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Differences in lobster fishing effort before and after MPA establishment

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ABSTRACT

In April 2003, California established a network of no-take marine protected areas (MPAs) around the northern Channel Islands located within the Santa Barbara Bight. Prior to the MPAs enclosing 17% of the islands' lobster fishing grounds, 25 commercial lobster fishermen caught 50% of the regional annual landings from the Channel Islands. To best manage MPAs and affected fisheries we ask a critical question: Where did the fishermen go? Spillover theory emerging from models of MPAs and adjacent fisheries suggests displaced fishermen will concentrate their effort along MPA borders; a phenomenon called "fishing the line". These models do not consider habitat-specific fishing effort, habitat heterogeneity, nor fixed-gear fisheries such as lobster where traps are set, soaked for 1 to 3 nights, pulled and re-set. With fixed-gear fishing, space is "marked" or occupied, and reduces the possibility of another fisherman to fish that space. Lobster trap fisheries are notoriously territorial as a result. Lobster fisheries therefore stand to experience a skewed impact based on a priori territorial distributions and habitat quality. We use a Geographic Information System (GIS) to map 10 years (5 before reserves and 5 after) of fishery-dependent logbook data assisted with fishery interviews to test if commercial lobster fishermen aggregated fishing effort at MPA borders as an adaptive fishing strategy. We found that fishermen around the Channel Islands MPAs did not concentrate effort at MPA boundaries but instead the proportion of total traps pulled in close proximity (within 1 km of reserve borders) to MPAs declined from 10% to 5%. Chi^2 analysis found a significant decrease in the proportion of a season's traps pulled in areas near MPA borders ($n = 157{,}071$; $p < .001$). T test analysis testing the difference in CPUE between areas far from MPAs and areas adjacent to MPA borders showed a significant reduction in the difference between CPUE following MPA designation ($n = 50{,}206$; $p < .001$).

Introduction

Marine protected areas (MPAs) are an ecosystem-based management tool increasingly being established to protect sensitive habitats, their associated fauna, and ecosystem services (NRC, 2001; Roberts & Polunin, 1993). There is much evidence indicating that MPAs increase species abundance, biomass, and productivity within their borders (Gell & Roberts, 2003; Halpern & Warner, 2002; Lester & Halpern, 2008). Benthic fish and invertebrate species targeted by fisheries may especially benefit from MPAs given their relatively low mobility and small home range sizes. Intensively fished benthic species such as the California spiny lobster (*Panulirus interruptus*) exhibit dramatic and rapid increases within MPAs due to the same factors and, in addition, to their high site fidelity to rocky reef habitats (Kay, Lenihan, Miller, & Wilson, 2012; Withy-Allen & Hovel, 2013).

However, MPA benefits can vary according to a host of ecological and management conditions. For example, Rassweiler, Costello, and Siegel (2012) found that MPAs of equal size, but sited randomly, without consideration of fishing fleet behavior and target species population dynamics, can generate the opposite of the intended effect of improving fishery profits. Furthermore, the spatial extent of any anticipated benefits outside of MPAs is not well known (Hilborn et al. 2004; Parrish, 1999). As a result, the conditions under which MPAs export adult or larval subsidies to adjacent fishing grounds are frequently examined (Abesamis & Russ, 2005; Costello

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& Polasky, 2008; Hastings & Botsford, 1999; Hilborn et al. 2004; McClanahan & Mangi, 2000; Roberts, Bohnsack, Gell, Hawkins, & Goodridge, 2001; White & Kendall, 2007). A few studies considered the spatial adaptive behavior of fishermen and found that the redistribution of fishing effort is critical to an MPA's capacity to generate spillover benefits (Halpern, Gaines, & Warner, 2004; Sanchirico, Malvadkar, Hastings, & Wilen, 2006; Smith & Wilen, 2003). This is especially true if fishing effort converges on MPA boundaries and captures target species as they spill out of the MPA (Halpern et al. 2004).

Fishermen are predicted to "fish the line" as an adaptive strategy to recover any declines in catch associated with reduced access to fishing grounds resulting from MPA establishment (Kellner, Tetreault, Gaines, & Nisbet, 2007). Empirical studies of MPAs in the Gulf of Maine and the Mediterranean Sea found that fishing fleets allocated a substantial proportion of total fishing effort along MPA boundaries where catch per unit of effort (CPUE) was higher than in fishing grounds farther away from MPAs (Gonñi, Hilborn, Diaz, Mallol, & Adlerstein, 2010; Murawski, Wigley, Fogarty, Rago, & Mountain, 2005). This finding is consistent with previous work characterizing fishermen as optimal foragers who allocate fishing effort according to rates of catch return or efficiency (Aswani, 1998), rather than a direct relationship between MPAs and fishing effort. In other words, the MPA must be generating a spillover subsidy of legal sized animals with lower associated fishing costs that provides a net productivity greater than that of other open fishing areas. In some contexts there may not be sufficient MPA subsidy (Stevenson, Tissot, & Walsh, 2013) or the opportunity costs may be too high (Wilcox & Pomeroy, 2003) to attract fishing effort to MPA borders.

A number of factors can impact effort following MPA establishment, including the quantity and quality of remaining suitable fishing habitat, the avoidance of areas adjacent to boundaries, territoriality, crowding, and the potential expansion of effort into new places. First of all, fishers do not always follow ideal free distribution predictions, due to several factors limiting their freedom to distribute their effort in direct relationship with the resource. Imperfect knowledge of the resource combined with social, economic, and physical fishing skill factors can constrain fishermen's effort across an area (Abernethy, Allison, Molloy, & Côté, 2007). Further, the relative continuity of habitat across reserve boundaries can also impact fishing effort (see e.g., Freeman et al. 2009; Huserbråten et al., 2013, Kay, Lenihan, Kotchen, & Miller, 2012). Similarly, Horta e Costa et al. (2013) showed how different fisheries and gear types respond differently to a mid-latitude MPA where some fished a broader area and others kept preferred territories.

