrics and additional characteristics at our study sites:

1) Abundance, biomass, species richness and composition and size structure of surf zone fish, focusing on sport fishing targeted and nontargeted fish as well as trophic structure and family.
2) Abundance of freshly stranded thalli of three major species of drift kelps: two subtidal species *Macrocystis pyrifera*, *Nereocystis luetkeana, and one intertidal species Postelsia palmaeformis*
3) Abundance and species richness and composition of all birds on sandy beaches and surf zones including: shorebirds (including snowy plovers), seabirds, gulls, aquatic and wading birds and terrestrial birds
4) Abundance, and activities of people and dogs on sandy beaches and surf zones, including shore fishing
5) Physical characteristics of beach and surf zone habitats, including beach zone widths and slopes and wave and swash climate

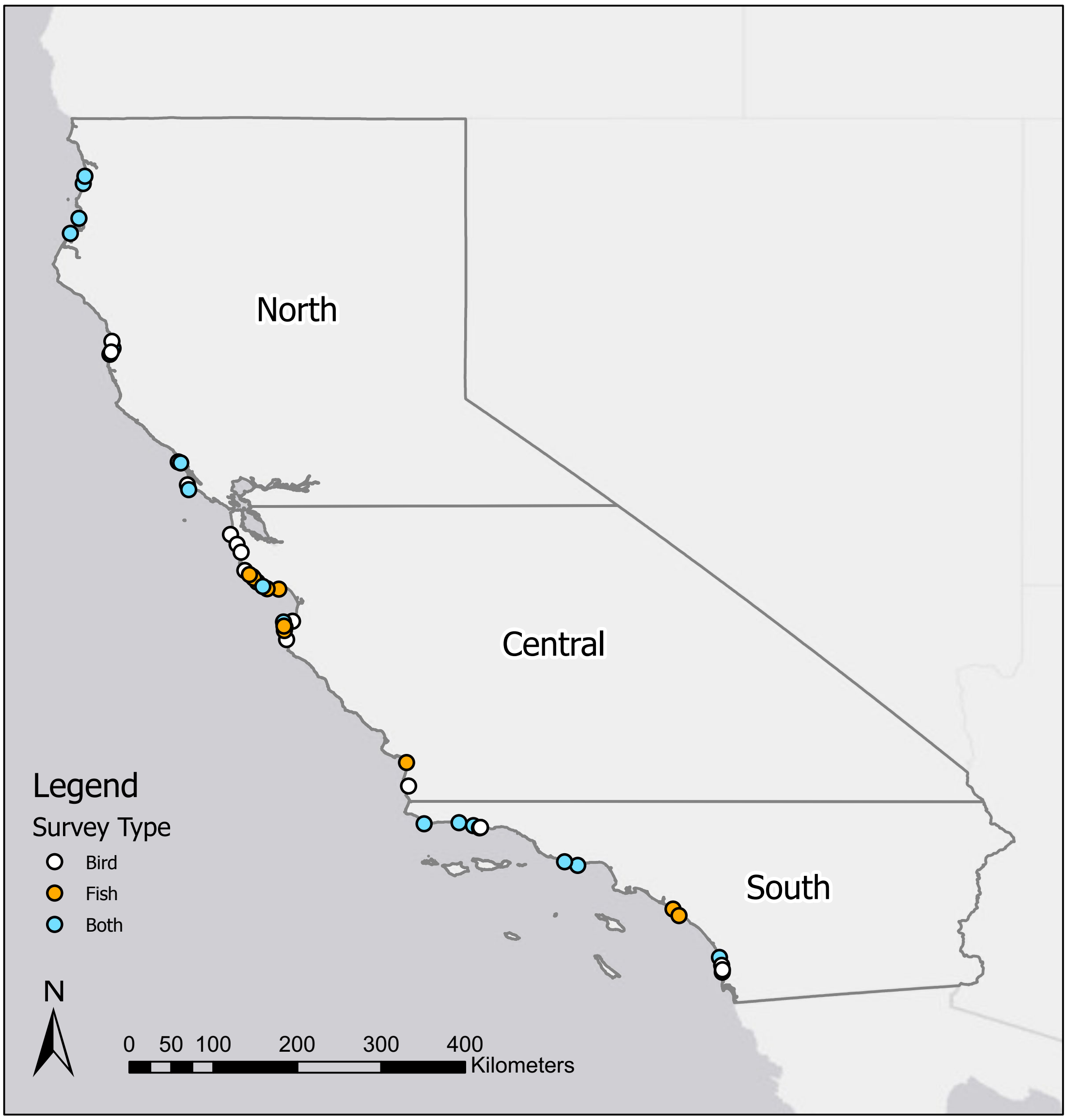

Figure 1 Locations of our beach and surf zone survey sites along the mainland coast of California by region. Both fish and bird surveys were conducted at some sites (blue dots) while other sites were used for one survey type depending on the beach characteristics and conditions.

Table 3 List of our MPA and Reference study site pairs (denoted by blue dotted lines) with site names (MPA names in bold, baseline status, region, site type, MPA tier, survey types and research teams as columns.

Site	Baseline	Region	Type	Tier	Fish Seine BRUV	Fish Hook & Line	Fish Team	Birds Wrack	Bird Team
Reading Rock SMCA (north of creek)	y	North	MPA	I	x	x	HSU	x	HSU
Gold Bluffs	y	North	Reference		x	x	HSU	x	HSU
Mad River	y	North	Reference		x	x		x	HSU
Samoa SMCA	y	North	MPA	III	x	x		x	HSU
Ten Mile SMR (north of river)		North	MPA	I	x		HSU		
MacKerricher SMCA (Virgin Crk)	y	North	MPA Reference	I	x		HSU		
Ten Mile SMR (north of river)		North	MPA	I				x	HSU
Blues Beach		North	Reference					x	HSU
MacKerricher Beach Ward Ave	y	North	Reference					x	HSU
MacKerricher SMCA (Virgin Crk)	y	North	MPA Reference	I				x	HSU
Bodega Head SMR (Salmon Crk)	y	North	MPA	I				x	BeachWatch
Great Beach, Point Reyes		North	Reference					x	BeachWatch
Doran Beach		North	Reference		x		HSU	x	BeachWatch
Point Reyes SMR (Drakes)	y	North	MPA	I	x		HSU	x	BeachWatch
Montara SMR (Ross Cove)	y	Central	MPA	I				x	Pt Blue
Half Moon Bay-south end (Redondo)		Central	Reference					x	Pt Blue
Tunitas Beach		Central	Reference					x	Pt Blue
Ano Nuevo SMR (Gazos Creek)		Central	MPA	I				x	Pt Blue
Ano Nuevo SMR (Ask GAVIN)		Central	MPA	I	x		MLML		
Greyhound Rock SMCA		Central	MPA Reference	I	x		MLML		
Ano Nuevo SMR (Waddell Creek)		Central	MPA	I				x	Pt Blue
Scott Creek Beach		Central	Reference					x	Pt Blue
Natural Bridges SMR (4 mile Beach)		Central	MPA	II	x		MLML		
Twin Lakes Beach		Central	Reference		x		MLML		
Monterey State Beach		Central	Reference					x	Pt Blue
Asilomar SMR (Asilomar beach)		Central	MPA	II				x	Pt Blue
Asilomar SMR (Spanish Bay)		Central	MPA	II	x		MLML		
Carmel Bay SMCA (Carmel Beach)		Central	MPA Reference	I	x		MLML		
Carmel Bay SMCA (Stillwater Cove)		Central	MPA Reference	I	x		MLML		
Pt Lobos SMR (Whalers Cove)		Central	MPA	I	x		MLML		
Carmel Bay SMCA (Carmel Beach)		Central	MPA Reference	I				x	Pt Blue
Garapata Beach		Central	Reference					x	Pt Blue
North VAFB (Minuteman Beach)	y	Central	Reference				UCSB	x	Pt Blue/UCSB
VAFB SMR (Wall Beach)	y	Central	MPA	I			UCSB	x	Pt Blue/UCSB
Pismo State Beach		Central	Reference		x		UCSB		
VAFB SMR (Wall Beach)		Central	MPA	I	x		UCSB		
Pt Conception SMR (Percos)		South	MPA	I	x		UCSB	x	Pt Blue/UCSB
Refugio State Beach	y	South	Reference		x		UCSB	x	UCSB
Haskells Beach	y	South	Reference		x		UCSB		
Campus Point SMCA (West)= SANDS	y	South	MPA	I	x		UCSB		
Haskells Beach		South	Reference		x		UCSB	x	UCSB
Campus Point SMCA (South Campus)		South	MPA	I	x		UCSB	x	UCSB
Campus Point SMCA (East)= Isla Vista	y	South	MPA	I				x	UCSB
East Campus Beach	y	South	Reference					x	UCSB
Leo Carrillo State Beach	y	South	Reference		x		UCSB	x	UCSB
Point Dume SMR = Dume Cove	y	South	MPA	I	x		UCSB	x	UCSB
Laguna Beach SMR= Sleepy Hollow		South	MPA	I	x		UCSB		
Dana Pt SMCA (Strand Beach)		South	MPA Reference	I	x		UCSB		
Swami's SMCA (San Elijo)	y	South	MPA	I			UCSB	x	UCSB
Torrey Pines State Beach		South	Reference					x	UCSB
Swami's SMCA (San Elijo)	y	South	MPA Reference	I	x		UCSB		UCSB
Scripps/Matlahuayl SMR (Scripps)	y	South	MPA	II	x		UCSB		UCSB
Scripps/Matlahuayl SMR (Scripps)	y	South	MPA	II			UCSB	x	UCSB
Black's Beach	y	South	Reference				UCSB	x	UCSB

Field Methods

Surf Zone Fish surveys- We surveyed surf zone fish communities at each site during the summer months at four to six week intervals for a total of three surveys per year (June to October 2019-2020). Surf zone fish were surveyed during standardized tide windows (3 ft or less) using replicated 50 ft beach seines and Baited Remote Underwater Video cameras (surf-BRUVS) (Vargas-Fonseca et al.

2016, Borland et al. 2017) which are considered complementary techniques for this habitat (Esmaeili et al. 2021).

The fish community was sampled using a beach seine (15 m long x 1.8 m high, 1 cm mesh with poles attached and a 1.8 m x 1.8 m x 1.8 m bag). Seining was conducted within two hours before or after a low tide to control for the effect of tides (Marin Jarrin et al. 2009). For each tow, two-four people carried the net into the surf zone to approximately 1.5 m in depth and open it in a wide V-shape, parallel to the shoreline, and then pulled it back to shore keeping the weighted line flush with the bottom. Six tows were taken at each site on each sampling date. Immediately after the seine reached the beach for each tow, all fish were removed from the seine, placed in labelled 5-gallon buckets of fresh seawater with aerators until they were identified, counted and measured to the nearest cm (first 30 individuals of each species per haul). After measurement, fish were placed in a recovery bucket and then released at the site of capture. Fish density was calculated as the catch per seine tow. Fish biomass was estimated for each species by calculating the weight of every fish captured, using published species-specific length-weight relationships where available (Froese and Pauly 2021); species for which this information was not available were sampled until adequate relationships were obtained (~30 individuals). In cases where more than 30 individuals were sampled, we used the average weight measured (for the first 30 individuals) and applied to additional fishes that were captured by not measured.

Fish assemblages in surf zones were also surveyed on each sampling date using purpose-built baited remote underwater video stations (Surf-BRUVS) (Vargas-Fonseca et al. 2016) to capture presence of animals typically undersampled in beach seines. Surf-BRUVS consist of a GoPro video camera mounted on a 10 lb flat weight that is attached to a 1 m pvc pole with a bait bag containing 500 g of chopped squid attached at the end within the camera's field of view. The Surf-BRUVs were deployed at regular intervals along a transect parallel to the beach and seawards of the first line of breakers. This location may be just outside the surf zone or in the first trough of the surf zone depending on the beach morphology and wave climate. On each sampling date, we deployed six benthic Surf-BRUVS per beach. Each surf-BRUVS deployment sampled fish for 1 h, giving a total video sampling time of 18 h per beach per year. Surf fish assemblages can exhibit high temporal variation with changes in season, diel period and tidal state (Layman, 2000; Beyst et al. 2002). To standardize for such temporal effects, we restricted surf-BRUVS surveys to daytime tides (i.e. within 3 h of high tide) during the summer and early fall months

Due to time constraints a minimum of three videos were processed for each survey (per year per site) resulting in unequal sampling efforts across the sites; therefore, results are presented as per unit effort for response metrics. Videos from BRUVs were processed using EventMeasure software for the Central and South coast sites and by hand for the North coast sites. A calibration of these two approaches to analysis conducted across the study teams yielded similar results. One hour of video was analysed for each BRUV. Fish abundance, species richness and community composition were quantified from Surf-BRUVS video footage using a standard Max N statistic (Murphy & Jenkins, 2010). In the North coast, lack of visibility due to nearshore turbidity did not allow us to always identify fish to species. Therefore, we often examine this data at a family, subclass, or functional group scale so that all data can be used. Six hours of video were collected in each of the three surveys a year for each site (36 hours/site) and at least 3 hours of video were processed for each site and date for (18 hours/site).

Fish data were summarized to produce metrics of species richness and total fish abundance, and biomass (from seines) for each site and year. Fish from seines and BRUVs were categorized into 1) trophic role (i.e. microbenthivore, piscivores, herbivore, and planktivores; (following Baker & Sheaves, 2005; Elliott et al. 2007); 2) functional guild (primary consumer, secondary consumer etc); 3) broader taxonomic group (e.g. surfperch, smelt, silverside, elasmobranch); and 4) targeted vs. non targeted by recreational fishermen for analyses of MPA effects (Love 2011). Size structure of selected species and species groups, such as surfperch, was summarized by site from the seine surveys. Microbenthivores included species that consumer large or small benthic invertebrates, while piscivores ate primarily fish. Planktivores were those that fed on plankton (either zoo- or phyto-plankton) and herbivores are known to feed on macroalgae. We defined targeted fish as those that are commercially or recreationally harvested in sandy beach ecosystems as the main target (i.e. not considered bycatch), this includes species harvested to be used as bait or for human consumption. Alternatively, a fish would be non-targeted if there is not a known history of exploitation, for instance fish considered too small or bad eating by local anglers. We determined these designations based on primary literature (Love 2011, Froese and Pauly 2021) and conversations with local experts (per. Comm. Ken Oda CDFW).

Bird, Wrack, People Surveys- These metrics were all surveyed at the same time. We used the standard survey protocols used in the baseline characterization studies of the North, North Central and South Coast Regions and previous studies (Dugan et al. 2015, Nielsen et al. 2014, 2017) to monitor the metrics of birds, wrack and people on sandy beaches. This facilitated our comparative analyses of MPA effects over time for selected sites. The distribution, abundance and seasonal occurrence of shorebirds, seabirds and other birds, was assessed by conducting regular, daytime surveys of birds on standardized transects during low tides at all MPA and reference sites. Surveys were conducted on a standard alongshore transect of 1 km, with endpoints recorded and described using GPS. Observers surveyed 2-4 sites per day; all sites were surveyed within a week to ten days each month and scheduled so that the condition of the tide was constrained (0.75 m (2.5 ft)) or lower tides spanning the two hours preceding and following low tide). During each survey, all shorebirds, gulls and other birds, including seabirds and terrestrial birds, were identified and counted using binoculars by a single observer walking the 1 km transect. Birds were assigned to intertidal zones (upper intertidal, mid-intertidal, below WTO, swash zone, surf zone) and habitats (rocks, pools, wrack) as they were counted and their behavior (feeding mode, roosting) noted. Kelp subsidies were monitored by counting the number of freshly stranded kelp plants and detached holdfasts of selected kelp species encountered on each 1 km transect. This measure was well correlated with overall kelp wrack cover in all the baseline studies. All pinnipeds were also identified and recorded. Oiled and dead birds and mammals encountered were recorded. The number of people, their activities (e.g., walking, fishing, surfing, sunbathing) and dog use (leashed/unleashed) and zones of occurrence on the transect were quantified during each survey.

Abundance and species richness of birds on the study beaches was expressed as the number of individuals km^{-1} of shoreline. Human and dog use was also expressed as the number of individuals km^{-1} of shoreline. The abundance and composition of wave cast drift kelp plants was expressed as number of plants km^{-1} of shoreline. Total abundance is defined as all of the birds observed on a given beach for the duration of the study period (seven months). Similarly, total richness is defined as the total of all of the bird species observed on a given beach for the duration of the study period. Similar estimates were made for kelp plants, people, and dogs on the study beaches. To calculate an average for a given sandy beach, survey month was used as a replicate and expressed as individuals km^{-1} of shoreline. We also examined monthly averages (temporal variation) of these metrics across MPAs and reference sites where individual beaches are averaged to a MPA or reference level. During this study, 7 monthly surveys were conducted at each of the 36 focal beaches between August 2019 and February 2020 for a total of 252 surveys. This number is two survey months (=72 surveys) short of the planned nine month survey period due to the implementation of COVID 19 restrictions on travel and research by our respective institutions and programs in March 2020. Following those March 2020 COVID-19 research shutdowns, it was not possible to complete the March and April surveys of all the study beaches. A number of surveys were conducted during March 2020 in the south and central regions and no surveys were conducted in April 2020. Any surveys we conducted in March 2020 were excluded from the below analyses. This only affected wavecast wrack, fresh kelp and bird surveys.

Beach and Surf Zone Characteristics- Beach width, slope, grain size, wave climate and other physical variables can strongly influence species composition and abundance of birds and fish on sandy beaches. Standard monitoring protocols from baseline characterization studies in the North, North Central and South Regions and earlier studies (Dugan et al. 2015, Nielsen et al. 2014, 2017) were used to facilitate comparisons of ecosystem conditions since MPA establishment. We measured overall intertidal width as well as widths and slopes of key ecological zones of the beach as indicated by the locations of the swash limits, the water table outcrop (WTO) and the high tide strand line (HTS) during each survey at all study sites. Measurements were taken along three vertically oriented transects during each survey in conjunction with bird, wrack and people surveys (see below). Physical parameters including wave height and period, beach slope at two intertidal levels, swash width and period and beach zone widths were measured on one of the transects during each monthly survey. When available, baseline information on beach widths and characteristics was incorporated into analyses. The same beach and wave climate measurements were collected on three cross-shore transects during each surf zone fish survey.

Analyses

Our MPA-reference site pairwise design allows us to explore if assemblages and indicator species of sandy beach ecosystems differ with respect to MPA status by testing the average log difference in values of the measured metrics termed the log response ration (LRR) (Hamilton et al. 2010, Thapa et al. 2018, Crystal-Ornelas 2020, Crystal-Ornelas and Lockwood, 2020). This can be written as:

$$ln(RR) = ln\left(\frac{MPA}{Ref}\right)$$

If the LRR is positive this indicates that on the MPA contains more of the response variable (i.e., larger sizes, higher abundance, elevated biomass, higher diversity, etc.), while if it is negative the reference site has more of the response variable. One limitation of this metric is that the response ratio cannot be calculated if the metric in either the MPA or Reference site is zero (Crystal-Ornelas 2020), therefore these measurements were removed from analyses. These are expressed as metric per unit effort or metric per survey given unequal sampling efforts.

Log response ratios were calculated for each metric at each survey and then visualized as means per MPA pair. We also tested if these LRRs were significantly different from zero using a two-tailed t-test (α=0.05) when assumptions of normality were met and a Wilcoxon-rank sign test when normality was not present. Additional linear analyses are also presented in the test to examine general metrics inside and outside MPAs (α=0.05; when assumptions of normality were met). All analyses were conducted in R version 4.0.2 (2020-06-22) (R core team 2020).

Community Analysis- multivariate statistics

To examine community composition, we used a non-metric multidimensional scaling graph. Using R package vegan, function metaMDS() with Brays-Curtis distance (Oksanen et al. 2020). All nMDS presented used a log transformation of the abundances prior to analysis. Two or three dimensions were used to reduce stress below 0.2. The arrow(s) shown on each graph point to the direction of most rapid change in the environmental variable (direction of the gradient). The length of the arrow(s) is proportional to the correlation between ordination and environmental variable (strength of the gradient). For each data analysis only significant environmental vectors and/or significant species are shown in the figures.

Reference Site Selection

Physical Characteristics of the Beaches

An important component of our study design was selecting suitable well matched reference sites for each of the MPA sites. For this effort, we relied largely on physical characteristics of the sites including habitat zone widths and slopes, and the wave and swash climate. The dynamics of sand, wind and waves, and the geologic features of the coast shape the physical characteristics of beach and surf zone ecosystems as habitat for indicator groups including fish, birds and wrack inputs. It is important to have well matched pairs in order to effectively compare MPA and reference sites. These characteristics may also be important environmental drivers of variation in response variables among MPAs. Below we present results for what we consider to be the key physical characteristics for matching MPA and reference site pairs, additional information is available in Appendix_Physicals_People.

Sandy beaches in California and the majority of our study sites can be generally classified as intermediate morphodynamic types (e.g. McLachlan and Brown 2006). Intermediate beaches are characterized by high variability in their intertidal and surf zone features and can range from nearly dissipative states to nearly reflective conditions, depending on season, wave climate and proximity to headlands (Wright and Short 1984, Short 1996). Despite the inherent variability in intermediate type beaches, many of the physical characteristics we measured overlapped for the MPA and Reference sites within a pair, suggesting that characteristics of site pairs were similar. This increased our confidence that any difference in response metrics within our MPA/Ref site pairs was not a function of differences in beach characteristics.

Results

Direct Responses to MPAs: Surf Zone Fish

We hypothesized that when protected from harvest in MPAs, surf zone fish assemblages and species could exhibit direct responses in abundance, biomass and size structure, species richness and community composition. Species that are targeted by fishing are generally expected to respond more clearly to MPA management, which reduces fishing effort and pressure spatially, than are non-targeted species. In this shoreline adjacent habitat, we expected recreational fishing to be a stronger pressure than commercial fishing

For this component of our study, which represents the first statewide baseline study for fish of open coast surf zones, we focused on the ecologically and culturally important surf zone fishes that could potentially directly respond to MPA protection including surfperch, croakers, atherinids, flatfish, smelt, sharks, and rays. Fish species are expected to respond to MPAs at different rates depending on a number of factors including population status, fishing pressure and history, life history, reproductive mode and dispersal, as well as access points and enforcement levels. The key metrics for our analyses for surf zone fish were overall and population abundance, biomass, and size structure, and diversity, community and trophic structure and species composition of targeted and non-targeted species.

Our study design and analyses for surf zone fish concentrated on aspects of two evaluation questions from the original MLPA Goals 1 & 2 and modified versions of the more recently articulated Decadal Evaluation Working Group questions.
MLPA Goals 1 & 2:

- Do indicator species inside of MPAs differ in size, numbers and biomass relative to reference sites?
- Does functional diversity and trophic structure differ in MPAs relative to reference sites?

Decadal Evaluation Working Group Questions: (increase over time removed)

- Do focal and/or protected species inside of MPAs differ in size, numbers and biomass relative to reference sites?
- Is the size/age structure of recreationally valued species greater in MPAs?
- Is there a difference between MPAs and reference sites in community structure and/or species diversity within any given functional group or assemblage?

Temporal trends in metrics of surf zone fish may exist but were not possible to evaluate in our two year study. With only two years of surveys, we did not have sufficient power to describe or resolve temporal trends or evaluate possible factors that might influence temporal variation in surf zone fish (**Appendix_Fish Figure 1**). Therefore, we chose to treat all fish survey results for these two methods, regardless of year, as replicates resulting in 30-36 surveys per site (Note: For beach seines some sampling sites have lower than expected numbers of hauls or surf BRUVs due to unfavorable ocean conditions and research restrictions required for state, county and institutional COVID protocols, **Appendix_Fish Table 1**).

When considering response variables (i.e. abundance, biomass, and size structure) it is important to keep in mind that the beach seine and surf BRUV survey methods we used are relatively non-selective compared to recreational fishing tackle. For this reason, our survey methods for surf zone fish can record a wider range of size classes of both targeted and untargeted fish, including juvenile and adult individuals, than other survey methods, such as hook and line.

Below we answer these questions about direct responses to MPA management using general patterns from surf zone fish, targeted and non-targeted groups, as well as selected focal species. More details on other grouping (trophic and families) and additional species accounts can be found in Appendix_Fish.

Do focal and/or protected species inside of MPAs differ in size, numbers, and biomass relative to reference sites?

Is there a difference between MPAs and reference sites in the abundance of a focal and/or protected species?

Abundance

The question of whether the abundance of surf zone fish inside MPAs differs relative to reference sites was evaluated using two methods, beach seines and surf BRUVS (Baited Remote Underwater Video), in each survey. **These two methods yielded strongly contrasting results with respect to the concerning patterns of abundance of surf zone fish in MPAs and reference sites**, as well as differences in regional patterns.

Beach seines

To answer the question of the effect of MPAs on the numbers (abundance) of surf zone fish we used statewide comparisons of mean values of abundance (CPUE, defined here and for further analyses as the average number of fish per seine) which did not differ significantly between MPAs and reference sites overall (ANOVA (MPA status (log(abundance) $F_{1,145}$=0.966, p=0.327)) (**Figure 2A**). Average CPUE in beach seines also did not vary significantly with MPA status within any of the three regions (standard errors for CPUE overlapped) and any differences observed were not consistent in direction among regions (**Figure 2B**). However, mean values of overall CPUE of surf zone fish in seines in our surveys varied significantly across the three regions (ANOVA (log(abundance) **$F_{2,145}$=22.01, p<0.001**). The Central Coast region had the highest overall CPUE in beach seines, especially in reference sites (>45 fish per seine), and the North Coast region had the lowest CPUE (< 10 fish per seine).

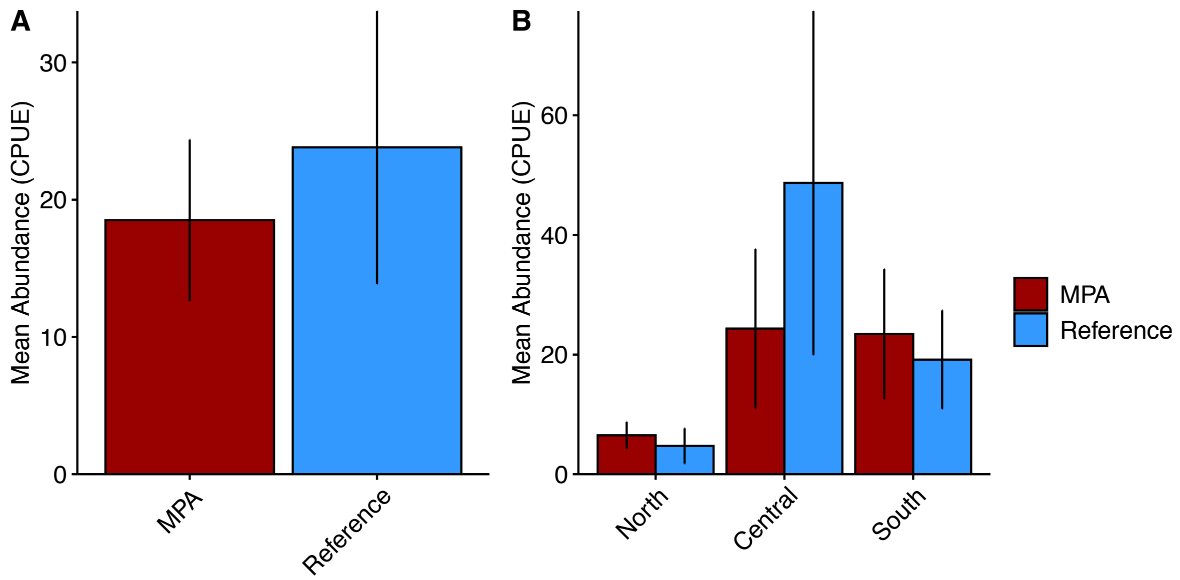

Figure 2 Beach seine results for A) overall mean values (± 1 standard error) for abundance (CPUE) of surf zone fish. B) Mean values (± 1 standard error) for abundance (CPUE) of surf zone fish divided into the three study regions. Mean abundance as CPUE is estimated by the number of fish per seine at a site.

To better evaluate whether the abundance of surf zone fish in beach seines inside of MPAs differs from reference sites, given the strong variation we expected among MPAs, we examined the CPUE of surf zone fish using the differences between each MPA site and its paired reference site. These differences were expressed as log response ratios (LRR) calculated per MPA/Ref site pair with the two sampling years combined. For these analyses, a positive LRR result indicates a higher CPUE inside MPAs compared to its paired reference site while a negative LRR result indicated higher CPUE in the reference sites. As in the preceding analysis, our beach seine results show that LRR of CPUE for fish did not differ significantly among MPAs and reference sites (Wilcoxon-signed rank test, p=0.17) suggesting that the abundance of surf zone fish did not differ inside and outside MPAs. Surf zone fish abundance as CPUE was greater in the MPA site at 7 of the 13 pairs of MPA/reference sites, did not differ at three pairs and was lower at three pairs. Interestingly the six MPA/reference site pairs with positive LRR values for abundance of surf zone fish in seines were distributed across all three regions (3 in North, 1 in Central and 2 in South (**Figure 3**). Negative LRR values for abundance of fish in seines occurred at three site pairs, one from each region.

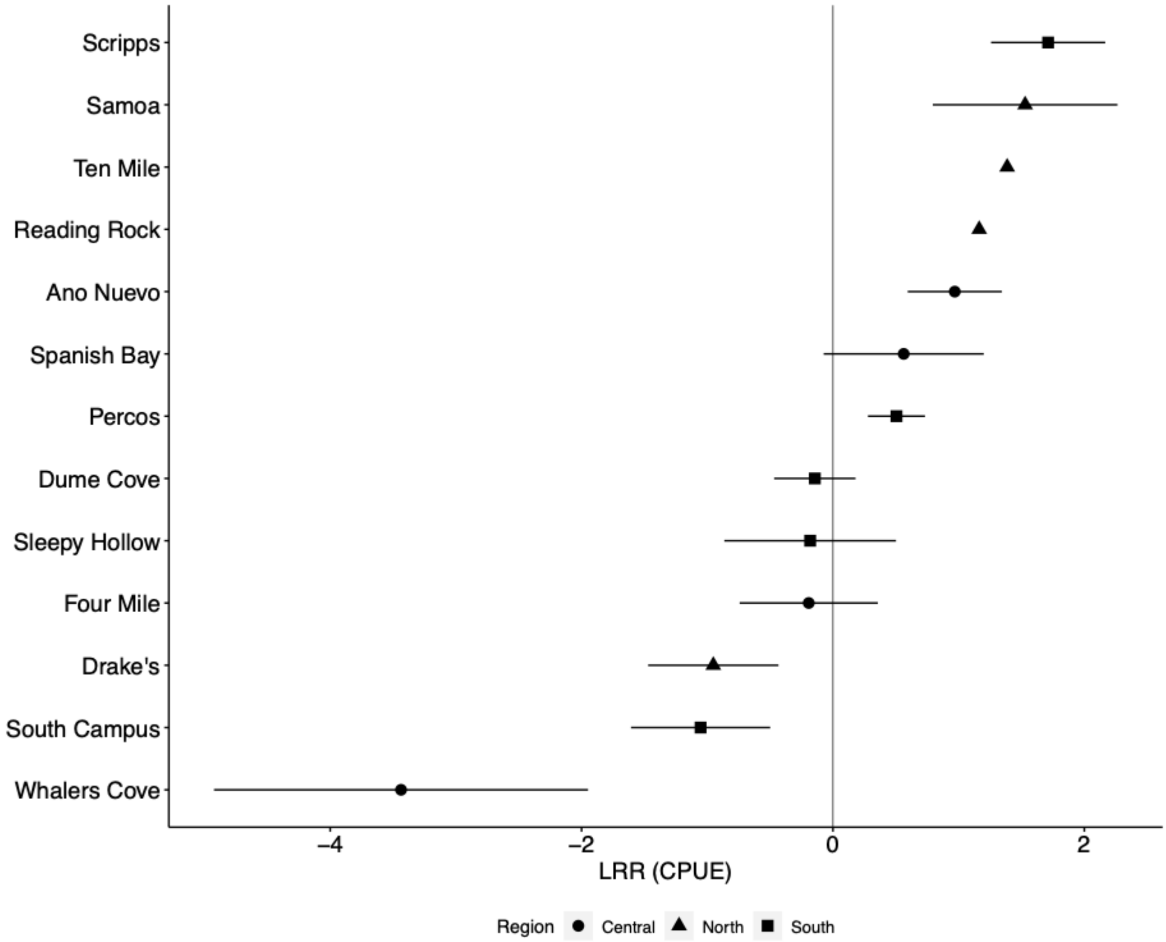

Figure 3 Beach seine results for mean values (± 1 std error) of Log Response Ratio (LRR) for surf zone fish abundance (CPUE) for each MPA/ reference site pair. Positive LRR indicates site pairs where MPAs have greater CPUE than their respective reference sites, while negative LRR are pairs where reference sites had higher CPUE than MPAs. Pairs are named for the MPA site. Pairs are sorted from largest LRR to smallest. Values of LRR means and standard errors are based on each sampling event.

As expected, we found high site to site variation in abundance (CPUE) of surf zone fish in seines. Mean values of fish abundance (CPUE) varied greatly among the MPA/reference site pairs (MPAs 0.8 to 63.44 CPUE in MPA, Ref 0.033 to 128.47 CPUE) in the seines **(Figure 4)**. The highest CPUE was observed at Stillwater Cove (Ref) in the Central coast while Virgin Creek (Ref) had the lowest CPUE. This result primarily reflects the very strong differences in surf zone habitat among MPA sites rather than a response of the abundance of surf zone fish in seines to MPA management.

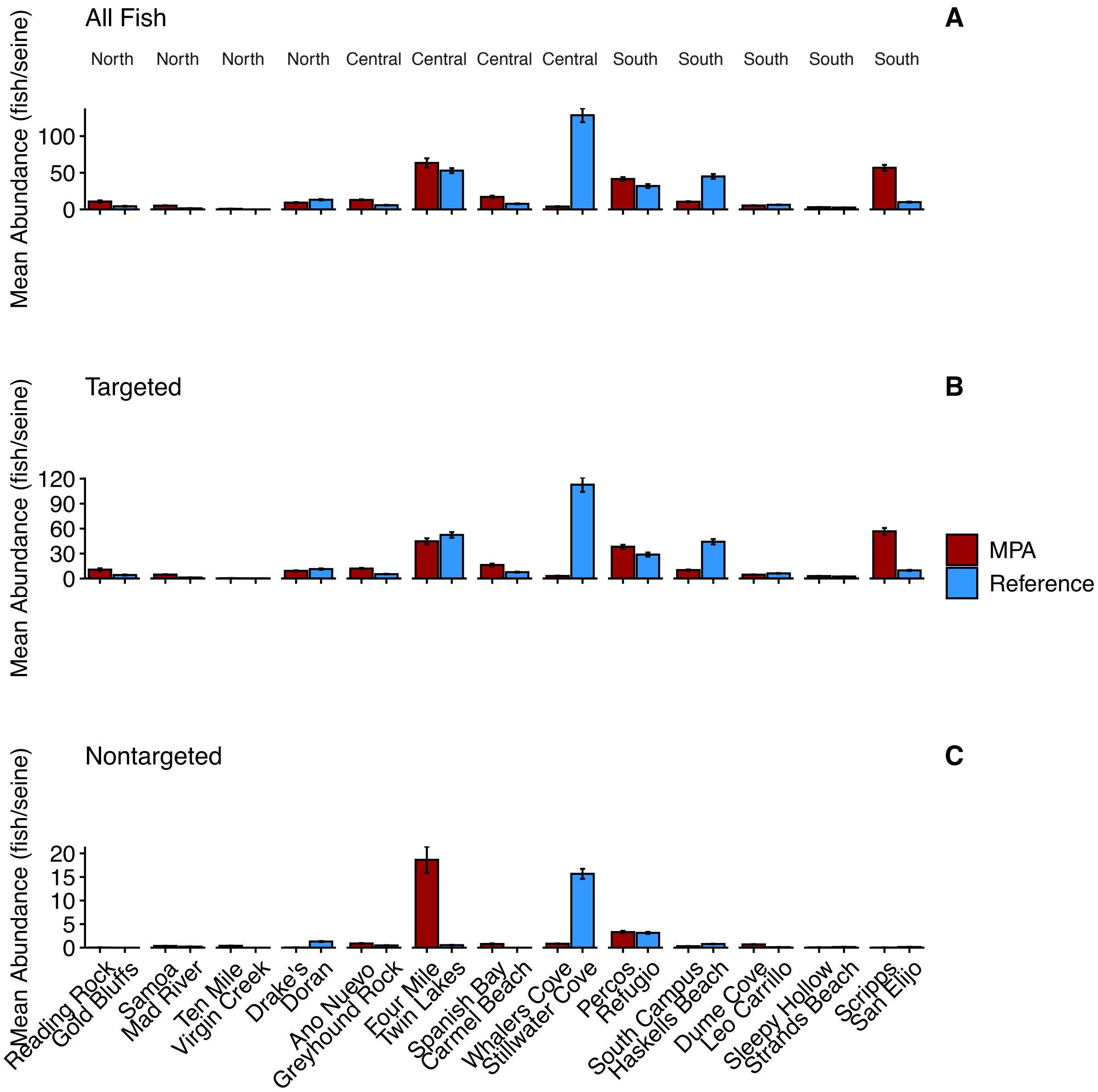

Figure 4 Beach seine results on mean values (± 1 standard error) of CPUE of surf zone fish by site and fishing category. All fish represent every fish observed while the targeted or non-targeted categories include only those identified to species level.

BRUV surveys

Observations and analyses from our surf BRUVs (Baited Remote Underwater Video) yielded contrasting results for the abundance of surf zone fish compared to those from our beach seines. In this method, abundance is estimated by the MaxN statistic which represents the maximum number of individuals belonging to each species counted in a single frame, across all BRUV sampling videos at each site (**Figure 5)**.

