Title: Preferential selection of marine protected areas by the recreational scuba diving industry
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Abstract

Extensive research has illuminated the diverse values of marine protected areas (MPAs), including protecting biodiversity, promoting climate change resilience, and enhancing spillover to fisheries. Comparatively less attention has been given to if and how MPAs can benefit and influence marine ecotourism. Here we use Automatic Identification System (AIS) vessel data to create a long-term, high-resolution portrait of how MPAs shape the behavior of one prominent form of marine ecotourism: scuba diving. Specifically, we explore how the spatial use patterns of scuba diving vessels are affected by MPAs in California's Northern Channel Islands when these vessels are engaged in two use scenarios: 1) non-extractive ecotourism diving (e.g., wildlife viewing, photography) and 2) recreational scuba-based lobster fishing. Using analyses of AIS data and resource selection models, coupled with insights from vessel operator surveys, we find that scuba diving vessels preferentially selected for MPAs when engaged in ecotourism activities, and for MPA buffer zones when engaged in lobster fishing (i.e., "fishing the line"). These conclusions provide strong evidence of the benefit of MPAs for the scuba diving industry in Southern California and highlight the value of engaging the ecotourism industry in MPA management decisions. This observation is especially timely as state, national, and international bodies advance on commitments to protect 30% of coastal waters in the coming years.

Keywords: Marine protected areas, scuba diving, ecotourism, lobster, automatic identification system, Channel Islands

1. Introduction

In the last few decades, extensive research has illuminated the diverse values of marine protected areas (MPAs). These include but are not limited to contributions to biodiversity and ecosystem health [1–4], climate change resilience [5], and fisheries spillover [6–8]. Comparatively less attention has been given to how MPAs can benefit and influence marine ecotourism, which not only provides significant income to local economies, but also offers meaningful benefits to human wellbeing and creates incentives for ecosystem-based management and conservation [9,10]. Quantitative research on how MPAs shape fine-scale spatial decision making of ecotourism businesses is even more rare.

One prominent form of marine ecotourism that can benefit from the positive effects of MPAs, as well as potentially impact the performance of MPAs, is scuba diving [11]. Scuba divers may be attracted to MPAs because of many of the commonly documented benefits that MPAs offer, including greater biodiversity and more and larger organisms [12]. The attraction of divers may be related to the pursuit of non-extractive activities such as underwater photography or extractive activities such as spearfishing or collecting. While strict no-take marine reserves generally forbid all forms of fishing, many MPAs allow some extractive activities within their boundaries [13,14]. In addition, as biomass builds up inside MPAs, individuals are expected to spillover into fished areas [7,15]. Previous work has documented increased fishing effort on the

boundaries of MPAs ("fishing the line") [16–18] as well as greater catches of trophy sized fishes near MPAs [19,20], but to the authors' knowledge limited other studies have documented this behavior for recreational fishing with scuba [21].

Past considerations about the establishment of new MPAs or changes to existing MPA management have focused primarily on engagement with fishers (large- and small-scale) and evaluations of how this management tool affects fishing. Ocean ecotourism, however, is a fast growing sector of coastal economies with a significant stake in the health of coastal biodiversity and the future of coastal planning. Marine and coastal ecotourism is one of the largest sectors in the ocean economy and alone constitutes 50% of all global tourism, equal to $4.6 trillion [22]. Between 8.9-13.6 million marine diving tourists support 124,000 jobs worldwide, global annual revenue is between $0.9-3.2 billion per year, and the broader economic impact is between $8.5-20.4 billion per year [23]. In California, marine and coastal tourism contributes approximately $26 billion in gross domestic product to the state's economy each year [24]. Based on surveys of 17 for-hire scuba diving vessel operators in Southern California, Guerra et al. [25] estimated 55,280 for-hire vessel diver days per year. Given the important role of the scuba sector in the blue economic portfolio of small and large coastal communities, it is important to understand how this stakeholder community relates to and is influenced by MPAs.

To elucidate the decision-making patterns by for-hire scuba diving vessels, this study leveraged insight from Automatic Identification System (AIS), an onboard vessel broadcast system that shares high-resolution vessel location and behavioral information [26]. Relationships between for-hire vessels and MPAs were investigated in California's four Northern Channel Islands – Anacapa, Santa Cruz, Santa Rosa, and San Miguel – a popular dive destination that hosts a mosaic of protected and fished marine space. At the federal level, the National Oceanic and Atmospheric Administration (NOAA) manages the Channel Islands National Marine Sanctuary, which encompasses 1470 square miles of ocean waters up to six nautical miles offshore of the Northern Channel Islands, plus Santa Barbara Island further to the south. Landside of these five islands, the National Park Service oversees the Channel Islands National Park. At the state level, the California Department of Fish and Wildlife has management authority over the state marine waters including 12 MPAs (10 no-take state marine reserves and two partial-take state marine conservation areas). Several of these MPAs also extend into federal waters (**Figure 1**).

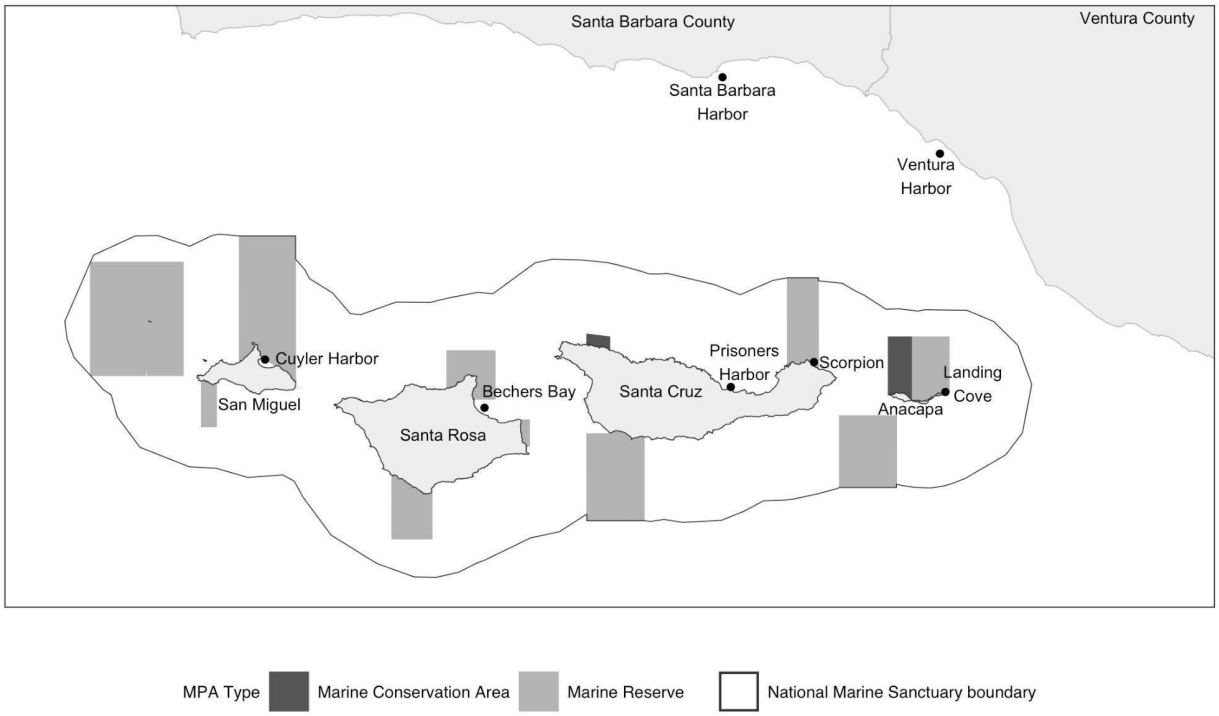

Figure 1. Map of the four focal Northern Channel Islands in this study indicating the boundaries of the National Marine Sanctuary and the marine protected areas, which are classified as marine conservation areas (MCAs; permit limited harvest including lobster) and marine reserves (MRs; fully no-take areas).