In April 2003 the state of California partnered with the U.S. National Marine Sanctuary and National Park Service in establishing a network of ten MPAs around the four northern Channel Islands off Santa Barbara (Fig. 1). Commercial lobster fishermen, university scientists, and the California Department of Fish and Wildlife (CDFW) formed a collaborative MPA monitoring program (www.calobster.org) to test hypotheses of MPA effects on commercial fisheries. The century old commercial lobster fishery brings >$3 million to the regional economy annually. The CDFW has managed this trap fishery with a minimum size limit (83 mm) and 6 month season since the turn of the 20th century. CDFW mandated an escape port for each trap in 1976 to reduce juvenile handling mortality. In 2005 the commercial lobster permit became transferable for 146 of 250 permit holders based their lobster landings history. At the time of this research the fishery did not have a Fishery Management Plan but was generally thought to be sustainable (Barsky, 2001). We mapped 10 seasons of commercial lobster fishermen's logbook data to examine spatial patterns of fishing effort before and after MPA implementation. While logbook data depends on faithful responses, our in-depth interviews suggest that there was no compelling reason in this context for inaccurate responses. We asked the following questions: How was commercial lobster fishing effort spatially redistributed in the five

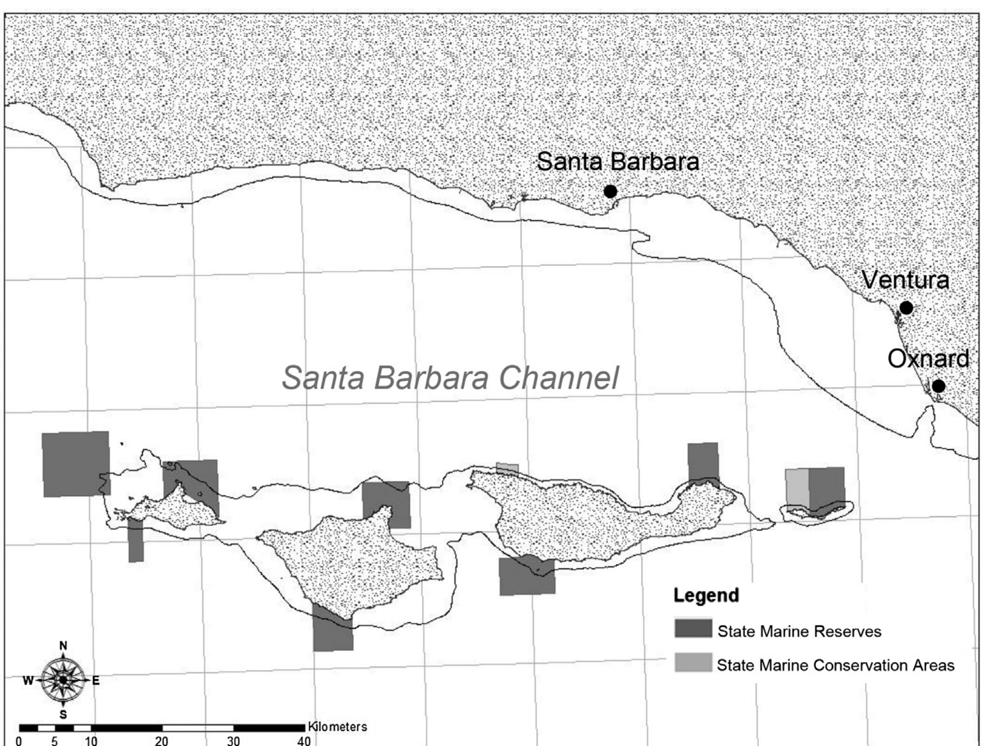

Fig. 1. Map of the northern Channel Islands State Marine Reserve network (est. 2003). Figure includes the 50 m isobath within which the majority of lobster fishing effort occurs.

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seasons after MPA designation? Were lobster fishermen at the Channel Islands targeting MPA borders? Was CPUE higher in areas near MPAs? Are there other adaptive strategies fishermen use when fishing within a network of MPAs?

Material and methods

A large body of literature has in recent years applied spatial methods to examine human-environment dynamics and spatial resource use (e.g., Brown, 2004; López-Carr et al. 2012; Raymond and Brown 2007), with a growing literature applying spatial methods to fisheries (Chen, López-Carr, & Walker, 2014; St. Martin & Hall-Arber, 2008). However, few of these studies have mixed various spatial methods and/or compared methodological outputs (Goodchild, 1992). Further, few studies have examined discontinuities in environments of apparent spatial continuity, or uniformity, such as heterogeneity in marine habitats. When human delineated boundaries are superimposed on poorly understood (or mapped) surfaces, as is the case with an MPA, human behavior may become spatially concentrated to such a degree that a model assuming spatial continuity no longer fits data. In the case of an MPA, fishing behavior may become concentrated along MPA boundaries in a place-based threshold effect more suitable to a binary place-based approach, as has been applied in land-based literatures on human migration (Davis & López-Carr, 2014) and on livelihood zones (Jankowska, López-Carr, Funk, Husak, & Chafe, 2012): in such cases, as with MPAs, you are inside or outside of the spatial area of interest.

As marine managers increasingly develop and apply spatial tools for fishery management and conservation we must improve our understanding of space vs. place effects in a complex system whose spatial heterogeneity remain largely unknown and unmapped or poorly mapped (Rassweiler et al 2013). Research is needed to further understand the limitations and opportunities of spatial techniques in the marine environment (Goodchild & Quattrochi, 1997).

Units of analysis often come pre-defined (e.g., census tracts data). Other times, researchers can control (to an extent) the smallest areal unit of analysis. Given that boundaries are forever imperfect, a challenge to researchers examining spatial patterns is to justify the most suitable areal unit to analyze and yet sometimes such units are defined by theory and prior empirical analysis as in our hypothesis here of "fishing the line". In either case, spatial autocorrelation remains a challenge. Given that areas that are closer in space (or time) will be more similar than those that are more distant, spatial theorists argue it is useful to model these associations to account for and potentially reduce spatial error (Getis, 2010). Ultimately, both for the protection of individual anonymity as well as for suitable comparisons to other data sets, and for empowering policy applications, spatial data may be usefully aggregated, weighted, and examined at scales consonant with spatial planning policies (Stein, Riley, & Halberg, 2001). Yet in the case of a coupled human-environment system with known or hypothesized thresholds, it may be more suitable to analyze data in discrete space to examine differences within a set area versus outside that fixed boundary, as is the case with MPAs. Few studies have combined quantitative spatial or ("platial") analysis with qualitative data to examine human-environment interactions in coastal marine ecosystems in general, or as we have done in this study of fishermen's use of space and place around MPAs.