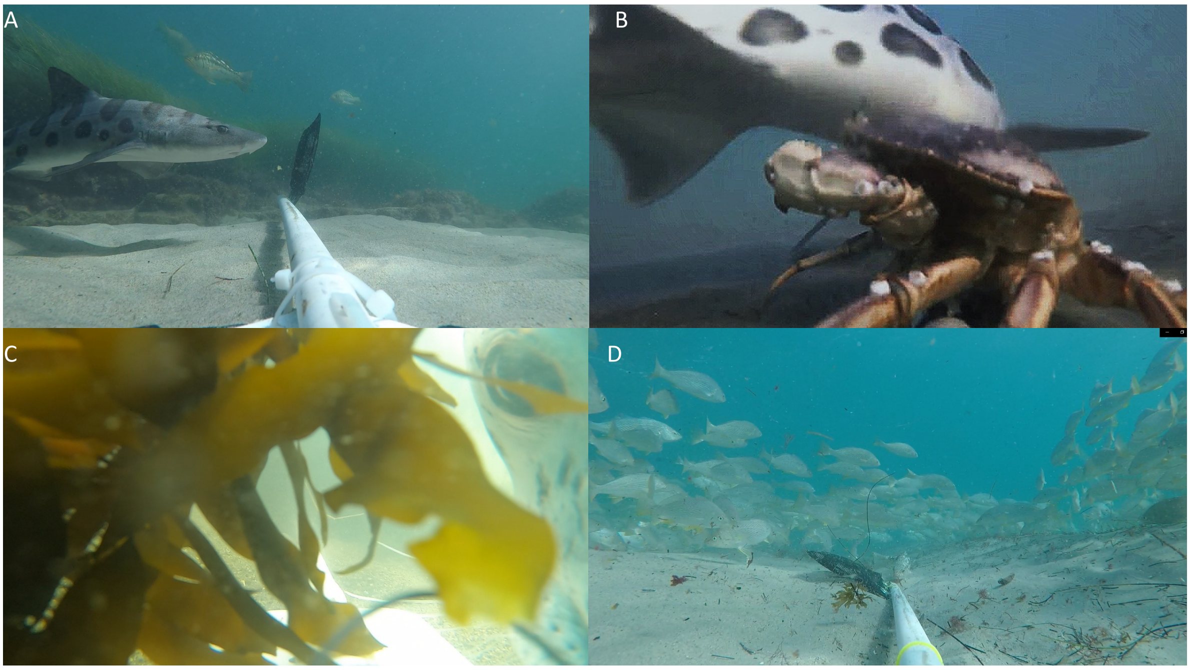

Figure 5 Example screen captures from selected surf BRUV footage. A) Leopard shark and kelp bass at Dume Cove (MPA). B) Dungeness crab and leopard shark at Drakes (MPA) C) Macrocystis and harbor seal at Whalers Cove (MPA). D) School of yellowfin croakers at Sleepy Hollow (MPA).

Overall, our BRUV results showed mean MaxN values were on average two times greater inside MPAs (**Figure 6A**). Our simple statewide analyses indicated abundance of surf zone fish (MaxN) is significantly greater in MPAs compared to reference sites (MPA $\mathbf{F_{(1,\ 696)} = 10.11,\ p=0.002}$) (**Figure 6A**). Region was also a significant factor for MaxN (Region $\mathbf{F_{(2,\ 696)} = 48.18,\ p<0.001}$) (**Figure 6B**) a result that may be related in part to ocean conditions that affect visibility as found at many sites of the North region. Our regional analysis of BRUV data at the MPA level revealed significantly greater abundance as MaxN (ANOVA; $\mathbf{F_{(1,\ 186)} = 16.81,\ p<0.0001}$) inside MPAs compared to reference sites in the South region, where the mean value of MaxN was three times greater in MPAs compared to reference sites. For the Central and North regions, where abundance as MaxN was much lower, (particularly in the North region), no significant differences in abundance of surf zone fish as estimated by MaxN were detected between MPAs and reference sites.

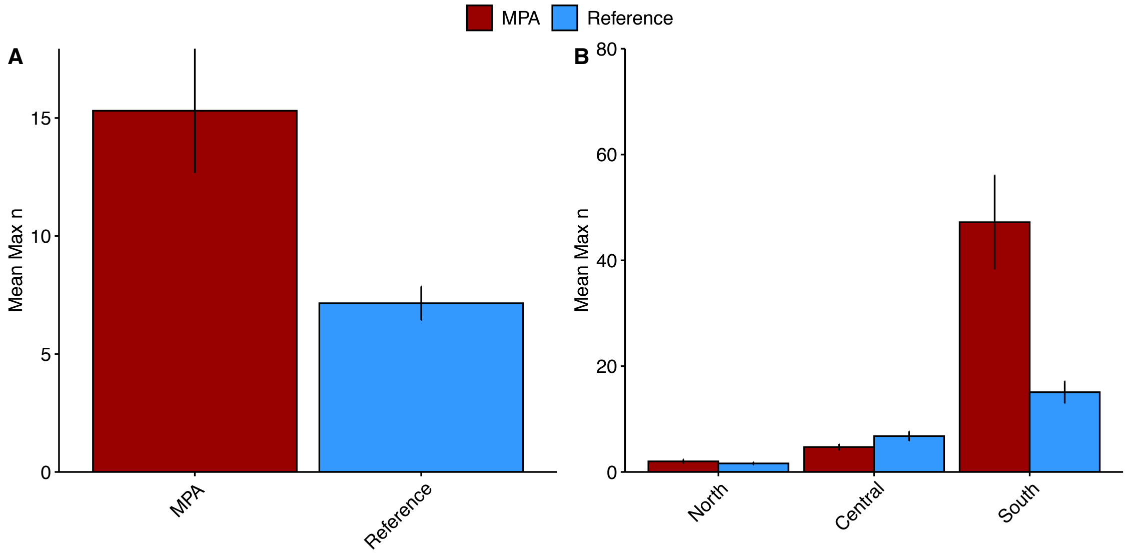

Figure 6 Surf BRUV results on the mean abundance (± 1 standard error) of surf zone fish as MaxN. n= 348 total BRUVs inside MPAs and n=351 BRUVs at reference sites. The MaxN statistic represents the maximum number of individuals belonging to each species counted in a single frame, across all sampling videos at each site. Mean values include all sites averaged to the MPA/reference level.

To more accurately evaluate our MaxN results given the strong MPA to MPA differences, we tested differences in the MPA/Ref site pairs using LRR values. The results for LRRs of MaxN measured by BRUVs showed a significant difference from zero (**two-tailed t-test t=2.59 and p=0.01**) meaning that on average MaxN was not equal inside and outside MPAs. To examine the direction of this difference, a one-tailed t test on LRRs showed MaxN was greater in MPAs compared to reference sites (o**ne-tailed t-test μ>0 t=2.59, p=0.005**). This result agreed with the statewide pattern for MaxN (**Figure 6**). Seven MPA/Ref pairs had positive LRRs, where the MPA had a greater MaxN than the reference sites, while three had negative LRRs where the reference site had greater MaxN than the MPA site (**Figure 7**). Three of our MPA/Ref site pairs showed no response in LRR (South Campus, Drakes, and Spanish Bay) (**Figure 7**). Our MaxN LRR results also varied strongly with region, LRRs were positive for all five of the South coast MPAs, two Central coast MPAs and one North coast MPA, highlighting the importance of regional differences in addressing this question on abundance of surf zone fish.

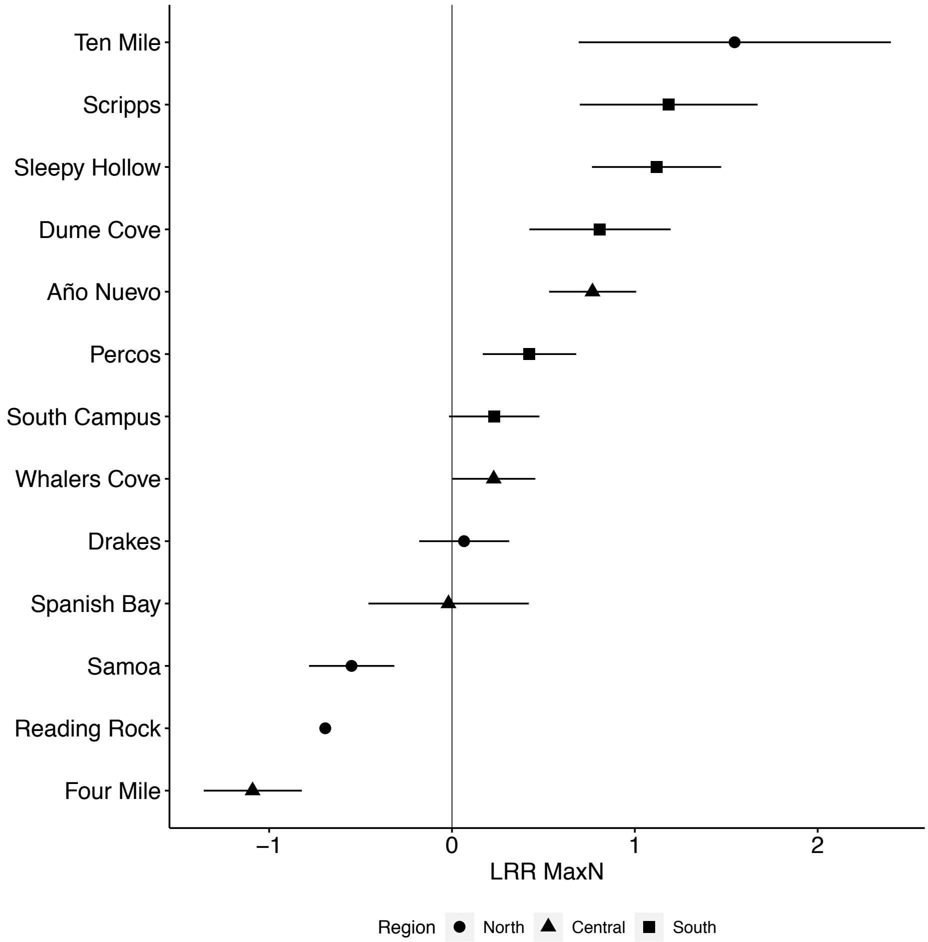

Figure 7 Surf BRUV mean (± 1 std error) of LRR for the abundance of surf zone fish (MaxN) for each MPA/reference site pair listed in order of LRR result. Values of LRR means and standard errors are based on each sampling event.

As in the beach seine results, the abundance of surf zone fish estimated using BRUVs varied strongly among sites (**Figure 8**) with mean MaxN values at each site ranging from 0.25 to 127.8 (CPUE, measured as fish observed per BRUV). The substantial regional differences shown above were clearly evident in the BRUV results for abundance of surf zone fish at individual sites with generally greater values of MaxN at sites in the South coast, particularly in MPAs (**Figure 8**). However, our surf BRUV results indicated the CPUE of surf zone fish (MaxN/BRUV) increased consistently from the North to the South compared to the results from beach seines, particularly in MPA sites **(Figure 8)**. Overall average MaxN values were highest for South coast sites, ranging from 7.9 to 127.8 individuals with the highest average MaxN, 127.8 (± 34.56) individuals, observed at our southernmost site, Scripps (MPA) **(Figure 8**). The lowest average MaxN, 0.25 (± 0.16) individuals, was observed at Gold Bluffs (Ref), our northernmost site. Generally, MaxN was very low for the 3 pairs of northernmost sites, a result that may be due in part to lower visibility in the wider more turbulent surf zones of those beaches which resulted in fewer observations.

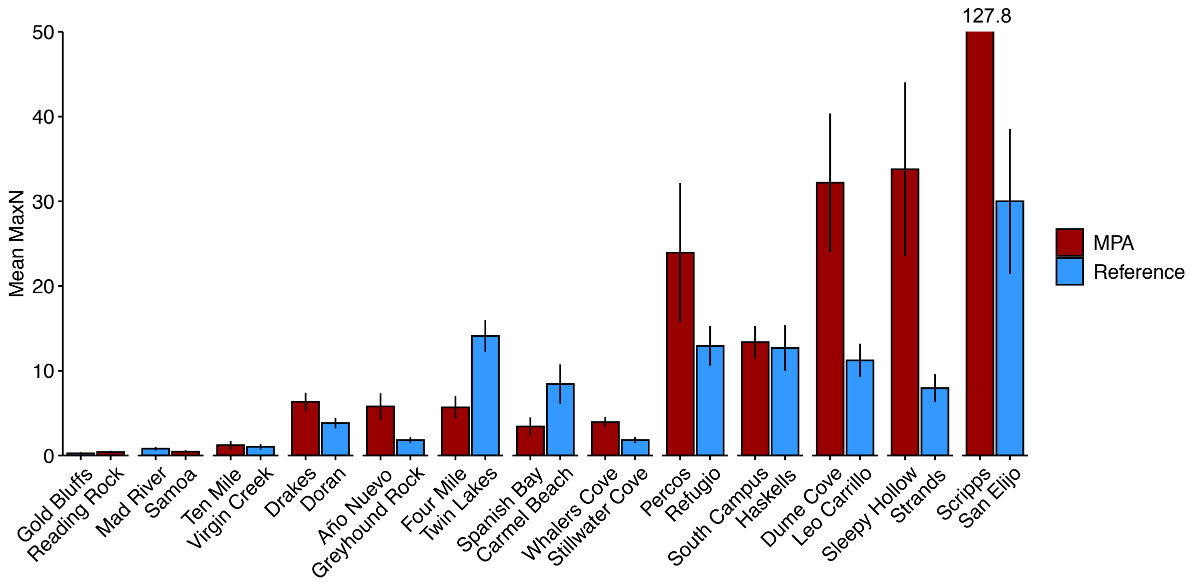

Figure 8 Surf BRUV results for mean (± 1 std error) abundance of surf zone fish as MaxN across our 26 surf zone study sites. Mean values of the MaxN statistic which represents the maximum number of individuals belonging to each species counted in a single frame, across all sampling videos at each site. Sites are listed from North to South. Scripps had a mean MaxN of 127.8 (±34.56) (extends beyond the y axis).

Is there a difference between MPAs and reference sites in the numbers/abundance of a focal and/or protected species?

To evaluate whether there are differences between MPAs and reference sites in the abundance of focal fish we examined the abundance of targeted (fished) surf zone fish using beach seines. Due to poor visibility in the surf zone at some of our sites, fish identification to the species level was difficult with BRUV videos, therefore we do not present analyses on targeted fish from surf BRUVs. Instead we highlight some of the focal higher taxa identified using the surf BRUVs, including surfperch, croakers, and elasmobranchs.

Beach seines

The majority of the surf zone fish caught in our seine surveys were targeted species including the barred surfperch, California corbina, walleye surfperch, silver surfperch, topsmelt, calico surfperch and leopard shark (present in >100 of 900 seines, **Appendix_Fish Table 3)**. The most abundant fish species caught in the seines were targeted species with the barred surfperch (4134 fish) most abundant followed by northern anchovy (3200 fish) (**Appendix_Fish Table 3**). Walleye surfperch, silver surfperch, queenfish, California corbina and topsmelt were also abundant with > 1000 individuals of each caught in our seines **(Appendix_Fish Table 3**). Barred surfperch, topsmelt, calico surfperch, and walleye surfperch were the most widespread taxa in our study each occurring at more than half (15 or more) of the 26 sites. One non-targeted species, the dwarf surfperch, was commonly caught and widespread **(Appendix_Fish Table 3**).

Our expectation of high MPA to MPA variation in response variables, was reflected in the abundance of targeted surf zone fish (**Figure 4**). Here and for all future analyses targeted fish were those identified to species and fished by commercial or recreational fishers (**Appendix_Fish Table 5**). Mean values of targeted fish abundance (CPUE) varied greatly among the MPA/reference site pairs (MPAs 0.40 to 56.74 CPUE in MPA, Ref 0.033 to 112.78 CPUE) **(Figure 4)**. Again this finding for abundance of targeted fish in seines primarily reflects the very strong differences in surf zone habitat among MPA sites rather than any direct or indirect response to MPAs. Overall, the numbers of targeted fish caught in beach seines did not vary with MPA status (log(abundance) $F_{1,142}=0.38$, $p=0.54$) but varied significantly with region (log(abundance) $\mathbf{F_{2,142}=21.39, p<0.001}$).

To address the strong variation among individual MPAs inherent in our study design we evaluated whether the abundance of targeted and non-targeted taxa of surf zone fish inside of MPAs differ from reference sites, using differences between each MPA site and its paired reference site from our seine results. Again, we examined the mean total abundance of targeted fish in seines as log response ratios (LRR) calculated per site pair with the two sampling years combined. The LRR values for total abundance (CPUE) of targeted fish species in seines did not differ from zero (LRR, two-tailed t-test, p=0.45) indicating CPUE did not differ inside and outside MPAs. For targeted fish, abundance as CPUE was greater in the MPA at 6 of the 13 pairs of MPA/reference site pairs, did not differ at three pairs and was lower at four pairs during the two years of our study (**Figure 9**). The site pairs with positive LRR values for abundance of surf zone fish were evenly distributed across all three regions (one per region).

Non-targeted fish taxa were not present in all MPA pairs and therefore could not be analysed for Scripps, Spanish Bay, Reading Rock, and Ten Mile MPA/Ref pairs. For the 9 sites with non-targeted fish, the LRR of CPUE of those fish did not differ from zero (two-tailed t-test, p=0.422) suggesting that abundance of non-targeted fish does not vary with inside and outside MPAs. For non-targeted fish taxa, the number of positive LRRs for abundance in seines was also low with positive LRRs at 4 of 9 MPA/Ref pairs, no difference at 1 pair and negative values at 4 pairs (**Figure 9**).

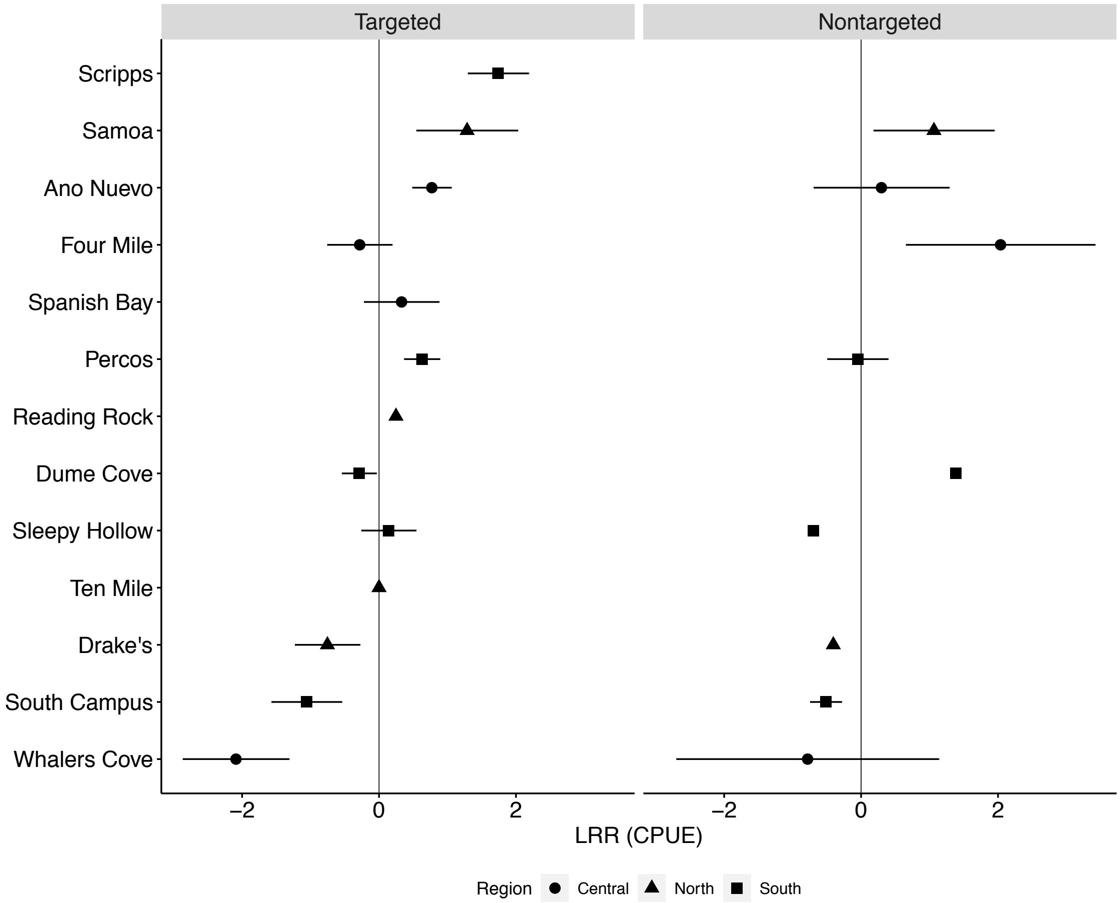

Figure 9 Mean (± 1 std error) LRR of abundance (CPUE) for targeted and non-targeted surf zone fish for each MPA/reference site pair. Positive LRR show pairs where CPUE is greater in MPAs than their respective reference sites, while negative LRR are pairs where reference sites had higher CPUE than MPAs. Pairs are named for the MPA site and sorted from largest LRR to smallest. Values of LRR means and standard errors are based on each sampling event.

We then examined the CPUE of the most abundant species (>650 fish) to evaluate their potential responses to MPA protection by calculating the LRR of individual species captured in our seines (**Figure 10**). Results varied among species. The LRRs of topsmelt and California corbina were positive indicating their CPUE was greater in MPAs (LRR>0) **(Figure 10**). The abundance of three of the seven species we analysed were similar inside and outside MPAs with LRRs close to zero including one non-targeted species, Dwarf surfperch. On the other hand, LRRs for silver surfperch and queenfish were negative indicating their CPUE was higher outside MPAs. Overall, values of LRR for seven most abundant species did not differ not significantly from zero (two-tailed t-test $t=0.567$, $p=0.57$) indicating there was no consistent difference inside and outside MPAs. In addition to being abundant these species were widely distributed, occurring at MPA and reference sites within a pair, making them suitable for the LRR analysis. For example, even though Northern Anchovy was the second most abundant species in our beach seines it could not be analysed using LRR because it was only found at five sites (four reference sites and 1 MPA) and did not occur at both the MPA and reference site of a single pair.

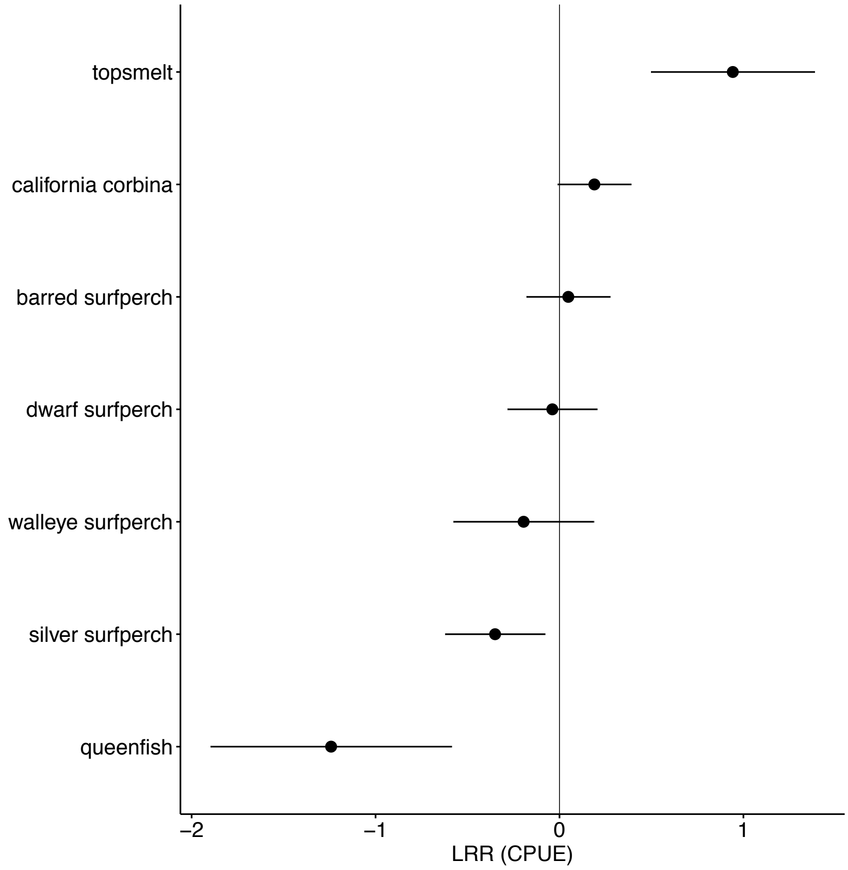

Figure 10 Mean values (± 1 std error) for LRR of CPUE of top most abundant fish species. Some abundant species were not recorded at both the MPA and reference site within a pair and could not be analysed using this method. Values of LRR means and standard errors are based on each sampling event.

BRUV surveys

The abundance (MaxN) of indicator groups/species of fish including a number of targeted species in the surfperch family (Embiotocidae), the croaker family (Sciaenidae), and the subclass of Elasmobranchii (sharks, rays, skates) (see **Appendix_Fish** for additional groups, including flatfish and pelagic fish) were recorded in our surf BRUV surveys. A number of reef fish species, such as kelp bass, opaleye, sargo, and sheepshead, were also recorded on BRUVs and were most abundant in the South region and in MPAs (**See Appendix _Fish**). In agreement with our seine results, surfperch, family Embiotocidase, were found at every site giving this indicator group the widest distribution in our BRUV surveys (**Figure 11**). The peak MaxN for surfperch was recorded at Percos (Pt Conception MPA). Observations of fish in the croaker family on the BRUVs were restricted to South coast region sites (**Figure 11**) with no croakers observed north of Percos (MPA), generally agreeing with our seine results on distribution of this family.

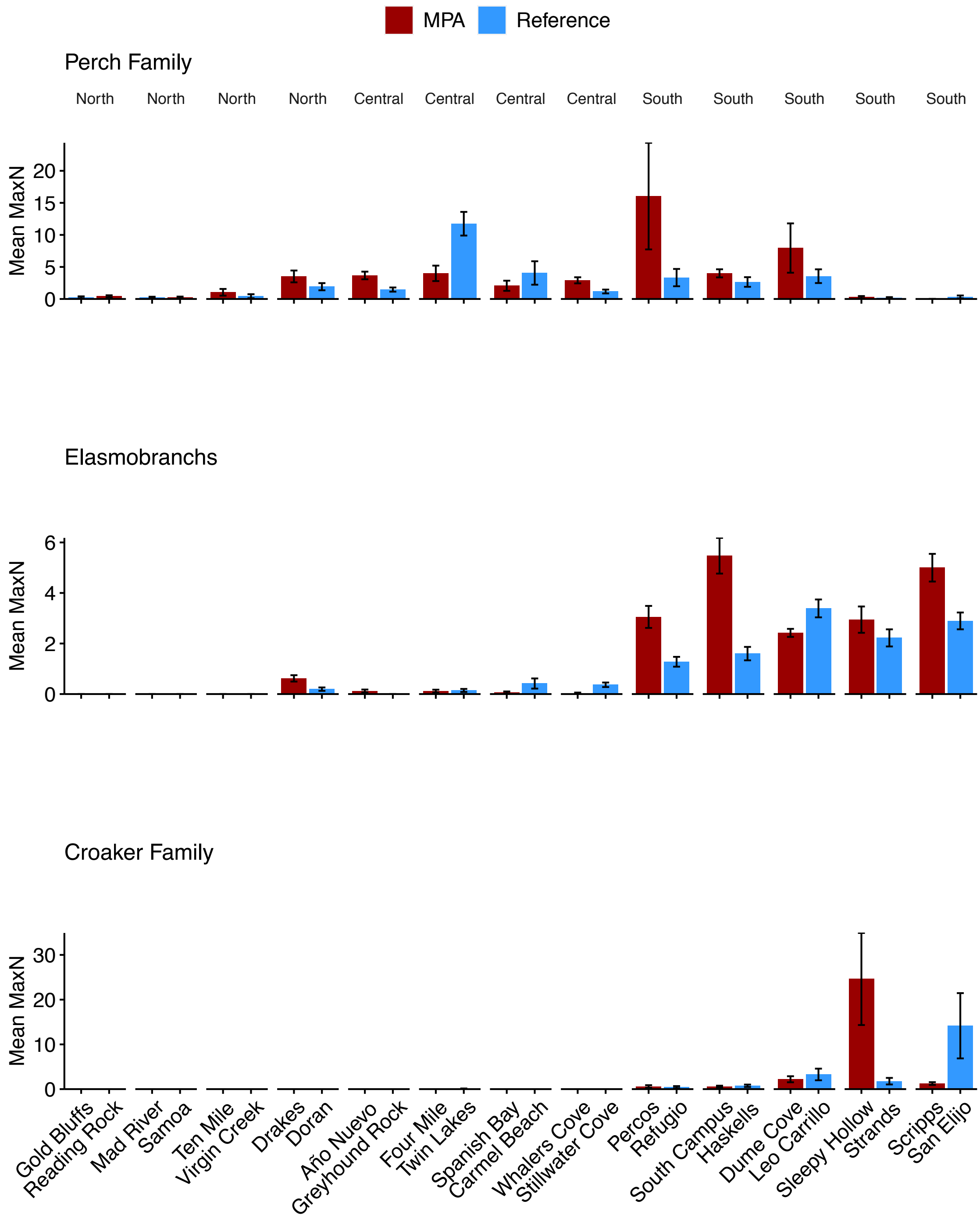

Figure 11 Mean values (± 1 std error) of MaxN at each site for three common groups of fishes captured in our BRUV surveys. Surfperch, Embiotocidae, had the widest distribution being found in all pairs of sites. Elasmobranchs, subclass Elasmobranchii, were more limited in distribution and were not observed in many North coast sites. Croakers, Sciaenidae, were only observed at South region sites.

The surfperches, *Embiotocidae*, are a prime example of a targeted fish family of surf zone habitats that may respond to management using MPAs. Surfperch are targeted by recreational shore fishing and sport landings greatly exceed commercial landings for all fished species. As found in the seines, surfperch were the most widespread group of fish in our BRUV surveys. Although MaxN of this family was higher in MPA than reference sites overall that pattern varied greatly by region. For the South region, mean MaxN was more than two times greater in MPA than reference sites but for the Central region mean MaxN was more than 40% lower in MPA compared with reference sites (**Figure 12**). Overall, the difference in CPUE as MaxN of surfperch inside and outside MPAs was close to significant (log(MaxN) $F_{1,696}$=3.78 p=0.052). We also detected a significant difference in MaxN of surfperch among the three regions (**log(MaxN) $F_{2,696}$=39.84 p<0.0001**) with the highest MaxN in the South and the lowest MaxN in the North region (**Figure 12**).

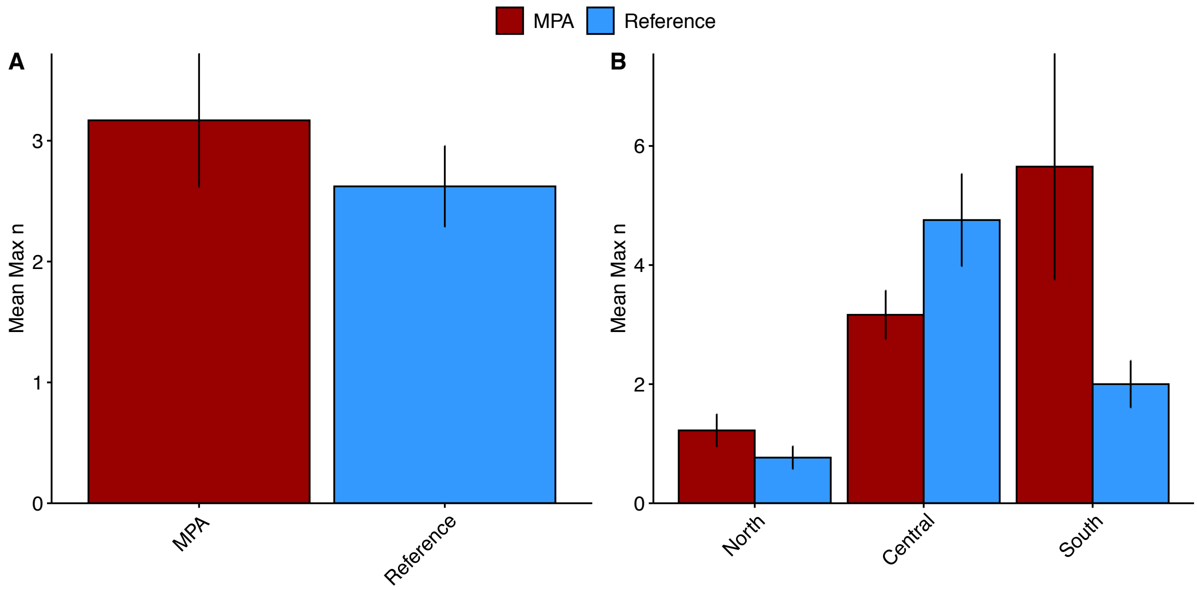

Figure 12 Mean (± 1 std error) MaxN of the surfperch family in MPA and reference sites in our BRUV surveys A. Statewide mean (± 1 std error) MaxN B. Regional mean (± 1 std error) MaxN. Surfperch, Embiotocidae, was the most widespread family in our BRUV surveys being found at most sites in all three regions.

When pair differences were examined, the LRRs of surfperch MaxN did not differ significantly from zero (two-tailed t-test t=0.325, p=0.75) suggesting no consistent differences between MPAs and their reference sites. However, the response varied by site, four site pairs showed positive LRR with higher MaxN of surfperch inside MPAs (two Central region, two South region), and one pair showed a clearly negative LRR with higher MaxN of surfperch in reference sites (**Figure 13**). Standard errors of LRRs of three of the site pairs overlapped zero and two pairs did not contain enough data to obtain standard errors. For this important family of recreationally targeted fish, overall patterns of abundance inside and outside MPAs were generally consistent across seines and BRUVs (seines CPUE: MPA $F_{1,139}$=0.28, p=0.59, BRUV MaxN: MPA $F_{1,696}$=3.78 p=0.052, **Appendix_Fish Figure 7**). However, patterns of regional and site to site variation in abundance of surfperch differed between BRUV and seine results.

The elasmobranchs, including leopard shark, thornback ray, bat ray, and shovelnose guitar fish, were more limited in distribution and only observed South of the Virgin Creek SMCA reference site in the North region in the surf-BRUVs (**Figure 14**). Although there was no difference in mean MaxN of elasmobranchs inside and outside MPAs (Kruskel Wallis chi^2=1.25, p=0.26), there was a significant difference with region (**Kruskel Wallis chi^2=483.0, p<0.0001**) with the majority of this group recorded in the South region. When we examine only the South coast,

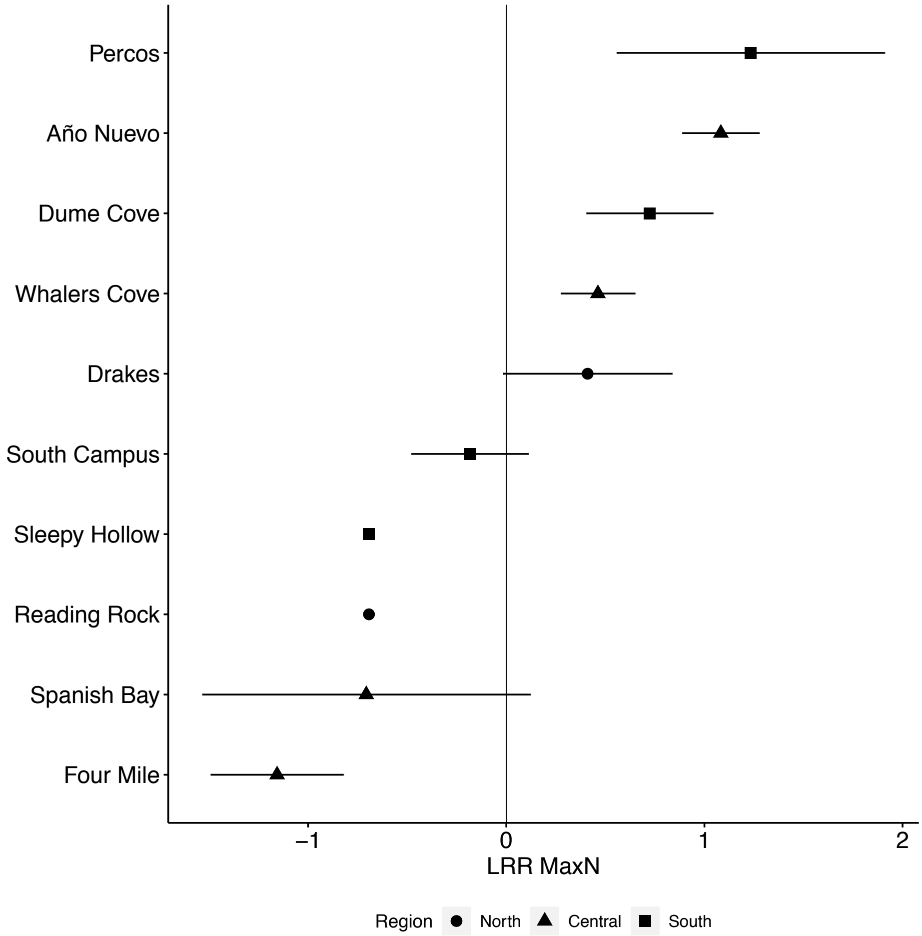

Figure 13 Mean (± 1 std error) LRR of MaxN for surfperch by MPA name listed from positive LRR to negative LRR. Only site pairs where surfperch were found at both the MPA and reference are pictured. Sleepy Hollow and Reading Rock pairs did not have enough observations to produce error bars. Regions are denoted by symbols. Values of LRR means and standard errors are based on each sampling event.

elasmobranchs were significantly more abundant inside MPAs than reference sites (**Kruskel Wallis chi^2=21.35, p<0.0001, Figure 14)**. When site pair differences for elasmobranchs were examined as LRRs, the LRRs of MaxN were significantly greater than zero (**Wilcoxon Signed Rank test v=1647, p<0.0001 Figure 15**) indicating elasmobranchs were more abundant in MPAs compared to reference sites. Our beach seine results also indicated that elasmobranchs showed a response to MPAs with significantly higher mean CPUE in MPAs (**MPA $F_{1,54}$=3.94, p=0.05**) (**Appendix Fish Figure 14)** but again high variation in abundance among and within the MPA/Ref site pairs was present.