Touted as the “Galapagos of North America”, the diversity and abundance of marine life make the Channel Islands a globally popular destination for ecotourism activities. The islands’ position at the confluence of two major ocean currents supports remarkable biodiversity and productivity, is home to endangered species and sensitive habitats, and hosts important commercial and recreational fisheries. Divers are particularly attracted to the complex habitat structure offered by towering kelp forests and rocky reefs, and charismatic megafauna such as giant sea bass and sea lions (**Figure 2**). The MPA network across the northern islands, interspersed between non-MPA zones that yet are encompassed by the Marine Sanctuary, and their relative proximity to populous and active harbors (Santa Barbara, Ventura, and Oxnard) makes this context particularly well-suited for exploring the contrast in use between the protected and fished areas by the scuba community.

Figure 2. The Channel Islands in California are a biodiversity hotspot and a globally popular destination for ecotourism. Top left: Scuba diver holds a California spiny lobster (*Panulirus interruptus*) near Anacapa Island (Derek Stein[1]). Top right: Giant kelp (*Macrocystis pyrifera*) tower through the water column (iStock). Bottom left: Scuba diver enters the water from a dive boat (Wallpaper Flare). Bottom right: Giant sea bass (*Stereolepis gigas*), a fish highly sought after by scuba divers in the Channel Islands (Douglas Klug).

Recreational scuba-based lobster fishing contributes an estimated $37 million to the California economy annually and is one the most popular and economically important recreational scuba-based fishing activities in the Channel Islands [27,28]. This is true in other regions; in Monroe County, Florida, the recreational lobster fishery contributed $8 million to the local economy in 2001 [29]. In California, approximately 21,521 lobsters on average were recreationally taken each year via scuba from 2016-2022 (**Supplemental Figure 1**; *pers. comm.,* California Department of Fish and Wildlife). Recreational take of lobster is permitted in two marine conservation areas in the Northern Channel Islands, but not in the marine reserves, and a common practice in the region is to fish along the border of reserves ("fishing the line") to take advantage of spillover [6,8,21].

[1] Photo by Derek Stein, California Department of Fish and Wildlife. "Kai Lampson, CDFW biologist, catches and releases giant California spiny lobster at Anacapa Island." Creative Commons 2.0, https://creativecommons.org/licenses/by/2.0/

In order to quantitatively evaluate whether the behavior of scuba divers revealed any evidence for deriving value from the enhanced non-extractive wildlife viewing opportunities and spillover of recreationally-caught species associated with the Northern Channel Islands MPAs, AIS data from for-hire scuba diving vessels was used to answer two questions: 1) What preferences do for-hire scuba vessels exhibit for MPAs when largely engaged in non-extractive underwater marine ecotourism? 2) What preferences do they exhibit when these vessels are largely engaged in recreational scuba-based fishing? To investigate scuba-based fishing, the analysis focused specifically on the recreational California spiny lobster (*Panulirus interruptus*) season. These patterns of activity of for-hire scuba diving vessels around the Northern Channel Islands can offer unique insight into the relationship between the recreational scuba diving industry and MPAs. Such associations are germane for conversations about the future of MPAs in California, as well as in global context where the world has recently formalized a commitment to ensure the conservation and management of at least 30% of coastal and marine areas by 2030 [30].

2. Methods

2.1 Study Area

This study examines spatial patterns of for-hire scuba diving vessels operating in the waters surrounding the four Northern Channel Islands: Anacapa, Santa Cruz, Santa Rosa, and San Miguel (**Figure 1**). The Channel Islands is an archipelago of eight islands located in the Southern California Bight in the Pacific Ocean off the coast of California. In 2003, the California Fish and Game Commission designated a network of MPAs in state waters, and in 2006 and 2007 NOAA extended these MPAs into the federal National Marine Sanctuary waters [31]. Two main types of marine protected areas are utilized in the Channel Islands region across state and federal waters: marine reserves (MRs) prohibit take of any marine resource except by scientific permit. Marine conservation areas (MCAs) are less restrictive and prohibit take of any marine resources except by authorized scientific, commercial, and recreational purposes that do not compromise protection of the species of interest, natural community, habitat, or geological features. The two Northern Channel Islands MCAs (Painted Cave MCA and Anacapa Island MCA) allow recreational take of spiny lobster and pelagic finfish; the Anacapa Island MCA also allows commercial take of spiny lobster. Today, there are 13 MRs and 10 MCAs spread throughout all eight Channel Islands in state and federal waters, and 10 MRs and 2 MCAs in the four focal islands of this study. The MPAs in the region of study encompass a combined area of 258 square miles, leaving the remaining areas open to consumptive recreational and commercial activities as otherwise regulated by federal and state agencies [32].

2.2 Recreational Scuba Diving Industry

This study focused exclusively on analyzing the behavior of vessels that offer for-hire individual and group recreational scuba diving as a proxy for the overall recreational scuba diving activity in the Northern Channel Islands. This analysis does not directly consider the patterns of scuba divers operating from private small boats or shore diving. To understand patterns of use by

these for-hire scuba diving vessels, a comprehensive list of 44 vessels in Southern and Central California was developed (**Supplemental Table 1**). After paring down the list to active for-hire scuba vessels, this list was matched by vessel name with the Global Fishing Watch (GFW) AIS database to identify vessels with available AIS data (vessels < 65 ft in length are not required to carry an AIS device). Possible matches from the GFW vessel database were identified for 13 vessels. These matches were cross-referenced in MarineTraffic using the Mobile Maritime Service Identities (MMSIs) and the current port, vessel type, and voyage information were used to verify the vessels were likely the same. Filtering these vessels for those that visit the Northern Channel Islands yielded a list of 10 vessels that were included in the analysis. This study presents data in aggregate to respect the privacy of these small business vessel operators.

To partially ground-truth the observations about vessel activity based on the AIS data, an in-depth survey for vessel operators and captains was developed and deployed. In total, owners and captains of six of the ten vessels responded to the survey; all of these vessels take regular trips to the Northern Channel Islands. Similarly, the names and responses from these surveys are kept confidential to respect the privacy of these operators. The survey results were used to inform the analysis of the AIS data (see below), but no further analysis was conducted on the responses due to confidentiality and small sample size.

The vessel operator survey included 20 questions covering subjects such as trip schedules, site preferences, perceptions of MPAs, and recreational harvest of wildlife (**Supplementary Materials**). Responses from this survey effort helped to inform how diving activity was defined (see below) as well as how other facets of this analysis were structured. The surveys revealed that the vessel operators interviewed were evenly split between those who run solely day trips and those that run overnight trips. There was a wide range in the number of recreational harvesting trips that operators take per year, ranging from one trip per year (on the lobster season opener date) to 50% of all trips. The primary target for recreational scuba harvest on their vessels was for California spiny lobster; some operators also reported that customers harvest rock scallop (*Crassadoma gigantea*), Kellet's whelk (*Kelletia kelletii*), sea cucumber (*Parastichopus spp.*), yellowtail (*Seriola dorsalis*), white sea bass (*Atractoscion nobilis*), California halibut (*Paralichthys californicus*), calico bass (*Paralabrax clathratus*), and California sheephead (*Semicossyphus pulcher*).

2.3 Defining Diving Activity

AIS data from Spire Global Inc. was cleaned and processed by GFW using the methods described in Kroodsma et al. [33]. 1.7M data points were obtained for 10 dive vessels from 2016-2022 to identify the locations of potential dive sites in the Northern Channel Islands. A high resolution grid of the study area (0.001 x 0.001 degree cells) was created and all cells where at least one vessel remained stationary (defined as moving slower than 1 knot) for a minimum of 1.5 hours were identified. All grid cells meeting this criteria were considered “dive sites”. The 1.5 hour threshold was based on survey results, in which operators were asked how long they typically spend at a given dive site for a single dive. Any data points that were more than 10 km from the nearest shoreline were also removed.

Each potential dive site was then classified as being inside, within a buffer, or outside a MPA. MPA shapefiles were obtained from the California Department of Fish and Wildlife [34], which classifies protected areas as either MRs or MCAs. For each scenario, a 500 m buffer around the MPAs was created to capture diving activities that might be occurring along the edges of an MPA, such as “fishing the line” for lobster.

