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Aerial surveys and distribution models enable monitoring of fishing in Marine Protected Areas

Amanda J. Zellmer[a,*], Heather Burdick[b], Ivan Medel[b], Daniel J. Pondella II[a], Tom Ford[b]

[a] Occidental College, Department of Biology and Vantuna Research Group, 1600 Campus Rd, Los Angeles, CA, 90041, USA
[b] The Bay Foundation, 1 LMU Drive Pereira Annex, Los Angeles, CA, 90045, USA

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ABSTRACT

Marine Protected Areas are rapidly becoming a central method for conservation of aquatic resources, but quantifying the success of these reserves in restricting fishing remains a challenge. Monitoring fishing has long been difficult - there are many types of fishers accessing resources in remote places from a diverse set of platforms (e.g., boat types). We used aerial surveys in conjunction with a novel application of species distribution modeling to develop a method for monitoring the change in fisher distributions following the implementation of MPAs. Aerial survey transects were conducted for 3.5 years before and after the implementation of 25 MPAs along the mainland southern California coast in 2012 and resulted in 13,558 vessel observations representing 19 different boat types. We compared actively fishing commercial and recreational vessels with non-fishing vessels to evaluate the use of MPA areas. There was a statistically significant decrease in proportion of vessels observed within MPAs from 17.5% before to 11.4% after MPA implementation, with MPA-implementation, fishing type, and the interaction all predicting the probability of a vessel being observed within MPA boundaries. Distribution models showed both an overall shift in distributions across all boat types and a decrease in predicted probability of habitat suitability of fishing within MPA boundaries after MPA implementation, although results differed among boat types. We illustrate the utility of distribution modeling for evaluating spatial patterns in human activities, providing a powerful tool for conservation biologists and demonstrate the importance of monitoring programs for establishing both baseline and response data needed for adaptive management of marine ecosystems.

1. Introduction

As overfishing continues to increase globally (Pauly et al., 2003), Marine Protected Areas (MPAs) are becoming a widely popular management strategy for protecting critical ecosystems (Edgar et al., 2014, 2007). By restricting harvest of marine resources, MPAs provide a crucial refuge for species and improve overall ecosystem health. Within MPAs, individuals grow larger, population sizes are larger (Lester et al., 2009), and spillover even improves ecosystems outside of MPA boundaries (Gell and Roberts, 2003). Yet, MPAs remain a challenge to study, monitor, and enforce (Agardy et al., 2011), and they frequently fail to fully limit illegal harvesting (Babcock et al., 2010; Edgar, 2011; Mora et al., 2006). They sometimes cover large areas on the open ocean, there is often a lack of baseline data, and traditional reporting structures exist at a different spatial scale than most MPAs. Further the socio-economic impacts of MPAs are difficult to predict (Gell and Roberts, 2003; Hilborn et al., 2006), an important consideration given the high cost of MPAs (Balmford et al., 2004). Novel methods are needed to adequately measure the successes and failures of MPAs for adaptive management. In this study, we use a unique approach integrating baseline research, aerial survey monitoring, and distribution modeling to evaluate shifts in the distribution of fishers following MPA implementation.

Understanding the success of any management approach requires the collection of baseline data prior to implementation, and this is especially true for studying the impacts of MPAs (Edgar et al., 2004). Marine productivity is highly variable and if there is bias as to where MPAs are placed, then outcomes may vary. For instance, MPAs placed in low productivity areas may have little effect on the distribution of fishers, limiting the impact of those MPAs (Edgar et al., 2004). In such cases, baseline data is essential to be able to successfully document these patterns. Further, as ecosystems change over time, it is crucial to continuously monitor MPAs for effectiveness of adaptive management practices (Pomeroy et al., 2005). Thus, to adequately quantify the

* Corresponding author.
E-mail address: zellmer@oxy.edu (A.J. Zellmer).

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impact of MPAs, it is essential that long-term baseline data are collected.

Aerial surveys provide one approach to overcome the challenges associated with studying management impacts over broad spatial scales and are particularly suited for the study of MPAs where access is limited. This method has long been used in conservation biology to estimate the abundance and distributions of wildlife (Pollock et al., 2006). Here we apply these survey techniques to studying human-related activities in critical ecological habitat. With aerial surveys, we can collect data across large areas in a short amount of time. Further this method has the benefit of providing data on all potential sources of fishing from boats and does not rely on fisher reported data. Although newer technologies, such as vessel monitoring systems, can provide detailed spatially-explicit fishing activities (Gerritsen and Lordan, 2011), implementation of these systems across all potential types of fishing and non-fishing vessels would be cost prohibitive. While aerial surveys can be expensive as well, volunteer supported flight operations can considerably lower the cost of these surveys. LightHawk, a nonprofit organization based in Telluride Colorado, U.S.A., coordinates flights between pilots and scientists. Such organizations represent a new dimension of citizen science, opening new possibilities for research.