We tested hypotheses of commercial fishing effort reallocation after establishment of a marine reserve network using qualitative and quantitative data. This approach utilizes a contextual complement of evidence that provides a ground-truthed rationale for fishing effort map construction and interpretation of results. The CDFW shared state-mandated captain's daily fishing logs, which report quantitative effort and catch data. In their logs, fishermen provide a spatial landmark for each grouping of traps set in an area, but these landmarks are not standardized, thus requiring a mapping exercise where commercial lobster fishermen defined their landmark areas by drawing them on maps. We use these landmark areas to spatially characterize and quantify fishing effort. Finally, we tested for any significant changes in the proportion of fishing effort concentrated on MPA boundaries, thereby testing if fishermen are "fishing the line" and if CPUE is significantly different near MPA borders. CPUE can vary temporally and spatially due to variations in target species behavior and abundance, and multiple other dynamic processes, including hyperstability and hyperdepletion (Hilborn & Walters, 1992). Nevertheless, it is a robust metric used to assess fishery population abundance and manage stocks. We used spiny lobster CPUE from the study region because total biomass of lobster landed, number of lobster traps pulled, and CPUE for the spiny lobster fishery were stable, changing less <4% across the southern CA region, over the course of our experiment (CDFW, 2012). Maunder and Punt (2004) provide methods of standardizing CPUE data so that external explanations for CPUE change are removed/reduced and CPUE can be a good indicator of resource abundance for use in stock assessments. But in our case we did not need to use any of these methods because measures of effort were constant (e.g., fishermen participating, number of traps per fisherman, boat and engine size, pot hauler, season length), we used a ten year time series to reduce the influence of interannual effects, and any decadal effects are documented to have had a positive effect on CPUE in the region (Guenther, 2010), thereby making any observation of reduced CPUE an effect of changes in fishermen's decisions regarding trapping location and frequency and the establishment of MPAs.

Mapping fishing data

Through a confidentiality agreement with the CDFW and local commercial lobster fishermen we obtained 10 seasons (1999 through 2008; five seasons before and five seasons after MPA network establishment) of commercial lobster fishing logbooks. Each day a fisherman fishes for lobsters he reports (1) how many traps he pulled, (2) how many legal-sized lobsters he retained, and (3) where he pulled them. The fisherman can divide his grouping of traps, or "string", into areas of any size (Strings of traps are not literally strung together in this fishery as they are in some other trap fisheries, but the jargon is maintained). Trap strings generally lie along depth contours and reef structure. As such, trapping areas with many contiguous reefs may be larger than areas with less hard-bottom or fewer isolated reefs. Individual fishermen may also parse fishing areas or reef structure differently, thereby requiring a master map of landmarks to attribute site selection or fishery productivity to space (and any characteristics of that space, such as distance from port, habitat, wave exposure, proximity to an MPA, etc.).

To construct a master landmark gazetteer, the lead author randomly interviewed 15 of the 37 commercial fishermen who reported fishing around the islands at any time during the ten seasons in this study. In these interviews, fishermen outlined their fishing areas and named them as they do when reporting in logbooks. Data was validated through triangulation techniques internally and externally. As fishermen drew their landmarks they instinctively provided a history and rationale for how they fish and why they fish these areas. The author conducted interviews during the summer of 2006, which was 3 seasons after the marine reserve network's designation. As a result, some landmarks came with an unsolicited oration describing why they are fishing an area

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differently or how they started fishing it to adjust for the reduced access to fishing areas after MPAs. Other times an area would be associated with a conflict with another fisherman over that space. The author compiled a list of the fishing strategies described during the interview process and we report them in the results. We also employed this list of strategies to develop hypotheses and interpret regression results.

Despite representing 41% of all commercial lobster operators at the Channel Islands, the 15 interviewed fishermen caught 76% of all lobsters caught around the MPA network during the ten season time period and pulled 78% of all the traps pulled at the islands. Therefore modeling their effort choices and adaptive behavior represents the majority of fleet dynamics. There is some error in fisherman recall and inconsistency in logbook reporting resulting in an estimated 50% loss of fishing events that map onto the landmarks provided in the interviews. We trimmed fishing events due to some discrepancies between fishermen name and logbook entry of polygon names and because some effort was executed by fishermen we didn't interview, creating unmatched, unmappable data. The average number of traps pulled per event we were able to map is 25, where the average number of traps pulled in the trimmed events is 15. Therefore, the total amount of effort represented in the data used is greater than 50%.

Fishermen identified, named, and sketched the 180 total fishing areas particular to each individual fisherman. Some areas, or polygons, overlapped and some areas were identified by a single fisherman. Names of trapping areas also sometimes agreed for overlapping areas, yet other apparently similar polygons did not share a landmark name. To map spatio-temporal distributions of fishing effort and catch data we created a landmark shapefile in ArcGIS v. 9.2 that included separate polygons for each fisherman's specific landmark area. We split each landmark area into 5 and 10 m depth zones (e.g., 0–5 m, 6–10 m, 11–20 m, 21–30 m, 31–40 m, 41–50 m) to best match daily fishing data at each landmark and depth ($n = 5233$ polygons). We joined the 10 seasons of landmark-depth fisherman's fishing data to these depth specific landmark polygons ($n = 8973$). We categorically defined fishing polygons as either "on a border" or "not on a border" according to the calculated centroid distance to the nearest MPA border. We defined a polygon as on the border if its centroid was as close as a kilometer or less from the nearest MPA border. Although interviewed fishermen defined fishing the border as within 100 m of an MPA, we expanded this definition an order of magnitude due to the coarse spatial resolution of the fisherman-drawn landmark polygons. To characterize fishing effort patterns at a 1 m scale would artificially assign a spatial accuracy much finer than our original polygon and logbook data could provide. It is important to note, however that this fishery actually operates on a scale much finer than we can detect and we therefore overestimate the proportion of fishing effort that occurs along MPA borders.

We mapped the depth, landmark, and fisherman specific daily fishing events to tally fishing activity in overlapping space. Through a series of geospatial processes, we divided each depth-landmark into 3826 small polygons (ranging from 1 m^2 to 7.4 km^2) according to where fishermen areas overlapped. We defined a centroid for each of these small polygons and calculated its distance to the nearest MPA border (.001 km–11.978 km). We assumed trapping effort was homogenously distributed across each of the depth-landmarks and divided catch and effort data among each small polygon according to its proportional size of the original depth-landmark. We used these data to summarize spatio-temporal fishing data (Fig. 2). No other changes aside from the MPAs in the fishery could have contributed to this result, with no changes in fishing technology, fleet demographics, etc.