Next the AIS data were used to estimate diving activity. A single "dive event" was any instance where a dive vessel remained stationary at a given dive site for at least 1.5 hours. The total number of dive events at each site for all vessels from 2016-2022 were then used to classify the dive sites into high, medium, and low frequency. Cutoffs for the number of dive events in each frequency category were based on the distribution of dive events per site. High frequency sites had more than three dive events per site (top 18% of sites aggregated across all vessels and years); there were 255 high frequency sites. Sites with two or three dive events were considered medium frequency (351 sites, 24%). The remaining 834 sites (58%) had only a single dive event and were classified as low frequency (**Supplemental Figure 2**).

Finally, two scenarios were developed to enable comparison of MPA usage across dive events with different objectives that may influence the way vessels behave with respect to MPAs. The first scenario was defined to largely encompass non-extractive ecotourism dive activity (e.g., underwater wildlife viewing, underwater photography; referred to throughout as the “ecotourism scenario”), and the second focuses on recreational scuba-based fishing activity, for lobster in particular (referred to throughout as the “lobster scenario”). For each scenario, a set of criteria observable in the AIS data were developed to characterize dive vessel behavior typically associated with each objective. Insights from interviews were incorporated to further define these two scenarios.

Ecotourism scenario dive events were defined as the subset of the complete AIS-derived dive dataset that met all of the following criteria: A) Occurred during the day (the first AIS timestamp at the site was between 6 am and 6 pm; 78% of all AIS-derived dive activity occurs during the day); B) Duration was between 1.5 and 5 hours (survey results suggest that vessels typically spend 1.5 hours at a given dive site; 5 hours should allow for some circumstances where vessels dive the same site twice); C) Excluded dive events that occurred during October to reduce the number of potential lobster fishing trips (October is the first month of lobster season which accounted for approximately 50% of the total seasonal lobster catch via scuba diving from 2016-2022; **Supplemental Figure 3**). In this scenario, both MRs and MCAs were combined into a broader MPA classification. As defined, the ecotourism scenario does not wholly exclude harvesting activities (e.g., spearfishing, lobster fishing) that can occur in a mixed fashion on these vessels.

The lobster scenario was defined as the subset of the complete AIS-derived dive dataset that met all of the following criteria: A) Occurred during the night (where the first AIS timestamp in the site was after 6 pm) or overnight (where the first and last AIS timestamps at the site were on different days); B) Duration was 1.5 hours or more (longer than the 5 hour limit for the

ecotourism scenario to account for overnight anchorages); C) Only included dive events that occurred during lobster season (beginning at 6 am on the Saturday preceding the first Wednesday in October and ending at 12 am on the first Wednesday night after March 15). This scenario focused only on night time diving activities to more exclusively capture vessel behaviors associated more specifically with lobster fishing activities and not driven by balancing harvesting and ecotourism. In this scenario, only MRs were defined as MPAs, because the two Northern Channel Islands MCAs allow recreational take of lobsters and the MPA effect would be expected to be less pronounced; thus, MCAs were defined as being outside MPAs.

The uncertainty in the lobster scenario should be noted, given that some mixed use does occur during these periods, and non-extractive ecotourism dives may be incidentally included. Additionally, some lobster fishing activities might have been incidentally excluded. For example, the captain of one vessel that was surveyed claimed that the business does allow lobster hunting; however, this business only offers day trips, implying that any lobster fishing occurs during the day. Based on the lobster scenario criteria, no lobster dives were detected for this vessel.

2.4 Resource Selection Model

To determine if vessels preferentially selected dive sites in MPAs versus outside MPAs in both the ecotourism and lobster scenarios, resource selection functions (RSFs) were estimated using the use-availability framework [35,36]. RSFs are a class of exponential models of space use that can be used to estimate the probability distribution of vessel locations using different resources (i.e., dive sites in MPAs versus dive sites outside of MPAs) in the seascape, while taking into account the availability of each resource. In doing so, this approach provides a measure of strength of selection of vessels for or against each resource.

To define the available seascape that vessels can use as dive sites, all dive location data for each vessel was plotted and a one nautical mile (1.8 km) boundary was created around each of the four Northern Channel Islands. A one nautical mile boundary was used because it was the minimum distance away from the shoreline that contained all vessel locations for each scenario. Beyond this boundary, bottom depths typically are greater than is accessible by recreational diving. The available seascape that could be used for diving for each scenario was the same. The available seascape was then differentiated into the three management zones: MPA, MPA buffer (i.e., 500 m area surrounding the perimeter of the MPA), or outside MPA based on the shapefiles described above.

Prior to fitting RSFs, the dive location data were split into their respective scenarios (ecotourism or lobster) so that each scenario only contained vessel location data specific to dive events identified in each scenario. This enabled the generation of available locations for each scenario respectively. Within the available seascape for each scenario, used locations (i.e., where dive events occurred) were paired with randomly generated available locations. Five times more available locations than used locations were specified [37]. This approach reduces bias and improves the interpretation of coefficients obtained from RSF models [38]. Resource selection

followed a Design III protocol where available points were generated randomly for each vessel [35]. Finally, the associated management zone (MPA, MPA buffer, or outside MPA) was assigned for each used and available point based on its location.

Resource selection was estimated for each scenario (ecotourism and lobster) using a separate generalized linear mixed effects model with a binomial error distribution and logit link function using the lme4 package in R [39]. For both models, the dependent variable was a binary variable representing use versus availability. The environmental variable considered in both models was the management zone class (i.e., MPA, MPA buffer, or outside MPA). These two models enabled the determination of whether a vessel's selection of a specific management zone class differed depending on the diving activity (i.e., ecotourism or lobster fishing). For each model, random intercepts and random slope coefficients were included to account for unequal sample sizes and vessel-specific differences in the use of the different management zone classes [40]. When fitting logistic regression models, Fithian and Hastie [37] suggest assigning a large weight to each available location. As such, a weight of 5000 was assigned to all available locations and a value of 1 to each used location [41]. For categorical environmental variables such as the different management zone classes, preference was modeled with respect to a reference category [42]. Areas outside the MPA were selected as the reference category because this management zone class was used less than expected based on its availability in the seascape in both scenarios **(Supplemental Figure 4)**.

3. Results

The AIS data were obtained for 10 unique dive vessels originating from four ports from San Diego in the south to Santa Barbara in the north, with the majority of the diving activity in the region of study coming from the ports in Santa Barbara, Ventura, and Oxnard. In evaluating the data for behavior suggesting diving activity, 1440 grid cells were characterized as possible dive sites around the four Northern Channel Islands, and 4890 total dive events occurred at these sites during this seven year observation period.

3.1 Ecotourism Scenario

Of the 10 vessels included in the study, 10 demonstrated ecotourism activity. In the ecotourism scenario, 3014 dive events at 807 dive sites were identified. Of these sites, 219 were classified as high frequency (more than three dive events per site), 231 were medium frequency (two or three dive events), and 357 were low frequency (one dive event). Of the 3014 total dive events, 75% occurred at one of the high frequency sites.

3.1.1 Dive Sites

The largest proportion of overall dive sites was situated outside of MPAs, which were defined as MRs and MCAs (**Figure 3A**). However, a higher proportion of the more popular, high frequency

dive sites were located within MPAs (38% or 84 high frequency sites in MPAs versus 24% or 55 in medium and 17% or 60 in low frequency sites).

3.1.2 Unique Dive Events

The largest proportion of detected dive events were conducted inside MPAs (**Figure 3B**). On average across the seven years of this study, 45% of all dive events or 1389 were conducted in MPAs versus 41% or 1233 outside MPAs and 14% or 392 in MPA buffers. This proportion varied only minimally between years.

3.1.3 Resource Selection Model

The resource selection model that included a consideration of the relative availability of MPA, outside MPA, and MPA buffers revealed pronounced selection by the recreational scuba diving industry vessels for areas within the MPAs (β=0.997; **Table 1**). Vessels also selected preferentially for buffer zones immediately surrounding MPAs (β=0.459; **Table 1**). Qualitatively, the signs and absolute magnitude of the coefficients can be used to rank each management zone class in terms of the selection strength as outside MPA < MPA buffer < MPA (i.e., MPAs are the preferred management zone class for ecotourism dives).