Croakers, family *Sciaenidae,* were the most restricted in distribution and found exclusively at sites in the South coast on the surf-BRUVs (**Figure 16**), which broadly corresponds to their known distribution. Overall, we did not detect a significant difference between MaxN of croakers inside and outside MPAs (Kruskel Wallis chi^2=0.408 p=0.52). When we examined site pair differences, the LRR of MaxN for

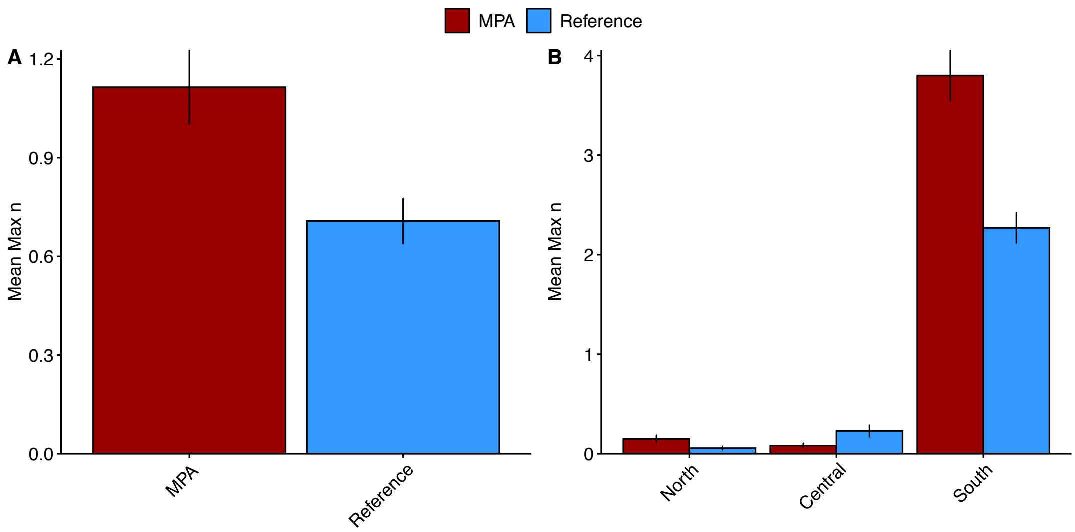

Figure 14 Mean values (± 1 std error) MaxN of Elasmobranchs in our BRUV surveys. Elasmobranchs were most abundant at the South coast sites.

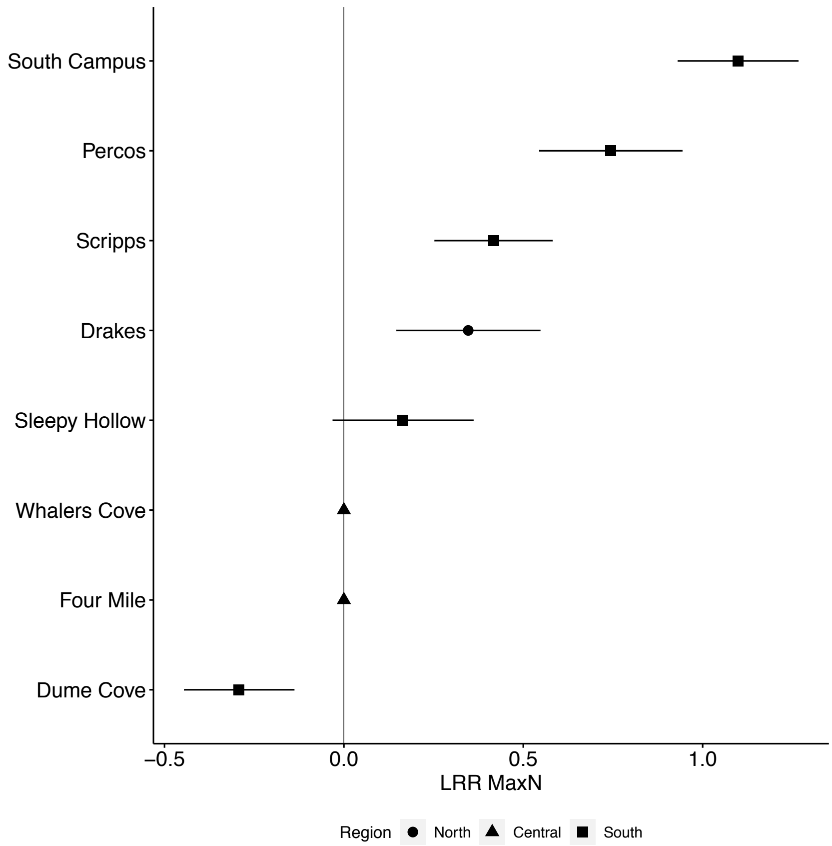

Figure 15 Mean values (± 1 standard error) for LRR of MaxN for Elasmobranchs. Only pairs where elasmobranchs were found at both the MPA and reference site are shown. Whalers Cove and Four Mile did not contain enough observations to produce error bars. Values of LRR means and std errors are based on each sampling event.

croakers did not differ significantly from zero (two-tailed t-test t=-0.60, p=0.55). Two site pairs had positive LRR showing higher MaxN of croakers inside these MPAs while one site had higher MaxN at the reference site (**Figure 17**). In comparison in our seine results, similar patterns were found with no MPA effect on mean CPUE of croakers (MPA $F_{1,60}$=0.46, p=0.50; **Appendix_Fish Figure 10**).

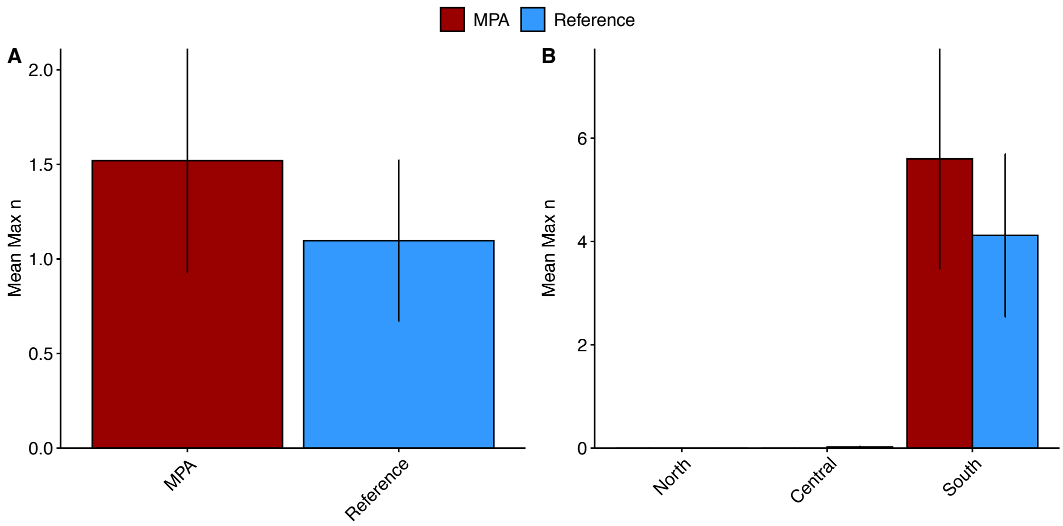

Figure 16 Overall mean values (± 1 std error) of MaxN of Croakers in our surf-BRUV surveys for MPAs and reference sites. A. Statewide values B. Regional values.

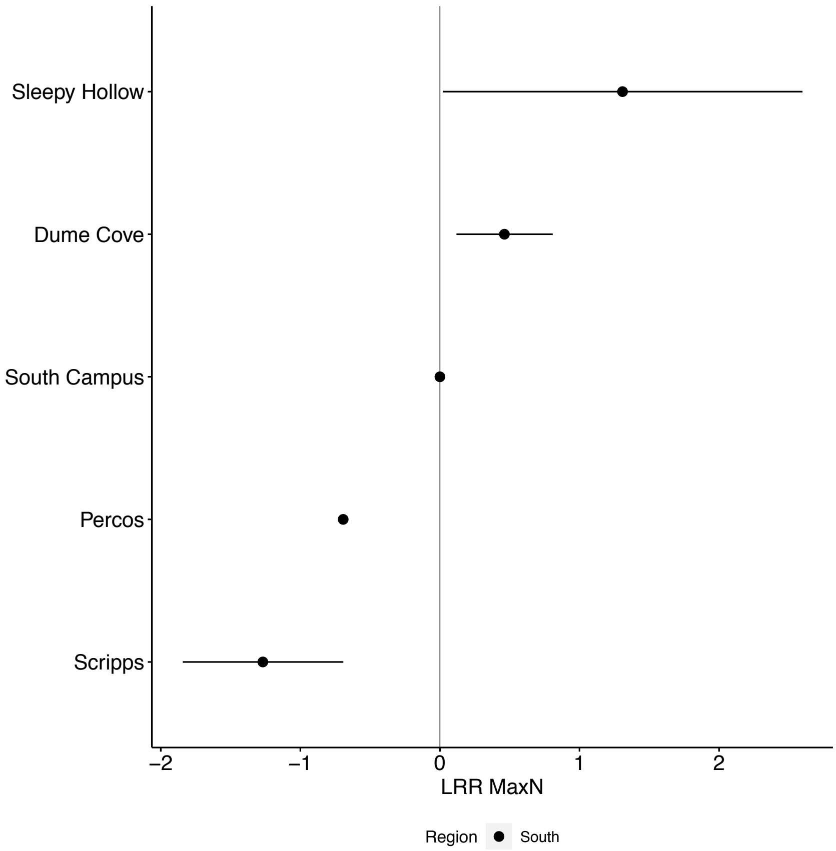

Figure 17 Mean values (± 1 std error) of LRR for MaxN of croakers from surf BRUVs at study sites where they occurred. Only pairs where croakers were found at both the MPA and reference sites are shown. South Campus and Percos site pairs did not contain enough observations to

produce error bars. Values of LRR means and standard errors are based on each sampling event.

Invertebrates, especially decapod crabs (family Cancridae) were observed with the surf BRUVs in all regions. This included species targeted by commercial or recreational fisheries, such as Dungeness crab and rock crab. In the North region, the commercially and recreationally important Dungeness crab, *Metacarcinus magister*, was regularly observed on surf BRUVs (**Figure 5**) but average MaxN did not differ significantly between MPA (1.3) and reference sites (1.2). The commercially and recreationally fished spiny lobster, *Panulirus interruptus*, was observed on a few BRUVS in MPAs in the South region but numbers were too low for comparisons (see **Appendix_Fish** for more information).

Is there a difference between MPAs and reference sites in the biomass of a focal and/or protected species?

We addressed this question on biomass for surf zone fish using our results on surf zone fish from our beach seines where live fish were individually measured before release. Fish size data were not available for the surf BRUV surveys. Comparisons of the biomass of surf zone fish (biomass per unit effort or BPUE) yielded a contrasting result to abundance with respect to differences between MPA and reference sites for surf zone fish.

Values of overall means of biomass of fish were > 30% greater for MPA sites than for reference sites (**Figure 18**). A broad simple analysis did not detect that difference in mean BPUE between MPAs and reference sites (log(BPUE) ANOVA; $F_{1,145}$= 0.807, p=0.37), because it is not able to account for the very high variation among the 13 pairs of MPA/Ref sites. The broad pattern we found in fish biomass for MPAs is likely influenced by other factors including biogeographical region. Fish biomass generally increased from the North to the South region when years were combined **(Figure 18)** with region being a significant predictor of mean BPUE (2-way ANOVA on log(BPUE)**; $F_{2,145}$= 47.19, p<0.001**) and in each of the years (**Appendix_Fish Figure 1**). This pattern may be related to low catch rates in seines at the North coast sites, and high numbers of larger bodied fish, including elasmobranchs such as Triakidae and Rhinobatidae, caught in seines at the South coast sites (Tukey's HSD showed comparisons with North region differed significantly, **p=0.05**) **(Figure 18B)**.

A more accurate evaluation of the question of whether the biomass of surf zone fish differed inside and outside MPAs achieved by examining the log response ratio or LRR of the 13 pairs of MPA/Ref site yielded a significant statistical difference between MPAs and reference sites. Values of LRR for biomass of all fish in seines differed significantly from zero (**two-tailed t-test p=0.04)** and were significantly greater than zero *(***one-tailed t-test μ >0 t=2.033 p= 0.02***)* indicating the BPUE of surf zone fish was greater in MPAs than reference sites. Seven out of 13 MPA/Ref pairs had a positive LRR ratio, indicating that those seven MPAs support higher mean biomass of surf zone fish than their reference sites (**Figure 19**)
). At least one MPA/Ref pair had a positive LRR in each of the regions (**Figure 19).** Only two of the site pairs had negative LRRs, both located in the Central coast (**Figure 19**)

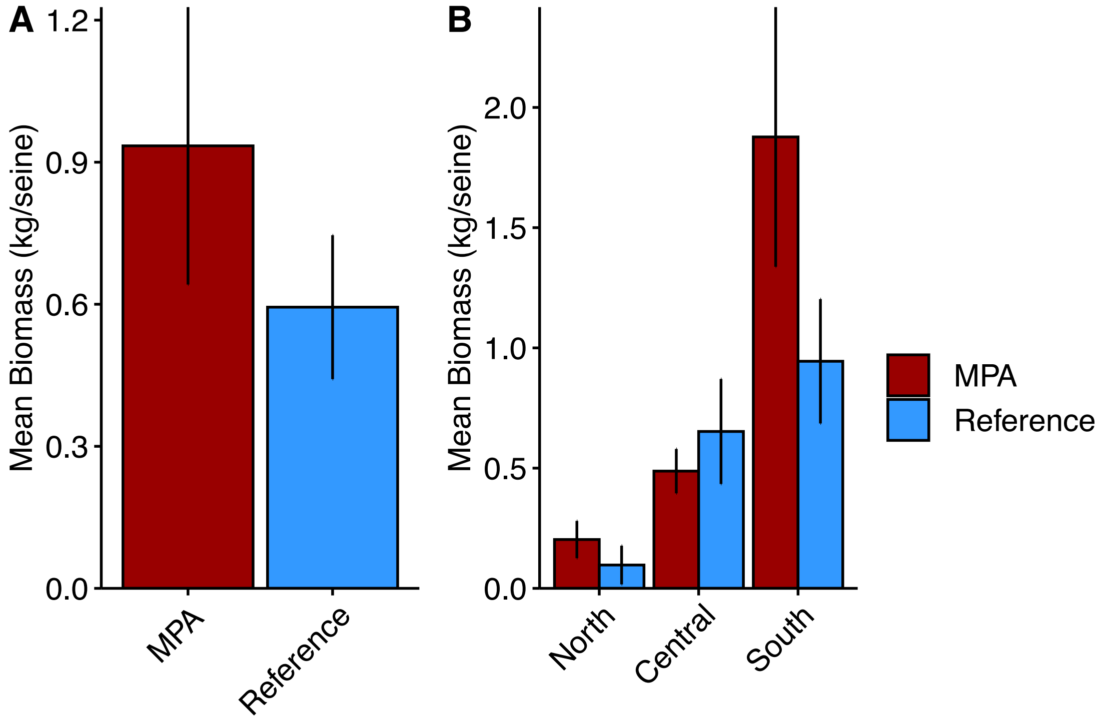

Figure 18 Mean values (± 1 std error) of biomass of surf zone fish in our beach seine results A. Statewide means and B. Means by region (2019 and 2020 combined). Mean biomass is kilograms of fish per seine at a site (BPUE). The small number of fish caught that were not identified to the species level were not used in biomass calculations.

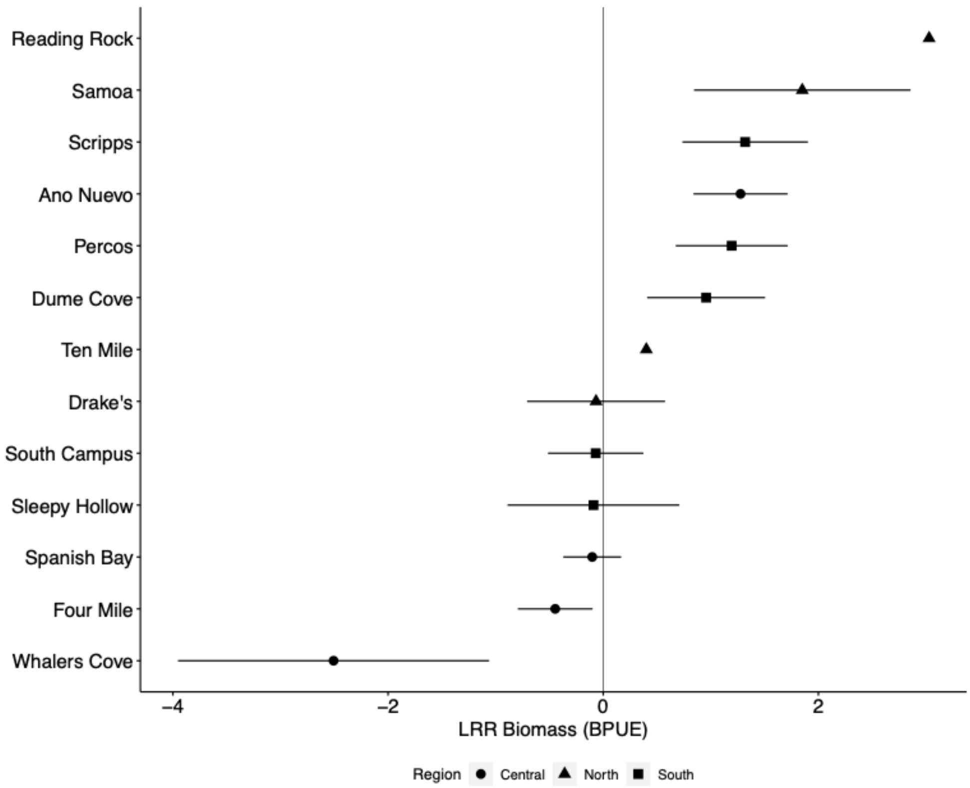

Figure 19 Beach seine results for mean (+ 1 std error) LRR of BPUE. Only fish identified to species were used in biomass calculations. Values of LRR means and standard errors are based on each sampling event.

Across the state, the mean values of biomass per seine haul (BPUE) varied over 3 orders of magnitude among sites ranging from 0.002 kg/seine to 3.020 kg/seine (**Figure 20**). High variation among pairs of MPA/Ref sites was also evident within the regions (**Figure 20**). For the South coast, four of the five MPAs had higher values of mean biomass of all fish in seines than at their respective reference sites. Specifically, Percos (MPA), Dume Cove (MPA), Sleepy Hollow (MPA), and Scripps (MPA) all had higher mean biomass than their respective Ref sites (**Figure 20A**). Dume Cove (MPA) had the highest mean biomass in the study with an average of 3.020 kg/seine but biomass also exceeded 2 kg at Percos (MPA) and Scripps (MPA) (**Appendix_Fish Table 1**). This pattern of higher biomass in MPAs for the South Coast sites held for targeted fish but not for non-targeted fish (**Figure 20B-C**).

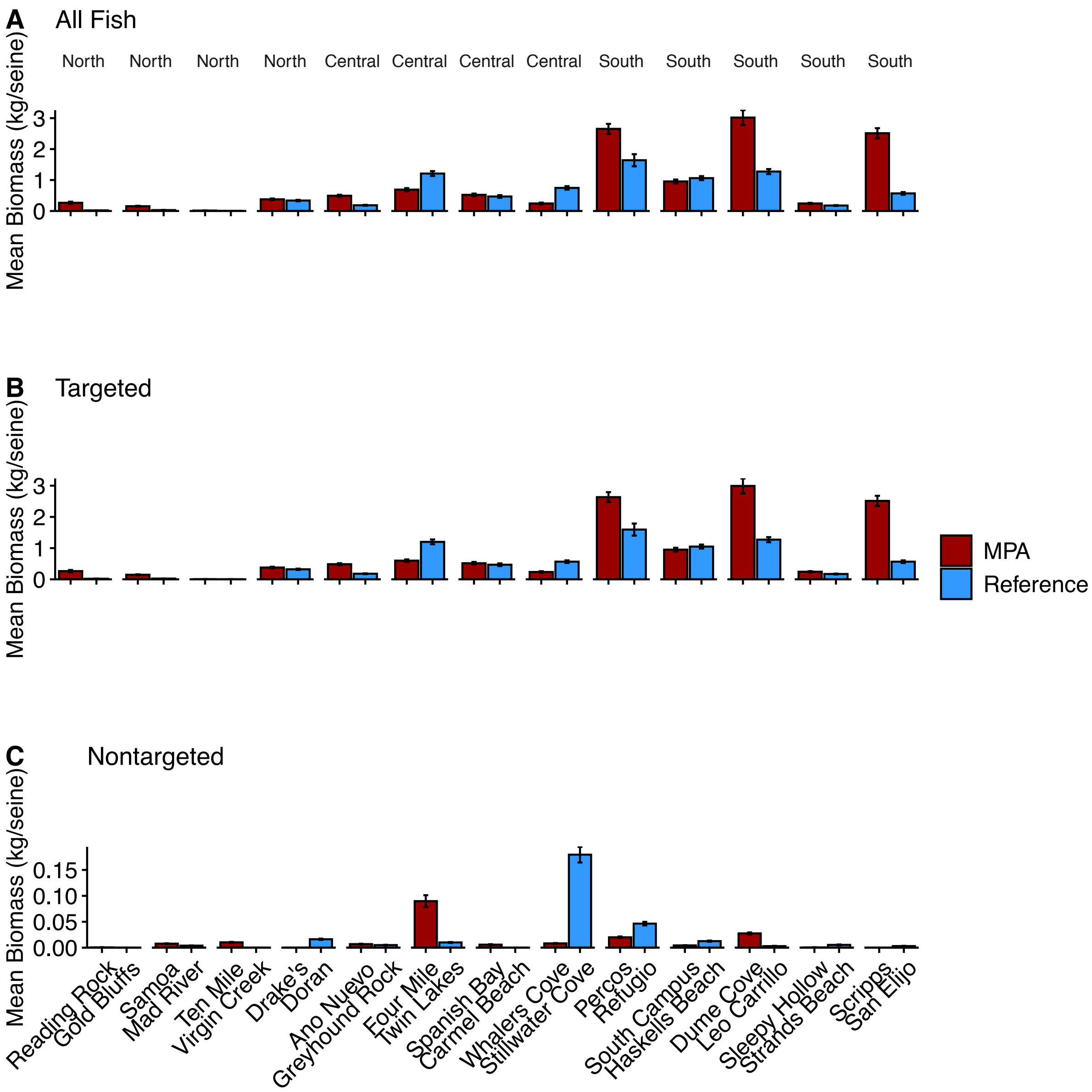

Figure 20 Beach seine results for mean (±1 standard error) of biomass (kg/seine) of A) all fish B) Targeted species only and C) non-targeted species. Bars show average BPUE at each site across all surveys. Note Y axis scales differ for C. Only fish identified to species were used in biomass analyses.

However, it is important to note that non-targeted fish occurred in much lower biomass in the seines at most sites with the exception of Stillwater Cove **(Figure 20C)**. Biomass may vary among sites may be related to site level differences in abundance and composition. For example, large bodied targeted elasmobranchs in the families Rhinobatidae and Triakidae (thornback rays, guitarfish, and leopard sharks) were frequently caught in seines at Percos (MPA) and Dume Cove (MPA) respectively. At the Scripps site (MPA) bat rays in the family Myliobatidae were caught in high abundance. On the North coast, Reading Rock (MPA), some large schools of silver surfperch were caught in seines accounting for most of the seine catch at this site.

Is there a difference between MPAs and reference sites in overall biomass of fished species relative to species that are not fished?

To evaluate possible differences in the biomass of fished and non-fished species found in our study we separated surf zone fish caught in our beach seines into targeted and non-targeted groups and selected species (for more information on see **Appendix_Fish**). It is not possible to use our BRUV results for this comparison.

Beach seines
Targeted fish species represented the greatest amount of biomass caught in the seines (**Figure 20).** The top most abundant species in our seines and the top biomass contributors in our seines generally match with the exception of leopard sharks. Leopard sharks, although low in abundance (258 fish, 14th most abundant) were high in biomass (135.67 kg, total across all catches, 3rd most biomass) due to their large average individual size **(Appendix_Fish Table 3, 4**).

The number of MPAs where mean values of biomass of targeted fish exceeded the reference site varied with region (**Figure 20B**). On the South coast targeted fish biomass was greater in MPAs for four of the five MPA/Ref pairs and nearly equal in the fifth (South Campus/Haskells). On the Central coast, mean values of biomass for targeted fish were greater in the MPAs for 2 of the four pairs (Año Nuevo (MPA) and Spanish Bay (MPA)) **(Figure 20B)**. For the North coast, targeted fish biomass was greater in the MPA for three of the four MPA/Ref site pairs (Samoa (MPA), Reading Rock (MPA), and Drakes (MPA)) **(Figure 20B)**.

Our simple overall comparisons indicated that the BPUE of targeted fish in seines although greater in MPAs, did not vary significantly inside and outside MPAs but di d vary significantly across regions (**2-way ANOVA log(BPUE), MPA $F_{1,142}$= 3.027, p=0.084, Region: $F_{2,142}$= 55.013, p<0.001**) **Figure 21).** Mean values of BPUE for targeted fish were highest for the South region (Tukey's HSD p<0.05 for all comparisons) (**Figure 21B**).

Given the large MPA to MPA variation in BPUE of surf zone fish expected and observed in our surveys (**Figure 20**), we examined the differences in total BPUE of targeted and non-targeted species inside and outside of MPAs as differences using LRR values. Overall LRR for the BPUE of targeted surf zone fish differed significantly from zero (**LRR**: **two-tailed t-test p=0.02**) indicating that BPUE of targeted fish differed inside and outside MPAs and was greater in MPAs than in reference sites (**one-tailed t-test μ>0 p=0.08**). Statewide, six out of 13

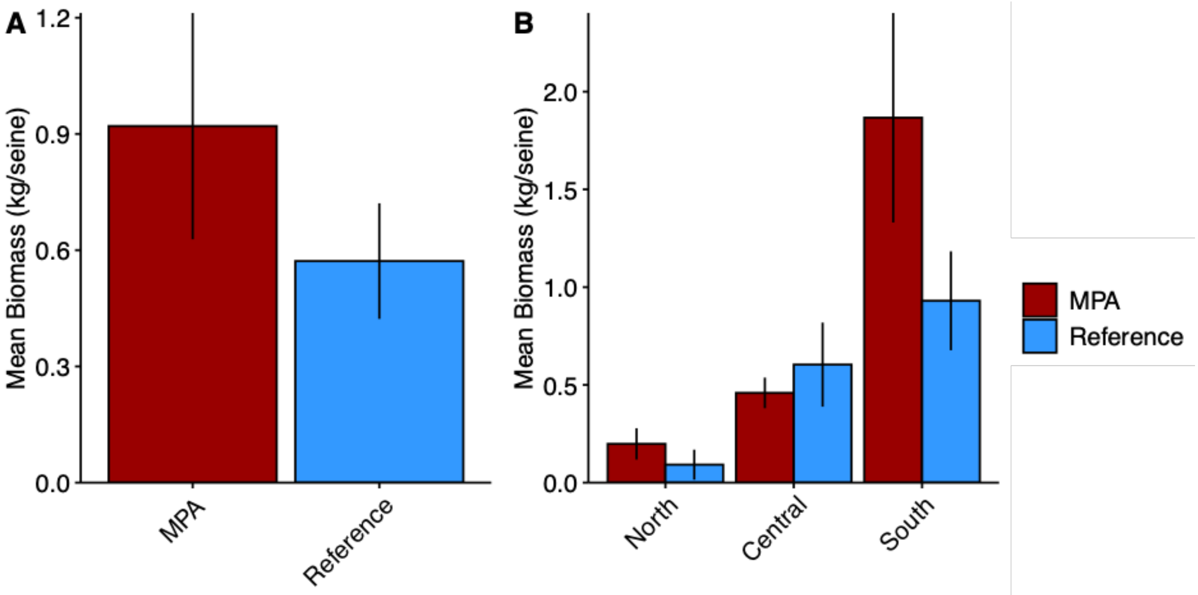

Figure 21 Mean (± 1 std error) BPUE of targeted species at A) the statewide MPA and reference level and B) the regional level differences in MPAs and References. Biomass was the highest inside MPAs in the South coast.

MPA/reference site pairs had overall higher BPUE of targeted fish inside MPAs compared to their reference site suggesting an MPA effect on the BPUE of targeted surf zone fish **(Figure 23)**. The BPUE of targeted fish was lower in MPAs compared to reference sites at only two of the 13 pairs and the BPUE of targeted fish was similar inside and outside of MPAs (LRR overlapping with zero) at the five remaining pairs of sites (**Figure 23**).

For non-targeted fish, variation in BPUE was present among sites but no MPA pattern was evident (**Figure 22A)**. In the central region, mean BPUE of non-targeted fish was greater at reference sites but site to site variability was high (**Figure 22B**). Mean values of LRR for these fish did not differ significantly from zero (LRR: two-tailed t-test p=0.68) suggesting that on average the BPUE of non-targeted fish was similar inside and outside MPAs. On a site level, far fewer MPA/reference site pairs showed positive LRRs, three, indicating higher non-targeted fish BPUE inside MPAs while negative LRRs were found in three pairs indicating (**Figure 23)**. The remaining seven MPA/reference site pairs either had no difference between their non-targeted fish BPUE inside and outside MPAs while four had no non-targeted fish caught at one or both sites in that pair.

Non-targeted fish had the highest mean values of BPUE in some of the South and Central coast MPAs including Four Mile (MPA), Dume Cove (MPA) and Percos (MPA) (**Figure 20C**). In the Central coast, Stillwater Cove (Ref) had much greater BPUE of non-targeted fishes (179.36 g/seine) compared its MPA counterpart, Whalers Cove (8.29g/seine) (**Figure 20C**) (**Appendix_Fish Table 1**).

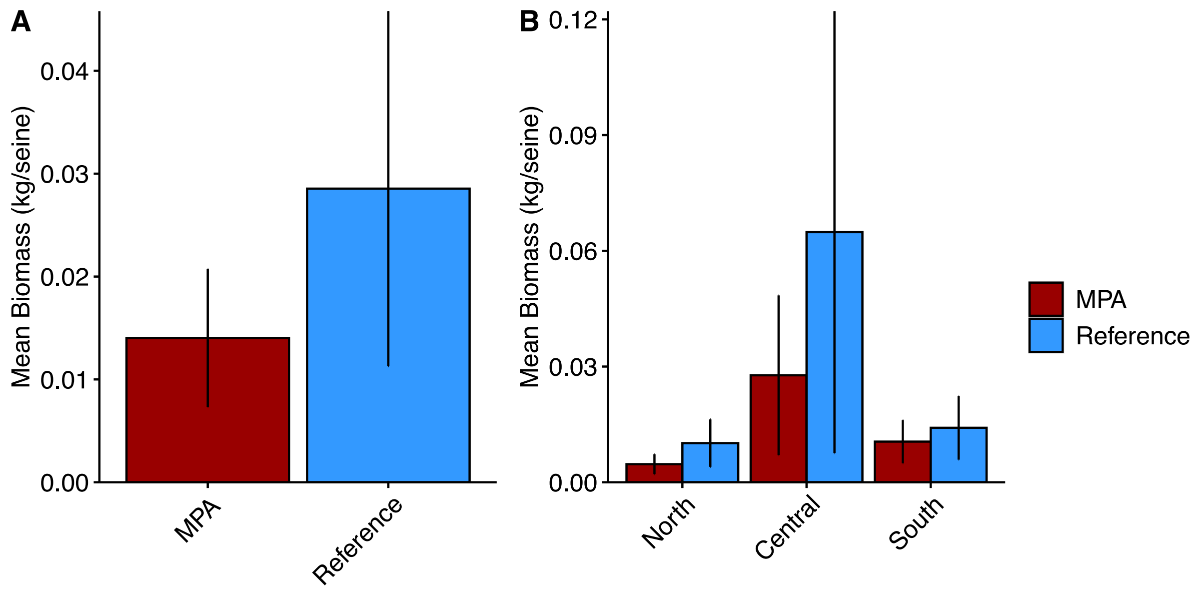

Figure 22 Mean values (±1 std error) BPUE of non-targeted species in MPAs and reference sites at A) statewide scale and B) regional scales

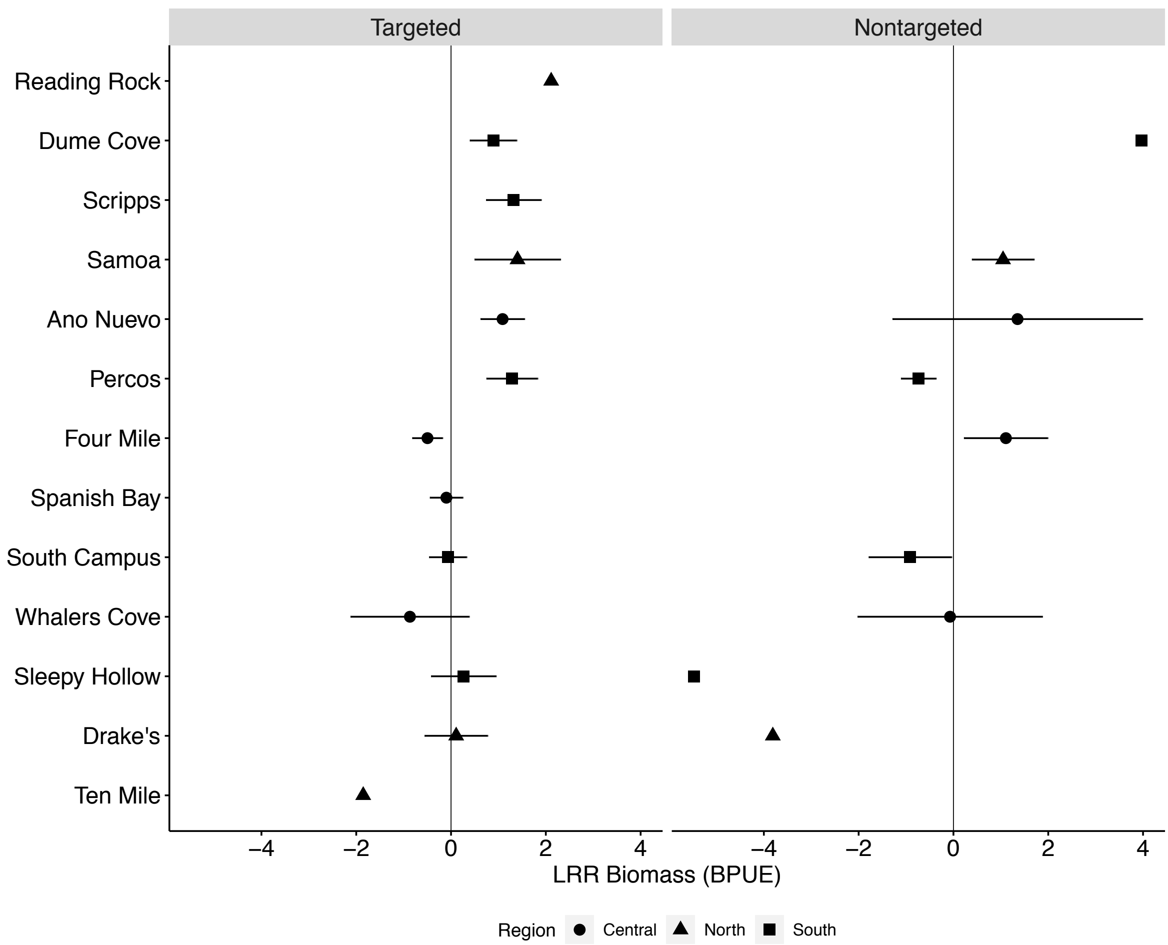

Figure 23 Beach seine results for mean values (± 1 std error) of LRR for BPUE of targeted and non-targeted fishes by site pair. Biomass(kg) was only examined in fish identified to species. Four pairs did not record non-targeted fish at one or both sites and are not shown here. Values of LRR means and standard errors are based on each sampling event.

We also examined this question on a species level to see if the biomass of selected targeted species responded to MPA management. For five of the eight species of fish that had the highest biomass in the seines, the standard errors of their LRRs overlapped with zero indicating no difference in BPUE between MPAs and reference sites. For three targeted fish species, topsmelt, barred surfperch, and leopard sharks, positive LRRs indicated greater BPUE in MPAs compared to reference sites (**Figure 24**).

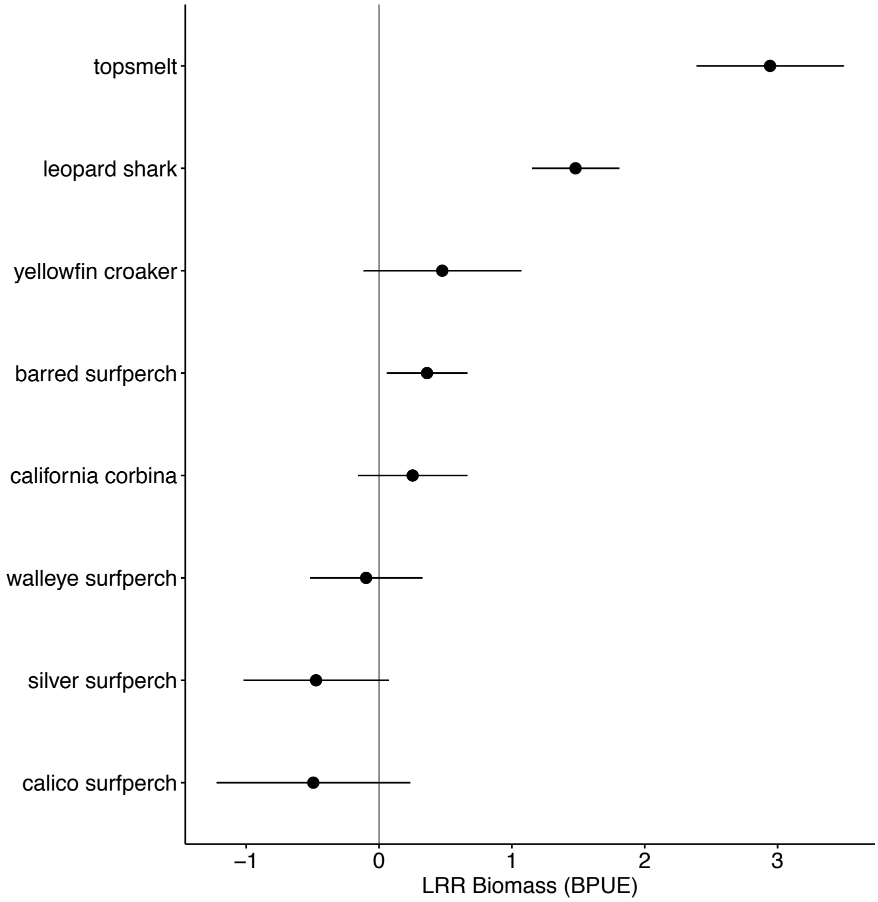

Figure 24 Mean values of LRR (± 1 std error) for BPUE of the eight species of fish with the highest total biomass caught in beach seines. All are targeted by recreational fishing. Values of LRR means and standard errors are based on each sampling event.