Statistics

We tested whether fishing effort aggregated along MPA borders using a Chi^2 analysis of the mean proportion of effort that occurred in polygons near MPA borders compared to effort that occurred farther away from an MPA border before and after the Channel Islands MPA network designation. We expected fishing effort to aggregate along MPA borders if CPUE within 1 km of the borders was significantly higher than the CPUE in other fishing grounds farther away from MPAs. We used 1 km as it was the finest scale at which we could resolve the data. We tested if CPUE was higher along MPA borders using a paired Student's t-test of the mean difference of a fisherman's daily CPUE in a non-MPA border area minus his CPUE in an MPA border area before and after the MPA network designation.

Results

We found fishing effort at the islands showed a discernable pattern of densely fished areas compared with other areas that were less frequently fished. By mapping the logbook data we tracked the total number of traps pulled each season in each polygon. We generated a gradient of mean total trapping effort across all 5 seasons before MPA designation (Fig. 2). Some areas experienced very little, if any fishing activity (<15 traps in an entire 6 month season) and others had as many as 3100 traps pulled within a single season. A few of the more intensely fished areas were those that became MPAs in April 2003.

We also mapped the mean total trapping effort across the 5 seasons after MPA network establishment (Fig. 3). Generally, we found spatial expansion and an increased trapping effort along western San Miguel, Santa Rosa, and Santa Cruz islands. These areas contained relatively small sites of high trapping effort prior to MPAs and became larger areas with more traps after MPAs. We did not observe an increase in trapping effort along MPA borders. It appears there was a reduction in effort in the areas that became MPA borders (Figs. 3 and 5).

When we mapped the mean percent change in total traps pulled in each area per season (Fig. 4) we found that most areas experienced a 10–500% increase (areas shown in tan colors) in total traps pulled. A few of the blue areas had either no change or a reduction in mean seasonal trapping effort after MPAs. The total footprint of area fished after MPAs is bigger than before MPAs therefore indicating a spatial expansion into areas generally farther away from MPAs.

Statistics

Our Chi^2 analysis of the proportion of traps pulled in areas within 1 km of an MPA border versus areas greater than 1 km of an MPA showed a significant decrease in the proportion of a season's traps pulled in areas near MPA borders ($n = 157{,}071$; $p < .001$). In the 5 seasons prior to MPA network establishment, the areas that were within 1 km of to-be-designated MPAs received 10.6% of the total traps pulled at the islands compared to 5.3% after MPAs (Fig. 5).

Our t test analysis of the difference in CPUE between areas far from MPAs and the CPUE in areas along MPA borders also showed a significant reduction in the difference between CPUE in the two areas after MPA designation ($n = 50{,}206$; $p < .001$). The relatively higher CPUE experienced in areas that were to become MPA border areas compared with the areas further than 1 km from a to-be MPA border was reduced 78% from a .05 lobster/trap pull advantage to only .01 more lobsters/trap pull. This pattern appeared to be related to the reduction in mean daily CPUE in areas along MPA borders (.75 lobster/trap pull compared to .71 lobster/trap pull) because the

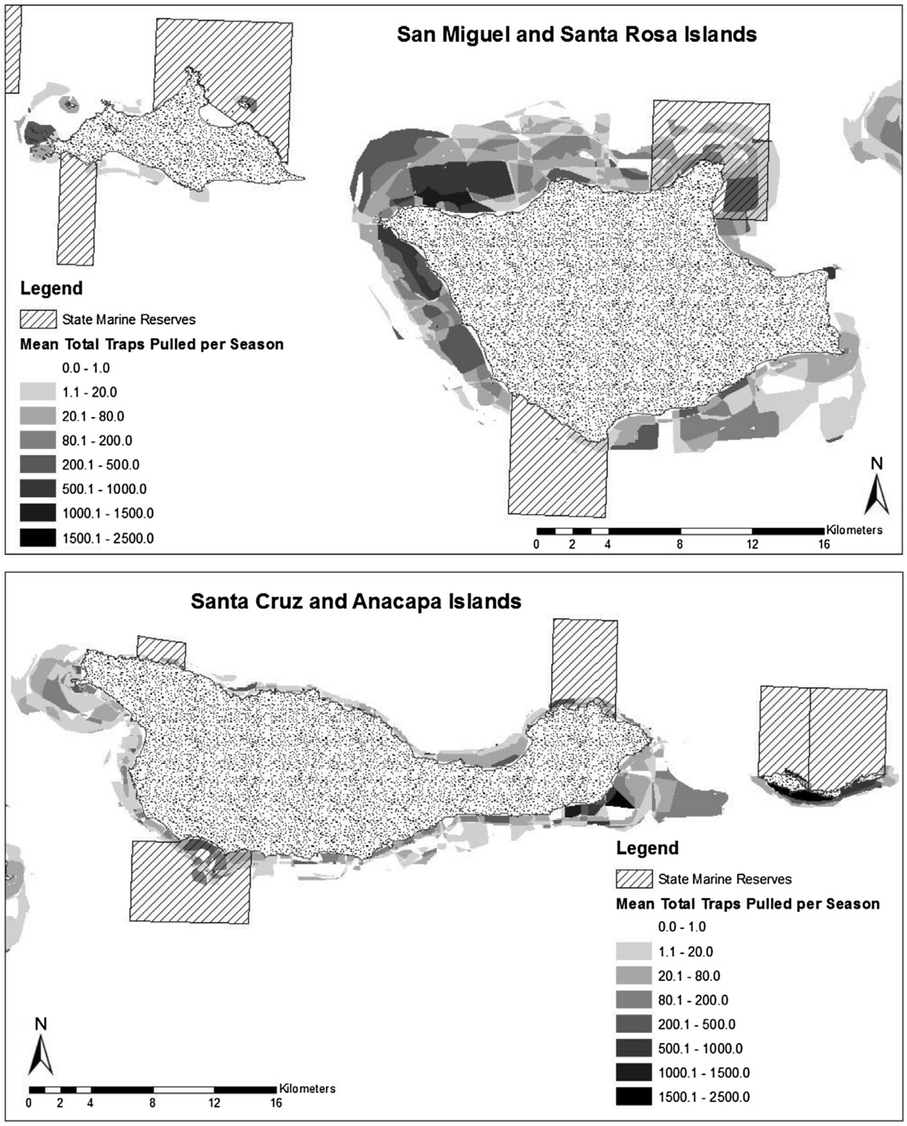

Fig. 2. Mean seasonal distribution of trapping effort before MPAs ($n = 5$).

mean CPUE in the other areas (.69 lobster/trap pull) did not change after MPA designation.