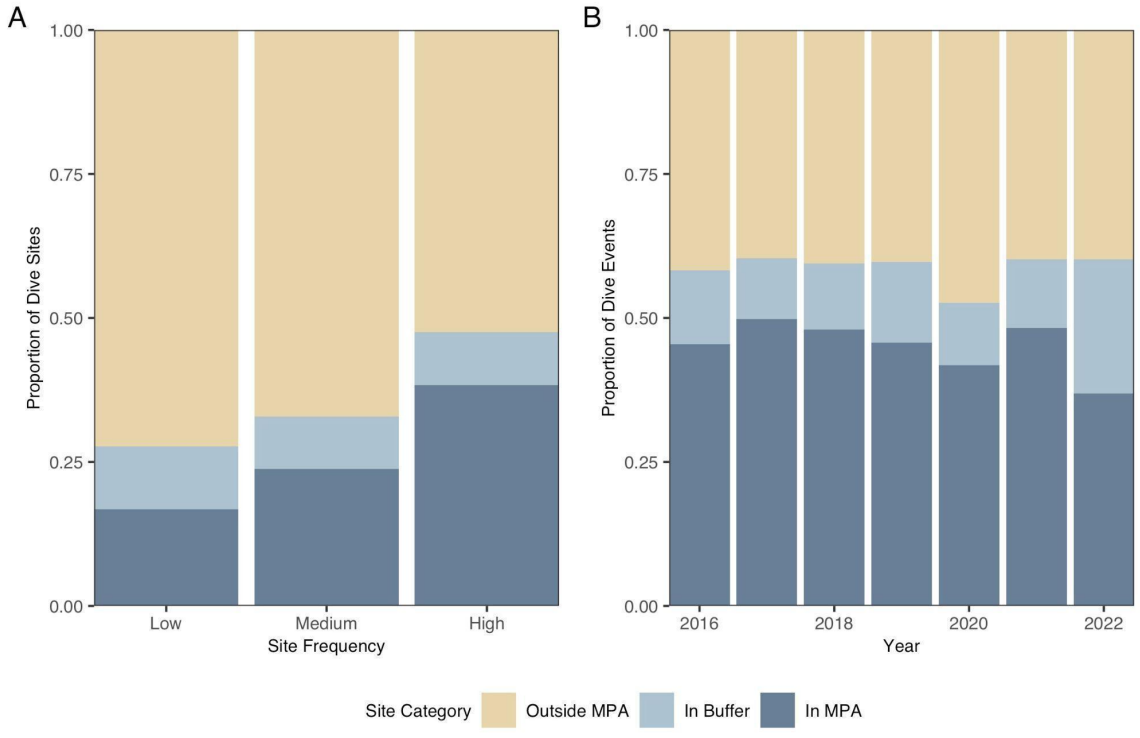

Figure 3. Proportion of A) low, medium, and high frequency dive sites and B) unique dive events from 2016 through 2022 that fell in MPAs, outside MPAs, or in MPA buffers for the ecotourism scenario.

Scenario	Coefficient	β	SE

Ecotourism	Intercept	-2.010	0.127
	MPA	0.997	0.302
	MPA Buffer	0.459	0.438
Lobster	Intercept	-1.660	0.087
	MPA	-0.161	0.293
	MPA Buffer	0.994	0.231

Table 1. Standardized model coefficients (β) and standard errors (SE) describing selection of dive locations for vessels in both the ecotourism and lobster scenarios. Covariates include three management zone classes: MPA, MPA buffer, and outside MPA. For both scenarios, areas outside MPAs are set as the reference category.

3.2 Lobster Scenario

Of the 10 vessels included in the study, 8 demonstrated lobster fishing activity. In the lobster scenario, 346 unique dive events were conducted at a total of 249 dive sites. As defined, the lobster scenario attempted to largely isolate recreational diving activity associated with scuba-based lobster fishing. Compared with the ecotourism scenario, a larger fraction of these lobster scenario dive events were in low and medium frequency sites (54% compared with 25% of ecotourism dive events).

3.2.1 Dive Sites

The largest proportion of lobster scenario low, medium, and high frequency dive sites occurred outside MPA areas, which were defined as MRs only (75% low frequency; 64% medium frequency; 78% high frequency; **Figure 4A**). Thirteen percent (10 sites) of high frequency sites were inside MPAs.

3.2.2 Unique Dive Events

In the lobster scenario, by far the highest proportion of unique dive events occurred in areas outside of MPAs (average 78% over the seven year study period; **Figure 4B**). Some proportional use of MPAs was detected in 2016-2019 and 2021-2022, likely reflecting scuba activities not associated with lobster fishing that could not be wholly removed from this lobster scenario using this filter criteria. MPA buffer zones were used on average 10% of the time over the course of this study. Regions outside MPAs were used exclusively in 2020.

3.2.3 Resource Selection Model

Results from the resource selection model applied to the lobster scenario revealed strong selection for MPA buffer zone areas (β=0.994; **Table 1**). Unsurprisingly, vessels in the lobster scenario visited MPAs less than expected based on the availability of this management class zone in the seascape (β=-0.161; **Table 1**). Qualitatively, each management zone class can be

ranked in terms of the selection strength as MPA < outside MPA < MPA buffer (i.e., buffer zones are the preferred management zone class zone for diving during lobster season).

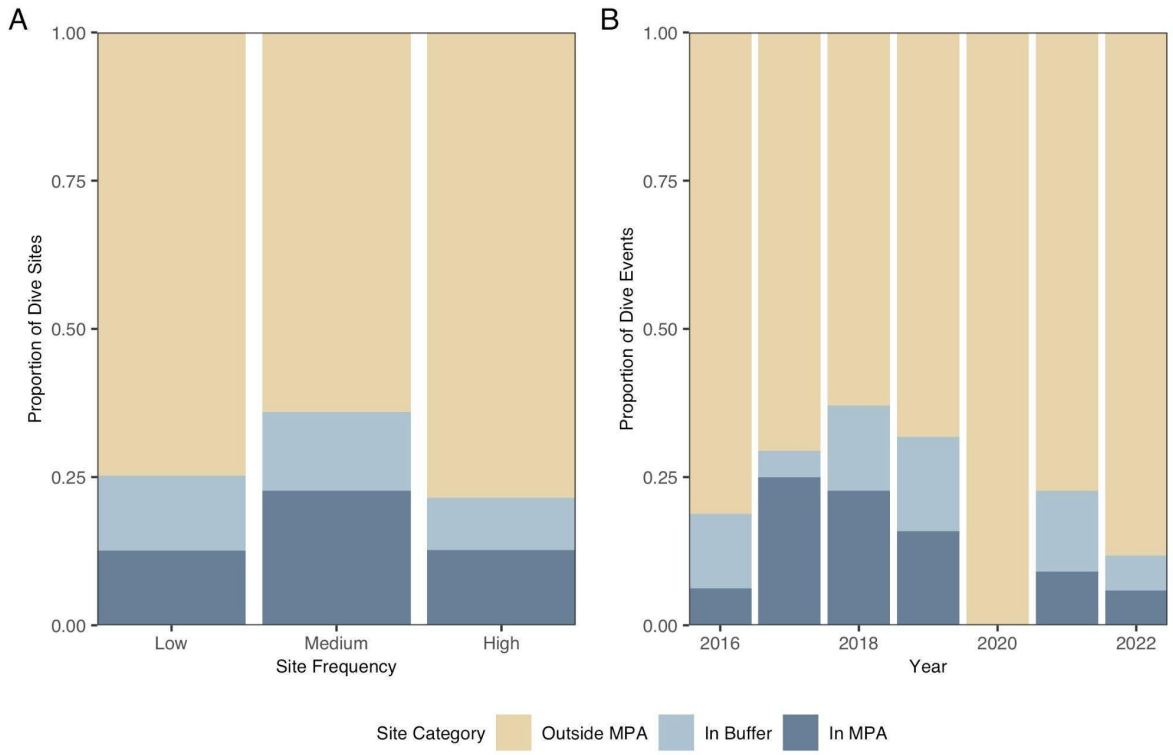

Figure 4. Proportion of A) low, medium, and high frequency dive sites and B) dives from 2016 through 2022 that fell in MPAs, outside MPAs, or in MPA buffers for the lobster scenario.