Is there a difference between MPAs and reference sites in the size of individuals of a focal and/or protected species?

Beach Seines

Abundance of Large Fish

To broadly address questions about differences between MPAs and reference sites in regard to body size of fishes, we examined the abundance of fish above the 90th percentile biomass for each individual species using our beach seine results (**Figure 25**). Average CPUE of fish above the 90th percentile size did not vary inside and outside MPAs (Kruskal-Wallis, chi^2=2.45, p=0.118) but did vary significantly with region (**Kruskal-Wallis, chi^2=13.36, p=0.001**) with the overall mean abundance of large fish in both MPA and reference sites increasing from North to South (**Figure 25B**). Similar to other metrics, we used LRR comparisons to address the high MPA to MPA variability in the CPUE of big fish. The LRR of CPUE of big fish did not differ significantly from zero (LRR t-test t=1.16, p=0.25) suggesting that the abundance of large fish did not vary between MPA and reference sites. Of our 13 pairs of MPA and reference sites only two pairs showed a clear positive LRR and two showed a clear negative LRR (**Figure 26**).

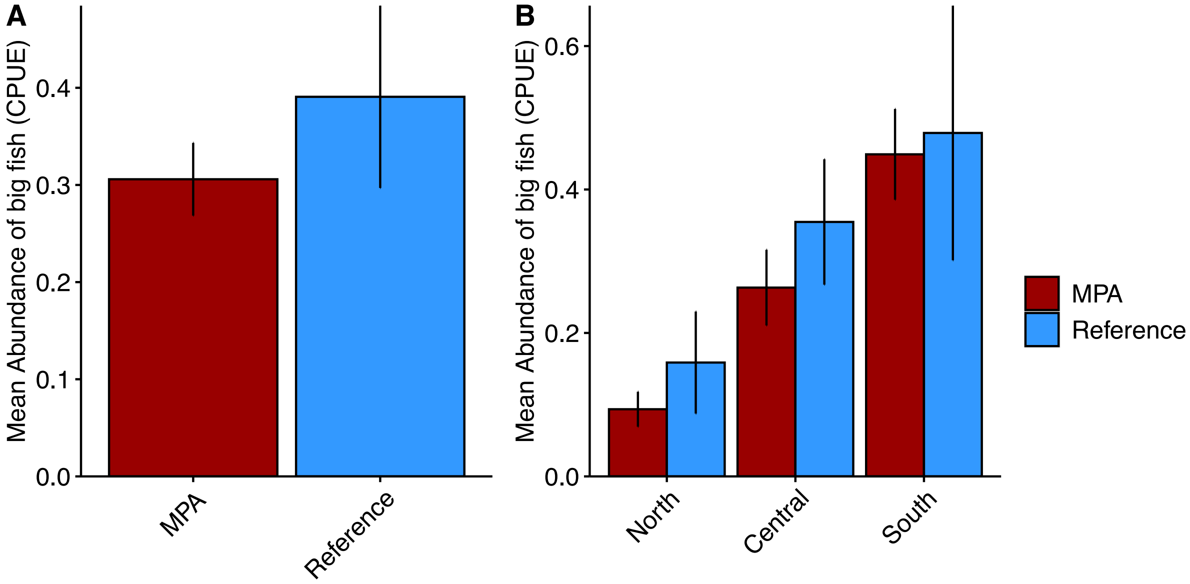

Figure 25 Beach seine results for mean (± 1 std error) of CPUE of big fish inside and outside of MPAs. Shows average catch of fish above that species 90th percentile in biomass.

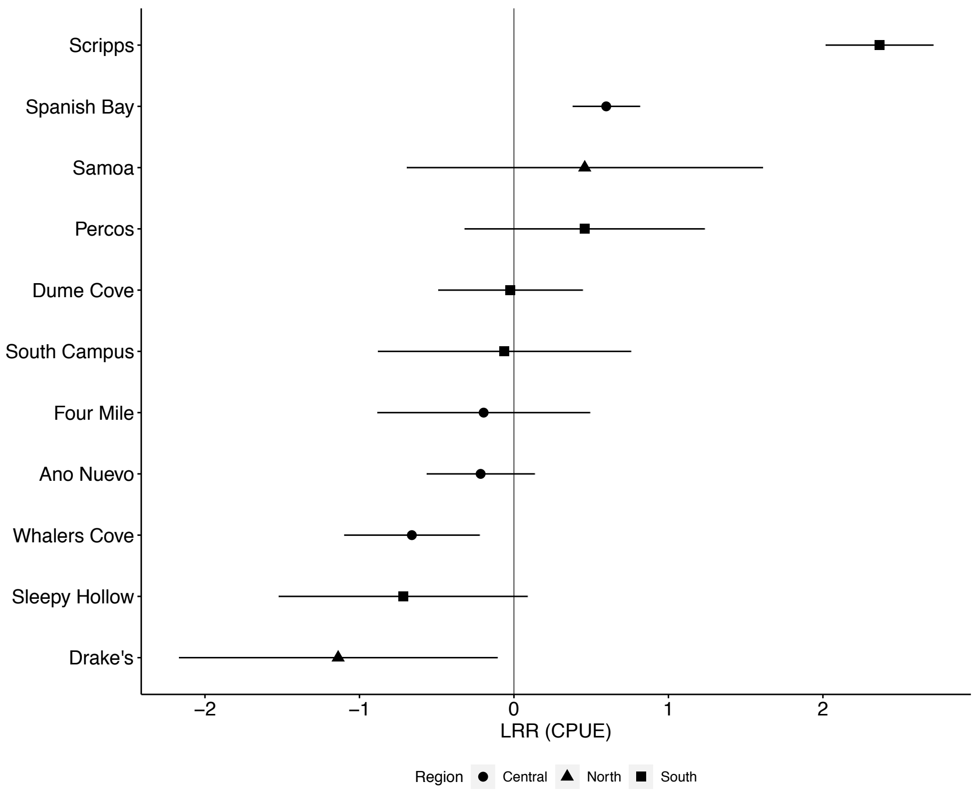

Figure 26 Beach seine results for mean (± 1 std error) of LRR of CPUE of big fish by MPA site pair, listed by LRR direction and amount. Shows average log difference between catch of fish above that species 90th percentile in biomass inside and outside MPAs. Symbol type indicates region. If large fish were not caught in either the MPA or reference of a pair that pair is not pictured here. Values of LRR means and standard errors are based on each sampling event.

Abundance of Large Targeted Fish

We observed more large targeted fish than non-targeted fish in all of our surveys (**Figure 27**). This may in part be due to fewer non-targeted fish being caught in seines overall and/or different life histories and habitat preferences. In overall comparisons, we did not observe a significant effect of MPAs on CPUE of large targeted fish (Kruskal-Wallis, chi^2=3.66, p=0.06) nor of large non-targeted fish (Kruskal-Wallis, chi^2=1.35, p=0.24) but MPA to MPA variation was large (**Figure 19**).

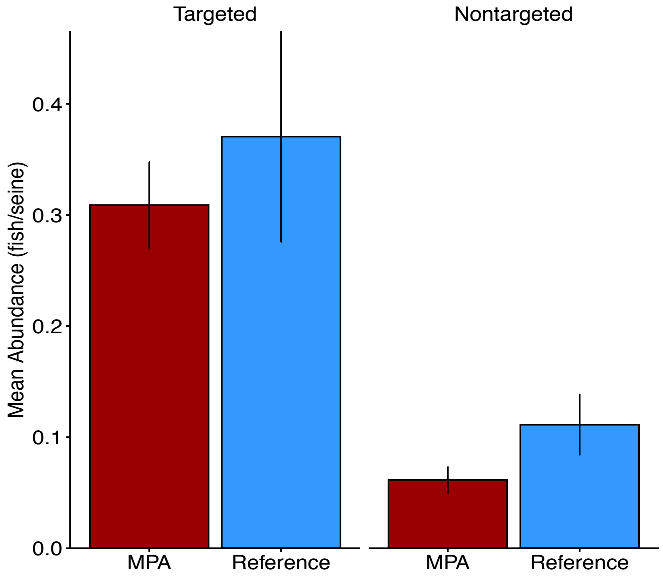

Figure 27 Beach seine results for mean (± 1 std error) CPUE inside and outside of MPAs of big fish (90th percentile size) separated by fishing pressure. Bars are mean values of sums of average catch of fish above the 90th percentile in biomass for all species caught. There were fewer non-targeted fish in general, especially big individuals, these fish represent only 31 out of 149 observations used in this figure.

Is the size/age structure of recreationally valued species greater in MPAs?

To address this question, we evaluated the size structure of several species of abundant and regionally important of recreationally fished surf zone species in our MPAs and reference sites using our beach seine results. The species selected for these analyses included two surfperch, barred and silver surfperch, that inhabit the South and Central regions and the Central and North regions, respectively and one croaker, the California corbina which inhabits the South region.

Barred surfperch

Barred surfperch, *Amphistichus argenteus,* a popular species for shore fishing, were the most abundant, widespread, and most frequently observed species in beach seines in our study and were caught at ten MPA/Ref pairs in 2019 and 2020 (19 sites, **Appendix_Fish Figure 8**). We caught 4134 individuals, comprising 27.9% of all fish caught in surf zone seine sampling across the three regions (14,765 individuals). Overall more barred surfperch were caught in MPAs than in reference sites (2294 fish inside MPAs and 1840 fish in reference sites) in seines, but mean CPUE varied strongly among sites (**Appendix_Fish Figure 8**).

Tagging studies indicate that this fish which inhabits shallow surf zones moves very little (usually less than 2 miles) and they bear live young (Carlisle 1960) traits that make them good indicators for the effects of MPA management. Their northern range limit is Bodega Bay and our study did not detect this species north of our study site at Doran Beach (Ref) located just inside Bodega Head (**Appendix_Fish Figure 8**).

To evaluate possible MPA patterns in the size structure of barred surfperch populations, we first compared the total lengths (TL) of fish caught in beach seines for MPAs and reference sites **(Figure 28)**. We caught more than twice as many juvenile barred surfperch (2856) than adult fish (1240) overall. A higher proportion of juvenile and of large (TL > 300mm) individuals of barred surfperch were caught at

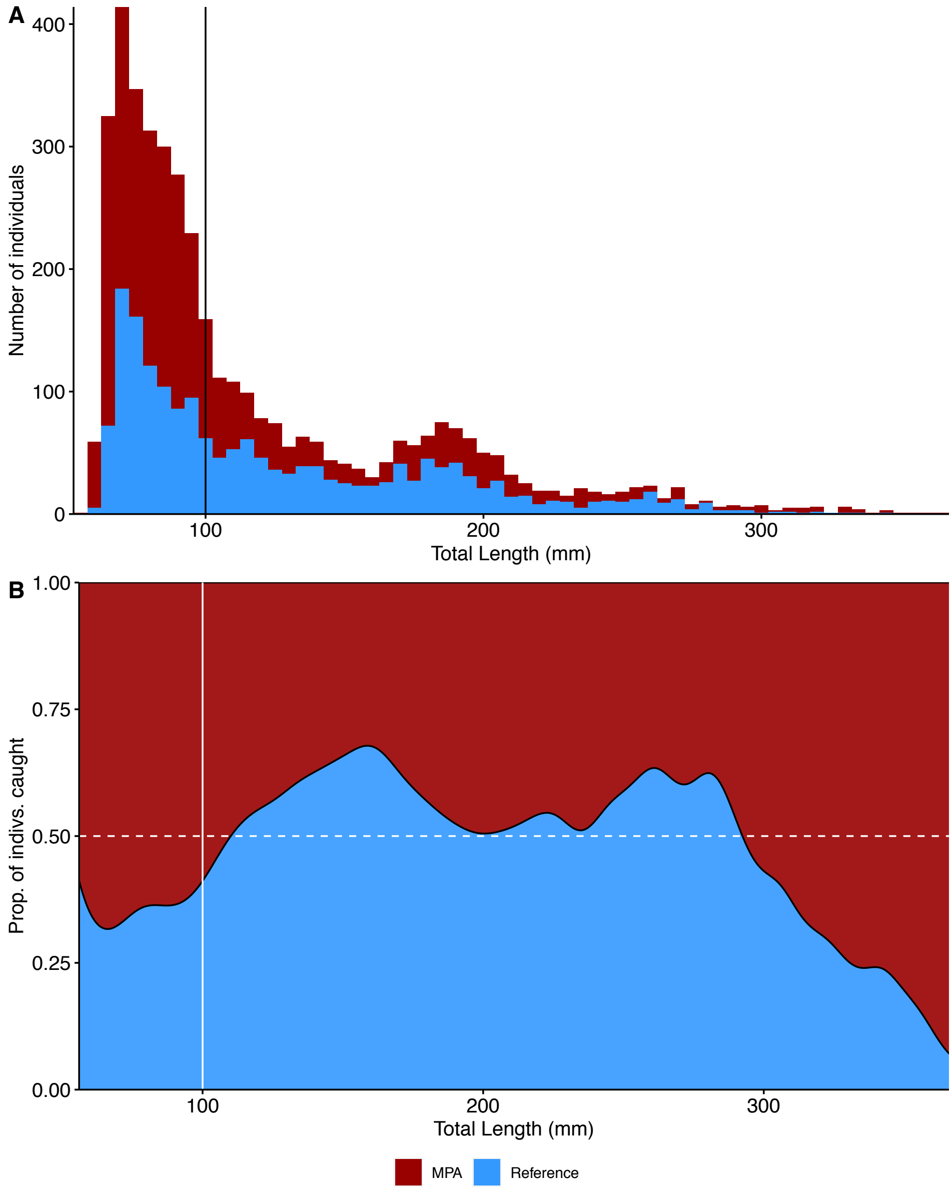

Figure 28 Size structure summary for Barred surfperch, *A. argenteus*, as TL for beach seines A) Stacked histogram of TL (mm) of all individuals recorded, Colors reflect if they were caught at MPA or reference sites. B) Proportion of individuals caught in MPA and reference sites by total length (mm) (n = 2294 inside MPA vs n= 1840 in Ref). Horizontal dashed line is along the 50:50 ratio. The vertical solid line is the size cut off for juvenile *A. argenteus* (TL < 100mm). N=4096 fish, 2856 juveniles and 1240 adults.

MPA sites compared to reference sites, whereas a higher proportion of mid-sized individuals (TL 100 – 200mm) were caught at reference sites. More large fish (>250mm TL) were caught at MPA sites compared to reference sites however there were fewer of this size class caught in general (**Figure 28**).

Looking at more closely at adult fish size (TL >100 mm), mature barred surfperch were generally larger in size in MPAs in beach seines (**Figure 29**). Values for the 90th percentile size of individual adult biomass were higher in the MPA site for seven of the ten MPA/reference pairs where this species was caught (**Figure 29** points **Appendix**). The median individual biomass of adult barred surfperch (total length >100mm) varied less among sites (**Figure 29**) and no general pattern with respect to MPAs was apparent. When averaged by MPA or Reference, mean 90th percentile individual biomass of adult fish was more than 40% higher in MPAs but those differences were not significant (**Figure 29**). Average individual biomass of adults (TL>100mm) was also larger inside MPAs (108.4g) than reference sites (97.6g) for of all fish while overall average individual size was smaller in MPAs (42.1g) than reference sites (55.5 g), reflecting the larger numbers of juvenile fish in MPAs.

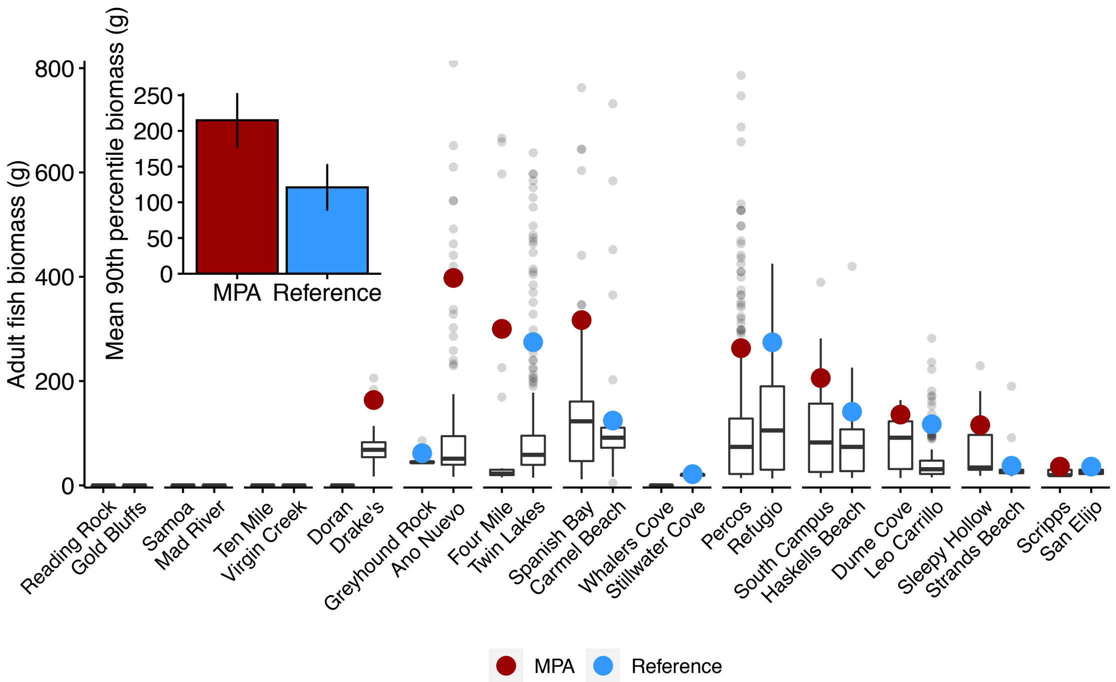

Figure 29 Individual biomass (g) for adult Barred surfperch, *A. argenteus* in beach seines. Sites are ordered from North to South and shown in MPA and reference pairs. Colored points are the 90th percentile biomass size of adult (TL >100mm) barred surfperch at a site. Inset shows average (± 1 standard error) adult 90th percentile biomass size inside and outside MPAs. Box and whiskers, the horizontal line in each box represents the median size, the lower and upper hinges correspond to the first and third quartiles (the 25th and 75th percentiles), the upper whisker extends from the hinge to the largest value no further than 1.5 * IQR from the hinge (where IQR is the inter-quartile range, or distance between the first and third quartiles); the lower whisker extends from the hinge to the smallest value at most 1.5 * IQR of the hinge.

Silver Surfperch

Silver surfperch (*Hyperprosopon ellipticum*) are one of the main sportfishing species for beach anglers as well as pier fishermen in central and northern California. This surfperch was the 6th most widespread species in our study occurring at 14 out of 26 sites but was rarely caught in the South (**Appendix**), except for Percos (MPA) located just south of Point Conception, despite being reported to range from Baja California to British Columbia. This species was the 7th most abundant fish in seines with 1057 individuals caught, making up 7.2% of the fish in 117 seines (6th most caught). Overall, more silver surfperch were caught in MPAs (746 fish total) than reference sites (311 fish total) but mean CPUE varied among sites (**Appendix_Fish Table 3**). This fish reaches 270 mm (TL) but all fish we caught were 235 mm TL or less (**Figure 30**). The 90th percentile biomass of all fish we caught in this species was 67.3 g with ~7% of fish reaching this weight.

We evaluated possible patterns in the size structure of silver surfperch populations by comparing total lengths (TL) of fish caught in seines and measured in the field for MPA and reference sites (**Figure 30A)**. The majority of fish caught and measured

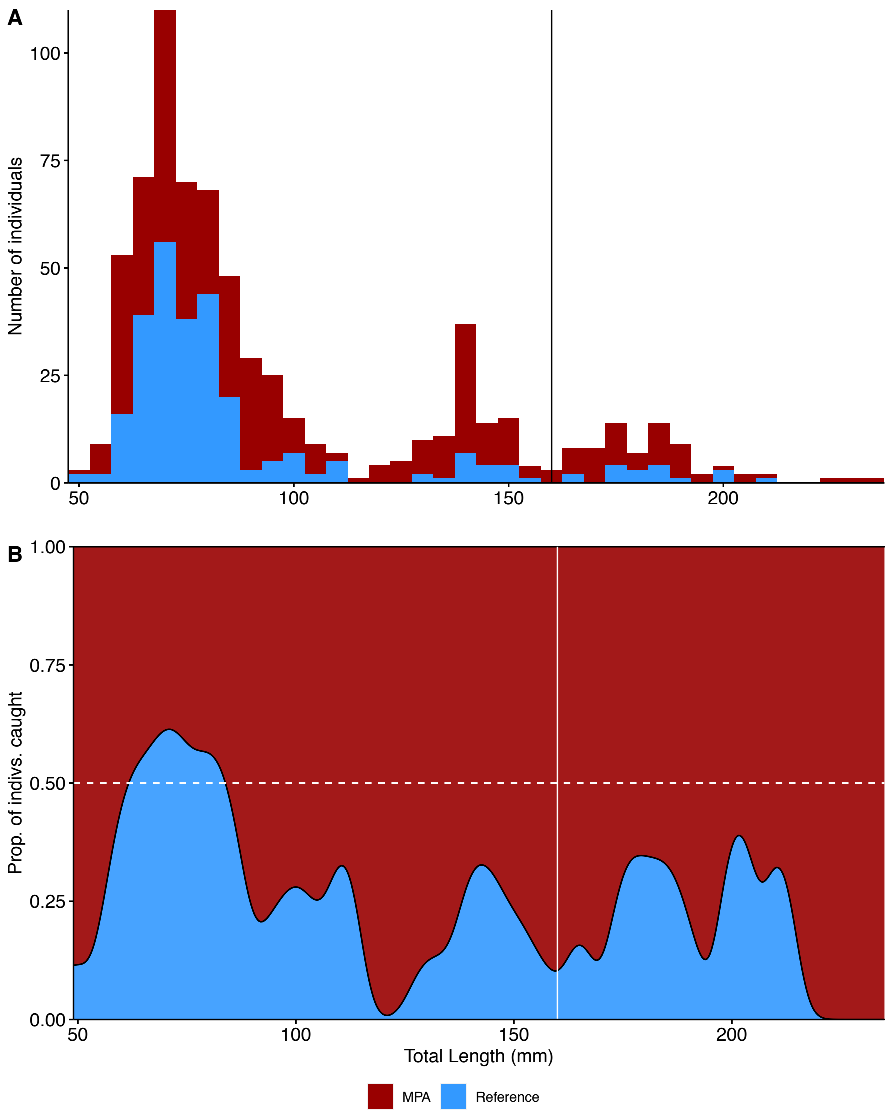

Figure 30 Size structure summary (TL in mm) for Silver surfperch, *Hyperprosopon ellipticum*, in beach seines. A) Stacked histogram of TL(mm) of all individuals recorded, colors indicate MPA or reference sites (n=693). (B) Proportion of individuals caught in MPA (red) and reference (blue) sites by total length (mm) (n=693). Horizontal dashed line denotes the 50:50 ratio, vertical solid line represents size bound for juvenile and adult *H. ellipticum* (TL < 160mm, 50% maturity Love 2011). 363 fish not measured in the field are not included

in seines were juveniles (619 compared to 74 adults) (**Figure 30**). Overall a higher proportion of juveniles (>90 mm TL) and of adult individuals (> 160 mm TL) were caught at MPA sites compared to reference sites. Large mature fish (>220mm TL) were also caught more frequently at MPA sites compared to reference sites, however there were fewer of this size class caught in general (**Figure 30)**.

Adult fish (TL >160 mm) were only caught at seven study sites, all on the North coast (**Figure 31**). There was no overall pattern of median individual biomass of adult fish with respect to MPAs and variation in median individual biomass among sites was low. However, largest values for 90th percentile adult biomass were observed in MPAs (Samoa and Reading Rock) (**Figure 31**). In general the 90th percentile adult biomass was greater inside MPAs, averaging ~140 g while in reference sites the average was ~90g suggesting that the larger adults were observed in MPAs.

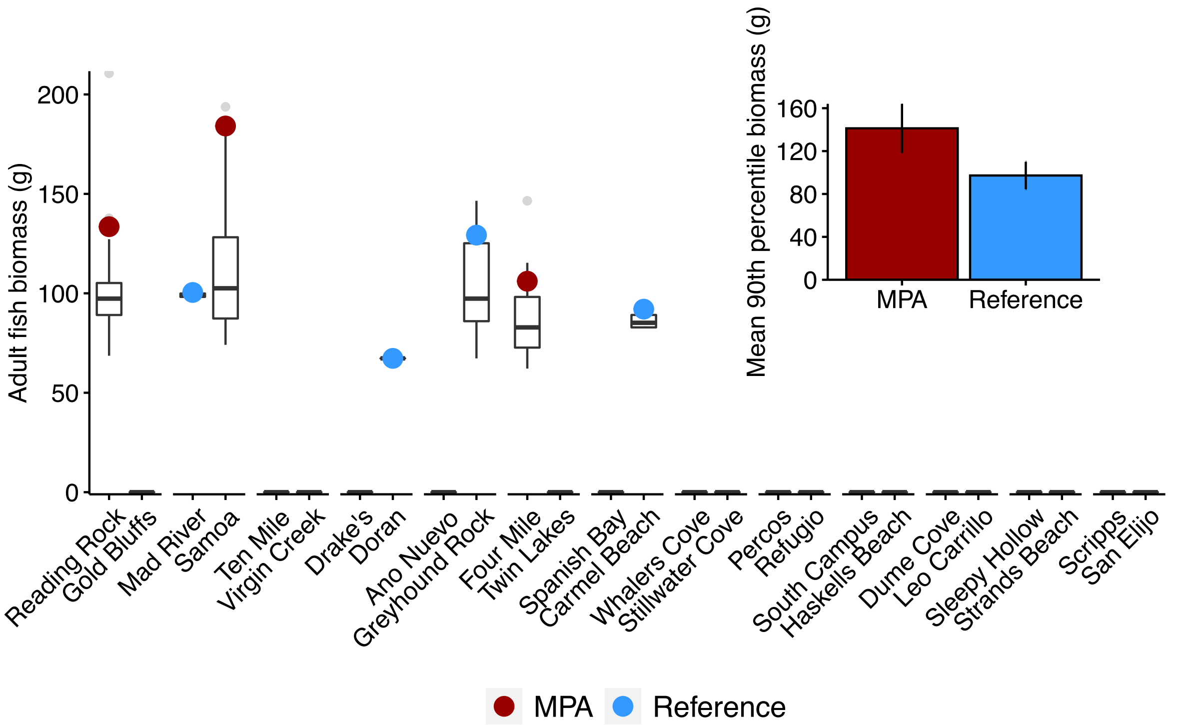

Figure 31 Individual biomass (g) of adult Silver surfperch, *Hyperprosopon ellipticum*, caught in beach seines and measured in the field. Adults are fish > 160mm TL. Sites are ordered from North to South and shown in MPA and reference pairs. Colored points are 90th percentile biomass size for adult (TL >100mm) silver surfperch at each site. Inset shows average (± 1 standard error) adult 90th percentile biomass size inside and outside MPAs. Box and whiskers, as in Figure 29.

California Corbina

California corbina, *Menticirrhus undulatus*, is an important recreationally fished species of surf zone fish in the South coast region. Corbina were a regionally abundant and widespread species and were caught at all ten MPA/Ref pairs on the South coast. We caught a total of 1095 individuals, making up 7.4% of the total catch in seines but site to site variation in CPUE was high (**Appendix_Fish Figure 9**). Overall, we caught far more small juveniles (922 fish) than large adults (170 fish). More than twice as many corbina (of all sizes) were caught in MPAs (754 fish inside) compared to reference sites (341 fish outside) (**Appendix_Fish).**

To evaluate possible patterns in the size structure of corbina populations we compared the total lengths (TL) of fish caught in beach seines and measured in the field for MPAs and reference sites **(Figure 32)**. There was a higher proportion of

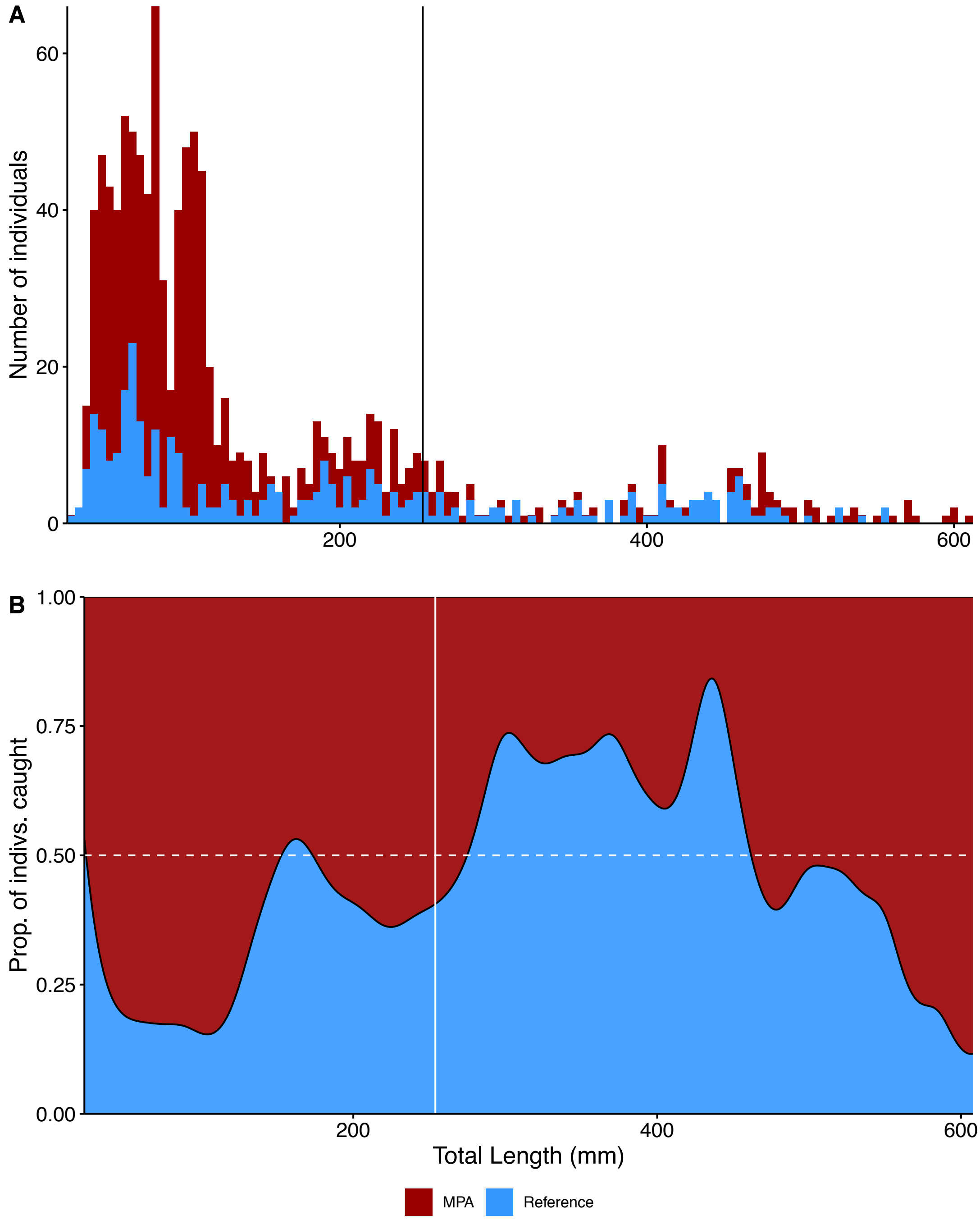

Figure 32 Size structure summary (TL in mm) of California corbina, *Menticirrhus undulatus*, caught in seines. A) Stacked histogram of TL (mm) of all individuals recorded colors indicate MPA or reference sites (n=1093). (B) Proportion of individuals of M. undulatus caught in MPA and reference sites by total length (mm) (n = 1093). Horizontal dashed line is along the 50:50 ratio, vertical solid line represents the size bound for juvenile and adult fish (TL < 254mm, 50% maturity for male fish Love 2011). We caught 170 adults and 923 juvenile corbinas, 2 were not measured in the field.

juveniles and of large (TL > 460mm) individuals caught at MPA sites compared to reference sites, whereas a higher proportion of mid-sized individuals (TL 260 – 460mm) were caught at reference sites (**Figure 32**). Larger fish (>525mm TL) were caught more often at MPA sites compared to reference sites, however there were fewer of this size class caught in general.

The adult biomass of California corbina caught in seines varied across our sites. In all surveys combined, adults inside MPAs were smaller with an average biomass of 107g while in reference sites average biomass was 208 g. Values of individual adult biomass varied by site with no clear pattern across the MPA/Ref site pairs. The smallest median adult biomass occurred at Scripps (MPA) and the highest adult median biomass at Percos (MPA). The 90th percentile biomass of adults also varied by site with Scripps (MPA) having the largest fish and Sleepy Hollow having the smallest fish. We found no MPA effect on big (90th percentile biomass), adult fish with MPA and reference sites having a similar overall mean values (~900-1100g (**Figure 33** inset) suggesting that little or no MPA effect on this largest size class.

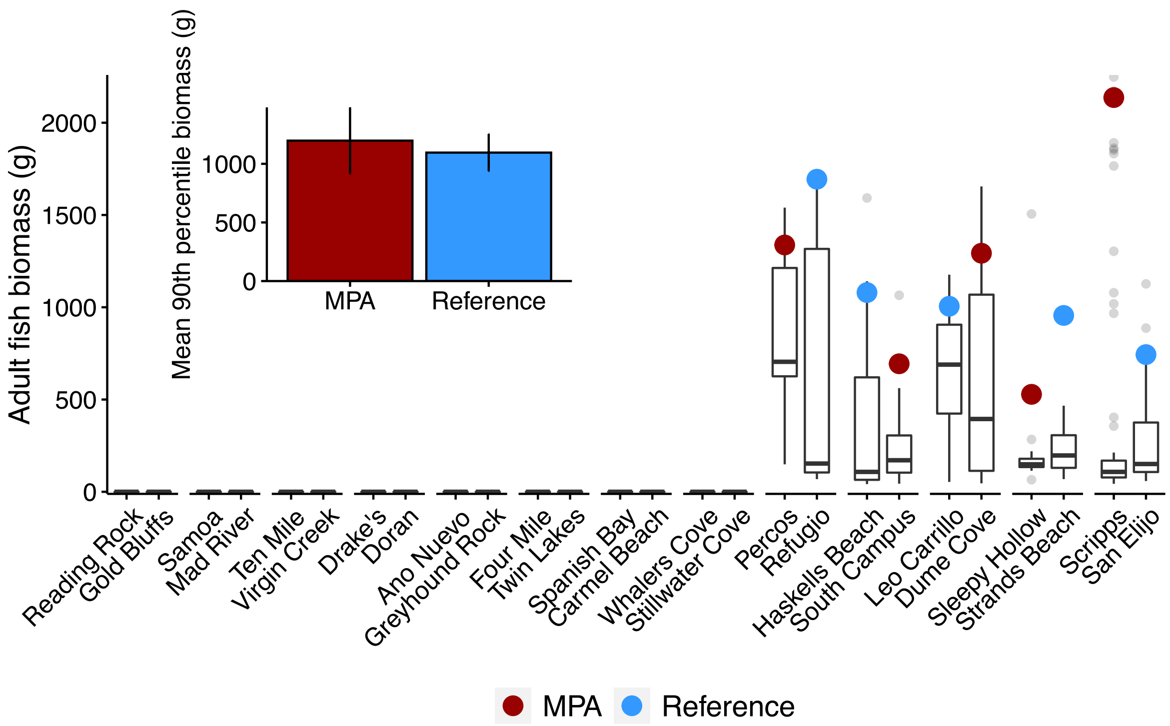

Figure 33 Individual biomass (g) of adult fish for California corbina, Menticirrhus undulatus, 34 caught in beach seines. Sites are ordered from North to South and shown in MPA and reference pairs. Colored points are the 90th percentile biomass for adult (TL >100mm) corbina for each MPA and reference site. Inset shows the average (± 1 standard error) adult 90th percentile biomass inside and outside MPAs. Box and whiskers, as in Figure 29.

Is there a difference between MPAs and reference sites in community structure and/or species diversity within any given functional group or assemblage?

We evaluated the question of whether the species richness of surf zone fish inside MPAs differs relative to reference sites using two methods, beach seines and surf BRUVS (Baited Remote Underwater Video), in each survey. **These two methods yielded strongly contrasting results for the species richness of surf zone fish in MPAs and reference sites**. Community structure of surf zone fish communities was evaluated using our seine data only, due to visibility issues in some BRUV videos limiting the identification of species.

Species richness

Beach seines

We recorded 53 unique species and a further seven genera or higher designations of fish in the beach seines which were not identified to species in the field. For species richness in seines the results of overall tests and difference for MPA/Ref pairs tests using LRR were in agreement that we did not observe a difference in species richness. For the beach seine results, overall mean values of species richness did not vary significantly between MPA and reference beaches (Kruskal Wallis chi^2=1.48 p=0.22) (**Figure 35**). However, mean species richness varied significantly with region (**Kruskal Wallis chi^2=37.38 p<0.001).** Mean values of species richness were two times greater in the Central and South regions compared to the North region.