Interview-generated context

During the mapping interviews fishermen often described their strategies to fish certain areas. Frequently these described possible fishing strategies for adapting to MPAs. We grouped each of these strategies and present them with their supported rationale below:

Fishing the line

- There is not much suitable habitat around borders of Channel Islands State Marine Reserve (CISMR) network. Only 30–50% of the borders lie on habitat they might otherwise fish, but because of wind and swell direction they are reluctant to set gear close to a border. Traps can easily be carried into reserves overnight given the right sea conditions. This results in maybe 20% of reserve borders being "fishable".
- The first three seasons after the CISMR network designation brought uncharacteristic heavy rain events that washed a lot of trees and other large debris into the nearshore trapping areas. Floating debris frequently got hung up in trap buoy lines and dragged traps unpredictable distances away from where they were set. This phenomenon also discouraged fishermen from fishing close to reserve borders for fear of being fined or losing their permit.
- Related to the lack of lobster fishing habitat along reserve borders is the expectation that adult lobsters will not migrate out of reserves along most borders. In areas where there is no contiguous reef leading lobsters from inside to outside of reserves, fishermen do not expect to catch many lobsters spilling into open areas and are therefore allocating fishing effort elsewhere. The MPAs in this network were designed to protect complex habitat by completely enclosing reefs so most of the MPAs did not have contiguous habitat extending from inside to outside of reserves.
- Fishermen described three specific border areas where they set traps to target predicted spillover along reef structure that could facilitate lobster migration out of reserves. After reserves were established, Kay, Lenihan, Kotchen, et al. (2012) found evidence of lobster spillover in these three areas (Gull Island, Scorpion, and Carrington Point) *visa vis* examination of fine-scale, habitat-

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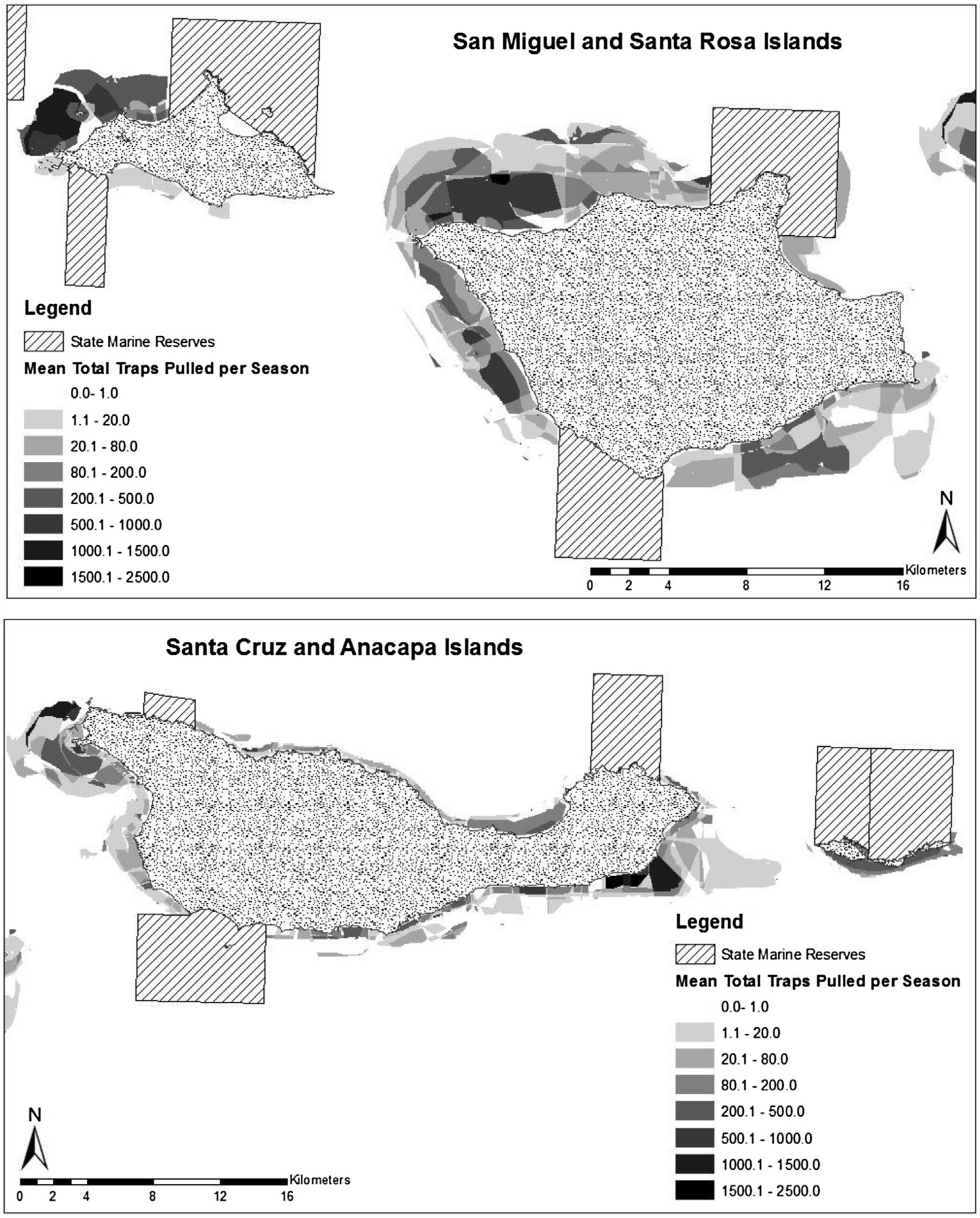

Fig. 3. Mean seasonal distribution of trapping effort after MPAs (n = 5).

specific trap data collected along the contiguous reef habitats. Nevertheless, Kay, Lenihan, Miller, et al. (2012) found no evidence of fishing the line through analyses of spatial trap distribution.

Fishing areas known to be of equivalent quality

- Fishermen claimed the CISMR enclosed the prime fishing areas and habitats, thereby leaving many of the less productive (and in some cases lesser known) reefs open to fishing. As a result some fishermen mentioned increased competition for space to fish on some of the more popular and also more productive reefs.

Following senior/more knowledgeable fishermen

- The more experienced fishermen commented on feeling crowded and followed by younger, less experienced lobster fishermen. They referred to some other fishermen as "mosquitos"; not revealing any deep frustration or anger, but describing their annoyance with no longer having some space to themselves.