4. Discussion

To the authors' knowledge the present study represents a first attempt to assay behavioral responses from recreational for-hire scuba diving vessels to MPAs using AIS data. This approach confers the advantage of being able to obtain long-term (e.g., > 1000 observation days), fine-scale, spatially-explicit insight into how the industry interacts practically with the different management zones around the Northern Channel Islands without some of the biases (e.g., survey biases) associated with other methods used in isolation.

Over the course of this study (2016-2022), scuba vessels in the ecotourism scenario that were putatively engaged primarily in non-extractive diving exhibited strong preferential selection for MPAs. A high proportion of the most popular, high frequency, dive sites were located in MPAs (38%), a large proportion of the total number of unique ecotourism dive events were conducted within MPAs (45%), and vessels engaged in ecotourism diving exhibited high selection of MPAs

(β=0.997). These same dive vessels also exhibited some positive selection for buffer zones immediately surrounding MPAs (β=0.459), but these trends were far less pronounced.

These observed preferences by ecotourism divers for MPAs are perhaps most likely driven by the higher fish density, higher fish biomass, higher frequency of certain large fish, and higher frequency of select marine invertebrates previously documented inside versus outside the MPAs of the Northern Channel Islands [2,6]. These local patterns are largely mirrored in global meta-analyses comparing fish and invertebrate communities in similar contexts worldwide [1]. This hypothesis of higher quality marine wildlife viewing opportunities inside these MPAs attracting these ecotourism divers is at least provisionally supported by interviews with the dive vessel operators included in the study. When asked an open-ended question about why they take customers to MPAs, 50% of respondents said because of the biomass, biodiversity, and opportunities for underwater photography, and some noted the larger and healthier fish found in MPAs. Additionally, when asked whether they thought more of California state waters should be fully protected (no-take), 83% said more than is currently fully protected (9%), and 67% said at least 15% should be fully protected.

Scuba diving vessel behavior in the lobster scenario, in which vessels were putatively engaged largely in recreational lobster fishing, showed quite different patterns. A smaller fraction of popular (high frequency) dive sites were situated within MPAs (13%), the majority of the dive events detected occurred outside of the MPAs (78%), and these dive vessels exhibited preferential selection for the buffer zones around the MPAs (β=0.994). Eighty-three percent of survey respondents said they noticed that hunting (spearfishing, lobster fishing) was better near an MPA – presumably due to the spillover effect – and half of respondents said they considered this factor when deciding where to hunt.

The different behavioral associations to MPAs of these vessels when they are largely engaged in scuba-based lobster fishing provide some preliminary evidence of “fishing the line” behavior, or preference for buffer zones immediately outside MPAs where resource spillover occurs. Previous studies in the Northern Channel Islands have specifically documented higher densities and larger lobsters with MPAs [6]. Fishery dependent data (landings and effort) were used to demonstrate strong preferences for fishing in some of these same MPA buffer zones: Lenihan et al. [8] found significantly higher lobster abundance, fisher effort, and commercial landings in areas near MPAs compared with areas further from MPAs, despite a decrease in the fishable area due to MPA regulations. Such preferential selection for MPA buffer zones by commercial, recreational, and artisanal fishers has been documented in contexts ranging from tuna purse seine fisheries to red drum (*Sciaenops ocellatus*) sport fishing and has been documented in other invertebrate fisheries [16–19,43]. These results suggest that spillover benefits from MPAs may be similarly germane to the portion of the recreational scuba diving industry that engages in fishing activities.

It cannot be determined within the specific confines of this study whether these observed behavioral preferences emerged after the creation of these MPAs. High quality AIS data does not pre-date the establishment of the MPAs in the Channel Islands. However, results from

another study that relied on analyses of aerial imagery collected before and after MPAs were created within the Channel Islands would suggest that these observed preferences materialized post-MPA establishment [21]; that study found that for-hire scuba diving vessels were found closer to MPA borders after MPA establishment than before and exhibited “fishing the line” behavior. These AIS methods described herein provide a relatively low-cost methodology for observing any changes in vessel behavior that may occur in other contexts where MPAs were more recently established (post-2016).

It is important to note additional limitations of AIS data. First, this limited the analysis to dive vessels equipped with AIS, the use of which is variable on for-hire dive vessels because it is only required on vessels 65 ft or more in length and some vessels may be under this size requirement. Second, terrestrial AIS receivers based on the California mainland may have difficulty receiving signals from the far side of the Channel Islands, which leaves these signals dependent on satellite receivers. In areas with high vessel traffic, such as nearshore areas or shipping lanes, AIS messages can interfere with one another limiting the ability of satellites to receive these messages [44]. This interference could result in some AIS messages from dive vessels not being received, reducing the number of dive sites or dive events that can be inferred from the AIS data; however, AIS reception is generally strong for the study area, so this is not likely a significant limitation. Third, AIS data provides information on vessel location and behaviors from which we can infer activities (e.g., transiting or diving), though these activities are not directly observable. Distinguishing between ecotourism and scuba-based fishing activities therefore required imperfect assumptions based on the timing of the lobster season and known scuba-based lobster fishing behaviors. For example, a night dive in November may be for the purpose of viewing nocturnal wildlife, and not necessarily entail lobster harvesting; or it may entail both. In many instances specific dive logs for trips can be viewed as confidential or proprietary information, but such additional data could be cross-referenced to further improve the precision of these types of analyses.

This study was limited to a subset of the Channel Islands that are highly-sought-after diving destinations, and to for-hire scuba diving vessels. To understand the patterns of scuba diving in others of the 124 California MPAs, these methods could be extended to include for-hire scuba diving operators throughout the state. To understand scuba diver behavior more broadly both around the Channel Islands and throughout the state, future research could include any vessels that do not use AIS – which is primarily smaller-capacity commercial vessels (< 65 ft) and private household vessels – as well as individuals diving from shore. This could be achieved by surveying a representative number of divers and operators via web surveys, in-person surveys at dive shops or harbors, and intercept surveys in the water or at the entry points to shore dives. A broader view of vessel-based recreation in the Channel Islands using web surveys estimated that 51% of vessels participated in both consumptive and non-consumptive activities, and 47% participated in non-consumptive activities only, with the most popular activities being “just relaxing, exploring using a dinghy, hook and line fishing, kayaking, and diving” [45]. However, surveys can be subject to biases that can be avoided with AIS data. Other methods such as aerial surveys have been used to estimate the number of trips per year (1621) by private

household vessels for non-consumptive recreation [46]. Future research could build on these findings by isolating recreational scuba divers specifically.

This study overlapped temporally with a couple of impactful events that may have influenced the data and results. In September 2019, a fire caused the sinking of the *Conception* dive boat, which was based out of Santa Barbara Harbor. Thirty-three divers and one crew member died in this tragedy, the effects of which rippled through the local dive industry. In March 2020, the governor of California declared a state of emergency due to the Covid-19 pandemic, leading to several waves of lockdowns and business closures or restrictions in the ensuing months. These two events led to fewer dive trips – overnight trips especially – which is evident as visible reductions in the number of AIS data points in this study. The number of data points increased from 2016 to 2018, then decreased sharply in 2019 and 2020 (**Supplemental Figure 5**). Since then, the number of points have recovered slightly, but in 2022 were still only 54% of the 2016 levels. The effect of having fewer overnight trips may have led to a higher proportion of trips at dive sites closer to the mainland, e.g., on Anacapa and Santa Cruz Islands. Though not the focus of this study, future research on the impact of the *Conception*'s sinking and the Covid-19 pandemic on the Southern California dive industry could examine these patterns and track the recovery of the industry's activity in the years following the pandemic. Beyond these two specific isolated events, AIS data may also be useful for detecting changes in for-hire scuba dive vessel (or other vessel-based industry or stakeholder) operations over time relative to other impacts such as establishment or removal of a MPA or changes to MPA boundaries.