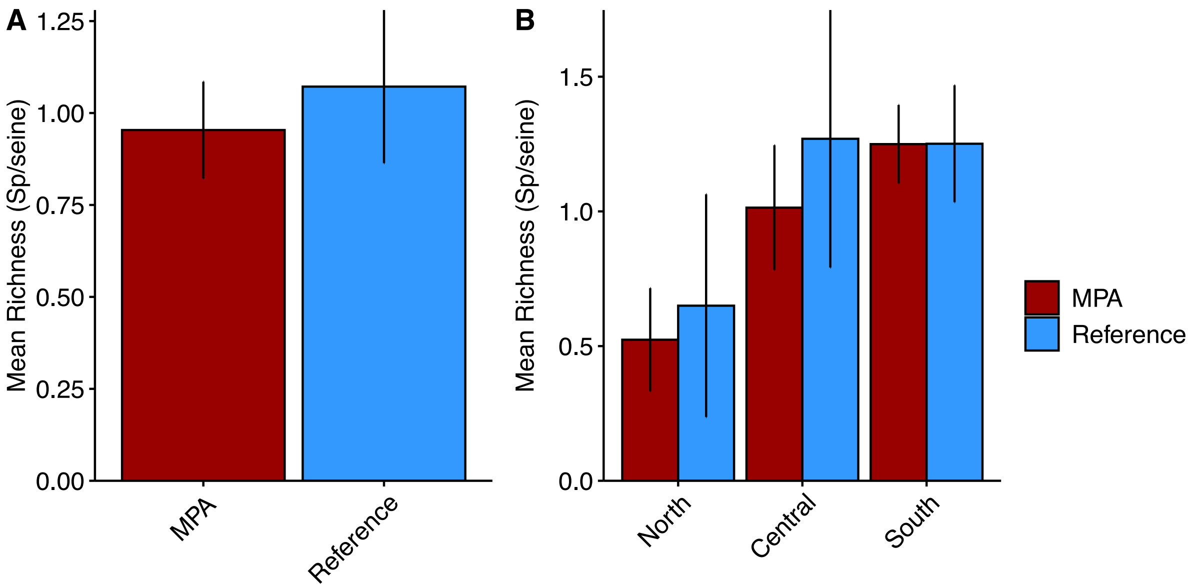

Figure 35 Beach seine results for mean values (± 1 std error) of species richness of surf zone fish by region. Mean richness is estimated as the number of species per seine, at a site.

To address the inherently high variation between MPAs we examined possible trends in species richness of fish caught in beach seines inside and outside MPAs as LRRs for each pair of MPA/Ref sites. LRR for species richness in beach seines did not differ significantly from zero (two-tailed t-test p=0.15) indicating that species richness of surf zone fish in seines is similar inside and outside MPAs. Six MPA/Ref site pairs had positive LRRs while two had negative LRRs. The remaining five pairs showed no effect of MPAs **(Figure 36)**. Similar to other metrics we found variability in MPA effects for richness suggesting that some MPAs perform well and act as a hotspots for surf zone fish diversity.

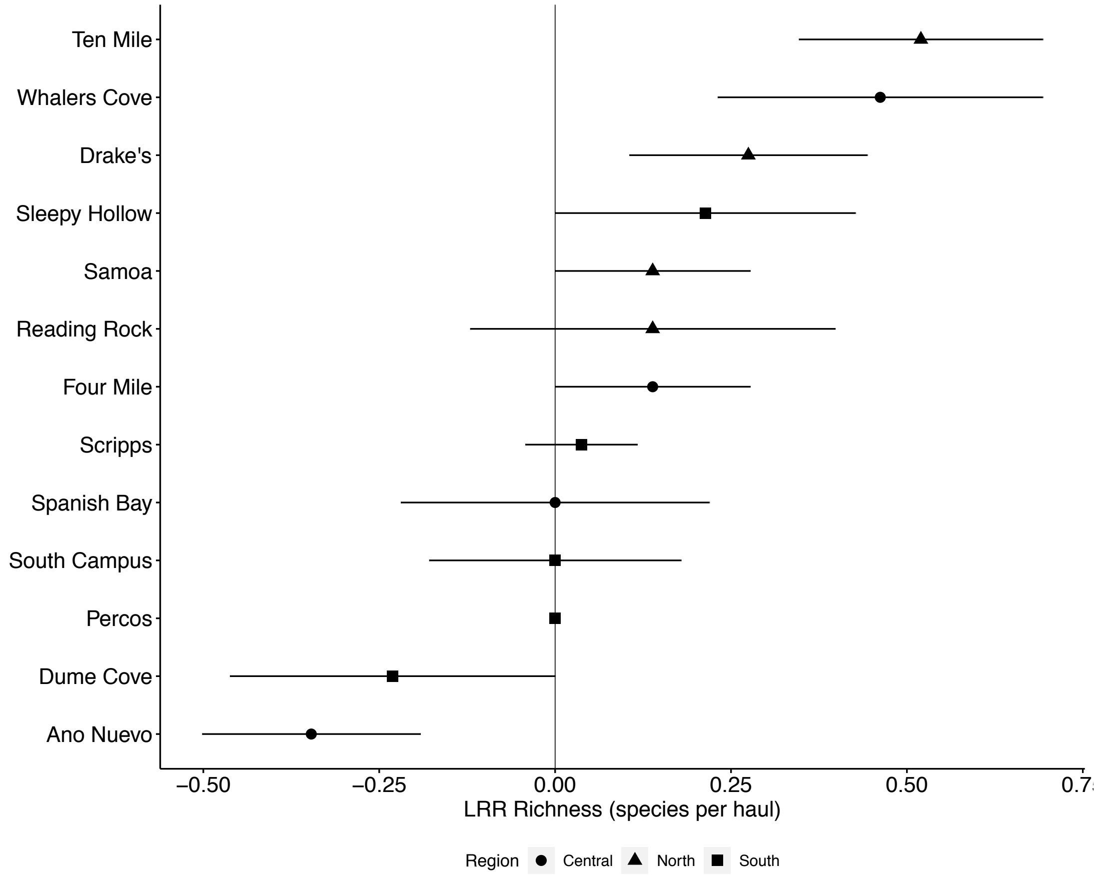

Figure 36 Beach seine mean (± 1 std error) LRR of species richness of surf zone fish per unit effort. Species richness was measured as the number of identified taxa in the seines at a given sampling event. Six MPAs showed positive LRR showing higher richness inside those MPAs while two showed negative where richness was higher outside the MPA. Values of LRR means and standard errors are based on each sampling event.

Mean values of species richness for all surf zone fish ranged from 0.07 at Virgin Creek (Ref) to 0.83 species per haul at Stillwater Cove (Ref) (**Appendix_Fish Table 1)**. Mean richness of targeted fish species was highest in Stillwater Cove (Ref) in the Central coast with 0.47 species per seine and lowest at Virgin Creek (Ref) and Reading Rock (MPA) in the North coast with 0.03 species per seine (**Appendix_Fish Table 2)**. For non-targeted fish, the highest mean richness in seines was found at the Central coast sites of Stillwater Cove (Ref) and Four Mile (MPA) with 0.31 and 0.19 fish species per seine, respectively (**Figure 37, Appendix_Fish Table 2**). Although MPA to MPA variation was large, in general, MPAs and their paired reference sites had similar mean species richness in beach seines suggesting our MPA/Ref site pairs are well matched and this variation is due to background factors such as species ranges and physical environmental factors (**Figure 37**).

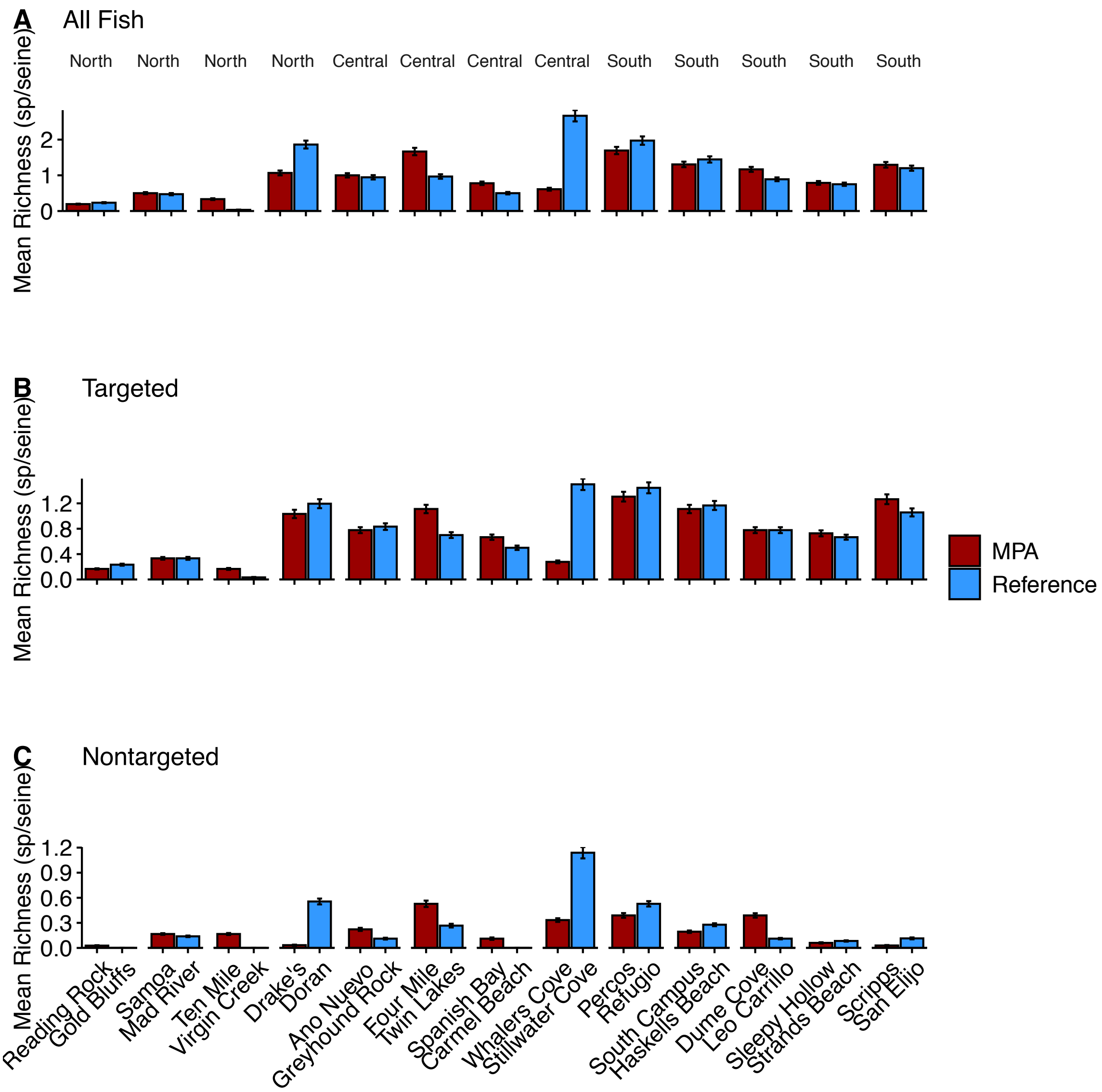

Figure 37 Beach seine results for mean values (± 1 std error) of species richness of fish per haul. Stillwater Cove (Ref) showed the highest mean richness across all sites for all fish. When divided into targeted and non-targeted, richness per haul was lower on average but variability was wide as some hauls were diverse while others caught a single species of schooling fish.

For the beach seines in general, species richness of targeted fish was higher than non-targeted fish but this is not surprising as the potential species pool of targeted fish in the surf zone is larger than the non-targeted species (41 targeted species compared to 18 non-targeted) **(Figure 37).** We used LRRs to examine differences in species richness of targeted and non-targeted fish inside and outside MPAs. Targeted species richness LRR did not differ from zero (Wilcoxon-signed rank test, p=0.17) suggesting richness of targeted fish does not differ inside and outside MPAs. For targeted species of fish three MPAs had positive LRRs while two had negative LRRs and LRRs of the remaining eight sites overlapped zero (**Figure 38)**. Nontargeted fish only observed in 9 MPA pairs and the LRR also did not differ from zero (t-test p=0.16). Five MPAs had positive LRRs for non-targeted fish, the remaining four pairs had LRR that overlapped zero suggesting that MPAs were not affecting species richness of non-targeted fish (**Figure 38**).

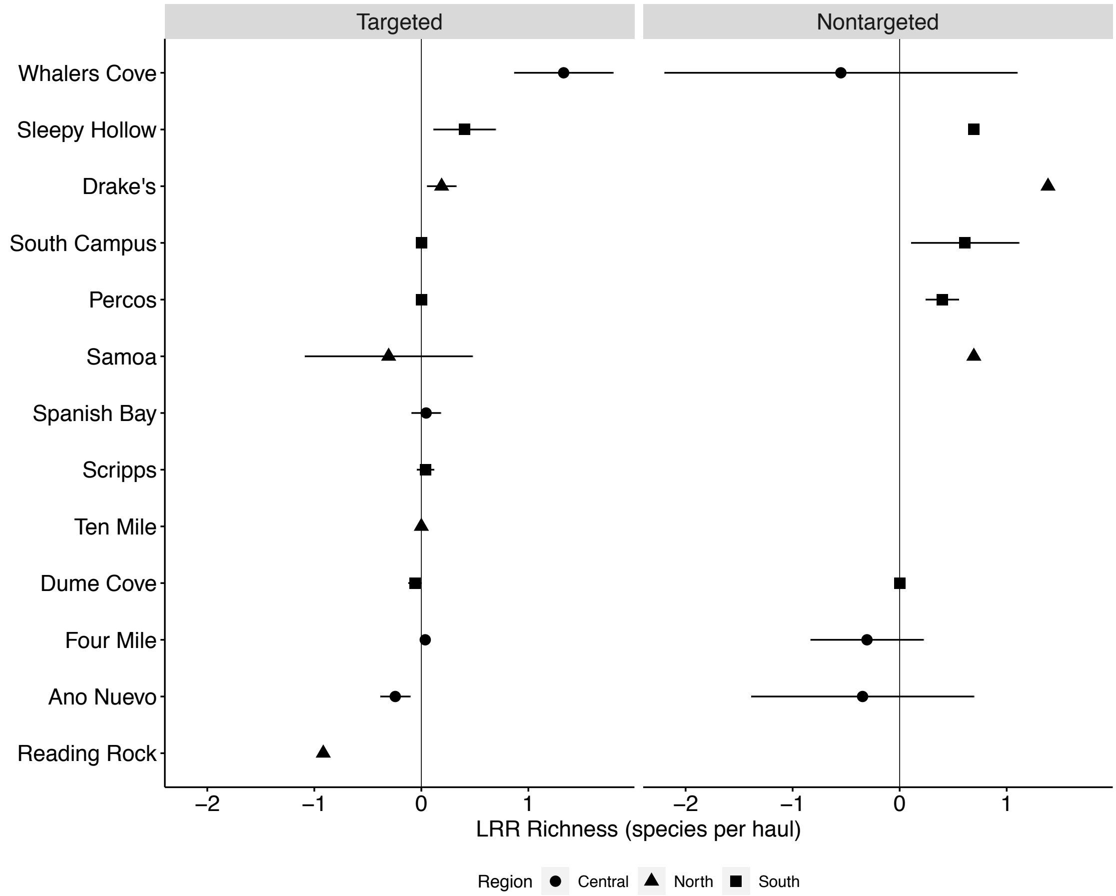

Figure 38 Beach seine results for mean values (± std error) of LRRs for species richness per unit effort of targeted and non-targeted fish. Species richness was measured as the number of identified taxa in the seines at a given sampling event. Values of LRR means and standard errors are based on each sampling event.

BRUV surveys

For our surf BRUV results, overall mean values of species richness of surf zone fish were greater in MPA than reference sites (**Figure 39**). In contrast to beach seine results, our overall analyses of BRUVs revealed significantly higher mean species richness of fish in MPAs compared to reference sites (**two way ANOVA, MPA status, $F_{(1, 696)} = 4.94$, $p=0.026$**) (**Figure 39A**). Species richness in BRUVs also varied significantly by region (**two way ANOVA, $F_{(2, 696)} = 432.89$, $p<0.001$**) and the interaction of MPA and region was significant (**two way ANOVA, $F_{(2, 696)} = 3.507$, $p=0.035$**) (**Figure 39B**). Analysis of BRUV data at the MPA level conducted for each region (given differences in sampling effort and analysis) revealed that there was significantly greater species richness (**$F_{(1, 186)} = 23.11$, $p<0.0001$**) inside MPAs in the South region, again in contrast to the seine results. Species richness comparisons in the Central and North regions yielded non-significant results for MPA and reference sites. This suite of broad results suggests that while overall species richness was higher inside MPAs, this pattern was largely driven by the strong differences and higher values in richness in the South coast MPA and reference sites (**Figure 39B**) highlighting the spatial variability of this fish community and the contrast with our seine results.

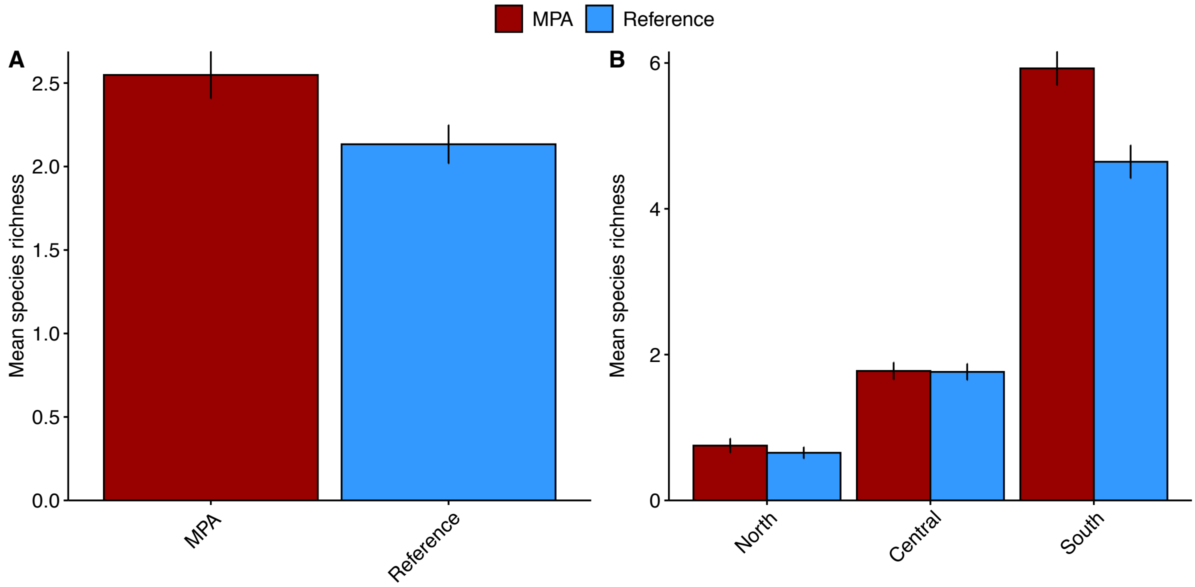

Figure 39 Surf BRUV results for mean (± 1 std error) of species richness A) statewide and B) by region. The South coast had the greatest richness and more species inside MPAs while the other two regions had much lower species and they were similar inside and outside MPAs. Here and for future analyses, species richness represents the number of unique species of fish and elasmobranchs (Actinopterygii, Elasmobranchii) observed on the surf BRUVs.

To address the inherently high variation between MPAs in our evaluation of possible trends in species richness of fish measured by surf BRUVs inside and outside MPAs we examined differences in species richness as LRRs for each pair of MPA/Ref sites. In contrast to the seine results, LRR results for species richness from surf BRUVs differed significantly from zero (two-tailed **Wilcoxon Signed Rank test V=6423.5, p=0.009**) suggesting that surf zone fish species richness differed inside and outside MPAs and was higher in MPAs than in reference sites (**one-tailed Wilcoxon Signed Rank test v=6423.5 p=0.004**). The four MPA/Ref pairs with clearly positive average LRRs were located in the South coast. Two pairs had a negative average LRRs, and the standard errors of the remaining seven pairs overlapped with zero (**Figure 40**).

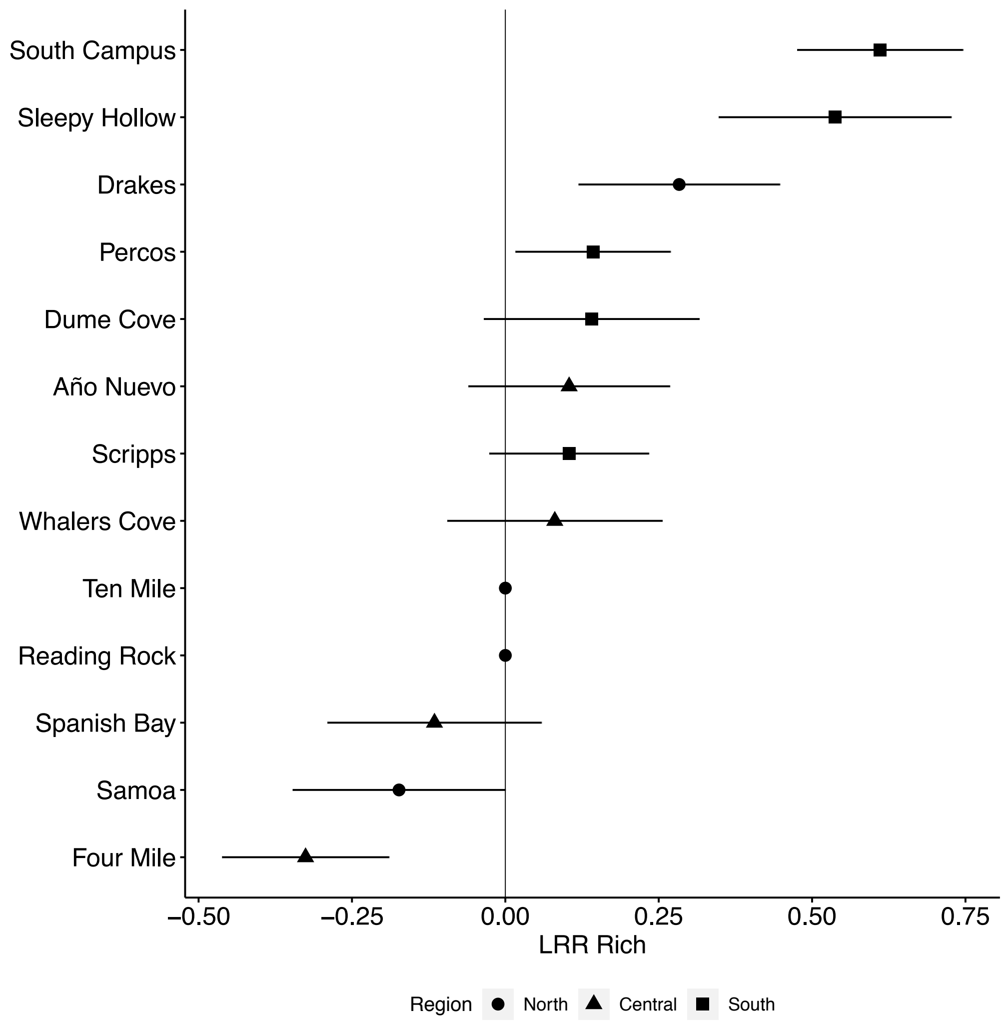

Figure 40 Mean (± 1 std error) LRR of species recorded in BRUV surveys. Richness is measured as taxonomic unit here as some fish could not be identified to species. Values of LRR means and standard errors are based on each sampling event.

The surf BRUV observations revealed stronger regional differences in surf zone fish species richness than found in our beach seine results. Species richness of fish and elasmobranchs on the BRUVs increased strongly from the North to the South region (**Figure 41**). The South coast had the greatest richness with a total of **47 species** belonging to **23 families** recorded from 188 BRUV deployments at 10 sites. For all five MPA/reference pairs in the South, species richness was greater at the MPA site. Species richness in this region varied among sites from 13 to 24 species, for Leo Carrillo (Ref) and Sleepy Hollow (MPA) respectively. A total of **41 species** belonging to **21 families** were recorded from 269 BRUV deployments at 8 sites in the Central coast region. Species richness in this region ranged from 9 to 21 species, recorded at Carmel Beach (Ref) and Four Mile (MPA) respectively. For the North coast region, species richness was less than third of that observed in the other two regions with a total of **13 species** belonging to **6 families** of fish and elasmobranchs recorded from 245 surf BRUV deployments at 8 sites. Species richness at individual North coast sites ranged from 2 to 10 at Gold Bluffs (Ref) and Drake's (MPA) respectively. Of the three regions, the North region had the most unidentified species on surf BRUVs due to poor visibility in the surf zone.

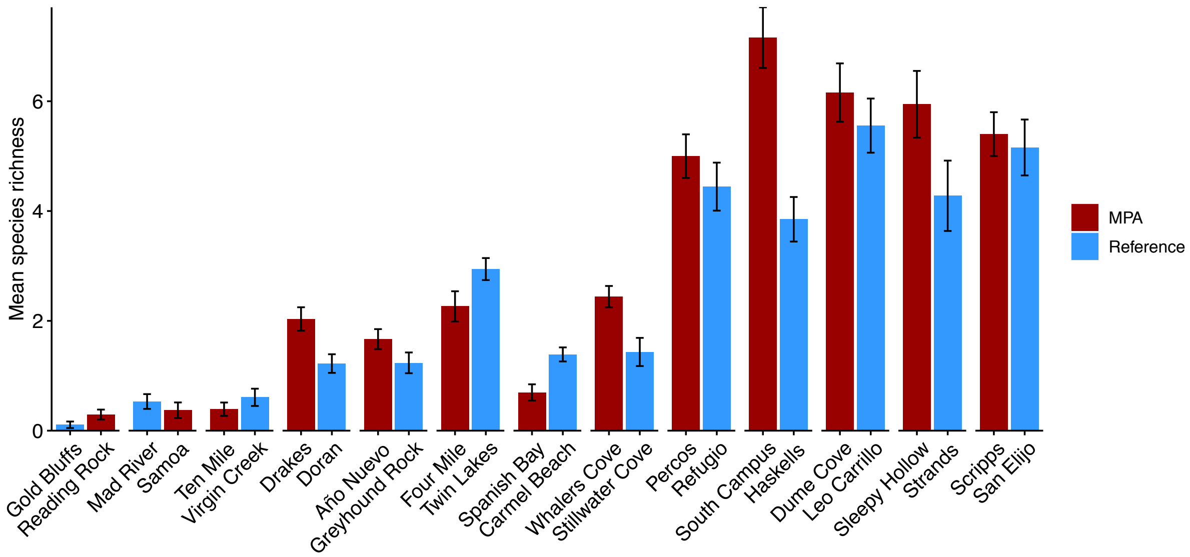

Figure 41 Mean (± 1 std error) of species/taxon richness of surf zone fish by MPA/Ref site pair as measured by BRUVs (n= 348 total BRUVs inside MPAs and n=351 BRUVs at reference).

Community Composition

Beach seines

We examined community composition inside and outside MPAs using nMDS plots and PERMANOVAs on our beach seine data to evaluate possible patterns with MPA status and region. The same statewide nMDS analyses were not possible for the surf BRUV results and none of the nMDS analyses on BRUV data converged on a solution. Along with the low numbers of fish recorded due to poor visibility in the surf zone on the majority of North coast sites, this lack of convergence may be related to data limitations which resulted in unequal samples for different communities or communities in this dataset may be categorized by rare species where there is little to no overlap among beaches. However, there was no clear differentiation in the community composition of surf zone fish between MPA and reference sites in the nMDS analysis (**Figure 42**A). Results of PERMANOVA showed no effect of MPA ($p>0.9$) but a significant effect of region (**$p=0.001$**) on community composition. The interaction of MPA and region was not significant ($p >0.9$).

The strong regional patterns apparent in the community composition of surf zone fish caught in beach seines (**Figure 42B**). For all fish combined, the assemblages of North coast sites have a wide range of composition which does not overlap with those of South coast sites and minimally overlaps with those of Central coast sites. This may be partially due to the lower catch in seines reported for the North coast sites. South coast sites supported croakers and corbinas, as well as leopard sharks, while the Central coast sites were defined by high abundance of surfperch, topsmelt, and Pacific sardines. The North coast was largely separated by the presence of silver surfperch and Pacific sand sole.

Similar to the pattern for all fish, the assemblages of targeted and non-targeted fish also showed a significant effect of region (**$p=0.001$**) but no effect of MPA or the interaction of MPA and region ($p >0.05$ in both groups) (**Figure 43,** for non-targeted fish see **Appendix_Fish Figure 16).** The differences in targeted fish assemblages

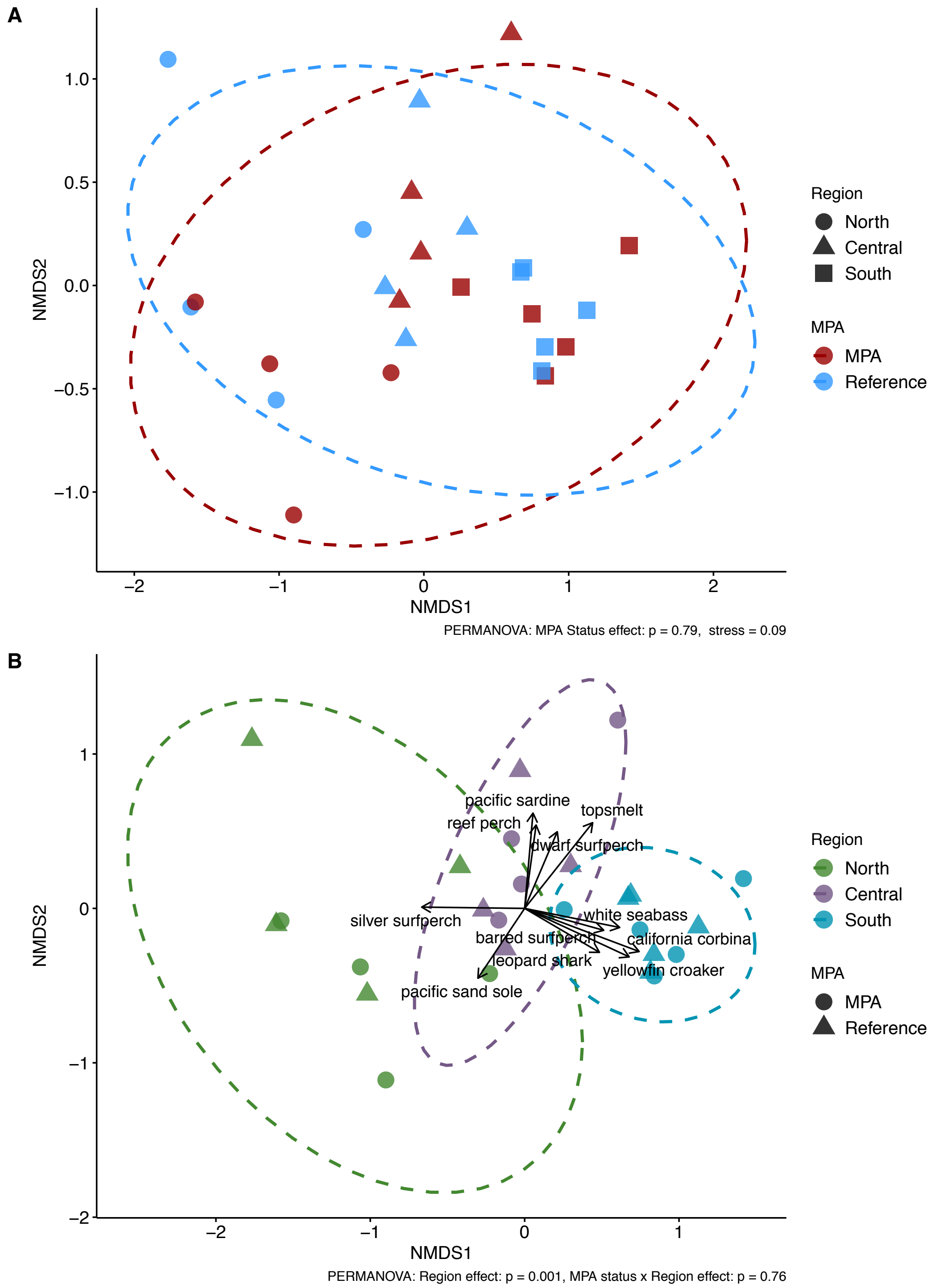

Figure 42 Beach seine results for nMDS and PERMANOVA results for all surf zone fish species. PERMANOVA showed an effect of region but not MPA status. A) MPA vs reference site groupings for all surf zone fish. B) Shows regional groupings for all surf zone fish and which species drive those community differences. North coast sites have a wide range of composition which does not overlap with South coast sites and minimally overlaps with Central coast sites. Only significant species are shown here (p<0.05).

showed similar significant vectors to those for all fish with corbina, yellowfin croaker and leopard shark being significant on the South coast (**Figure 43**). While calico surfperch, speckled sanddab, pacific sardine, topsmelt, and California halibut pushing communities in the opposite direction, corresponding to Central coast communities (**Figure 43**). Silver surfperch and Pacific sand sole again were significant vectors for North Coast surf zone fish communities (**Figure 43**).

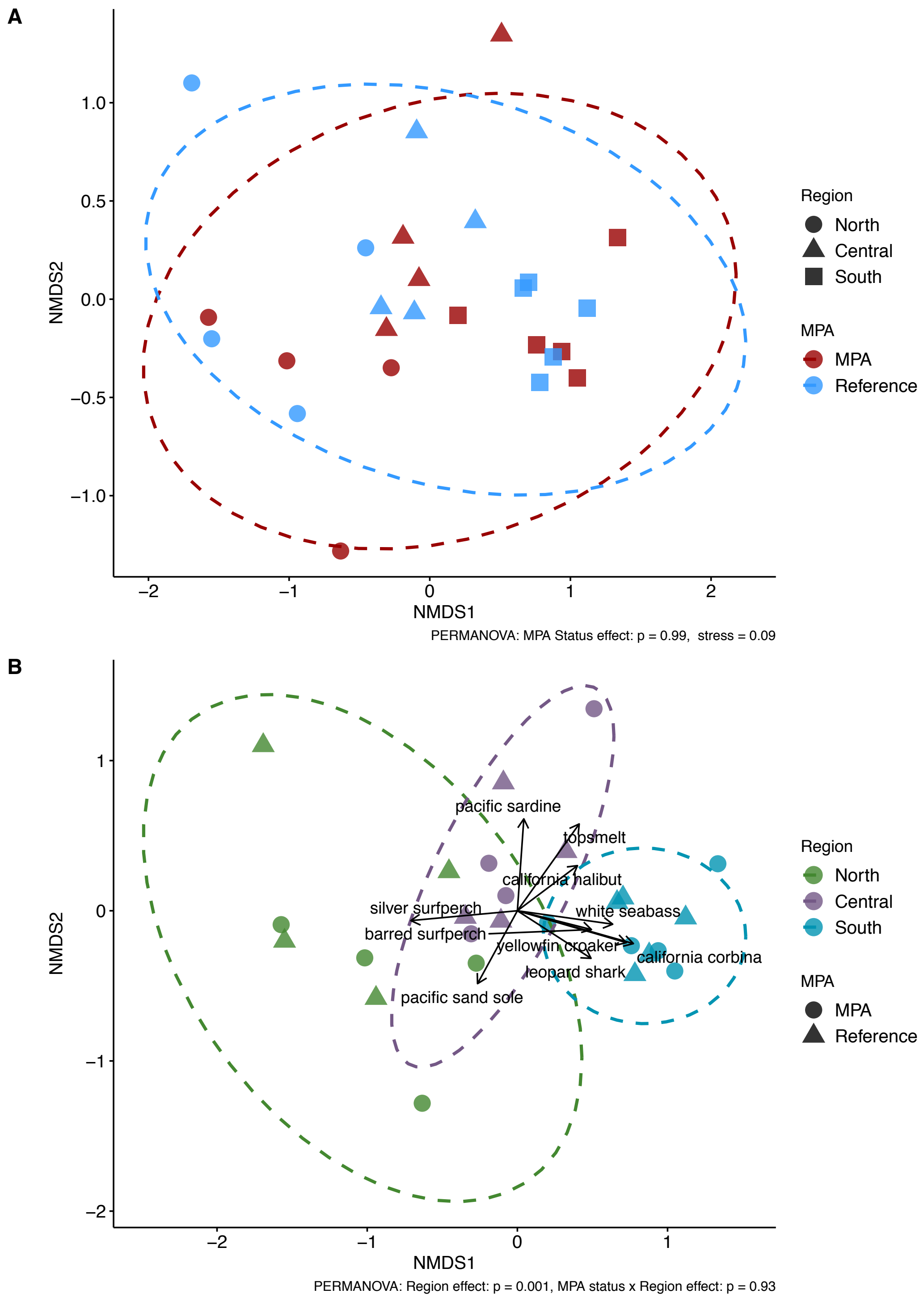

Figure 43 nMDS and PERMANOVA results for targeted fish species in beach seines. Only significant species are shown here (p<0.05). A) MPA vs reference site groupings for targeted surf zone fish. B) Shows regional groupings for targeted surf zone fish and which species drive those community differences.

Does functional diversity and trophic structure differ in MPAs relative to reference sites?

Beach Seines

To address this MLPA question we split the surf zone fish into four broad trophic groups of fish, planktivore, microbenthivore, piscivore, and herbivore. Overall no patterns in the CPUE of trophic groups of fish with MPA status were evident in seines. However, values of mean CPUE varied across three trophic groups (**Appendix_Fish Figure 2**). Planktivores, such as anchovies and smelt, returned the highest mean value of CPUE with up to 87.7 fish per seine, however this group was not caught at every site (20 out of 26, **Appendix_Fish Figure 2**). Microbenthivores, such as surfperch, were widespread and caught at every site with mean CPUE ranging from 0.03 to 62 fish per seine (**Appendix_Fish Figure 2**). Piscivores, such as white seabass, were found at only 11 sites with low mean values of CPUE (< 0.75 fish per seine) and only juvenile individuals were caught. Herbivores, such as opaleye, were uncommon and only recorded at 4 sites, all in the South coast region, with mean values of CPUE < 0.20 fish per seine. Differences for each MPA/Ref site pair as LRRs indicated the distribution of some trophic groups varied between MPAs and reference sites. Planktivores were more abundant inside MPAs compared to outside while piscivores were more abundant outside MPAs (**Appendix_Fish Figure 3**). Microbenthivores were similar in abundance inside and outside MPAs (**Appendix_Fish Figure 3**).

