MPA Beach and Surf Zone Study Sites and Methods

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 1).

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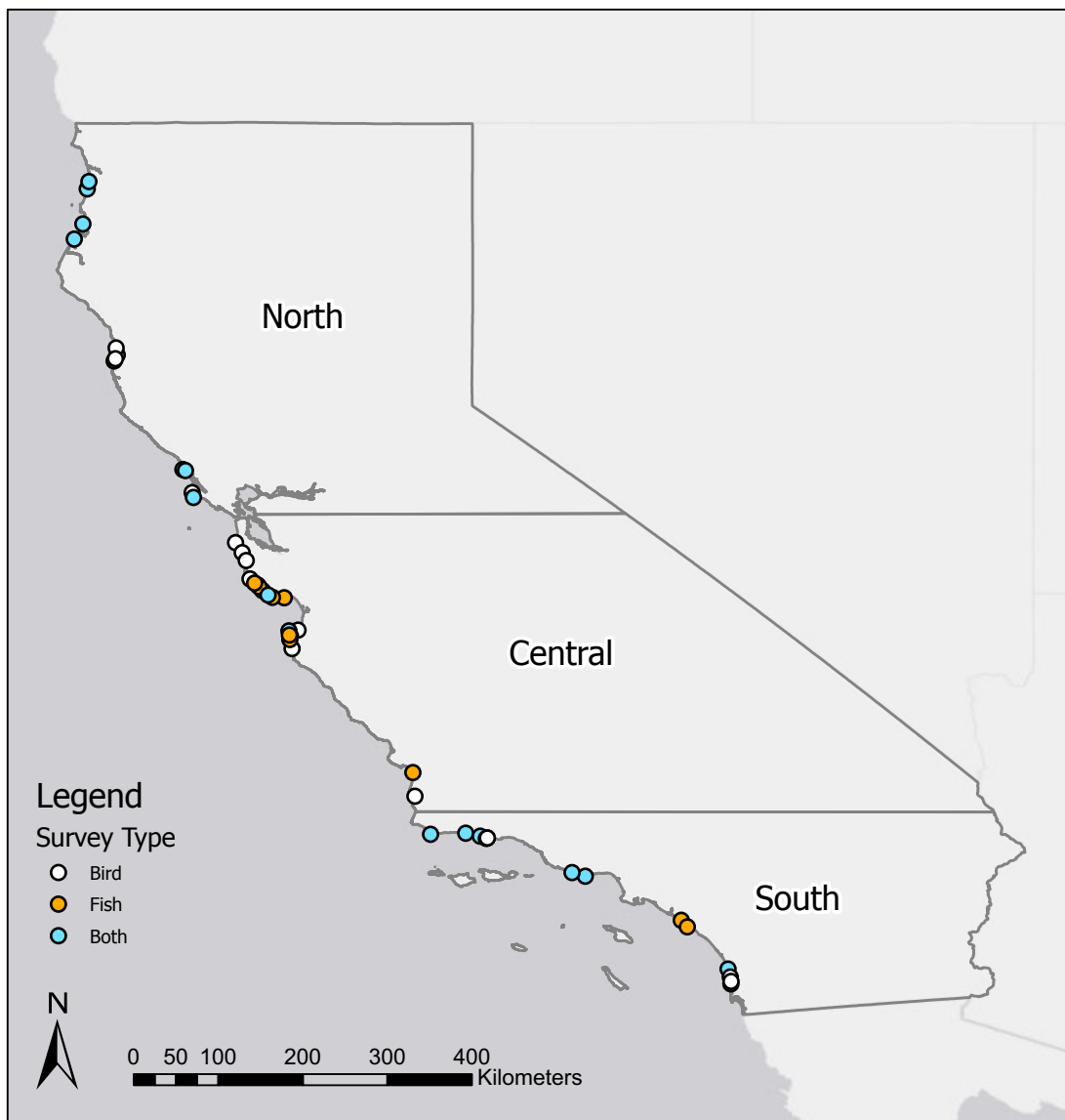
Figure 1 Locations of our beach and surf zone survey sites along the mainland coast of California by region. Both fish and bird surveys were conducted at some sites (blue dots) while other sites were used for one survey type depending on the beach characteristics and conditions.

Table 1 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		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.