While the specific value of protected areas to terrestrial naturalists and ecotourists (e.g., bird watchers, hikers) is so well known as to often be taken as self-evident [47,48], illuminating some of these same values and preferences in a marine context remains useful. Researchers working in other geographies and using methods other than direct observation of dive vessels have observed similar patterns of benefit and attraction to MPAs. For example, previous studies examining scuba diving selection for MPAs have surveyed both dive vessel operators [11] and dive ecotourists [49], as well as analyzed articles in dive magazines [50]. Operators in Italy and Mozambique recognized the importance of MPAs for the ecosystem recovery and protection benefits they offer for divers [11]. Divers in Jamaica emphasized their preference for seeing a "variety of fish," "abundance of fish," and "unusual fish," attributes that were characteristic of protected areas [49]. Analysis of 53 years of dive magazine articles revealed that articles about MPAs emphasized "beauty, color and condition" of and "sizable fish/abundance" in marine parks, and revealed observations about positive responses in fish abundance and reef health in MPAs [50]. Previous studies, such as Tonin [51], have also used economic methods such as contingent valuation methods to understand people's willingness to pay to visit an MPA.

At some scuba diving destinations within MPAs, experiences with single marine species generate millions of dollars in revenue and assume a dominant position in local tourism economies. This is true for whale, white, gray nurse, and reef sharks in several different marine parks off Australia's coast, which attract over $25 million in diver expenditures each year [52]. Pacific gray whales in Vizcaíno Biosphere Reserve [53] and bull sharks in Cabo Pulmo National Park [54] benefit local economies in Mexico by $3 million and $8 million each year, respectively.

In Southern California, diving for giant sea bass (*Stereolepis gigas*) – which, anecdotally, are often seen in the Channel Islands MPAs – has been estimated to have a value of $2.3 million per year [25]. The general recreational value of charismatic megafauna in protected areas underscores the importance of MPAs for ecotourism by supporting the conservation of these species and creating desirable ecosystems for wildlife viewing.

Relative to the more limited body of existing literature on how MPAs influence the behavior of scuba divers, numerous studies focus on the physical impacts of scuba diving on MPA habitats and wildlife. Long-term, measurable impacts are mixed, and may depend on the level of diver experience and training as well as the vessel operators' practices (e.g., anchor locations) and inherent fragility of the ecosystem (e.g., coral reef versus rocky reef) [55–57]. The apparent attraction observed here of recreational ecotourism divers to these MPAs does remind of the importance of educating operators and divers about responsible diving practices and MPA regulations so as to preserve the ecological characteristics that make these sites attractive.

The importance of MPAs to the scuba diving industry underscores the importance of assessing the value of MPAs more holistically. Conversely, MPAs can gain financial, educational, and governance benefits from supporting scuba diving tourism [11]. De Groot and Bush [58] reported on a MPA in Curaçao that was managed de facto by the dive industry for conservation in the absence of effective government management. Such "entrepreneurial MPAs" are managed from the perspective of local communities and private operators and can offer additional enforcement capacity and build greater awareness of marine protection. Additionally, in some contexts MPAs can offer alternative employment and income-generating opportunities for fishers as business owners, employees, or guides for scuba diving [59]. However, in some communities, training and education may be necessary to ensure that those with all levels of education are able to access these opportunities [60,61]. Despite these benefits, the scuba diving industry has traditionally had a limited voice in MPA governance decisions, especially relative to fishing and environmental conservation interests. The vast majority of past research on the value of MPAs and stakeholder conversations have focused on the non-diving fishing community, which includes extensive research on MPA spillover and climate resiliency benefits to these stakeholders [8,62–64]. However, in the last several decades the diversity of ocean users and their relative importance in the blue economy has increased. This includes not only ecotourism, but also ocean energy, aquaculture, shipping, and seabed mining [65,66]. It is becoming increasingly clear that modern conversations about the value of existing MPAs and decisions concerning expanding or establishing new MPAs should not be dominated by a few narrow and/or vocal ocean interests, but should be inclusive of this broader set of blue economy stakeholders.

California is concluding its decadal review of the statewide MPA network which has yielded a useful opportunity to retrospectively examine the ecological implications of use of these management tools for the state [67]. These same patterns considered here are also useful when looking forward. California has recently embarked on a journey towards conserving 30% of lands and coastal waters by 2030 [68], and a parallel effort is underway at the national level in the United States government under the auspices of the America the Beautiful Initiative [69].

At the global level, a similar drive is underway. The Kunming-Montreal Global Biodiversity Framework recently agreed upon in December 2022 establishes the goal of putting 30% of the planet into protected areas by 2030 [30]. Insight from this research adds more breadth to the general understanding about which community members may benefit from such efforts to better protect marine ecosystems and serves as a reminder that stakeholders from the marine ecotourism industry should be properly included in all consultations and planning concerning the future of MPAs. As this study shows, protecting more marine spaces will not only have direct biodiversity benefits, but also have economic and human well-being benefits deriving from marine ecotourism and recreation.

This study provides additional quantitative insight into the diverse ways that the recreational dive industry may relate to MPAs and reasons for these behaviors. Future work will improve the understanding of the ubiquity of these patterns, how they may change over time, and how they may differ in other contexts. Such insight can help us plan towards using MPAs as a tool to create optimal spatial design solutions that maximize benefits for all coastal stakeholders in an increasingly busy ocean.