Indirect Responses to MPAs: Wrack, Kelp Plants and Birds

Highly productive kelp forests are key donor ecosystems for recipient sandy beach ecosystems where in situ primary production is very low and food webs depend on allochthonous marine inputs. The influence of MPA protection on kelp forests could cascade through sandy beach ecosystems that receive and utilize much of the abundant drift kelp exported by healthy kelp forests. Indirect responses to the protection of rocky reef habitats in MPAs could be manifested via inputs of drift kelp to sandy beaches located inside and adjacent to MPAs. Those inputs of drift kelp or wrack support highly productive and rich intertidal invertebrate communities on beaches which provide important prey resources for migrating and wintering shorebirds, an indicator group, with numerous species that are experiencing population declines. We hypothesized that the response variable of wrack inputs to beaches could be greater for MPAs compared to reference sites. In response to greater wrack inputs and resulting higher prey availability, we hypothesized the richness and abundance of migrating and wintering shorebirds using beach habitats would be greater in MPAs than in reference sites. The results of our set of monthly surveys of MPA/Ref site pairs for wrack and birds are used to evaluate potential indirect effects of MPA protection on beach ecosystems.

Our study design and analyses for indirect effects concentrated on the following evaluation questions from the original MLPA Goal 1 and modified versions of the more recently articulated Decadal Evaluation Working Group questions.

MLPA Goal 1:

- Do indicator species inside of MPAs differ in size, numbers and biomass relative to reference sites?

Decadal Evaluation Working Group Questions: (increase over time removed)

- Do focal and/or protected species inside of MPAs differ in size, numbers and biomass relative to reference sites?
- Have endangered species and/or culturally significant species benefited from the presence of California's MPAs?
- Is there a difference between MPAs and reference sites in community structure and/or species diversity within any given functional group or assemblage?

Below we discuss patterns of general abundance and composition for wrack, fresh wave cast kelp, and birds on the study beaches. We highlight some group and species-specific analyses where appropriate. Additional results on groups and species accounts can be found in Appendix_Birds_Wrack, and analyses of human activities can be found in Appendix_Physicals_People. All of these metrics were collected at the same time during each survey.

Do indicator species inside of MPAs differ in size, numbers and biomass relative to reference sites?

Do focal and/or protected species inside of MPAs differ in size, numbers, and biomass relative to reference sites?

For postulated indirect effects of MPAs on beach and surf zone ecosystems, we addressed these related questions using two major response variables, connectivity and inputs from kelp forests and reefs to beaches, as wrack and wavecast kelp plant abundance, and the abundance of higher level predators, as birds, on beaches and surf zones, including shorebirds, gulls, seabirds, and other bird groups.

Inputs from Kelp Forests and Reefs to Beaches

To evaluate this potential indirect effect of MPAs that relies on connectivity with kelp forests and reefs to provide major inputs of wrack to sandy beaches we compared these inputs at sites inside and outside of MPAs. We used two methods to estimate wrack inputs, the cover m^2/m of wrack on cross-shore transects, and the abundance of wavecast kelp plants per km of beach. The cover of marine wrack included all major types of macrophytes. Counts of wavecast kelp plants per km focused on numbers of fresh thalli of three species of kelp, *Macrocystis pyrifera, Nereocystis luetkeana* and Postelsia *palmaeformis.*

Wrack Abundance

The macrophyte wrack observed as cover on the study beaches consisted primarily of the kelps, *Macrocystis pyrifera*, *Nereocystis luetkeana, Egregia menziesii,* and *Postelsia palmaeformis*, and seagrasses including surfgrass *Phyllospadix* spp, and eelgrass *Zostera marina.* A variety of other brown, red, and green macroalgae also occurred as wrack on the study beaches, usually in smaller quantities and cover. Invasive species of brown macroalgae including *Sargassum muticum* and *S. horneri* were also recorded at eight of the study beaches, all located in the South coast region: Refugio (Ref), Haskell's Beach (Ref), Campus Point West (MPA), Dume Cove (MPA), San Elijo (MPA), Scripps (MPA, Torrey Pines State Beach (Ref), and Black's Beach (Ref).

In our broad statewide comparisons, mean values of wrack abundance (cover) did not differ significantly between MPAs and reference sites overall (ANOVA (MPA status (log(mean cover) $F_{1,30}=0.00$, $p=0.995$). Average wrack abundance did not vary significantly with MPA status within any of the three regions and differences observed were not consistent in direction among regions (**Figure 44**). However, although mean values of wrack cover in our surveys varied considerably across the three regions, that variation among regions was not significant (ANOVA (log(abundance) $F_{2,30}=2.56$, $p<0.09$) in our comparisons and site to site variation was high. The highest abundance of wrack was observed on beaches of the South coast region and the lowest on the North coast. Average wrack abundance increased by >4 fold from the North to South coast region for both MPAs and reference sites (**Figure 44)**.

There was also no general pattern in the cover of different major wrack types inside and outside MPAs (**Figure 45**). Kelps were generally more abundant in MPAs compared to reference sites (**Figure 45**) but that difference was not significant (ANOVA (MPA status (log(mean cover) $F_{1,29}=1.95$, $p=0.17$). Site to site variation in wrack abundance and composition was striking across and within regions (**Appendix_Birds_Wrack),** a result that is likely related to the proximity and condition of reef and other source habitats and beach condition and orientation relative to prevailing wind and swell directions. The proportion of kelp wrack relative to other types of wrack varied with region with far more kelp present on beaches in the Central and South regions compared to the North region (**Appendix_Birds_Wrack**).

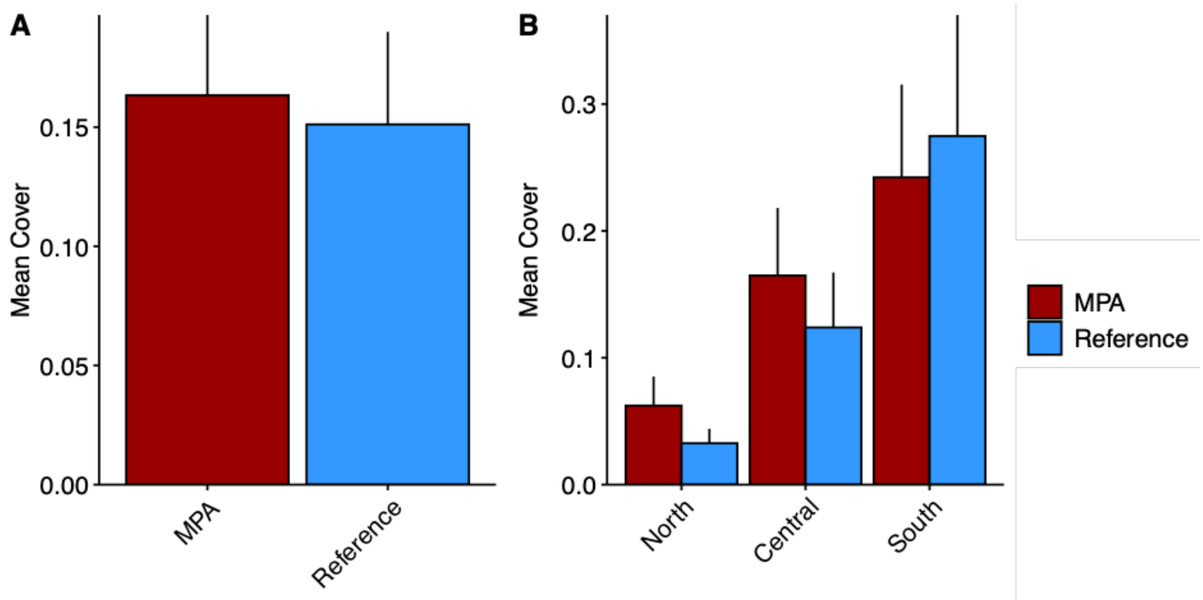

Figure 44 Mean abundance (± 1 std error) as cover ($m^2\,m^{-1}$) of all marine macrophyte wrack measured on cross shore transects at the study beaches, N= 36 sites. A) Averaged to the statewide level and B) averaged to the region level.

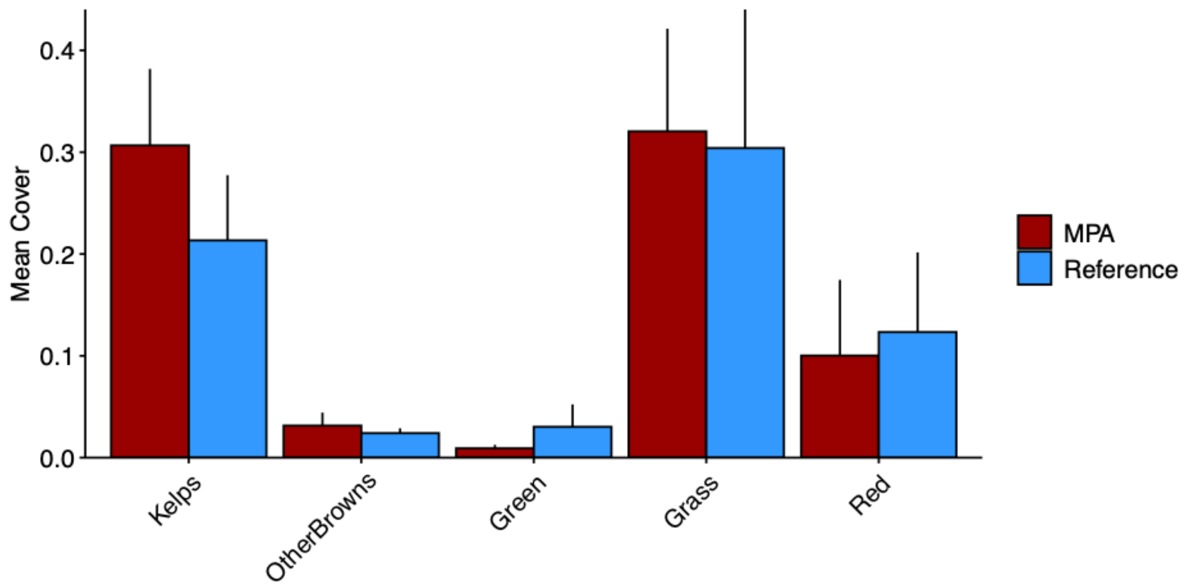

Figure 45 Mean abundance (± 1 std error) as cover ($m^2\,m^{-1}$) of major wrack types on the study beaches, N= 36 sites. Large kelps include *Macrocystis, Nereocystis, Egregia menziesii, Postelsia palmaeformis* and *Pterygophora* californica. Grasses include surfgrass *Phyllospadix torreyi,* and eelgrass *Zostera marina*. Red and green algae groups were not generally identified to species but they likely include turf and blady reds, and *Ulva* spp., The other browns group includes brown algae including kelps not denoted as a large kelp including *Stephanocystis osmundacea, Desmerestia, Laminaria, Sargassum*, and unidentified brown algae.

Similarly, the LRR for total wrack (all macroalgae) did not vary significantly from zero (two-tailed t-test, p=0.53), suggesting that differences in total cover of wrack between

MPAs and reference sites were highly variable and not related to MPA status. This result also indicates that our MPA and reference sites are well matched in terms of wrack inputs from nearby marine and estuarine systems. Despite this overall result, LRRs for six MPA/Ref site pairs were positive indicating higher wrack abundance inside MPAs across the three regions, including the MPA/Ref pairs of Salmon Creek, Virgin Creek, Montara, Carmel Bay, Percos, and Scripps (**Figure 46**). However, cover of wrack was greater at the reference sites for six of the site pairs, including Ten Mile, Asilomar, Dume Cove, San Elijo, Campus Point West and Gazos Creek, with negative LRRs again spread across regions (**Figure 46**). **Our results indicating similarity of wrack abundance (cover) across MPA/Ref site pairs, provides limited evidence for an indirect effect of MPAs of this response variables on the spatial scale of our current study design, however more information on the connectivity and transport dynamics of kelps and other macrophytes from MPAs would provide needed insights on this question.**

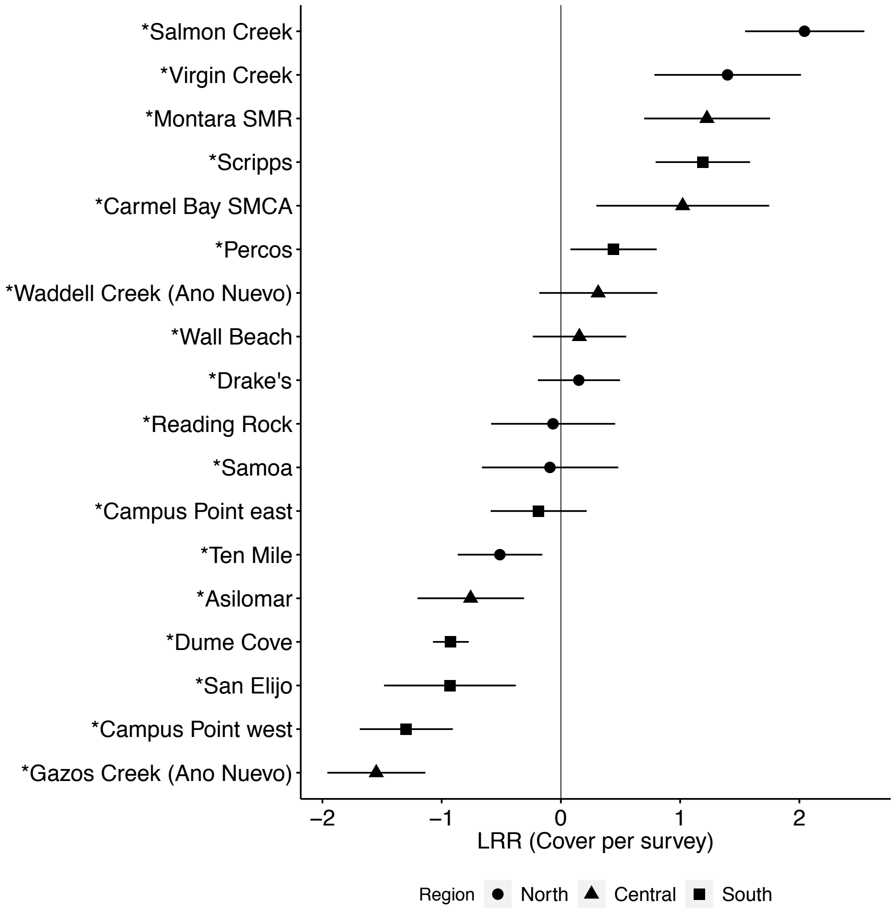

Figure 46 Mean values (± 1 std error) for log response ratio (LRR) of cover of all marine wrack. Symbols represent region and MPA pairs are plotted from highest mean to lowest. Values of LRR means and standard errors are based on each sampling event.

Fresh Wave cast Kelp Plants

Wave cast plant counts conducted during each of the monthly bird surveys focused on numbers of fresh thalli of three species of kelp, *Macrocystis pyrifera, Nereocystis luetkeana* and *Postelsia palmaeformis.* Although the overall average abundance of wave cast kelp plants was slightly higher in MPAs (**Figure 47 A**) that difference was not significant (log(abundance of all kelps)~ MPA $F_{1,214}$=0, p=0.99). However,

regional differences in the abundance of wave cast kelp plants on beaches were striking and highly significant (log(abundance of all kelps)~ **Region $F_{2,214}$=33.28, p<0.0001)** with very high abundance of kelp plants observed in the Central region (**Figure 47 B**)
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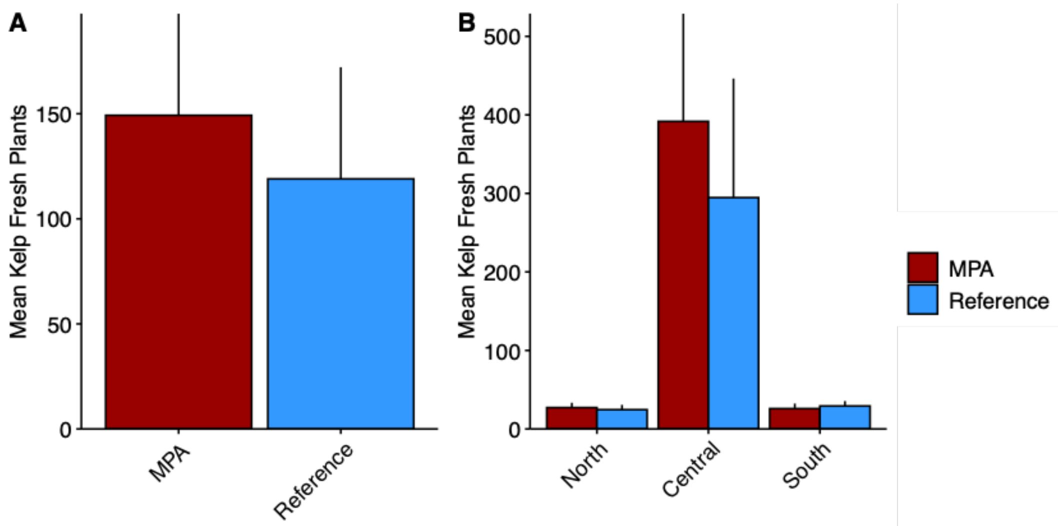

Figure 47 Mean abundance (+ 1 std error) of all types of fresh wave cast kelp plants A) in MPAs and reference sites and B) inside and outside MPAs separated by region. Abundance of all kelp plants from each survey was averaged to the statewide or regional level for MPA and reference sites.

Given the wide variability among our MPA study sites in orientation and proximity to kelp forests, we examined the differences in the abundance of fresh wave cast plants for each MPA/Ref site pair as LRR (
Figure 48). For fresh wave cast kelp plants (all species combined) LRRs did not differ significantly from zero (two-tailed t-test, p=0.50) meaning there was no consistent difference between MPA and reference sites. We found that while abundance across MPA/Ref site pairs varied, the amount of total kelp plant inputs were similar for many pairs, generally matching our result for wrack cover and suggesting MPA/Ref site pairs were well matched.

Beaches in the Central region had all three species of kelps and the highest average abundance of fresh wave cast kelp plants, dwarfing the smaller numbers of kelp plants reported on beaches in the North and South regions (Figure 47) The highest abundances of kelp plants (all species together) per site by an order of magnitude were recorded on Central coast beaches with > 4000 plants observed at three beaches (Waddell Creek (MPA), Scott Creek (Ref), and Asilomar (MPA)**)**. These high counts were largely composed of fresh bull kelp, *Nereocystis,* plants. Stranded fresh kelp plants were lowest in abundance with mean values of <10 plants km^{-1} at the six northernmost sites of the North coast (Gold Bluffs (Ref), Reading Rock (MPA), Mad River (Ref), Samoa (MPA), Blues Beach (Ref) and Ten Mile (MPA) where bull kelp forests disappeared and were transformed to urchin barrens during and prior to our survey period (McPherson et al 2021).

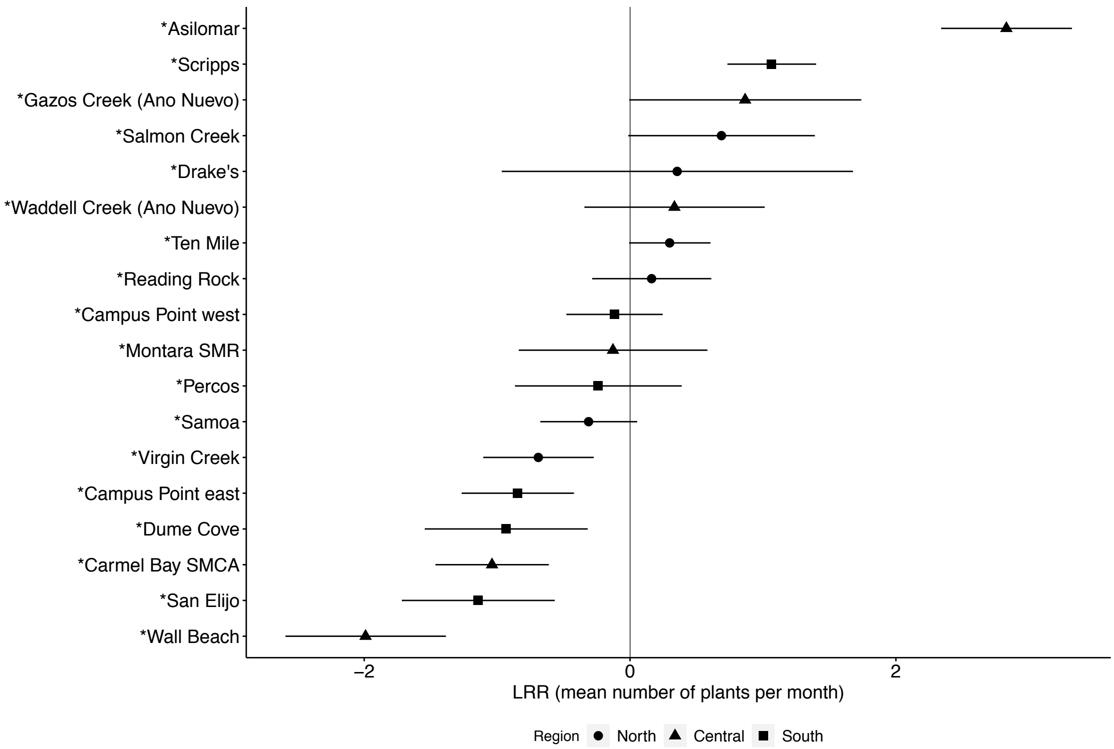

Figure 48 Mean (± 1 std error) of LRR for fresh wave cast kelp plants. This metric included all species observed in a given survey. Values of LRR means and standard errors are based on each sampling event.

The mean abundance of fresh beach-cast kelp plants and holdfasts (*Macrocystis pyrifera, Nereocystis luetkeana,* and *Postelsia palmaeformis* combined) varied over several orders of magnitude (from 0.9 to 370.5 plants km^{-1}) among sites and surveys, averaging 43.8 plants km^{-1} overall (**Appendix_Birds_Wrack Figure 25**). The peak number of kelp plants and holdfasts observed was 6319 *Nereocystis* plants km^{-1} in September 2019 at Scott Creek (Ref) (**Appendix_Birds_Wrack**). The two beaches with the lowest mean values for abundance of fresh kelp plants were San Elijo (MPA) and Samoa (MPA) (2.7 and 5.1 plants km^{-1}, respectively). **These results highlight the importance of statewide long term monitoring to help capture the loss and possible recovery of habitat forming kelps, such as *Nereocystis* and *Macrocystis*.**

Do indicator species inside of MPAs differ in numbers relative to reference sites?

Do focal and/or protected species inside of MPAs differ in numbers relative to reference sites?

Abundance of Predators: Birds

As sensitive indicators of habitat quality and environmental conditions, birds are predators may respond to MPAs that protect habitat or enhance prey resources (such as intertidal invertebrates). We expect to see an indirect effect of MPAs that reflects the bottom up inputs from kelp forests and reefs to sandy beaches food webs (additional wrack leads to additional prey). To evaluate this indirect effect we compared the abundance of birds, including all birds, shorebirds, seabirds, gulls and other bird types, at sites inside and outside of MPAs. If there was an indirect effect of MPAs (more wrack inside MPAs) we would expect a possible trophic response in the form of increased abundance of birds or groups of birds inside MPAs.

Birds of beaches and surf zones

For the combined abundance of the bird groups we observed, overall mean values for all birds across the state did not vary inside and outside MPAs (log(abundance) $F_{1,246}$=0.48, p=0.49) (**Figure 49**A). However the abundance of all birds varied significantly across the three study regions (**log(abundance) $F_{2,246}$=4.2, p=0.016**) with greatest abundance for the Central coast sites (**Tukey's Post hoc P<0.001**) (**Figure 49**).

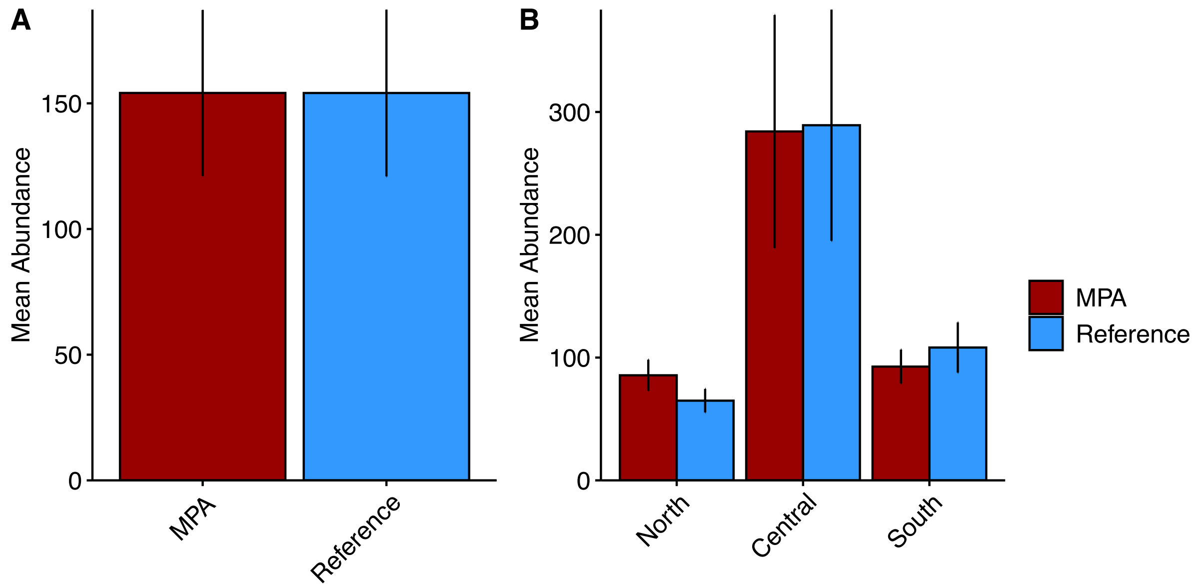

Figure 49 Mean abundance (±1 standard error) of all birds (bird groups combined) observed in our study. A) Averaged to the statewide MPA and reference site level. B) Averaged to the regional level.

To more accurately evaluate the abundance of all birds inside and outside MPAs we used LRR comparisons. Overall differences between MPA/Ref sites as LRR did not differ from 0 (two-tailed Wilcoxon Signed Rank test v=3853 p=0.47) indicating that the abundance of birds did not significantly differ inside and outside MPAs. However, the variability in LRR among MPA/Ref site pairs was high for all birds (**Figure 50**). Out of 18 MPA/Ref site pairs, nine showed positive LRRs indicating abundance of all birds combined was higher inside MPAs representing all three regions (**Figure 50**). Five pairs of sites showed a negative LRR where abundance of birds was greater at reference sites (**Figure 50**). The remaining four sites showed no MPA effect on abundance of all birds combined.

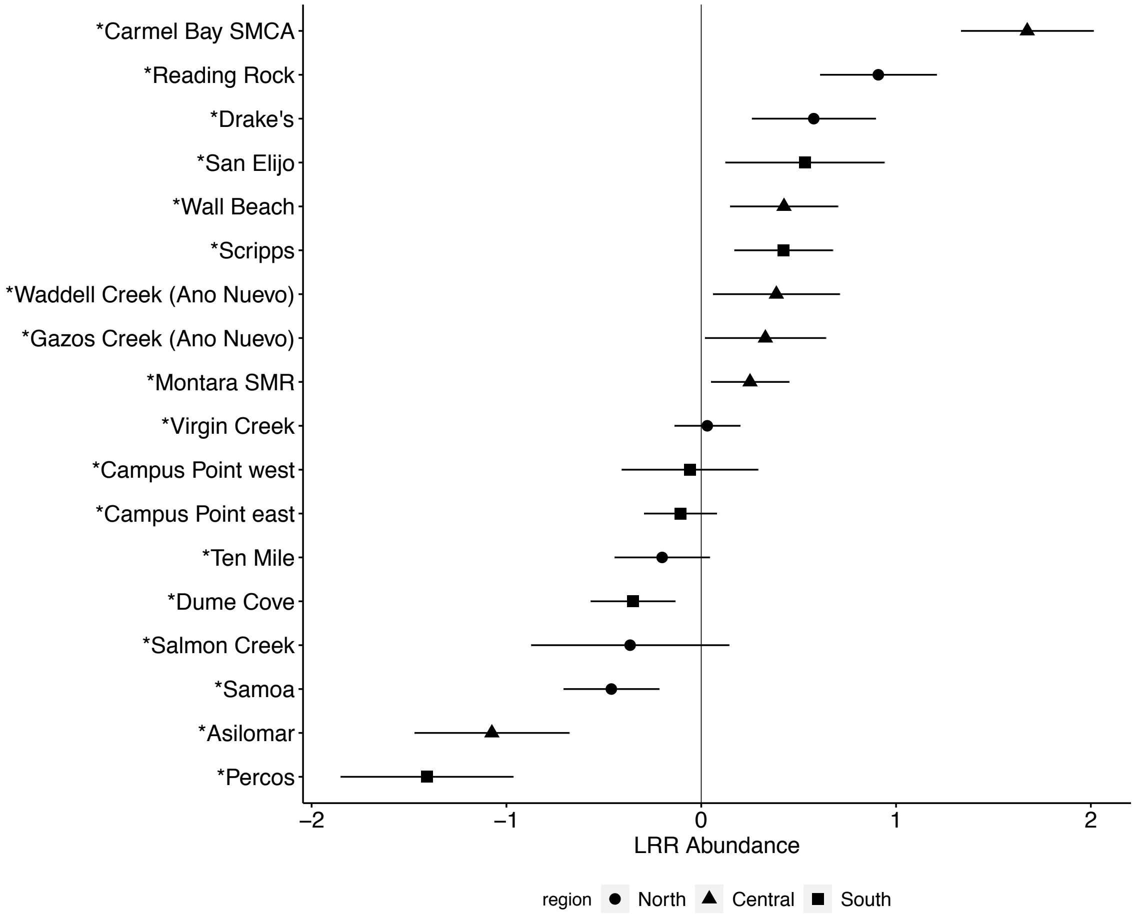

Figure 50 Mean values (±1 standard error) of log response ratios (LRR) for abundance of birds (all birds) listed in order of LRR result. Values of LRR means and standard errors are based on each sampling event.

Birds were abundant on a number of the study beaches. On average we observed 154.1 birds km^{-1} in the monthly surveys with averages of 45.1 birds km^{-1} for shorebirds, 82.8 birds km^{-1} for gulls and 27.0 birds km^{-1} for seabirds (**Appendix_Birds_Wrack Table 2**). We recorded large MPA to MPA variation in mean abundance of birds across beach and surf zone ecosystems (**Figure 51**). Mean abundance of birds at individual beaches was relatively similar within most of the MPA and reference pairs, with more variation present across pairs and within and among regions (**Figure 51**). This is not surprising considering the landscape and beach differences among MPA/Ref site pairs and the habitat preferences of different bird species and groups, as well as our site matching process. The highest values of mean abundance for all birds and for shorebirds, seabirds and gulls were observed in Central coast region (**Figure 51, Figure 53**) but that regional pattern was strongest for seabirds and gulls.

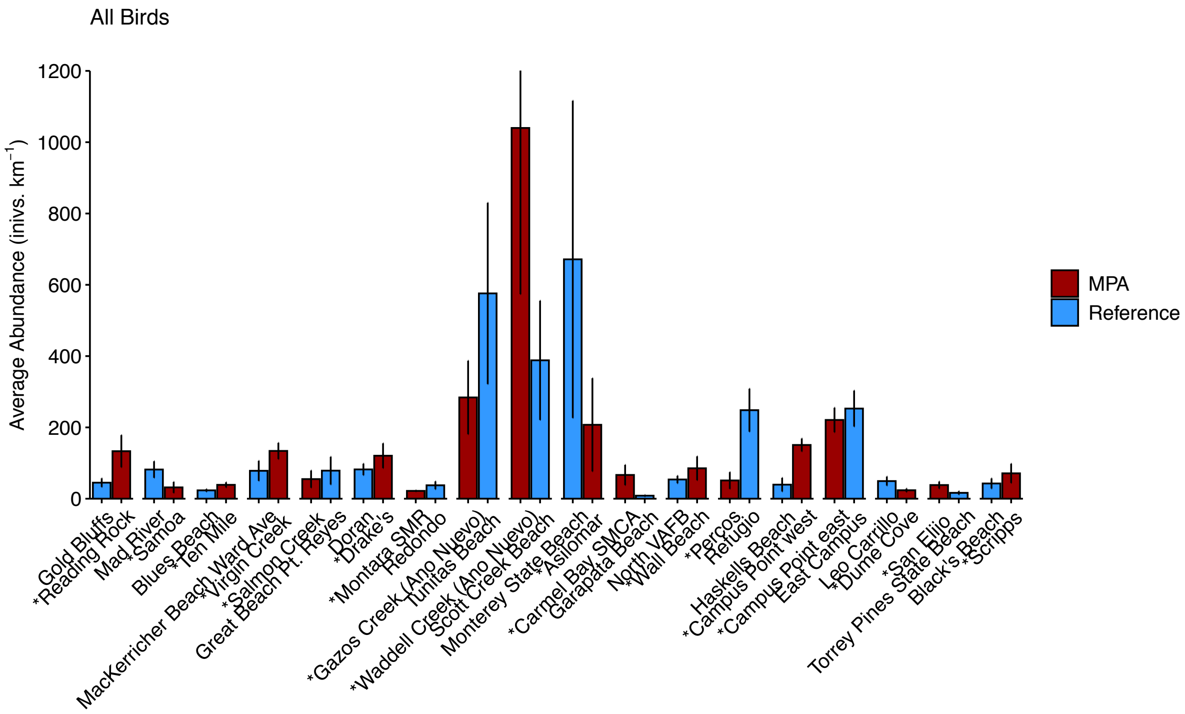

Figure 51 Values of mean abundance (± 1 standard error) of birds observed at each site with MPA/Ref site pairs listed from North to South. MPAs are shown as red bars while reference sites are blue bars. Sites in MPAs have an asterisk before the name on the x axis.

Do indicator species inside of MPAs differ in numbers relative to reference sites?

Is there a difference between MPAs and reference sites in the numbers or abundance of a focal, and/or protected species?

Birds of beaches and surf zones

To address this question, we examined patterns of abundance of the major groups of birds, namely shorebirds, gulls, seabird, aquatic and wading birds and terrestrial birds, we observed in surveys inside and outside MPAs (**Figure 52)**. Overall, the mean abundance of shorebirds and seabirds was greater in MPAs while the mean abundance of gulls was greater at reference sites (**Figure 52**). In general, mean abundance of gulls was highest while that of aquatic and wading birds was lowest. Shorebirds and gulls were the most important groups of birds observed on the study beaches making up 79% of the birds observed in the study. Overall the composition of the birds observed in our surveys was 54% gulls, 25% shorebirds, 18% seabirds, <1% aquatic/wading birds and 3% terrestrial birds.

Given the important links between shorebirds and wrack-feeding invertebrates on beaches we focused on the potential for shorebirds to show an indirect link to MPAs through the mechanism of healthy kelp forests providing subsidies to intertidal food webs and enhancing their prey resources. Here we discuss our results for shorebirds as a group. Details on the other bird groups and species accounts can be found in **Appendix Birds_Wrack**.

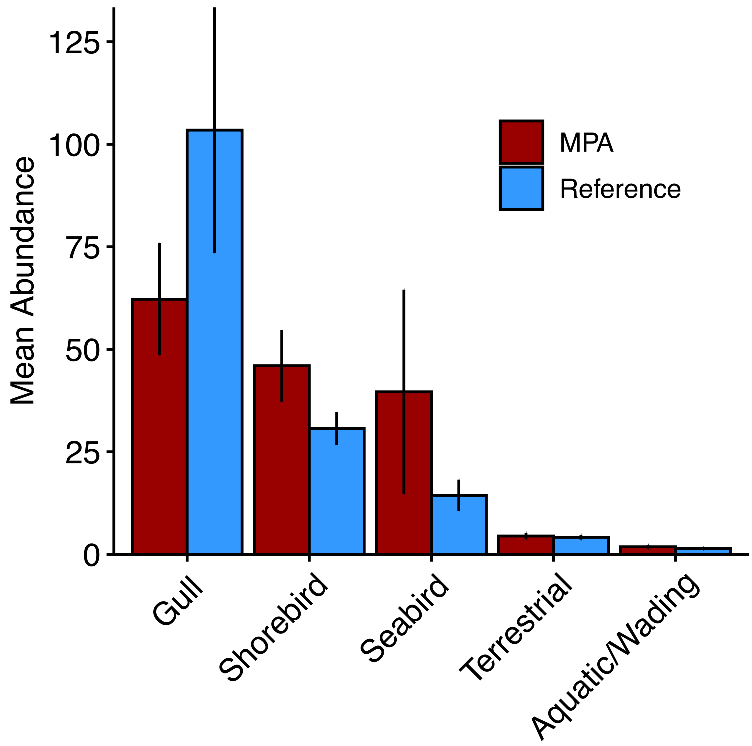

Figure 52 Mean values (± 1 standard error) of the abundance and richness of birds by group observed on beaches located inside MPAs and on reference beaches. All groups showed overlapping (within one std. error) of average abundance between MPA and reference sites.

Shorebirds are listed as indicators in the MLPA Action Plan and can be sensitive metrics of the condition of beaches (Schlacher et al. 2014, Piersma and Lindström 2004), including the abundance and diversity of their sandy intertidal invertebrate prey and the condition of beach habitat, including modifications such as coastal armoring (Dugan et al. 2003, 2008). Many species of the invertebrate prey of shorebirds are associated with inputs of kelp and wrack to beaches. The majority of shorebird species we observed migrate to and winter on California beaches and wetland habitats with only a few nesting species. However, many species of shorebirds spend most of their year in California, arriving during late July and August and departing in April and May to migrate to northern and inland breeding sites.