Learning new fishing areas

- Some fishermen drew landmarks and described wanting to start exploring them. They had set a few "feeler" traps in such areas to see if they warrant a full shift in effort.
- A few other fishermen described a strategy to move more gear into deeper water or look for offshore reefs. Traditionally this fishery traps lobster in shallower (0–50 m) nearshore waters. With marine reserves, fishermen started to consider exploring grounds further offshore.
- Fishermen were looking for new or underutilized areas to fish within remaining open spaces between MPAs in order to shift

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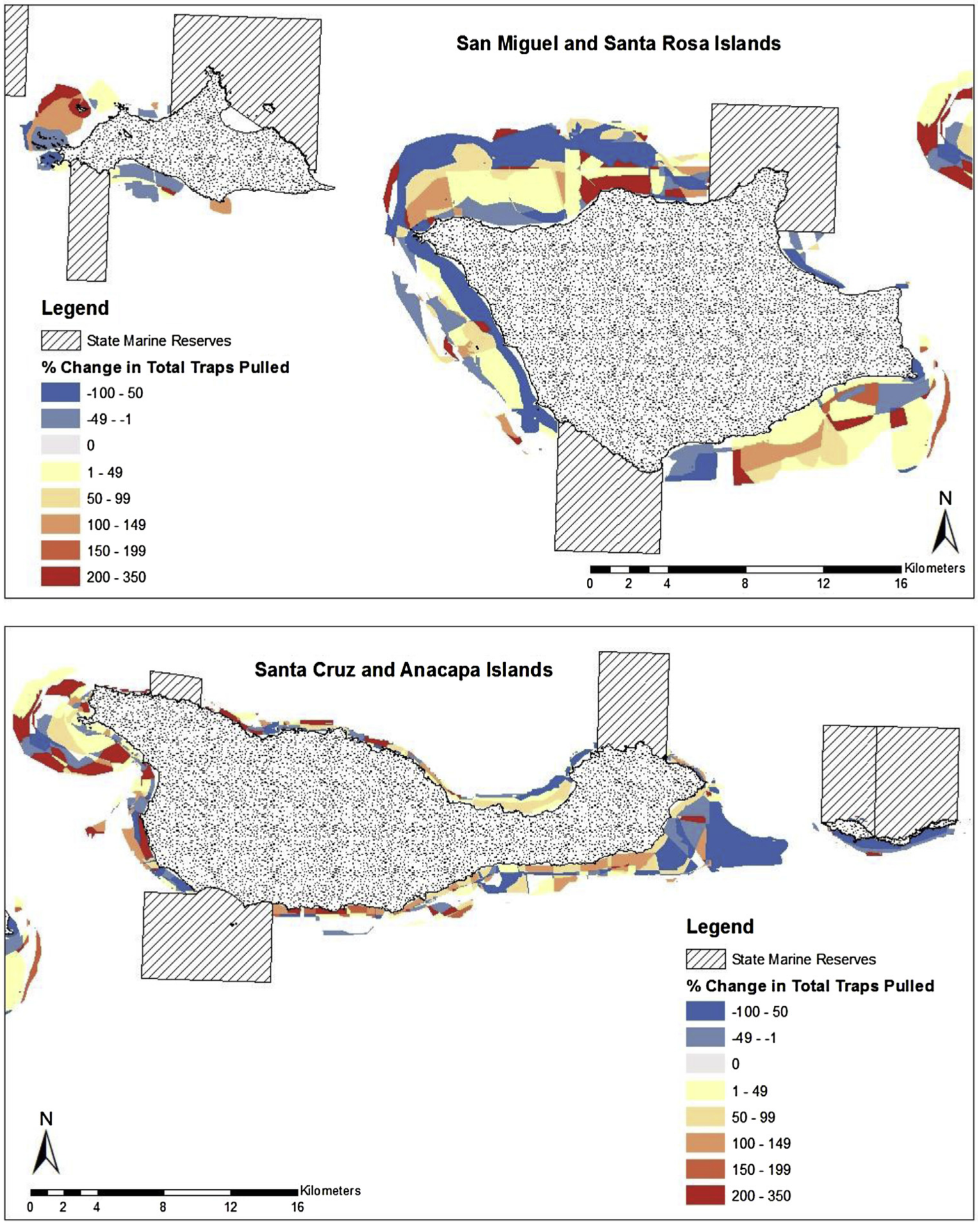

Fig. 4. Percent change in total trapping effort over 5 seasons after MPAs.

their trapping portfolio to more efficient distributions. For example, one fisherman shifted a large portion of gear from the opposite side of the island to an 'underfished' area because the new trap area and portfolio afforded travel and fishing efficiency because it was a large area not divided by an MPA. When fishermen transit through MPAs they must stow all gear thus disrupting fishing operations and established work rhythm and pace. Some fishermen find setting and pulling traps in one large continuous open area is more efficient than fishing in two areas split by an MPA.

Discussion

We found that commercial lobster fishermen around the Channel Islands State Marine Reserve network were not aggregating effort at MPA borders. Instead they reduced their trapping effort near borders from 10% of the total island effort to only 5% after MPA designation. Echoing Daw's (2008) findings in Nicaragua, our findings suggest that CPUE in new areas, even if farther away, may provide higher catch rates. Based on fishing data and anecdotal interview evidence, commercial lobster fishermen appeared to be avoiding areas less than 1 km from the nearest MPA border. Our results are supported by those of Kay, Lenihan, Kotchen, et al. (2012) who analyzed the spatial distribution of trap numbers around three MPAs also examined in our study. Our results are also similar to those of Wilcox and Pomeroy (2003) who did not find that the California nearshore rockfish fishery allocated significant portions of effort along MPA borders. In that fishery the travel costs from the two main ports were thought to be too high compared with the possible catch to be had near MPA boundaries thus making it difficult or not possible to satisfactorily recoup fishing expenses. For our lobster fishery case, we also found the opportunity cost of either being fined or having a permit suspended for multiple seasons due to traps migrating accidentally into reserves was sufficiently high to actually deter fishermen from fishing MPA boundaries at the Channel Islands.