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873 **Supplementary Materials**
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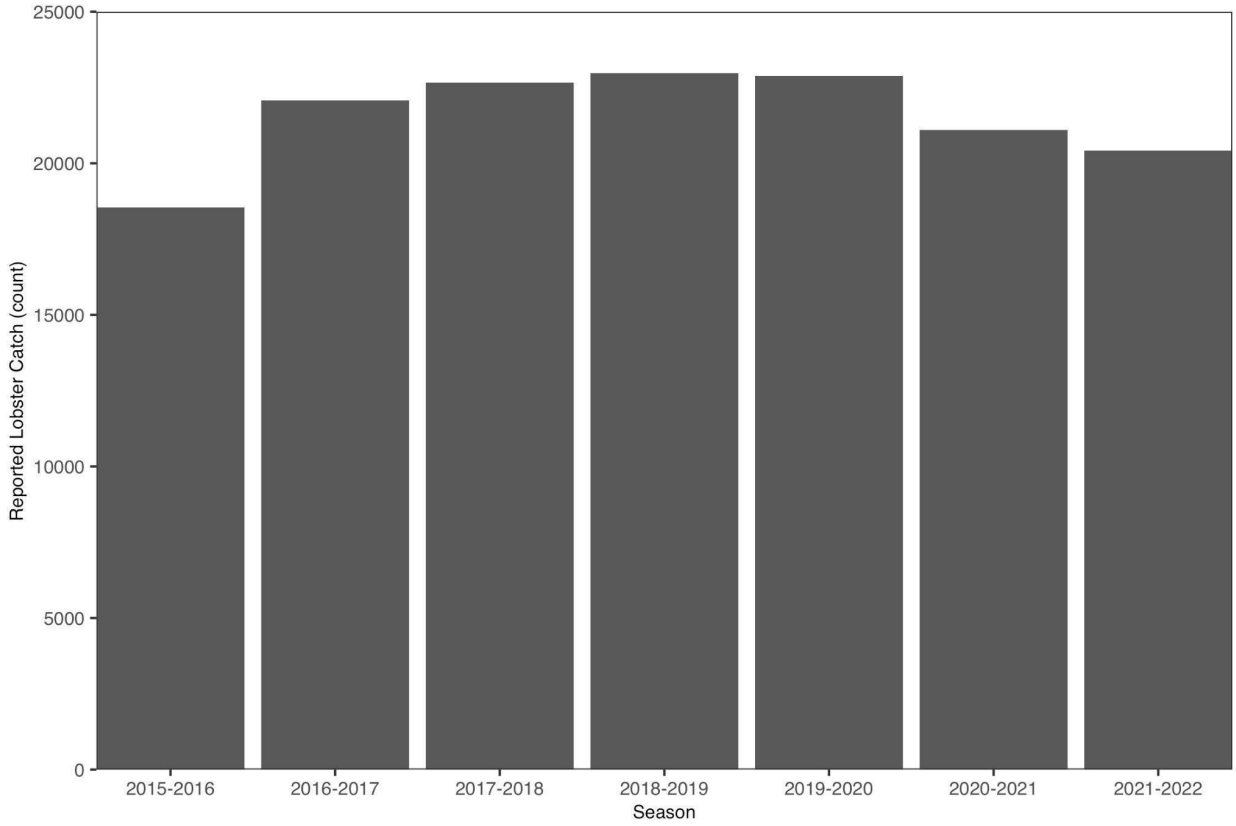
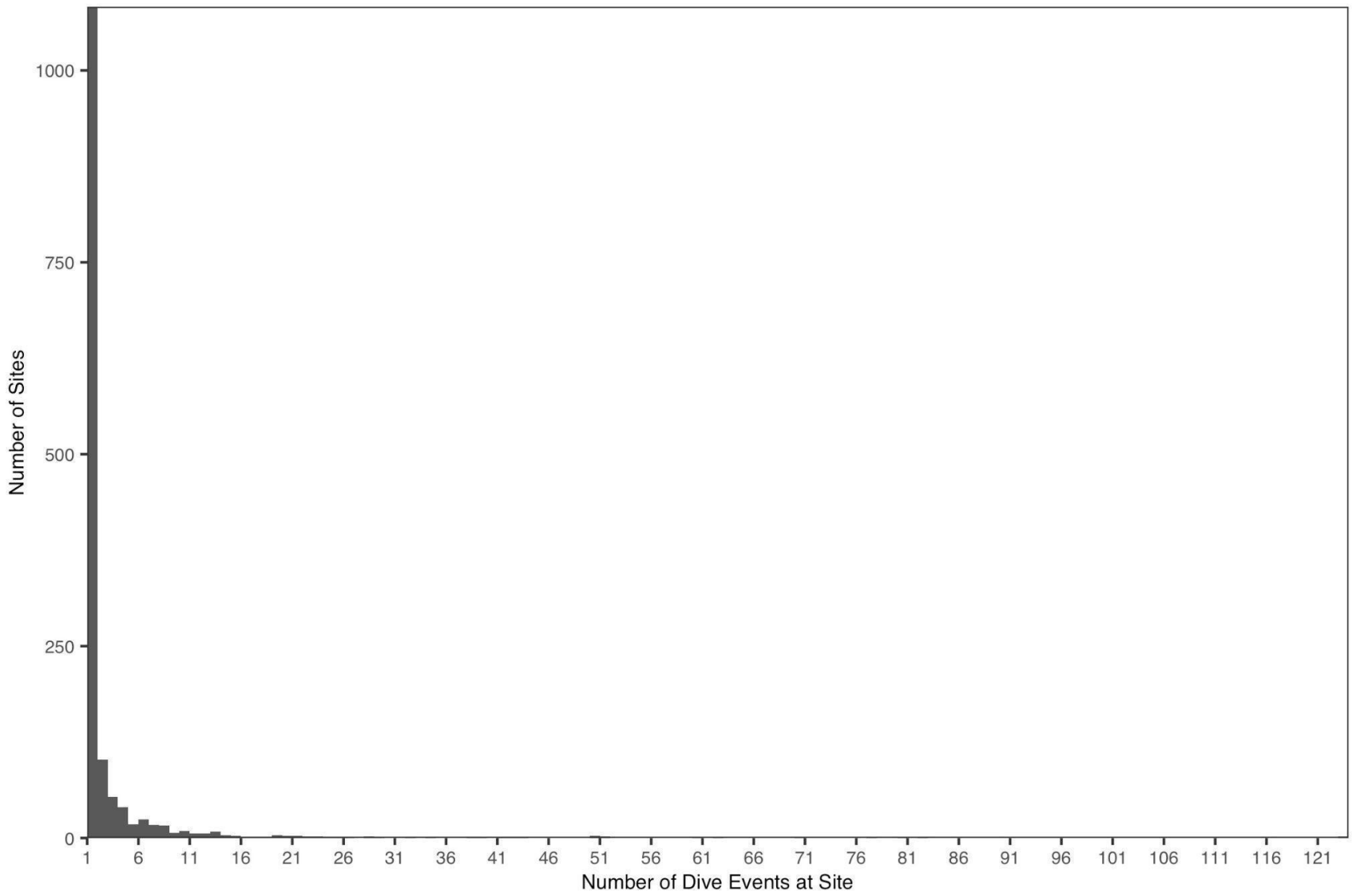
Vessel ID	County	Length (feet)	AIS Onboard Receiver	Included in Analysis	Surveyed
1	Los Angeles	63	Yes	Yes	Yes
2	Santa Barbara	65	Yes	Yes	Yes
3	Santa Barbara	80	Yes	Yes	Yes
4	Ventura	62	Yes	Yes	Yes
5	Ventura	46	Yes	Yes	Yes
6	Ventura	85	Yes	Yes	Yes
7	Los Angeles	65	Yes	Yes	No
8	Los Angeles	65	Yes	Yes	No
9	San Diego	80	Yes	Yes	No
10*	Santa Barbara	75	Yes	Yes	No
11*	Los Angeles	unknown	Yes	No	No
12	San Diego	88	Yes	No	No
13*	Ventura	53	Yes	No	No
14*	Los Angeles	unknown	No	No	No
15*	Los Angeles	unknown	No	No	No
16	Los Angeles	65	No	No	No
17*	Los Angeles	unknown	No	No	No
18	Los Angeles	36	No	No	No
19*	Los Angeles	unknown	No	No	No
20	Los Angeles	unknown	No	No	No
21	Los Angeles	65	No	No	No
22	Los Angeles	54	No	No	No
23	Los Angeles	46	No	No	No
24*	Los Angeles	unknown	No	No	No
25*	Los Angeles	48	No	No	No
26	Los Angeles	54	No	No	No
27	Los Angeles	48	No	No	No
28	Los Angeles	33	No	No	No

29	Los Angeles	21	No	No	No
30*	Orange	unknown	No	No	No
31	Orange	40	No	No	No
32*	San Diego	unknown	No	No	No
33*	San Diego	unknown	No	No	No
34	San Diego	46	No	No	No
35*	San Diego	35	No	No	No
36*	San Diego	unknown	No	No	No
37	San Diego	40	No	No	No
38*	San Diego	unknown	No	No	No
39	San Luis Obispo	26	No	No	No
40*	Santa Barbara	42	No	No	No
41*	Ventura	65	No	No	No
42*	Ventura	unknown	No	No	No
43	Los Angeles	unknown	No	No	No
44*	Ventura	45	No	No	No

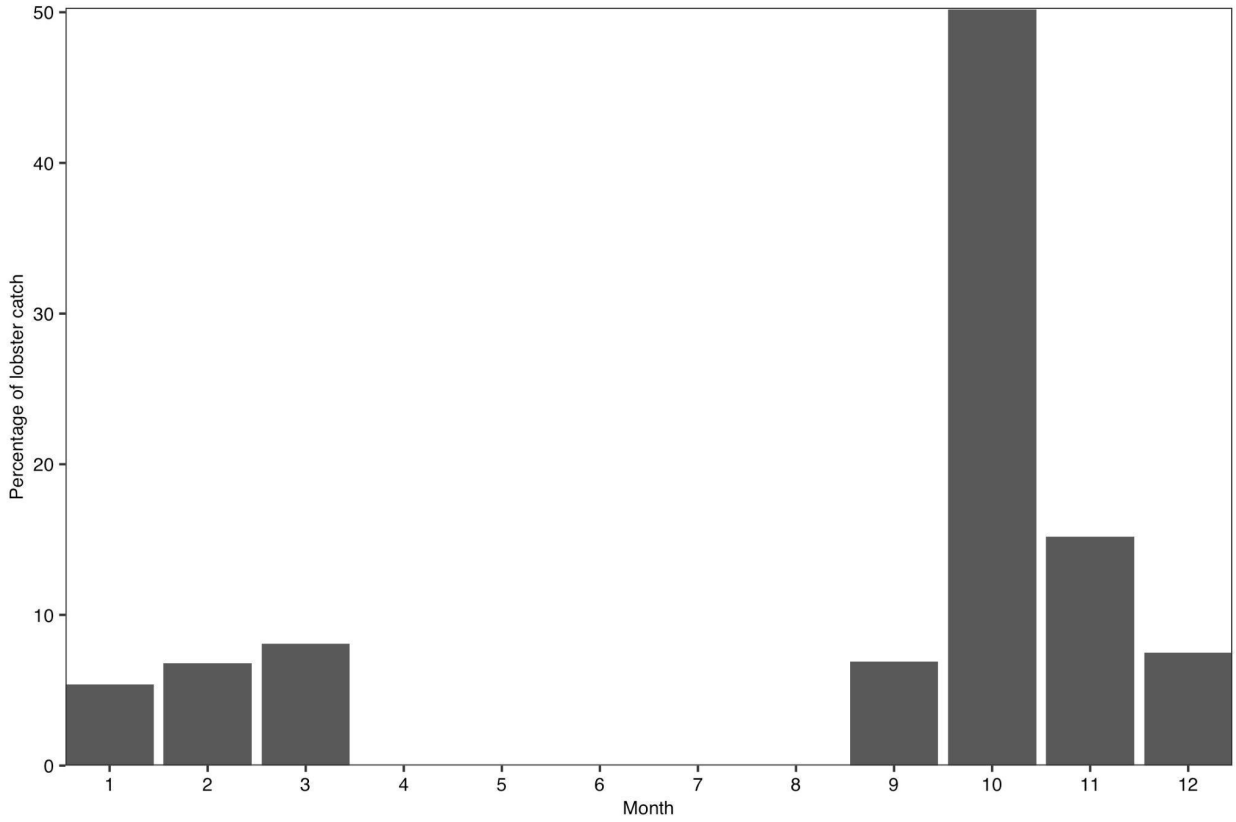
Supplemental Table 1. Detailed information for each for-hire scuba diving vessel considered for the analysis. Vessel IDs denoted with an (*) were deemed no longer operational at some point during the study period (2016-2022).