Shorebirds were the second most abundant bird group observed on our study beaches and made up more than 50% of the total birds observed in surveys at 17 of our study sites, including 9 MPA sites. The abundance of shorebirds varied widely among sites, with means ranging from 0 shorebirds km^{-1} at Garapata Beach (Ref) to 172 shorebirds km^{-1} at Asilomar Beach (MPA) (Appendix_Bird_Wrack Table 8, **Figure 53**). For 12 of the 18 pairs of MPA/Ref sites, mean abundance of shorebirds was higher in the MPA than in the reference site (**Figure 53**, Appendix_Bird_Wrack Table 8). This overall pattern broadly supports the hypothesis that this group of birds may be responsive to indirect effects of MPA protection that enhance connectivity and exchange between kelp forest and beach ecosystems but variation across site pairs was very high reflecting the wide variety of beaches in MPAs (**Figure 53**).

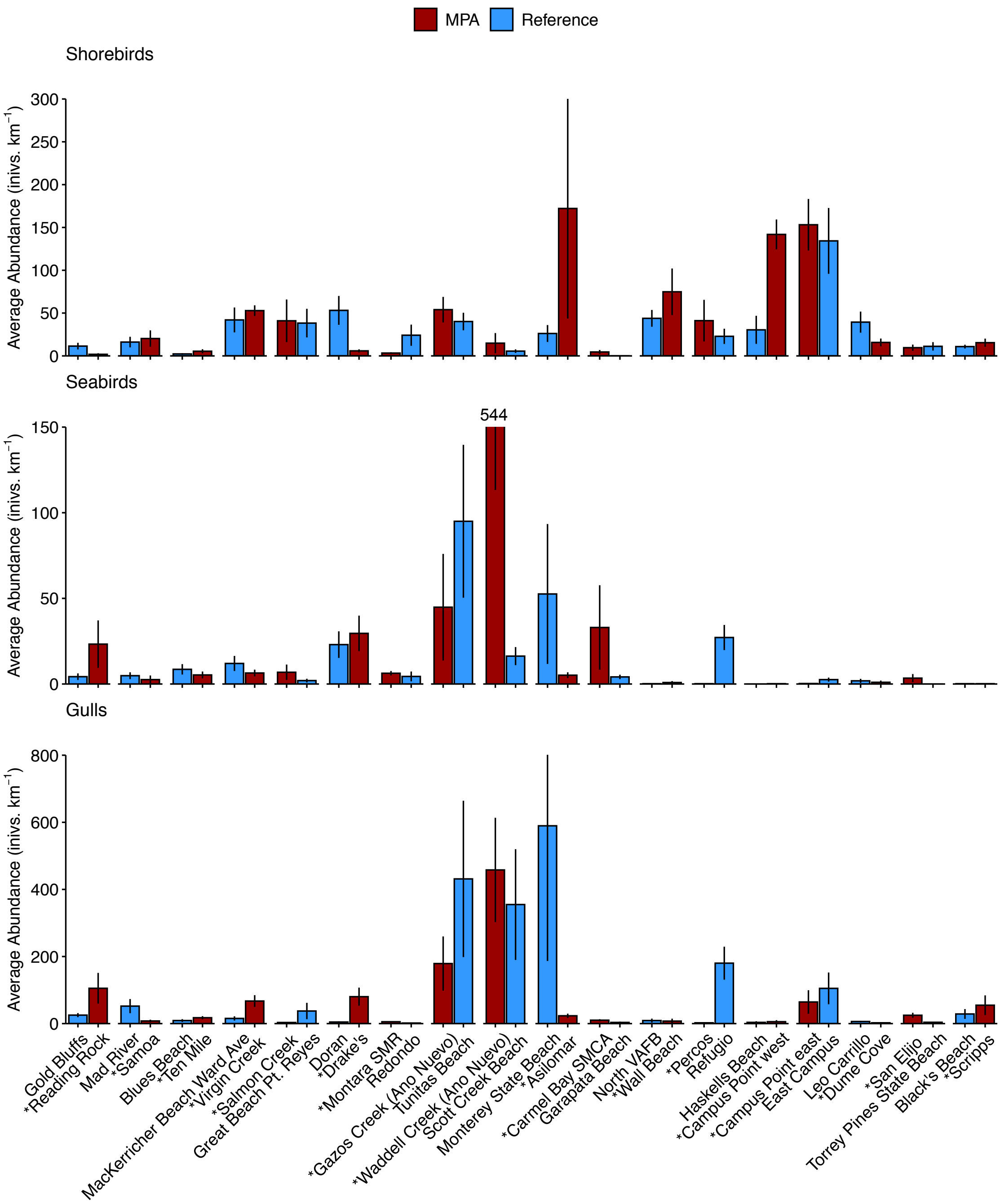

Figure 53 Values of mean abundance (± 1 std error) of shorebirds, seabirds, and gulls observed at each site with MPA/Ref site pairs listed from North to South. MPAs are shown as red bars while reference sites are blue bars. MPA sites have an asterisk before the name on x axis.

Although the value of mean abundance for shorebirds was 30% greater in MPAs than reference sites statewide (**Figure 54**) our overall analysis did not find significant differences in the abundance of shorebirds inside and outside MPAs (log(abundance) $F_{1,206}$=0.14, p=0.7; **Figure 54).** The mean abundance of shorebirds in MPAs generally increased from the North to the South region but did not vary significantly across the study regions (log(abundance) $F_{2,206}$=1.15, p=0.32, **Figure 54**) due to the high variability in abundance among sites. Patterns of mean abundance within region varied, with greater numbers of shorebirds in MPAs in the Central and South regions and greater numbers in reference sites in the North region

However, differences in mean abundance of shorebirds within the regions were not significant (p >0.30 for Central and South regions).

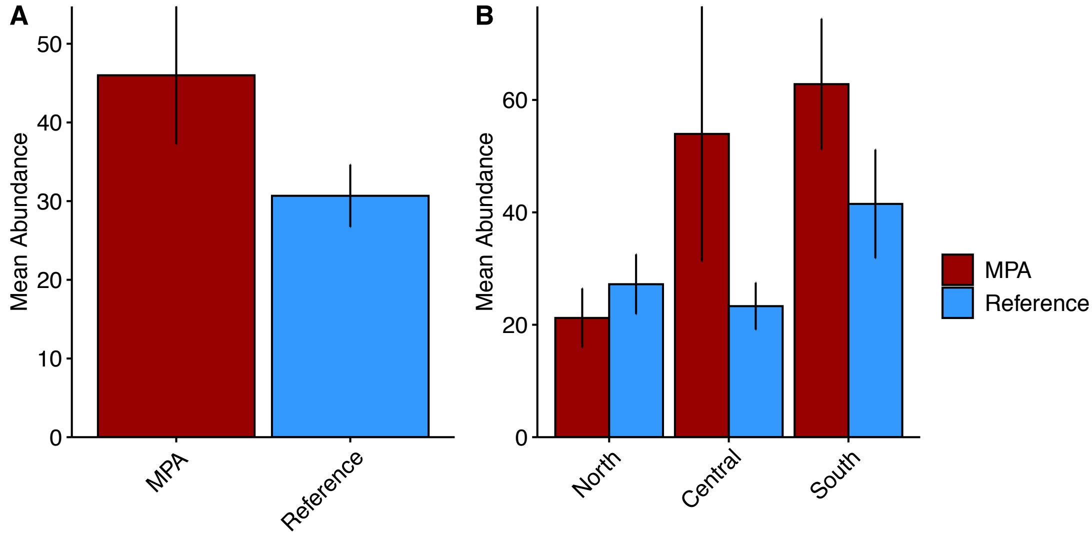

Figure 54 Mean overall abundance (± 1 standard error) of shorebirds for our MPA and reference study sites, A) Statewide means B) Regional means.

To address the strong differences in shorebird abundance across MPA sites in our analysis, we compared LRRs for our pairs of MPA and reference sites (**Figure 55**). Overall, the differences in shorebird abundance between MPA and Reference sites as LRRs did not differ from 0 (two-tailed Wilcoxon Signed Rank test v=5423.5 p=0.76) indicating their abundance did not differ inside and outside MPAs.

Although MPA effects were not detected overall for shorebirds, our results indicate that a number of MPAs are important habitat for shorebirds with large numbers of migrating and wintering shorebirds recorded on beaches located in MPAs. For each of the regions, the peak or near peak values for mean shorebird abundance were observed in MPAs (**Figure 53**, **Appendix_Birds_Wrack Table 8**). Those peak values in mean numbers of shorebirds varied with region, with lower values in the North (Virgin Creek SMCA, 53 birds), compared to the Central (Asilomar SMR, 172 birds) and South (Campus Point SMCA: 153 birds) regions (Appendix table 1,2). At some MPA beaches, shorebirds made up a major proportion of all the birds observed, for example 83% of all birds at Asilomar (MPA) were shorebirds. This finding suggests that sandy beaches located in California MPAs are regionally important as habitat for wintering shorebirds and should be considered in state and regional shorebird conservation planning (e.g. Hickey et al 2003). Populations of many species of shorebirds are declining in North America and on the west coast (e.g. Bart et al 2007, Brown et al 2001, Warnock et al. 2021). **Our finding for shorebirds highlights the conservation value of California's MPAs for species that are not fished or harvested and the potential for indirect effects of MPAs that benefit these species and enhance their conservation.**

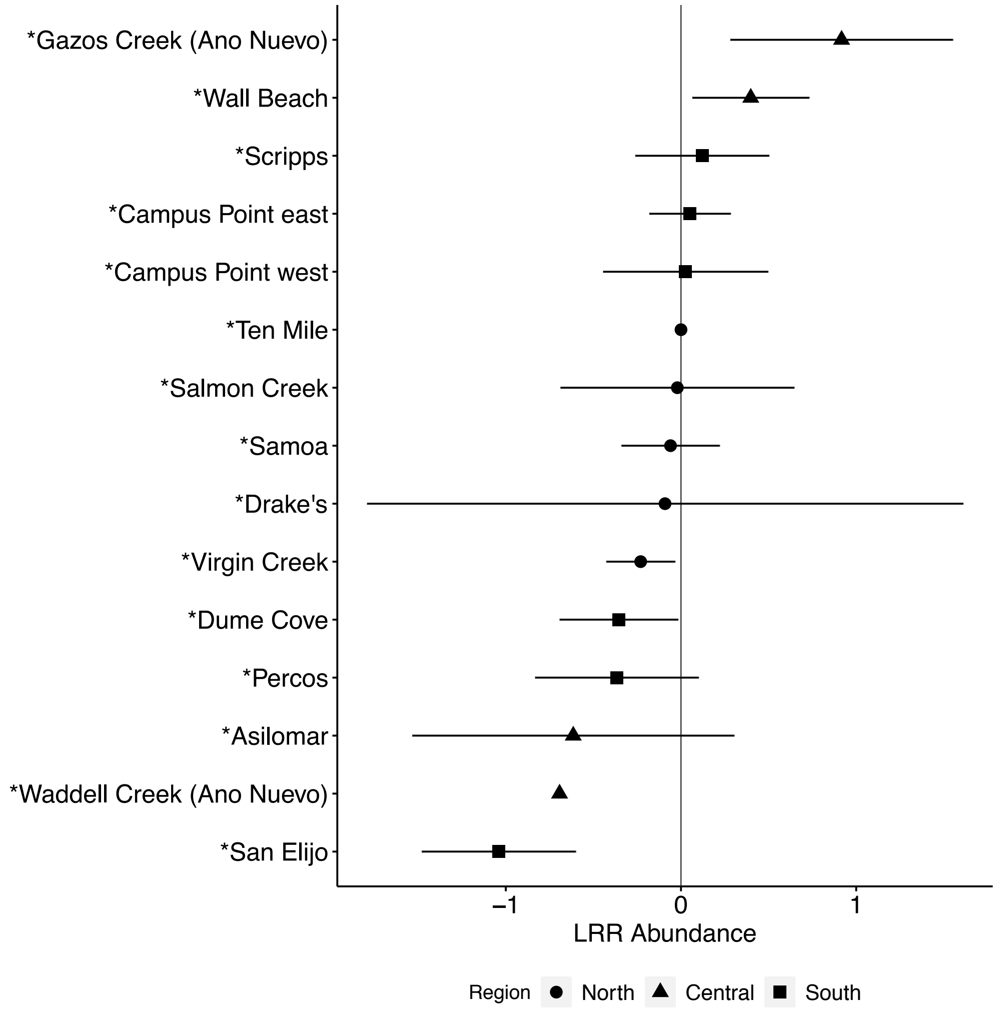

Figure 55 Mean values of LRR (± 1 standard error) for abundance of shorebirds in our pairs of MPA/Ref sites listed by the MPA site name for each pair. Symbols denote the three regions. Values of LRR means and standard errors are based on each sampling event.

Abundance and the differences in abundance between MPA and reference sites varied greatly among individual species of shorebirds, with overall average abundance ranging over more than 3 orders of magnitude across species (0.004 birds km^{-1} to 16.7 birds km^{-1}) (**Appendix Table 2**). Values of average abundance were greater for MPA compared to reference beaches for the three most abundant shorebird species, Sanderling, Western Snowy Plover and Black-Bellied Plover (**Figure 56, Appendix Table 2**). For example, the mean abundance of sanderlings was 50% greater in MPA sites (22 birds km^{-1}) compared to reference sites (11 birds km^{-1}) (**Figure 56**, **Appendix Table 2**) but that difference was not significant for MPA (ANOVA (log(abundance) $F_{1,96}$= 1.157.48, p=0.29) or region ((log(abundance) $F_{1,296}$=01.46, p=0.24). Black-bellied plovers are listed as an indicator bird species in the MLPA Action Plan and were observed on 21 of the 36 study beaches and during every month of our surveys. The average abundance of Black-bellied Plovers was significantly higher in MPAs (5.1 birds km^{-1}) compared to reference sites (1.3 birds km^{-1}) (**Figure 56**) (**Appendix_Birds_Wrack**; **$F_{1,248}$=8.48, p=0.004**). Black Oystercatchers, a resident breeding species of shorebird that prefers rocky habitat was also more abundant on average in MPAs. Details of our results for other species of shorebirds can be found in the **Appendix_Birds_Wrack.**

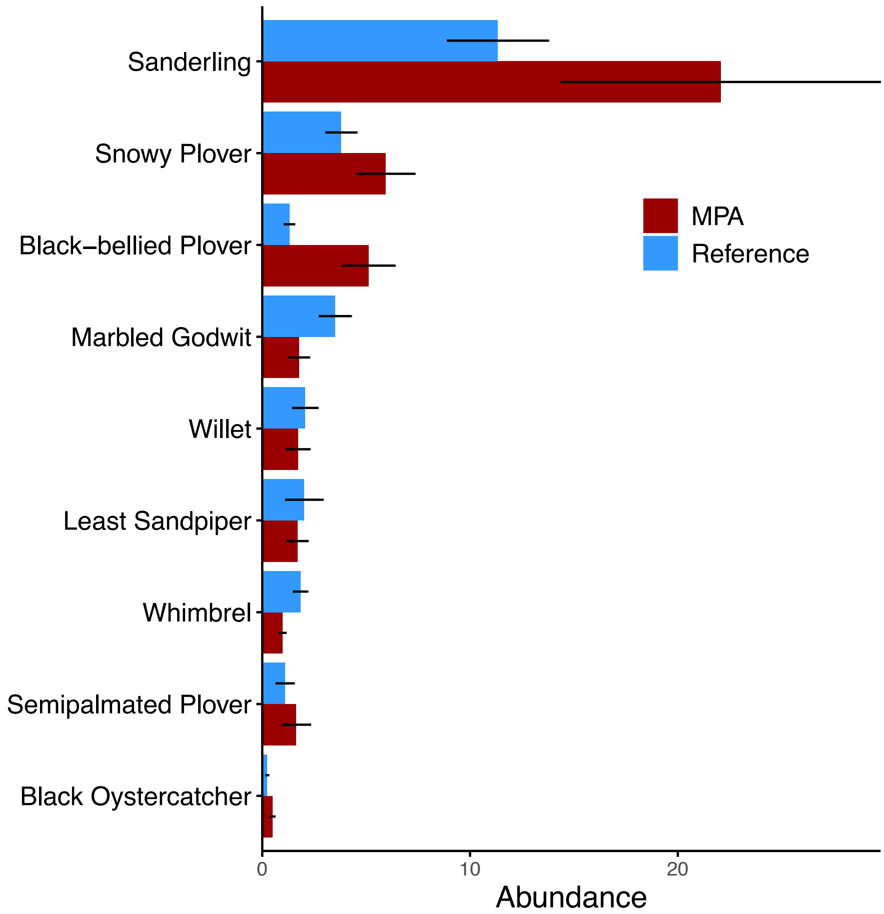

Figure 56 Mean (± 1 standard error) abundance (number of birds km^{-1}, ± 1 standard error) for the eight most abundant species of shorebirds and for Black Oystercatchers observed in our MPA and reference study sites, listed order of abundance.

Have endangered species and/or culturally significant species benefited from the presence of California's MPAs?

Western Snowy Plover

We used the results of our bird surveys for the threatened Western Snowy Plover to address this MPA question. Western Snowy Plovers are federally listed as threatened and listed a Species of Special Concern by the State of California. These resident breeding shorebirds nest on beach, river bar, salt flat and estuarine habitats from March through September and winter on beaches in all three regions of the state. Following post breeding dispersal from nesting beaches, birds aggregate, sometimes in flocks of 50 or more, at preferred winter roost beaches (October – March). These winter roost beaches can differ from or include nesting beaches.

On beaches, both adults and chicks depend largely on prey resources associated with kelp and macroalgal wrack making Snowy Plovers important indicators for indirect effects of MPAs on both abundance and reproductive success. This threatened species has specific landscape scale habitat preferences and tends to use wider beaches that do not have high bluffs, trees, and/or coastal development features that overshadow the beach and provide perches for avian predators for both nesting sites and overwintering roosts. For this reason, this species were regularly observed on half the study sites (18 sites), primarily open, lightly vegetated sandy beaches.

Our monthly surveys were designed to be conducted primarily outside the March to September nesting season for snowy plovers to avoid potential disturbance to chicks and nests. Thus our results largely reflect post breeding and wintering distribution of this special status species. Ten of our 36 study beaches currently support nesting of Western Snowy Plovers and 12 of our sites in the Central and South regions appear to support wintering populations, including several MPAs (**Appendix_Birds_Wrack,** Western Snowy Plovers, were the 2nd most abundant shorebird species in our surveys (overall mean 4.9 birds km^{-1}) making up 12.7% of the shorebirds observed with a total of 1228 individuals observed (**Appendix_Birds_Wrack Table 1,2**). The mean abundance of Western Snowy Plovers was more than 30% greater at MPA sites (5.9 birds km^{-1}) compared to reference sites (3.8 birds km^{-1}) (**Figure 57**) inset) but that difference was not significant in an overall ANOVA ($F_{1,64}$=0.93 p=0.33). The abundance of Snowy Plovers varied greatly among beaches, with means ranging from 0 to 52.9 birds km^{-1} **(Figure 57).** The peak abundance of snowy plovers observed in a single survey during the study was 94 individuals at Campus Point west (MPA) (**Appendix_Birds_Wrack Table 1, 2**), this MPA beach is an important wintering as well as a nesting site for this threatened species. Other study beaches

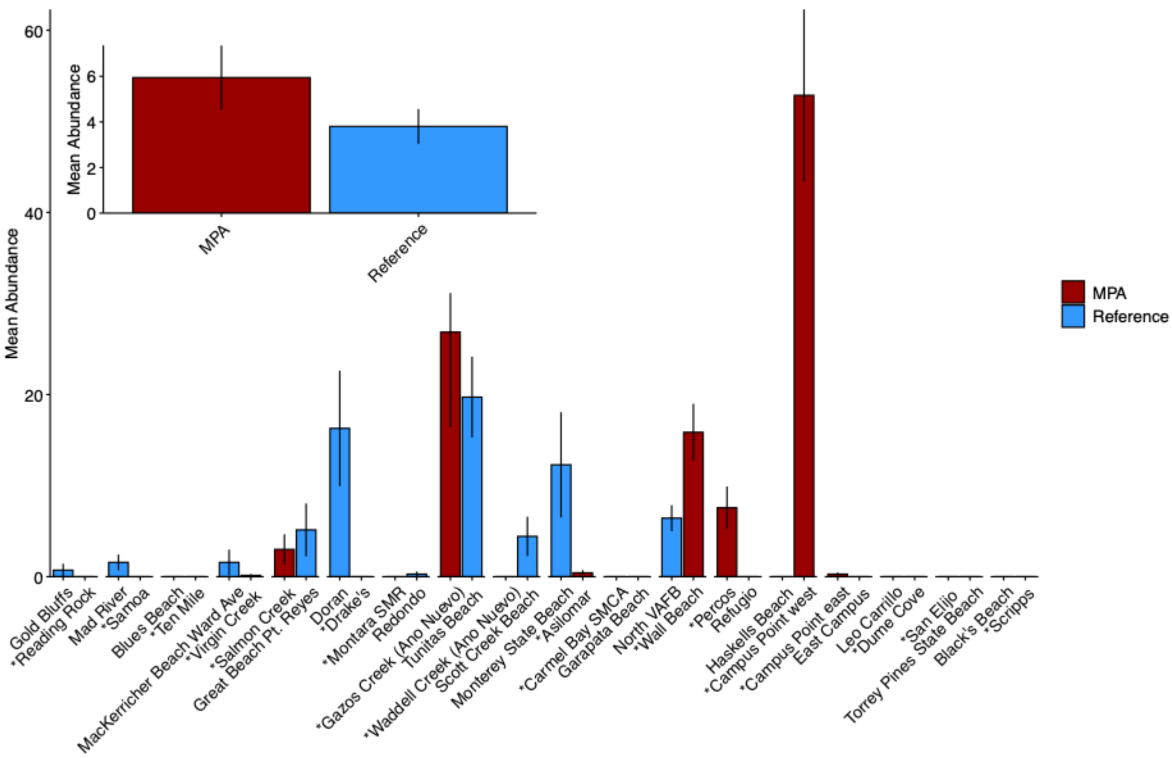

Figure 57 Mean abundance (± 1 standard error) of Snowy Plovers captured at all of our study sites. All monthly surveys at that site are averaged. Inset shows mean (± 1 standard error) abundance of Snowy plovers at MPA and reference sites statewide.

where average abundance of Snowy Plovers exceeded 10 birds per km included Doran (Ref), Tunitas (Ref), Gazos (MPA), Monterey State Beach (Ref), and Wall (MPA) (**Figure 57)**. In general, the strong spatial variation of distribution of Snowy Plovers in our results likely reflects the species preference for wider beaches with more open landscapes, such as dunes, and few overhead perches for potential avian predators, like falcons and ravens, as well as the wintering flock behavior of some species.

Does the difference between MPAs and reference sites in the numbers or abundance of individuals of a focal and/or protected species increase over time?

Shorebirds

To evaluate this question, we compared the abundance of a key indicator group, shorebirds, using results from pre-MPA, MPA baseline and our Phase 2 monitoring studies. The available pre-MPA and MPA baseline studies did not extend to the full range of our Phase 2 study sites, particularly on the Central coast, so we present results for only overlapping MPA and reference sites. We detected lower abundance for shorebirds in our current study than found in our earlier studies at a number of the study sites in all regions including MPA sites (**Figure 60**). For the eight sites in the North coast region where comparisons were possible, shorebird abundance at five sites (three MPA, two reference sites) was 68% to 83% lower in 2019-20 than in baseline studies. For the South coast, the abundance of shorebirds was much lower in our current study with declines of 41% to 84% at the three southernmost sites, San Elijo (MPA), Blacks (Ref), Scripps (MPA), and at Haskells (Ref) compared to the baseline study (**Figure 60**).

Major declines in shorebird numbers across the baseline and current study did not occur at all sites and no larger regional or MPA-related patterns were evident (Figure 60). On the North coast, the abundance of shorebirds was much greater in the current study than in the MPA baseline study at two sites, Gold Bluffs (Ref), and Salmon Creek (MPA) sites. On the Central coast, where only three sites were available for comparisons, the MPA site at Ross Cove and the MPA/Ref site pair (Wall and Minuteman) located on Vandenberg Air Force Base, maintained fairly similar shorebird numbers between baseline and our current study. On the South coast, abundance of shorebirds in the current study was slightly lower or similar to the baseline and pre-baseline studies at four sites (Campus Point West (MPA), Campus Point East (MPA), East Campus (Ref) and Dume (MPA)). For the 21 sites we could compare, appreciably higher numbers of shorebirds occurred at only four sites, Gold Bluffs (Ref), Salmon Creek (MPA), Refugio (Ref), and Leo Carrillo (Ref), in the current study.

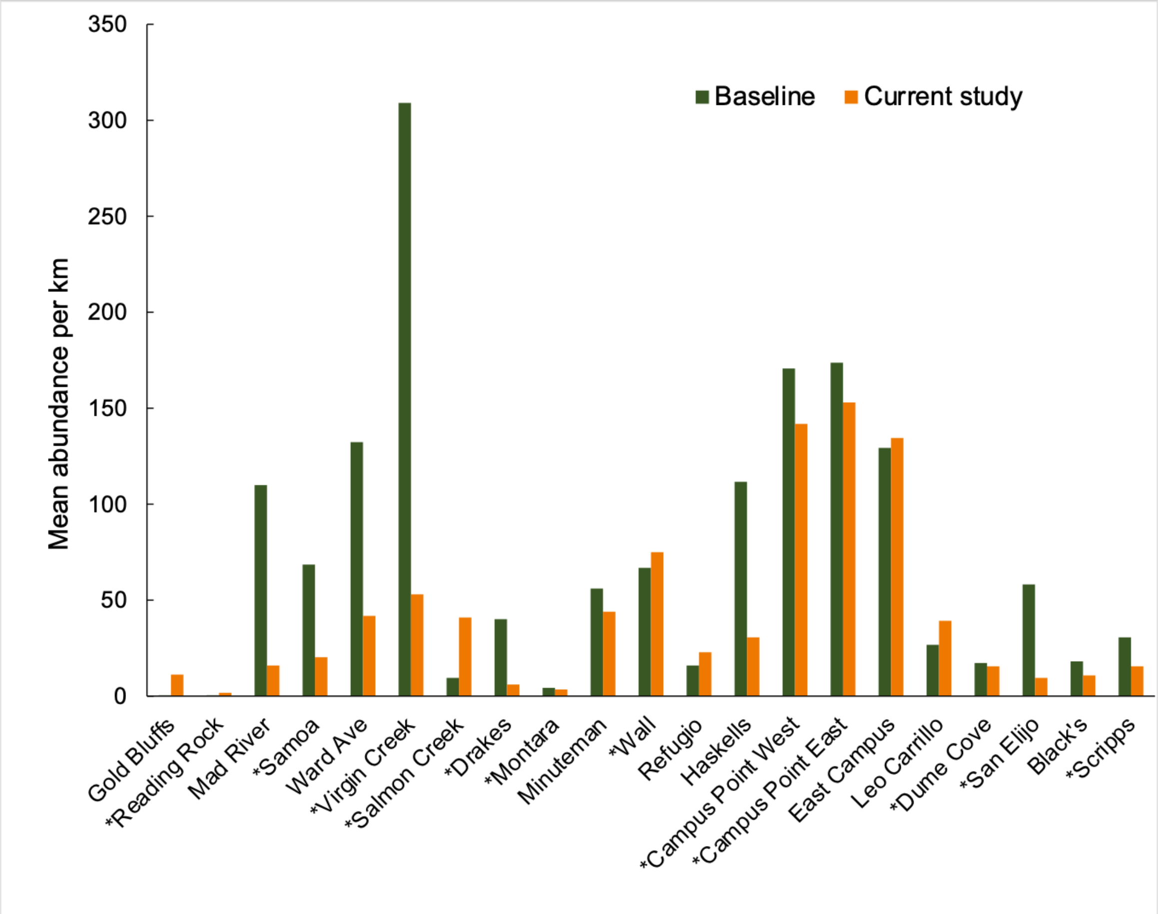

Figure 60 Comparison of mean values of abundance for shorebirds during baseline and current MPA studies for sandy beach study sites (MPA and reference) that were surveyed in at least two periods. Baseline values are represented by the dark green bars and the current study by the orange bars, n = 6 months. * denotes the MPA sites. Baseline periods differ by region and site: 2014-15 North coast sites, 2010-2011 North Central sites, 1998- 2001 Central coast sites (*Ross Cove, *Wall, Minuteman), 1998-2001 (Refugio, Haskells, *Campus Point West) and 2011-2013 South coast sites (*Campus Point East to *Scripps). Sites used in the available baseline studies did not fully overlap with our Phase 2 study sites, particularly on the Central coast where few baseline data exist. The Y-axis cropped at 200, the value for baseline abundance at Virgin Creek is listed at top of the column.

Our comparisons which show lower abundance of wintering shorebirds in both MPA and Reference sites including three site pairs suggest that this is more likely a response of shorebirds to larger factors affecting beach habitats and bird populations than to MPAs. Our finding that lower abundance of shorebirds was observed at sites in all regions during the current study is also informative. Although these comparisons represent multi-month views of wintering shorebirds on sandy beaches made in different time periods, the number of MPA/Ref site pairs where shorebird abundance was lower than in the baseline periods is notable as are the magnitude of the differences. **Collectively, these comparisons suggest that a statewide monitoring program for wintering shorebirds on sandy beaches is critically needed to understand how this key indicator group is responding to shoreline and ecosystem management, including MPAs, and to climate change and anthropogenic processes affecting the quantity and quality of sandy beach habitat**.

Is there a difference between MPAs and reference sites in community structure and/or species diversity within any given functional group or assemblage?

Inputs from Kelp Forests and Reefs to Beaches

Wrack surveys

The composition of marine macrophyte wrack varied among the study beaches but not with MPA status. Kelp and other brown macroalgae made up 0.04 to 76% of total cover and giant kelp (*Macrocystis)* alone made up 40% or more of the marine wrack at five study beaches across the Central and South regions: Garapata Beach (Ref), Carmel Bay (MPA), Asilomar (MPA), Campus Point west (MPA), and Leo Carrillo (Ref) **(Figure 58)**. Surfgrass, *Phyllospadix* spp. and eelgrass *Zostera marina* made up 0.01 to 96% of the total cover of marine wrack and surfgrass alone made up >50% of the wrack cover at 19 of the 36 study beaches **(Figure 58)**. The dominance of surfgrass at some beaches may be associated with the proximity of surfgrass beds (Leibowitz et al. 2016) and the rapid turnover and processing of kelp wrack by beach consumers, such as talitrid amphipods that do not consume surfgrass (Lastra et al.2008). Red algae was not observed at the North Coast sites.

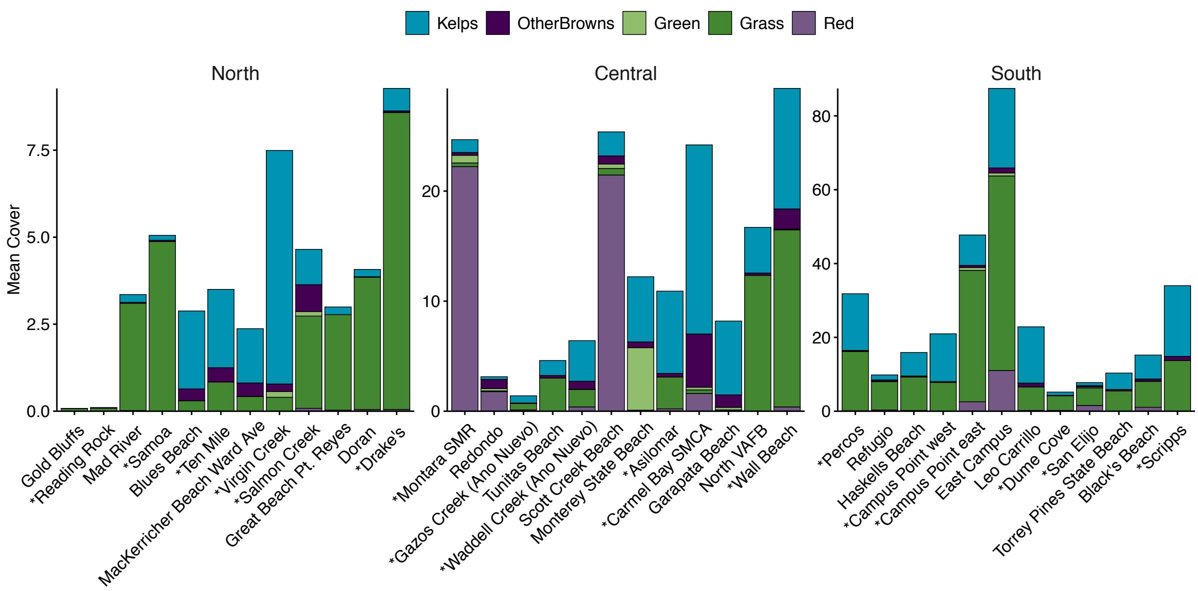

Figure 58 Mean cover of macrophyte wrack recorded at study beaches by major type and region. Kelps include Macrocystis, *Nereocystis, Laminaria, Postelsia palmaeformis, Egregia menziesii, and Pterygophora californica. Grasses include* surfgrass *Phyllospadix torreyi*, and eelgrass Zostera marina. Red and green algae groups were not generally identified to species but they likely include Turf and blady reds, and Ulva spp.. Other browns group includes brown algae including kelps not denoted as a large kelp including S*tephanocystis osmundacea, Desmerestia*, *Sargassum*, and unidentified brown algae.

Fresh wave cast Kelp Plants

The composition of fresh wave cast kelp plants observed varied among regions but not with MPA status. *Macrocystis* was largely limited to southern beaches while *Postelsia* was largely limited to northern beaches (**Figure 59**). All three kelp species were found in the Central region leading to high numbers of kelp plants on some of the study sites. Fresh *Postelsia* and *Nereocystis* plants dominated the beaches of the North region, while *Macrocystis* plants dominated beaches in the South region of the state.

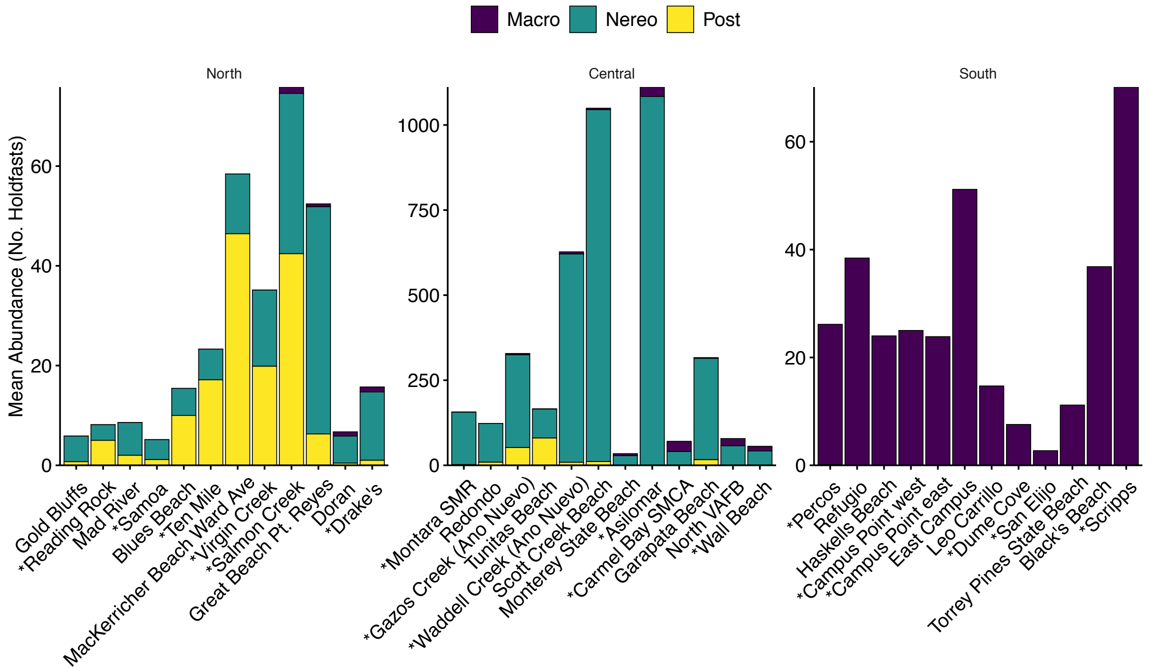

Figure 59 Mean values of abundance of three species of fresh wave cast kelp plants, *Macrocystis*, *Nereocystis* and *Postelsia*, in 1 km surveys across sites and by region. MPAs are denoted with an asterisk in front of the site name.

Birds of beaches and surf zones

Overall means of species richness of birds (all bird types) statewide did not vary inside and outside MPAs ($F_{1,246}$=0.2, p=0.65) or across regions ($F_{2,246}$=0.32, p=0.72) (**Figure 60**). This is not an unexpected result given the wide variety of bird species we observed, many of which would be expected to respond differently to MPA protection, if at all. The overall mean number of species of birds observed in our surveys was 8.3 species km^{-1}. See **Appendix_Birds_Wrack** for more details.

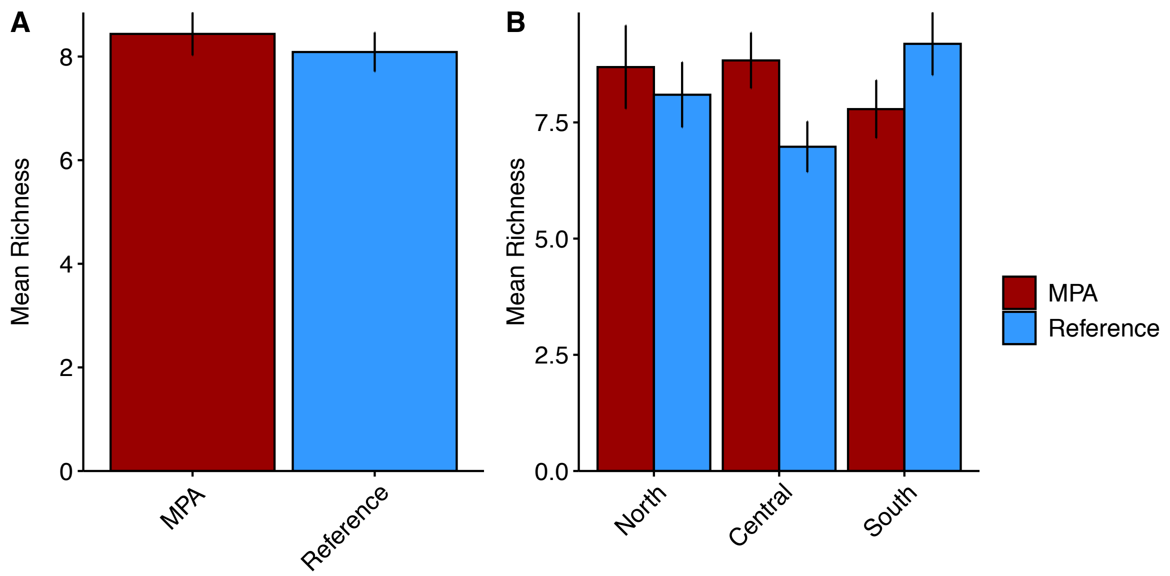

Figure 60 Mean richness(± 1 standard error) of all birds (types combined) examined as A) statewide MPA and reference site differences and B) regional MPA and reference site differences.