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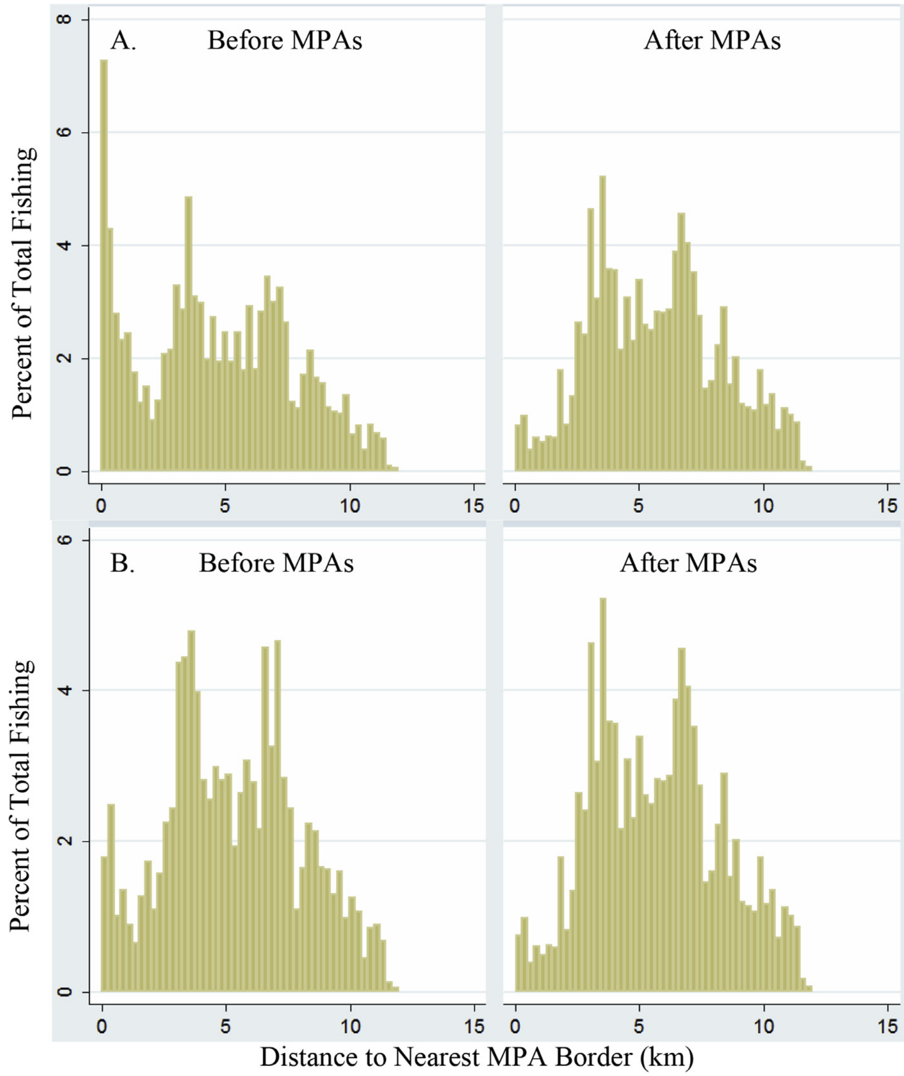

Fig. 5. Percent distribution of fishing events Relative to distance to the nearest MPA border before and after MPAs. A. Includes fishing effort in areas that become MPAs B. Excludes fishing effort that occurred in areas that become MPAs.

This begs the question-why/how are the opportunity costs of fishing MPA boundaries in the Mediterranean (Gonñi et al. 2010) and Gulf of Maine (Murawski et al. 2005) realized? Lobsters have shown little evidence of adult spillover from MPAs, therefore MPA benefits in lobster fisheries are expected to be driven by larval export due to the long larval development period, allowing for lobster larvae to cover great distances as they drift in the water column (Huserbråten et al., 2013; Kay, Lenihan, Kotchen, et al., 2012). It could be because the MPAs in the Mediterranean and Maine studies had been protected longer (8 and 10 years) than in the California studies (3 and 5 years), where spillover benefits may have been occurring but was not yet recognized or exploited (Kay, Lenihan, Miller, et al., 2012). Another possibility is longer term commercial fishing history of the regions studied. The Mediterranean and Gulf of Maine marine ecosystems have supported extensive commercial fishing pressure for at least 100 years longer than California. It is also possible that the eastern Pacific fishery stocks are sufficient in number outside MPAs that there is not a sufficiently significant difference in CPUE or productivity between MPA borders and open fishing grounds to warrant a redistribution of fishing effort (Kay, Lenihan, Kotchen, et al., 2012; Kay, Lenihan, Miller, et al., 2012).

In order to understand if our results are place-specific due to the species of resource harvested, the ecological context of this MPA network, or socio-political effects, our methods would need to be applied to cognate examples elsewhere. More research is needed to understand potential changes in effort following MPA establishment, (Abernethy et al. 2007), including the relative level of habitat continuity across reserve boundaries (see e.g., Freeman et al. 2009) and fisher spatial understanding of the fishing resource (Rassweiler et al. 2012). More research is also necessary to understand the role of adaptive behavior among fishermen in the redistribution of fishing effort and impacts on spillover (Halpern et al. 2004; Sanchirico et al. 2006; Smith & Wilen, 2003).

Unlike the more developed terrestrial resource use literature (Cheong, Brown, Kok, & López-Carr, 2012), few studies have combined quantitative spatial analysis with qualitative data to examine human-environment interactions in coastal marine ecosystems in general or in relation to MPAs specifically. Our combination of the two techniques facilitated the establishment of statistically significant quantitative patterns to be explained by the experts who understand the system, providing valid and reliable evidence for possible reasons for the observed patterns. While purely spatial models are useful for the protection of individual anonymity as well

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as for suitable comparisons to other data sets (Stein et al. 2001), in some cases, over-concern for spatial autocorrelation may belie more suitable methods appropriate for threshold effects that can be modeled quantitatively and corroborated qualitatively.

Conclusions

We examined fishermen adaptation to the establishment of no-take MPAs around the northern Channel Islands in the Southern California Bight. Specifically we tested spillover theory derived from MPA models and adjacent fisheries suggesting that displaced fishermen concentrate effort along MPA borders, a practice known as "fishing the line". We used a Geographic Information System (GIS) to map 10 years (5 before reserves and 5 after) of fishery-dependent logbook data complemented by fishery interviews. Our finding that fishermen near the Channel Islands MPAs did not concentrate effort at MPA boundaries has important implications to marine spatial planning policy, to spatial theory and methods, and suggests avenues for future research.

Our results suggest that MPA design must consider the stated objectives for their establishment. MPAs are most often created to be places where marine biodiversity and abundance is restored and preserved. Other times MPAs are created for fishery management, as protection for nursery grounds or spawning aggregations so that fisheries can be enhanced via protecting a biologically important place. Sometimes MPAs are created to achieve both objectives. Our results suggest that MPA design, specifically drawing its borders, is tantamount to determining an MPA's objectives; where placing borders on contiguous habitat facilitates spillover with fishery benefits and drawing borders so that critical habitats are encompassed by an MPA facilitates species retention and conservation objectives.