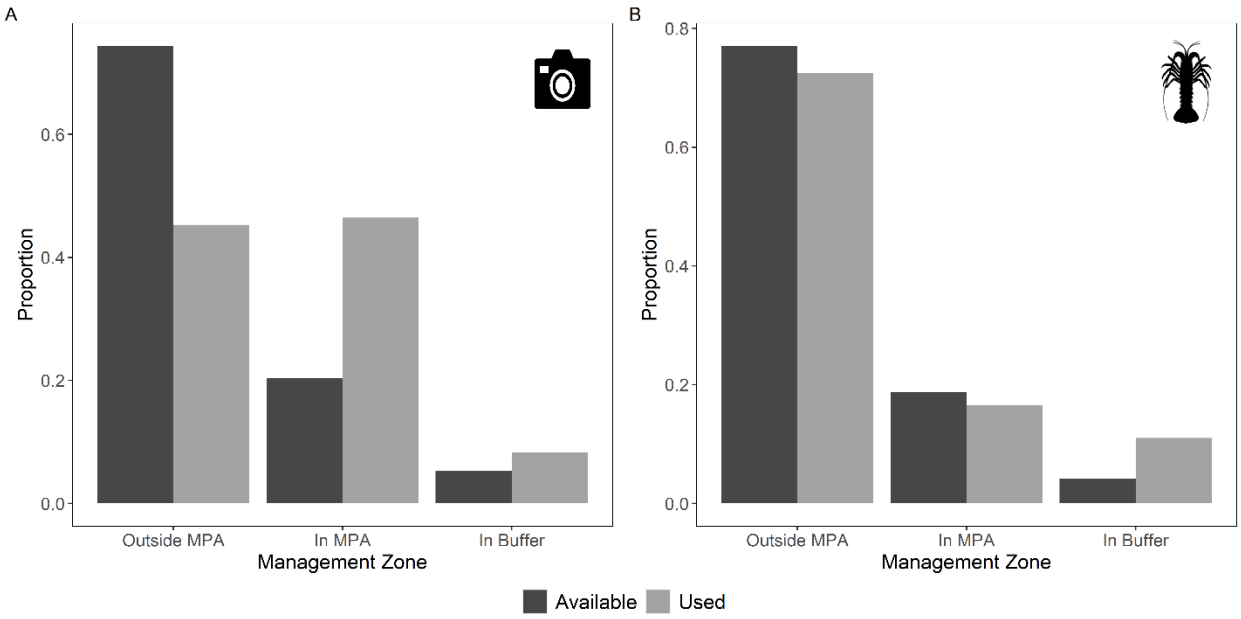
Supplemental Figure 1. Total recreational catch of California spiny lobster by scuba divers in California from the 2015-2016 season through the 2021-2022 season (*pers. comm.*, California Department of Fish and Wildlife).



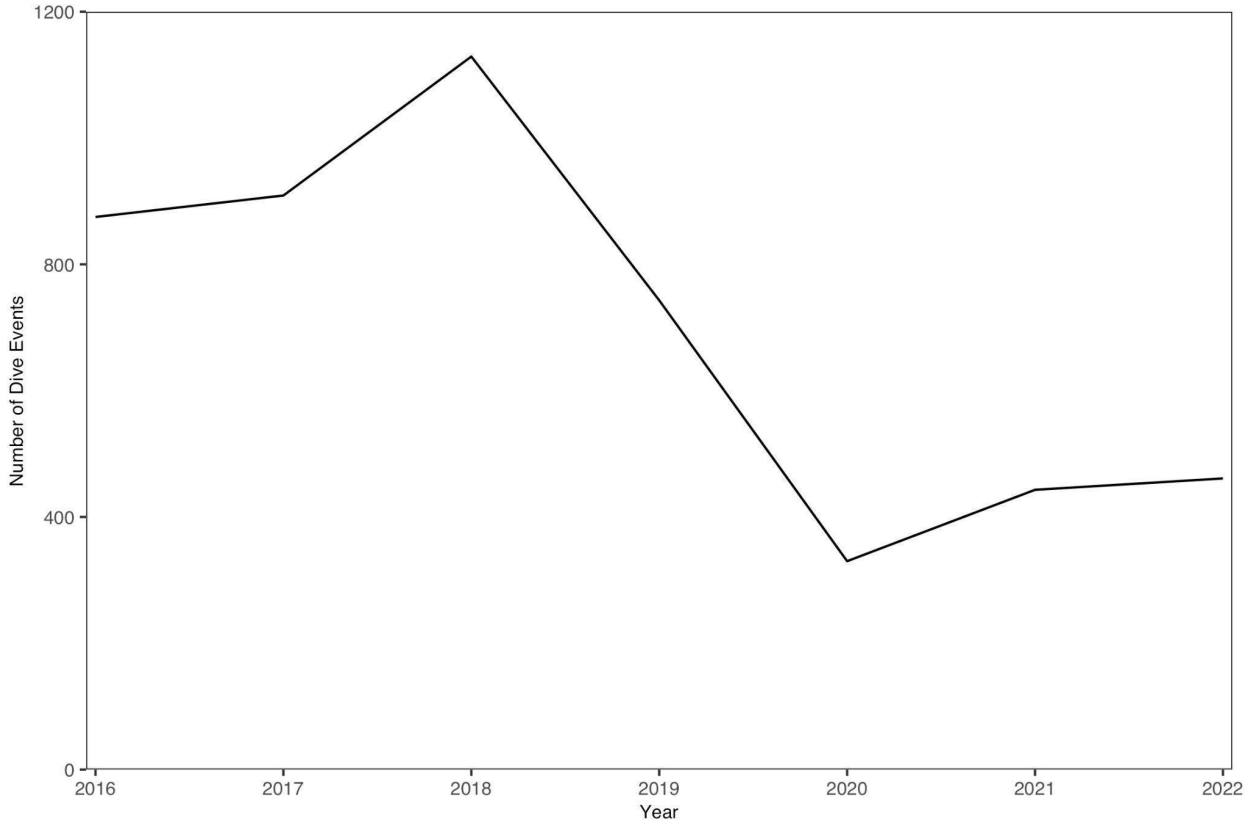
Supplemental Figure 2. Histogram showing the number of dive sites that had a given number of dive events occur.



Supplemental Figure 3. Average monthly percentage of total annual recreational California spiny lobster catch over the period 2015-2022, excluding out-of-season reported catch (*pers. comm.*, California Department of Fish and Wildlife).



Supplemental Figure 4. Proportion of each management zone class in the set of available and used locations for vessels during A) ecotourism dives and B) scuba-based lobster fishing dives in the Northern Channel Islands. The management zone class outside of MPAs was consistently used less than expected based on its availability by vessels in both scenarios and was therefore used as the reference category in the resource selection function model (see main text).



Supplemental Figure 5. The total number of dive events per year aggregated across all dive vessels from 2016-2022.