Species Distribution Modeling (SDM) (also referred to as Ecological Niche Modeling) is becoming an increasingly popular tool in ecology and conservation (Rodríguez et al., 2007) to study the distribution of organisms. Using spatial locality information for a species in combination with large-scale or global environmental data layers, SDMs can be used to predict a map of the distribution of a species based on underlying environmental variation (Elith and Leathwick, 2009). There many applications of SDMs in conservation biology, such as to identify potential habitat for endangered species reintroductions (Carroll et al., 2003), to estimate changes in species distributions under global climate change (Peterson et al., 2002), or to explore the potential spread of invasive species (Yap et al., 2015; Katz and Zellmer, 2018). SDMs have been used to study the distributions of a broad diversity of organisms, from terrestrial animals (Bryson et al., 2016; Pelletier et al., 2014), birds (McCormack et al., 2010), marine fish and invertebrates (Cheung et al., 2009), plants (Zellmer et al., 2012) and even pathogens (Yap et al., 2015), but have rarely been used to study the distributions of human-related activities. When interacting with the environment, such as through hunting and fishing, humans may likewise have predictable patterns that reflect the underlying environmental conditions that structure the species they utilize. In fact, SDMs have been successfully used to predict the distribution of species based on the environmental conditions of their food resources (Freeman and Mason, 2015). Thus, SDMs may be a useful tool for studying the distribution of human-related activities.

SDMs, and especially those that use a machine learning approach, take advantage of the power within large datasets to let the data determine the model (or set of environmental variables) that best describes the distribution of a species (Olden et al., 2008). This approach is particularly useful when there are a lot of potential contributing variables making it difficult to pre-designate models (Olden et al., 2008). The spatial distribution of fishers is a complex problem with many potential variables contributing (Jalali et al., 2015), thus is well suited for a machine learning SDM approach. Being able to investigate many different predictors allows us to go beyond just understanding how current MPAs structure fisher distributions, and instead determine importance of environmental predictors of where fishing is likely to occur, helping with better design of MPAs in the future.

By design, MPAs should have a significant impact on the distribution of fishers, but what specific impact they have is less clear. By limiting fishing and harvest within specific areas of conservation priority, the implementation of MPAs may result in spreading out the impacts of fishing across the entire region. Alternatively, MPAs may cause compaction in unprotected areas, which may be a significant deterrent to overall conservation of the region (Lester et al., 2009). Others have suggested that no-take MPAs will result in "fishing the line," with fishers locating right outside the boundaries of MPAs to catch spillover (Kellner et al., 2007). These various distributions have different consequences for fish and invertebrate densities across space, and therefore it is important that we understand how MPAs impact fisher distributions (Kellner et al., 2007).

Our goals were thus to 1) determine whether fishers were adhering to MPA boundaries and if there were any differences among fishing or boat types, 2) test whether MPAs impact the distribution of fishers, including their overall distributions and distance from port, and if there were any differences among fishing or boat types and 3) evaluate the potential use of SDMs to investigate the factors impacting the distribution of humans and human-related activities. If MPAs impact the distribution of fishers, then we expect 1) the proportion of actively-fishing boats observed within MPAs will decrease after MPA implementation, 2) there will be decreased overlap between SDMs pre- and post-MPA implementation, and 3) boats will be located either closer or further from port. As a control, we compare vessels on which there was active fishing occurring to non-fishing vessels (vessels that are not used for fishing and were not actively engaging in fishing), which should show no differences before and after MPA implementation, since they should not be directly affected by MPAs.

2. Methods

2.1. Study site

The Southern California Bight (SCB) has had a long history of fishing management, as it is a highly productive marine ecosystem (Horn et al., 2006; Horn and Allen, 1978; Hubbs, 1960; Pondella et al., 2005) located next to one of the largest cities on the west coast of the United States with extensive commercial and recreational fishing (Zellmer et al., 2018). A total of 50 MPAs (known as the South Coast MPAs) have been established in southern California in two efforts, the northern Channel Islands in 2002 and the mainland coast in 2012. Currently there are 25 MPAs on the islands including the southern Channel Islands (established in 2012 as part of the mainland effort) and 25 along the mainland coast. The established MPAs set aside habitat with little to no fishing or marine extraction.

2.2. Aerial surveys

We conducted aerial surveys to collect spatially explicit data regarding the distribution, type and activity of vessels operating in state waters following the implementation of MPAs in the south coast region. These surveys were conducted via two transects along the southern California coast starting in September of 2008 encompassing 2565 km^2, approximately 3.25 years prior to the implementation of MPAs, and continued through September of 2015. During 2008–2013, aerial surveys were flown monthly, and then in 2014 the surveys occurred quarterly. The northern transect ran from Santa Monica Bay north to Point Conception, while the southern transect ran from Santa Monica Bay south to the Mexican border. The aerial surveys covered 19 MPAs along the mainland southern California coast.

Small aircraft capable of high maneuverability and low speeds were used to fly directly over vessels while survey personnel searched for, identified, and recorded data on all vessels spotted within approximately 4.82 km (3 miles) of the shoreline along each transect. The collection of data from small fixed-wing aircraft allow for a transect to be completed in approximately two to two and one half hours depending on number of vessels encountered and other factors e.g., weather, airspace restrictions. Depending on weather conditions, aircraft were flown at an altitude of 152–254 m (500′ to 1000') and travel at 185–222 km/h (100–120 knots). Volunteer pilots, coordinated by LightHawk, flew the aircraft for each of the surveys.

The survey team consisted of a pilot, spotter, GPS technician and