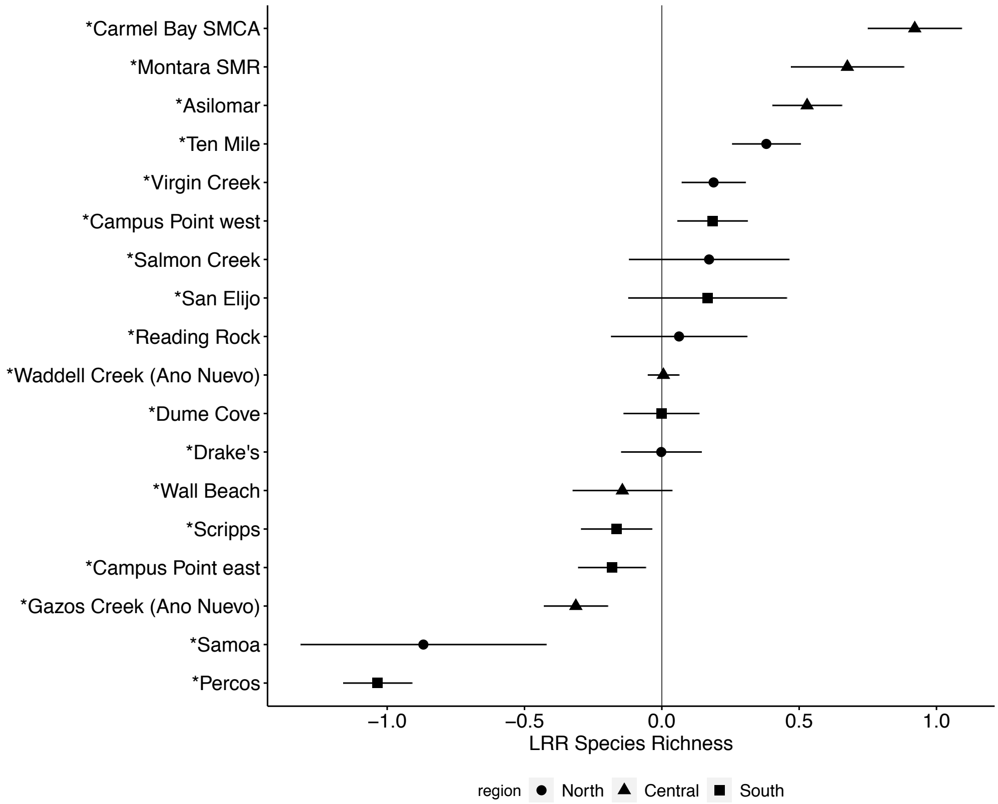

Figure 61 Log response ratio (LRR) of species richness for all birds. Here we show the mean for each MPA pair and the error bars represent one standard error. Values of LRR means and standard errors are based on each sampling event.

To examine more accurately whether there is a difference between MPAs and reference sites in species richness of birds we used the LRR (**Figure 61**). Six site pairs had positive LRRs showing higher richness inside MPAs; five had negative LRR showing lower richness inside MPAs; while the remaining seven pairs had a mean LRR that overlapped zero showing no difference in species richness inside and outside MPAs (**Figure 61**). The LRR values did not significantly differ from zero (Wilcoxon-Signed Rank test V=3226.5 p=0.38) indicating there was no consistent MPA signal in the overall species richness of birds.

Species richness varied among bird groups with greatest mean richness in the shorebirds, 3.7 species, followed by gulls,, 2.1 species, seabirds 2.0 species, and of other birds (terrestrial and aquatic/wading), 1.8 species. For each of the bird groups, the overall mean species richness observed was similar among MPAs and reference sites (**Figure 62**). Shorebirds and gulls accounted for 70% of the average richness but only 40% of the total species richness of birds observed in the study (41 out of 104 species). This result is related to the terrestrial birds observed on beaches which were diverse (22 out of 104 species) but occurred in low abundance. See **Appendix_Birds_Wrack** for more details.

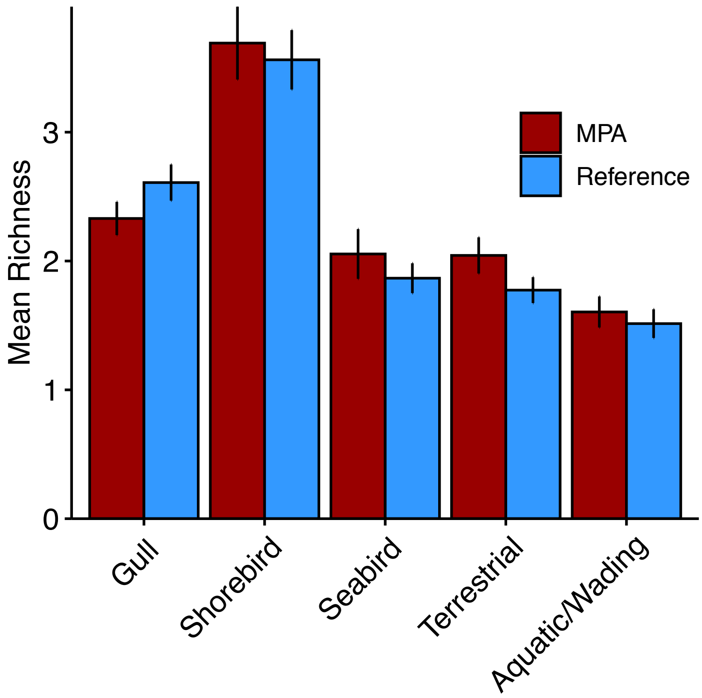

Figure 62 Mean species richness (± 1 standard error) recorded at each site averaged to MPA and reference for each bird type. Shorebirds had the highest mean richness while aquatic and wading birds had the lowest.

Community Composition

Birds of beaches and surf zones

To understand differences in community composition of birds inside and outside MPAs we examined nMDS (non-linear Multi-Dimensional Scaling) plots and preformed PERMANOVAs. Our nMDS analysis revealed that the community composition of birds across our sites (monthly surveys summed to total bird community at that site) did not vary significantly with any of the factors we evaluated including MPA status, Region, or their interaction (PERMANOVA) (**Figure 63**). None PERMANOVA suggesting overlap in community composition of birds among sites, regions, and in MPAs compared to reference sites. This is not unexpected given our study design with the strong differences among the 18 pairs of MPA/Ref sites for birds and associated factors. Despite this broad overlap, some bird species exhibited significantly different patterns forming three clusters of species. Environmental factors appear to be driving slight differences in some South region beaches, specifically the abundance of *Macrocystis* and the presence of people (**Figure 63**). However, substantial inputs of *Macrocystis* to the study beaches were almost exclusively found in the South and Central regions so this relationship may be related to the distribution of this kelp species which extends to Bodega Bay. A similar pattern of overlap of community composition across MPA and reference sites as well as across regions was found within each of the bird groups, shorebirds, seabirds, gulls, terrestrial birds and aquatic and wading birds (see **Appendix_Birds_Wrack**). The factors of MPA, region and their interaction were not important for shorebirds or any bird group (PERMANOVA) (see **Appendix_Birds_Wrack**).

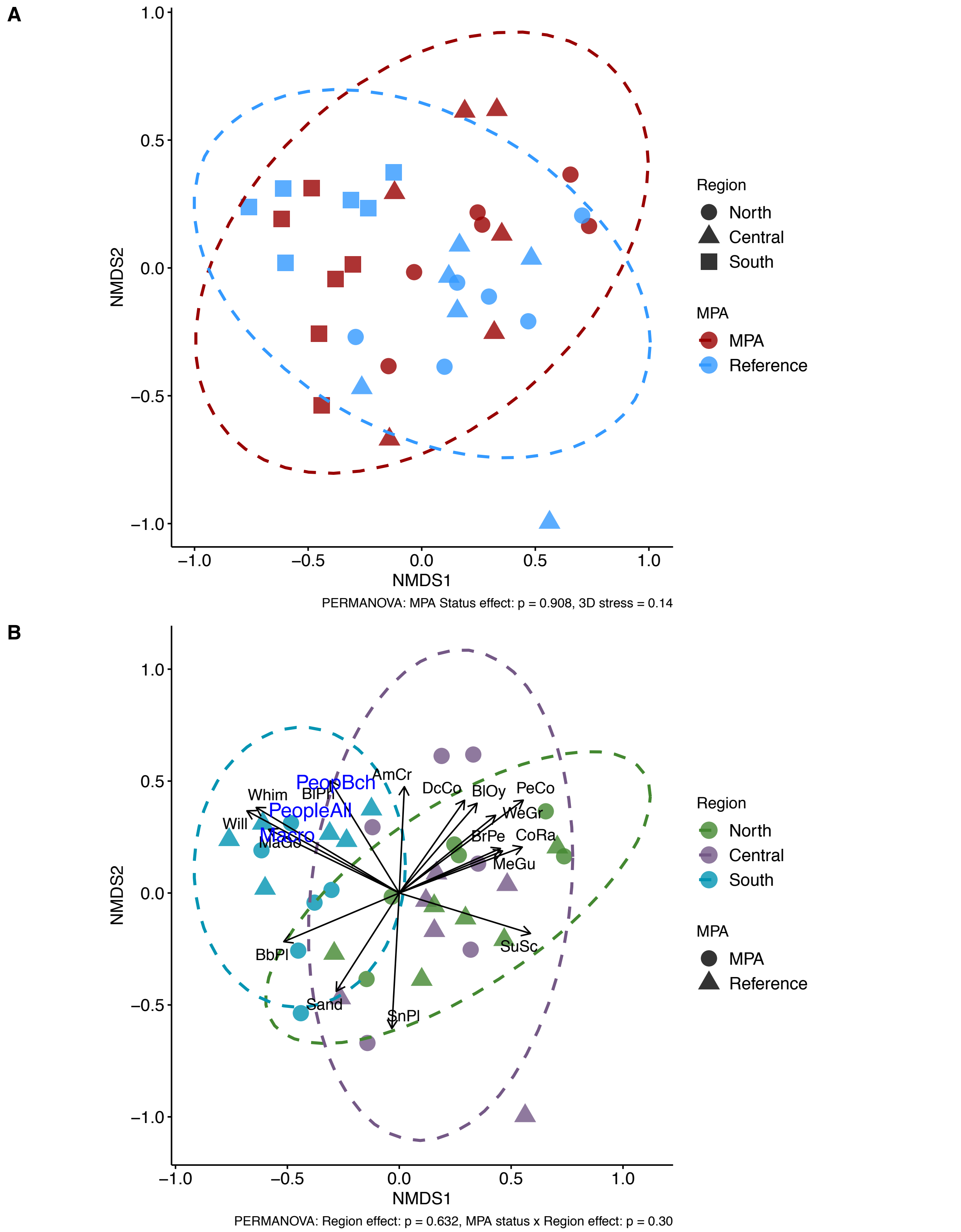

Figure 63 Site level nMDS plot for all birds. Shows site level abundances (all monthly surveys summed) with vectors of significant species by region and significant environmental factors. A) Shows MPA ellipses to highlight the overlap in community composition between MPA and reference sites. B) Ellipses show regional differences in community composition. Environmental factors appear to be driving slight differences in some South region beaches, specifically Macrocystis abundance and the presence of people. Analysis was completed on full dataset and the panels just show different plotting.

Responses to subsidies from kelp forests and reefs

Shorebirds

We explored the potential for indirect effects of MPAs on shorebirds by comparing the mean abundance and species richness of shorebirds with the abundance of wrack and of kelp plant inputs across the study beaches. In agreement with previous MPA baseline studies shorebird abundance was significantly correlated with the abundance of wrack (as cover) (**$y = 27x + 20$, $r = 0.50$, $p < 0.001$**) (**Figure 64**) indicating that beaches with more wrack supported greater numbers of shorebirds. The mean species richness of shorebirds was also significantly correlated with the abundance of wrack (**$y = 1.6x + 1.9$, $r = 0.54$, $p < 0.001$**) (**Figure 64**) indicating that more species of shorebirds occur on beaches with more wrack again in agreement with MPA baseline studies. Both of these relationships with wrack were strongest for results from the South region. Although these results strongly demonstrated the mechanism for potential indirect effects of MPAs on beaches via subsides from kelp forests and reefs, no effects of MPAs were evident in these relationships. This is not surprising given the lack of response of wrack abundance to MPAs in our results (**Figure 44)**.

In contrast to our results for wrack as cover, shorebird abundance and species richness were not significantly correlated with the abundance of all wave cast kelp plants (abundance, $R = 0.2$ $p=0.24$; richness, $R = 0.06$ $p=0.73$, $n=36$). Those relationships were stronger when only wave cast *Macrocystis* plants were considered, yielding a significant relationship with the mean richness of shorebirds (**$R = 0.416$, $p = 0.03$, $n = 28$**) but not with the abundance of shorebirds ($R = 0.29$, $p = 0.13$, $n = 28$) and again no MPA effect was evident. This result for abundance of shorebirds and kelp plants is surprising in view of the significant trends with total marine wrack as cover in this study and previous results for shorebirds and wave cast kelp plants on California beaches in the MPA baseline studies of North (2014), North Central (2010) and South (2012) coast regions and other studies (Emery et al. 2021). A number of factors that may affect both shorebirds and kelp plant delivery to beaches may be contributing to these results, including kelp forest condition, particularly the major loss of *Nereocystis* forests on the North coast, beach erosion, shorebird population trends, the presence of falcons, human activities and other factors. The intense population die-off of *Nereocystis* in the North region, a 95% decline these kelp forest over 350 km of coast beginning in 2014, (McPherson et al. 2021) may contribute to our finding of an altered relationship between kelp plants and shorebirds. **The statewide lack of long term monitoring of these key indicators on sandy beaches makes it difficult to evaluate this observed shift in the relationships between the abundance and diversity of shorebirds and kelp plant inputs to beaches.**

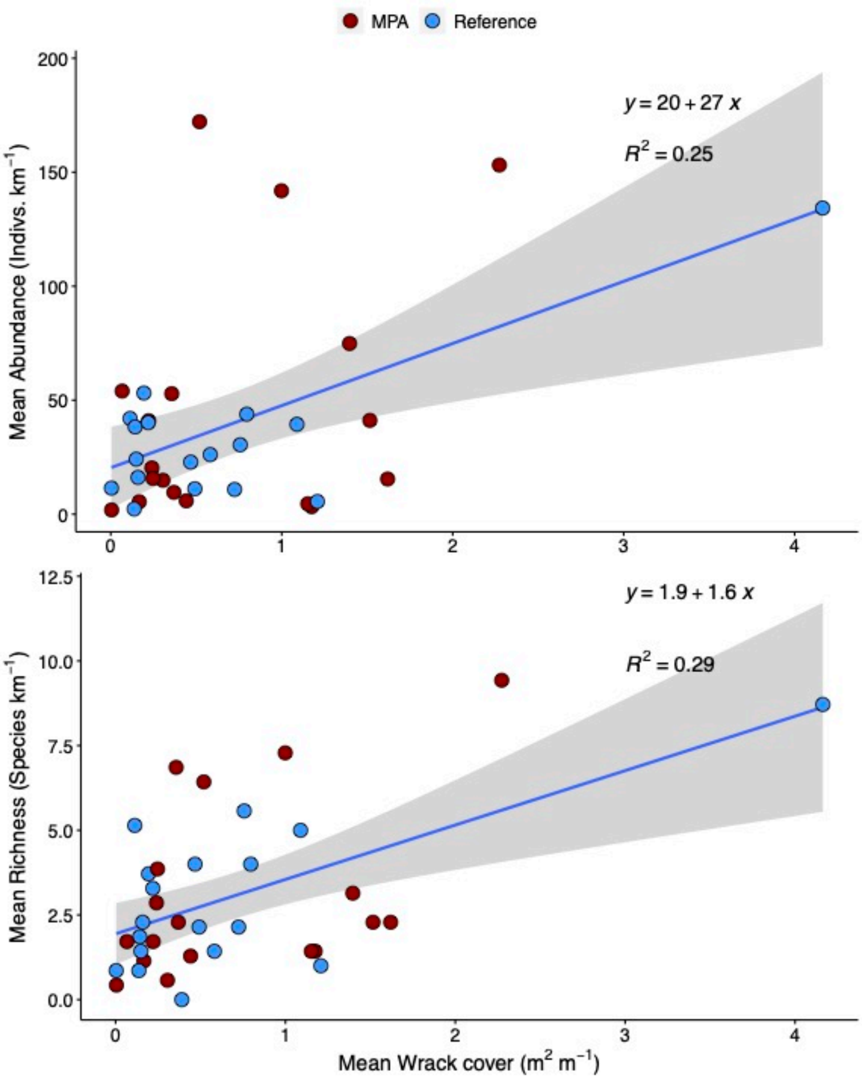

Figure 64 Relationship between the mean abundance of shorebirds and the mean abundance of marine wrack (as cover) on the 36 study beaches. Shows values for MPA (red) and reference sites (blue).

Discussion

In our statewide study of the responses of beach and surf zone ecosystems to MPA management we used our results to address two of the MPA Action Plan goals and a number of the recent Decadal Evaluation Working Group (DEWG) questions. Due to the lack of long term monitoring in this understudied ecosystem, we modified the DEWG questions to remove the aspect of "over time" for our comparisons.

Our results for beaches and surf zone evaluated and contrasted potential direct effects of MPA management on communities and populations that are harvested, namely surf zone fish and potential indirect effects on indicators are not harvested but might benefit from connectivity within MPA habitats, specifically kelp and wrack subsidies from rocky reef habitats to beaches and the birds that forage on beaches.

The high variability in local and regional conditions of beaches and surf zones in California MPAs requires that evaluations rely on well matched reference sites. Otherwise this naturally high variability could override MPA signals in biota or indicators. Observed patterns in community structure, abundance, and richness of target taxa (surf zone fish and shorebirds) and physical characteristics suggest that MPA and reference site pairs in this study were generally well matched with few exceptions. Despite our effort to minimize variability within an MPA and reference pair, background variability in species distributions, movement, and other characteristics can affect the ability to detect differences in ecological indicators inside and outside MPAs in a short term study like ours.

Direct effects of MPAs

Our evaluation of direct effects of MPAs for beaches and surf zone used surf zone fish, many of which are targeted by sport fishing from shore. Our study provided the first statewide comparisons of surf zone fish and evaluated potential ecological indicators for these fish communities. For surf zone fish, we focused primarily on questions concerning the abundance, biomass and population size structure of fish as well as their species richness and composition. Our results for surf zone fish found positive responses to MPAs for abundance, biomass and size structure as well as species richness but some of those results varied with survey method. Targeted species of surfperch, croakers and elasmobranchs showed the strongest potential responses to MPA management. Overall, our results provide new evidence supporting the direct effects of MPAs associated with protection from harvest for beach and surf zone ecosystems and add to the body of knowledge on responses of harvested species to MPA management in marine ecosystems.

The detection of direct effects of MPAs on surf zone fish varied among methods and metrics. The two survey methods, beach seines and surf BRUVs, we used are considered to be complementary for surf zone fish (Esmaeili et al 2021) but yielded largely contrasting results with respect to MPA effects on abundance and species richness. This may be a result of these survey methods detecting overlapping but different assemblages of fish. For example, a number of species of flatfish and of rocky reef fish were detected on the BRUVS that were not usually caught in the seines. Surf zone fish assemblages may also differ with water depth, the surf BRUVs are deployed in deeper water (6-10 ft) than the beach seines. Once deployed the BRUVs create far less disturbance than a seine and may be better for detecting schooling fish which could actively avoid beach seines. The BRUVs also contain bait which may attract fish of a wider variety of species,

Our fish survey methods are non-selective with regard to fish size which has important implications for interpreting our results on abundance and size structure of surf zone fish and for comparisons to results for fish in reef and other ecosystems. Surf zones can be nursery areas for a number of fish and floating macrophytes provide shelter to juvenile fish (Olds et al. 2018, Lenanton et al.1982, Robertson and Lenanton 1984). For the beach seines, fish numbers were largely dominated by juvenile fish, primarily targeted species, that were generally too small to be caught by recreational shore fishing. This means that comparisons of mean total abundance of surf zone fish in the seines included large numbers of juvenile fish that were not subject to harvest. This may contribute to the contrast of our seine results with those from surf BRUVs results, which found greater abundance of fish inside MPAs. This could also motivate additional analyses that separate adult and juvenile fish for surf zones more broadly.

Length measurements from our beach seines allowed comparisons of the size structure of populations of abundant species, like surfperch. The surfperches, Embiotocidae, are a prime example of targeted fish that may respond to MPA management. Surfperches are viviparous, producing small numbers of relatively large well-developed juveniles (Baltz 1984) that do not disperse far from their natal sites, making them potentially vulnerable to local fishing and excellent candidates for evaluating direct effects of MPAs. In contrast to species with planktonic larval or juvenile stages that use a variety of marine habitats before maturing, newly born surfperch remain in the adult surf zone habitat and adults of several species move to shallow zones of beaches to give birth. For this reason, increases in the numbers, biomass or size of adult surfperch as a result of MPA protection could lead to higher juvenile recruitment rates within that same MPA. Our results for two fished species, barred and silver surfperch, showed the abundance of both large adults and of juveniles were greater in MPAs than in reference sites. For both species of surfperch, the overall mean size of largest adult fish (90^{th}%ile size) was greater in MPAs than reference sites. These results suggest that responses to MPAs can include a wider range of sizes that reflect the productivity of large mature fish in an MPA. Hence, the abundance of juveniles, particularly for live bearing fish like surfperch where resident adults and their offspring occupy the same habitat, may represent an important MPA signal for surf zones.

The strength and direction of direct effects of MPA management on surf zone fish varied across the three regions of the mainland coast. Regional differences represented a substantial source of variation for surf zone fish and for their responses to MPAs. The greatest differences between MPA and reference sites were generally found in the South region, examples include overall fish abundance as Max N and total and targeted fish biomass as well at the abundance of selected species. For some metrics, MPA effects in the South region underlie the statewide patterns. The variation in the strength and direction of surf zone fish responses to MPAs with region may be related in part to regional differences in the fish assemblages. For example, elasmobranchs which responded positively to MPAs were more abundant in the Central and South regions while croakers were most abundant in the South. These findings may also be related other factors including the amount and distribution of recreational fishing pressure, public compliance, and the relative age of MPAs. Human population density is highest in the south coast region and sport fishing from shores and piers are very popular, the establishment of MPAs might have created a stronger spatial gradient in fishing effort than in other regions but data of fishing effort to evaluate this possibility are limited.

The variation in ages of the different MPAs may play a role in the relative level of responses we observed in surf zone fish. A relationship between response and MPA age was shown for the Channel Islands MPAs, (Caselle et al. 2018) and older vs newer parts of the Point Lobos MPA (Starr et al. 2015).The youngest MPAs in our study are located in the North coast region and the majority of these were established in 2014 (6 years before our study). The age of the Central Coast MPAs varies more with Pt Lobos established in the early 1970s being the oldest MPA while most of the others we studied were established in 2007 making them more than 10 years old during our study. Of the five MPAs we studied on the South mainland coast, three were established long before the MLPA process for the region (Scripps, Laguna Beach and Dume Cove). For example, the original Scripps marine reserve was established in 1957 making it one of the oldest MPAs in this study. The MPA site at Point Conception (Percos) is recently established but has historically had and continues to have very limited human access for shore fishing. The Campus Point SMCA (2012) is the most recently established MPA in the region that was accessible prior to the MLPA process for the South region.

Indirect effects of MPAs

Our evaluation of potential indirect effects of MPAs focused on wrack inputs to beaches and trophic links to birds using beaches and surf zones. For these response variables we addressed the questions concerning abundance and diversity with a focus on trophic connectivity between kelp, wrack and shorebirds. For shorebirds we also explored the potential effect of MPAs on abundance of the Western Snowy Plover, a resident breeding species listed as threatened. Overall, our results indicated much less support for indirect effects of MPAs that depend on connectivity and trophic exchange with kelp forests and reefs. However, the strong links between shorebirds and the abundance of wrack we found in this study support the underlying trophic connectivity by which indirect effects of MPAs could operate.

Macrophyte wrack is a key connection between beach and kelp forest and reef ecosystems (Dugan et al 2003). Primary production of marine macrophytes, such as kelps, red and green macroalgae and sea grasses, is a vital ecosystem function that provides food and habitat that supports food webs, secondary production, and biodiversity in rocky reefs and estuaries. Once macrophytes are removed from donor ecosystems by waves or life history, many of these drifting macrophytes are deposited on sandy beaches (Hobday 2000) where they are rapidly consumed fueling major components of the intertidal food web, including biodiversity and secondary production of endemic intertidal invertebrates (Dugan et al 2003, Lastra et al 2008, Emery et al. 2021). In turn these abundant invertebrates are prey for the diversity of birds and fish that inhabit and use sandy beaches and surf zones. Connectivity with kelp forest and reef ecosystems can greatly affect the quantity and quality of wrack subsidies to beaches. Heatwaves and ENSO events that impact the condition of kelp forests and of beaches can affect this trophic connectivity (Revell et al. 2011, Barnard et al 2017). The growth and impacts of invasive species of macroalgae in kelp forests (e.g. *Sargassum horneri, S. muticum*), many of which are less palatable to intertidal invertebrates, may also affect beach food webs.

For the majority of metrics, we evaluated for indirect effects of MPAs, significant MPA effects were not detected statewide but again effects varied among metrics and regions. Our surveys for these metrics were limited to a portion of a single season and temporal variability in wrack inputs and birds on beaches can be substantial (Revell et al 2011, Hubbard and Dugan 2003). Continuing surveys of these metrics for additional seasons will enhance the ability to evaluate potential indirect effects of MPAs as well as the effects of climate change on these vulnerable edge ecosystems.

The abundance of wrack and wave cast kelp plant subsidies did not vary with MPA status but these metrics varied among regions. Wrack cover was highest in the South region and generally increased from the north to the south for both MPA and reference sites. Kelp wrack was generally more abundant in MPAs but not significantly different. The abundance of wave cast kelp plants differed significantly with region and were far more abundant in the Central region where all three species of large kelps occur.

The large spatial differences we observed in macrophyte wrack accumulation and composition at the study beaches are also likely related to the proximity of rocky reefs and prevailing swell exposure and wind patterns (e.g. Cavanaugh et al. 2011). The presence of suitable upper beach zone is very important for the deposition and retention of wrack (Revell et al. 2011). This key zone is already affected by erosion and is projected to decline rapidly with sea level rise, particularly on bluff-backed beaches (Barnard et al 2021, Myers et al 2019). Human activities, like beach grooming and coastal armoring, both of which occur in MPAs, greatly reduce the retention of wrack subsidies on beaches, impacting intertidal food webs and shorebirds (Dugan et al. 2003, 2008, Dugan and Hubbard 2006, Schooler et al. 2017, 2019). The abundance of populations of the primary intertidal consumers of macrophytes, such as talitrid amphipods, can influence the turnover rates and affect the standing crop of macrophyte wrack observed on beaches, particularly for preferred taxa like the kelps (Lastra et al. 2008), a process that is likely reflected in our results on standing crop of wrack.

Large numbers of birds were observed in beaches and surf zones in our study, including gulls, shorebirds, seabirds and other birds indicating the importance of this habitat for marine birds. For birds (groups combined), abundance varied significantly among the regions, peaking in the central region, but not with MPA status. The most numerous groups of birds, gulls, were most abundant at sites on the central coast as were the seabirds.

Our study design and analyses of indirect effects for birds focused primarily on shorebirds due to their role as predators of intertidal invertebrates and food webs. The state's beaches represent an important ecosystem for migrating and wintering shorebirds including threatened and declining species. No overall effect of MPAs on shorebirds was detected, although average abundance was 30% greater in MPAs statewide. Within the central and south regions, average abundance of shorebirds was much greater in MPAs compared with reference sites. This was not the case in the north region where shorebird abundance was lower overall. In regions where wetlands have been degraded, such as Southern California, sandy beaches may represent more important foraging resources and habitat for wintering shorebirds.

Patterns of abundance in MPAs and reference sites varied among shorebird species. Although sanderlings, the most abundant species of shorebirds in our study, were overall more abundant in MPAs than in reference sites, that difference was not significant and variation among sites was high. The distribution of some shorebirds, such as the plovers, can be more strongly associated with the abundance of kelp and macroalgal wrack on California beaches (Dugan et al 2003) making them good potential indicators of indirect effects of MPAs associated with kelp forest condition and productivity. Black-bellied plovers, listed as an indicator bird species in the

MLPA Action Plan, were widespread across our sites and significantly more abundant in MPAs than reference sites. Western snowy plovers, a species listed as threatened, that can also be strongly associated with wrack occurred at many of our sites. However, abundance of wintering snowy plovers did not respond to MPAs although overall average abundance was greater in MPAs in our comparisons. Western snowy plovers were not widely distributed in our surveys, reflecting the strong landscape preferences for wider beaches with more open landscapes, such as dunes, and low availability of perches for potential avian predators, like falcons and ravens, as well as the wintering flock habits of this threatened species.

Although an overall effect of MPAs on shorebirds was not detected in our single season of surveys, the mechanism of trophic connectivity that would drive indirect MPA effects was present as significant relationships between the abundance and richness of shorebirds and wrack abundance on the study beaches. Shorebirds were more diverse and more abundant on beaches with that had higher abundance of wrack. This finding confirms that the large subsidies exported by kelp forests are important and that the condition of kelp forests can affect beach ecosystems. The unprecedented and sustained disappearance of bull kelp forests in the North coast region starting in 2014 and continuing through our 2019-2020 study period (McPherson et al 2021) has certainly affected subsidies of bull kelp to beaches with impacts to intertidal food webs and the prey resources available for migrating and wintering shorebirds. The low numbers of shorebirds observed on the north coast in our study are consistent with this pattern.

Despite the lack of evidence of indirect effects of MPAs detected for shorebirds, a number of beaches in MPAs appear to be important habitat that can support large numbers of migrating and wintering shorebirds. For each of the three regions, the peak or near peak values for mean shorebird abundance were observed in MPAs suggesting some California MPAs represent important habitat for wintering shorebirds and should be considered in state and regional conservation planning (Hickey et al 2003). This finding is relevant beyond the scope of our study as populations of many species of shorebirds are declining in North America and habitat conservation is needed for all life stages of these mobile sentinels (Bart et al 2007, Warnock et al 2021). Our findings for shorebirds on beaches highlight the conservation value of California's MPAs for species that are not fished or harvested and the potential for MPAs to provide benefits to these species and be used as a tool in their conservation.

Shorebirds are considered sentinels of global environmental change (Piersma and Lindstrom 2004). For our study sites where baseline information on shorebirds was available, major declines in abundance (40 to 84%) between the baseline and the current studies were evident at a number of MPA and reference beaches. These observed declines occurred in all regions and were not uniform within a region as some sites maintained or showed increased in shorebird numbers across the two survey periods. Gaps between the baseline surveys and the present survey varied widely by region ranging from 5 years to > 20 years. It is challenging to evaluate the generality of these observations on shorebirds without a broader context of long-term monitoring. However the results of these comparisons suggest that a statewide monitoring program for wintering shorebirds on sandy beaches is critically needed to understand how this key indicator group may be responding to shoreline and ecosystem management, including MPAs, and to the manifestations of climate change affecting the quantity and quality of sandy beach habitat for these avian sentinels.

Climate change and MPAs
Our findings for surf zone fish suggest that they are responding to MPA management. Many surf zone fish are microbenthivores (appendix) and several important species, such as barred and redtail surfperch and California corbina, that feed primarily on intertidal prey of sandy beaches. This strong food web connection means the intertidal prey resources and habitat quality for surf zone fishes as well as shorebirds are likely to be adversely affected by impacts to beaches from sea level rise and erosion associated with climate change (Myers et al 2019). Human impacts including coastal armoring, as well as widespread beach management practices, like beach grooming and beach filling, also adversely affect intertidal food webs for fish and shorebirds through impacts on intertidal invertebrates (Jaramillo et al. 2021, Dugan et al. 2003, 2008, Schooler et al. 2017, 2019). It is also likely that the prevalence and intensity of some of these human impacts, e.g., armoring and beach filling, may increase in response to the effects of climate change on the coast. Beaches and surf zones in MPAs have the potential to provide refuges for surf zone fish and birds in a changing climate but adjustments to beach management to reduce impacts would enhance the potential benefits of MPAs to these ecosystems, particularly along the developed mainland coast.

Conclusions and Management Recommendations

Our study is the first statewide baseline study for open coast beaches surf zones and has generated the first temporally comparable data across the entire state for these ecosystems. Overall, we detected a number of significant direct effects of MPAs for sandy beach and surf zone ecosystems, particularly for surf zone fish. However, the lack of statewide long-term monitoring of key indicators for sandy beaches and surf zones complicates the goal of evaluating the effects of MPA management.

The refined MPA questions from the Decadal Evaluation Working Group (DEWG) had to be modified for use with the majority of our results due to the inclusion of the phrase “over time” in those questions, however our results provide new insights and information on the responses of sandy beach and surf zone ecosystems to MPAs and on the presence of numerous indicator taxa and species not covered by any other MPA monitoring efforts. The initiation of long term monitoring programs and datasets on surf zone fish, as well as beach birds, wrack and characteristics, in MPAs and reference sites would allow the types of analyses needed to address the “over time” element of the refined DEWG MPA questions.

Although evidence for indirect effects of MPAs associated with trophic subsidies from kelp forest to beaches was not generally detected, continued monitoring appears to be warranted. At a subset of our sites where we have previous baseline data, some alarming declines in shorebird abundance were observed. It is difficult to evaluate the generality or impacts of these observations due to the lack of long-term monitoring of shorebirds at a broader scale. Given this, we recommend the implementation of long-term monitoring programs for surf zone fish, birds, and other taxa in order to understand the effects of MPA and other resource management and to evaluate climate change impacts on these vital coastal ecosystems.

Some MPAS appear to be ‘hotspots’ for surf zone fish and shorebirds, including some older MPAs or those where access has been limited historically. Specific MPAs (SMR and SMCA) and other sites with beaches and surf zones that support high abundances or species richness of important species or indicators are recommended as candidates for maintaining their current protections and adding additional protection to preserve these ecological hotspots.

Broadly speaking, California MPAs restrict extractive activities or consumptive uses within the boundaries of the MPAs, but do not restrict visitation, access or numerous other activities within their boundaries. Importantly, MPAs in California were not explicitly designed to protect entire sandy beach ecosystems. Many of the state’s MPAs currently do not include or protect a major portion of the intertidal zone of shoreline ecosystems because their jurisdiction only extends up to the mean high tide line. Sandy beach ecosystems encompass the sandy habitats and intertidal zones above the mean high tide level (MHTL), as well as the surf zone. Critical components of the structure and function of sandy beach ecosystems rely on the zones and habitats above the mean high tide line. These components include upper intertidal zones that support 40-50% of the intertidal biodiversity, wrack deposition and processing zones, essential spawning habitat for California grunion, nesting habitat for endangered and threatened birds and the coastal strand and dune zones that store sand. These zones are tightly linked ecologically and geomorphically and cannot be effectively managed in isolation from each other. For example, the highly mobile intertidal animals that are prey for surf zone fish and shorebirds use much of the available beach width to adjust to changing beach conditions and seasonal dynamics (Dugan et al. 2013).

Sandy beach and surf zone ecosystems can experience intense ecological impacts from destructive beach management practices, such as coastal armoring, beach grooming and beach filling , particularly above the mean high tide line (Jaramillo et al 2021, Dugan et al 2008, Schooler et al 2017, 2019). These impacts significantly affect intertidal biota and food webs as well altering beach habitat characteristics and quality. Without additional protection for entire beach ecosystems by adjacent management entities, such as state and national parks or reserves, these widespread management activities represent major threats to the health of sandy beach and surf zone ecosystems, regardless of MPA status. For example, in the South coast region, regular beach grooming occurs on 45% of the beaches (Dugan et al. 2003) including miles of beaches located in MPAs, degrading the intertidal zones of beaches (Schooler et al 2017, 2019). In addition, more than 25% of the coastline of the South coast region is armored with hard structures such as seawalls and revetments (Griggs 2005) many of which reduce beach habitat and affect biodiversity (Dugan et al 2008, Jaramillo et al 2021). The extensive armoring of sea bluffs has also reduced the supply of sediment to beaches by 10% (Runyan and Griggs 2003) in the region. Beach filling or nourishment, including dredge spoil disposal, is also widely practiced in the SC region, with >70 million m^3 of sediment added to south coast beaches in the past 75 years (Orme et al. 2011). However, little information on the ecological impacts of this and other sediment management practices to beach and surf zone ecosystems as well as to nearby rocky reefs and estuaries are available for California's coast, where a complex mosaic of these habitats prevails, including those in MPAs.

In summary our recommendations include

- Initiating and establishing long term monitoring programs for beaches and surf zone with metrics including surf zone fish, shorebirds, invertebrates, wrack and beach characteristics, in MPA and reference sites, that will
  - Provide the data for analyses needed to address the "over time" element of DEWG MPA questions
  - Track long term trends in these indicators across state and regional scales
  - Provide context that allows analysis of responses to climate change that can inform MPA management

- Leveraging the MPA network to encourage managers to provide greater protection to beach ecosystems above the mean high tide line and for ecologically important features including wrack, upper beach zones, surf zones, dunes, and sediment budgets as well as linked features like lagoon, river and stream mouths.

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