A parsimonious adaptive fishing strategy employed by MPA-displaced fishermen would be one consistent with optimal foraging theory. However, we think the ecological and/or social mechanisms that determine the relative costs and productivity of fishing grounds are largely context dependent. Future work should include an analysis of the economic and social variables that affect opportunity fishing costs toward identifying the process by which fishermen adapt to effectively fish around MPAs (e.g., Cinner et al., in press).

Future research dealing with threshold or place-based effects may consider binary or hierarchical modeling coupled with qualitative research. MPA studies specifically could usefully probe the "fishing the line" hypothesis to determine under what conditions and to what degree the phenomenon may or may not be observed in other MPA contexts globally. Future research may also be served by noting limitations to our research. We studied a human-coupled natural system with a high level of marine habitat complexity and a territorial fixed-gear fishery for lobster, which is a habitat-specific animal. All of these characteristics stand to bias our findings to value place greater than space. Such peculiarities based on species or human resource use practices that vary from place to place are critical to account for and model when possible. Careful attention to space versus place effects, and appropriate mode integration with place-informed qualitative research could usefully inform theory and policy towards sustainable fishing and elucidate complex coupled human-environment relations writ large.

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References

Abernethy, K. E., Allison, E. H., Molloy, P. P., & Côté, I. M. (2007). Why do fishers fish where they fish? Using the ideal free distribution to understand the behaviour of artisanal reef fishers. *Canadian Journal of Fisheries and Aquatic Sciences, 64*, 1595–1604.

Abesamis, R. A., & Russ, G. R. (2005). Density-dependent spillover from a marine reserve: long-term evidence. *Ecological Applications, 15*, 1798–1812.

Aswani, S. (1998). Patterns of marine harvest effort in southwestern New Georgia, Solomon Islands: resource management or optimal foraging? *Ocean & Coastal Management, 40*, 207–235.

Barsky, K. (2001). California spiny lobster. In CDFG (Ed.), *California's living marine resources: A status report* (pp. 98–100).

Brown, G. (2004). Mapping spatial attributes in survey research for natural resource management: methods and applications. *Society and Natural Resources, 18*, 17–39.

Chen, C., López-Carr, D., & Walker, B. L. E. (2014). A framework to assess the vulnerability of California commercial sea urchin fishermen to the impact of MPAs under climate change. *Geojournal*, 1–19.

Cheong, S.-M., Brown, D., Kok, K., & López-Carr, D. (2012). Mixed methods in land change research: towards integration. *Transactions of the Institute of British Geographers, 37*(1), 8–12.

Cinner, J. E., Daw, T., Huchery, C., Thoya, P., Wamukota, A., Cedras, M., et al. (2014). Winners and losers in marine conservation: Fisher's displacement and livelihood benefits from marine reserves. *Society and Natural Resources* (In press).

Costello, C., & Polasky, S. (2008). Optimal harvesting of stochastic spatial resources. *Journal of Environmental Economics and Management, 56*, 1–18.

Davis, J., & López-Carr, D. (2014). Migration, remittances and smallholder decision-making: implications for land use and livelihood change in Central America. *Land Use Policy, 36*, 319–329.

Daw, T. M. (2008). Spatial distribution of effort by artisanal fishers: exploring economic factors affecting the lobster fisheries of the Corn Islands, Nicaragua. *Fisheries Research, 90*, 17–25.

Gell, F. R., & Roberts, C. M. (2003). Benefits beyond boundaries: the fishery effects of marine reserves. *Trends in Ecology and Evolution, 18*, 448–455.

Getis, A. (2010). Spatial autocorrelation. In M. M. Fischer, & A. Getis (Eds.), *Handbook of applied spatial analysis: Software tools, methods and applications* (pp. 255–275). New York: Springer.

Gonñi, R., Hilborn, R., Diaz, D., Mallol, S., & Adlerstein, S. (2010). Net contribution of spillover from a marine reserve to fishery catches. *Marine Ecology Progress Series, 400*, 233–243.

Goodchild, M. F. (1992). Geographical information science. *International Journal of Geographical Information Systems, 6*, 31–45.

Goodchild, M. F., & Quattrochi, D. A. (1997). Scale, multiscaling, remote sensing, and GIS. In D. A. Quattrochi, & M. F. Goodchild (Eds.), *Scale in remote sensing and GIS* (pp. 1–11).

Guenther, C. (2010). *A socio-ecological analysis of marine protected areas and commercial lobster fishing in the Santa Barbara Channel*. California [dissertation]. Santa Barbara: University of California.

Halpern, B. S., Gaines, S. D., & Warner, R. R. (2004). Confounding effects of the export of production and the displacement of fishing effort from marine reserves. *Ecological Applications, 14*, 1248–1256.

Halpern, B. S., & Warner, R. R. (2002). Marine reserves have rapid and lasting effects. *Ecology Letters, 5*, 361–366.

Hastings, A., & Botsford, L. W. (1999). Equivalence in yield from marine reserves and traditional fisheries management. *Science, 284*, 1537–1538.

Hilborn, R., Stokes, K., Maguire, J.-J., Smith, T., Botsford, L. W., Mangel, M., et al. (2004). When can marine reserves improve fisheries management? *Ocean & Coastal Management, 47*, 197–205.

Hilborn, R., & Walters, C. J. (1992). *Quantitative fisheries stock assessment: Choice, dynamics and uncertainty* (p. 570). Springer.

Horta e Costa, B., Gonçalves, L., Erzini, K., Caselle, J. E., Cabral, H. N., & Gonçalves, E. J. (2013). Fishers' behaviour in response to the implementation of a marine protected area. *PLoS One, 8*, e65057.

Huserbråten, M. B., Moland, O. E., Knutsen, H., Olsen, E. M., André, C., & Stenseth, N. C. (2013). Conservation, spillover, and gene flow within a network of Northern European marine protected areas. *PLoS One, 8*, e73388.

Jankowska, M., López-Carr, D., Funk, C., Husak, G., & Chafe, Z. (2012). Climate change and human health: spatial modeling of water availability, malnutrition, and livelihoods in Mali, Africa. *Applied Geography, 33*, 4–15.

Kay, M. C., Lenihan, H. S., Kotchen, M. J., & Miller, C. J. (2012). Controlling for habitat confirms robust marine reserve effects and gradients of abundance near borders for California spiny lobster. *Marine Ecology Progress Series, 451*, 137–150.

Kay, M. C., Lenihan, H. S., Miller, C., & Wilson, J. R. (2012). Collaborative assessment of CA spiny lobster (*Panularis interruptus*) population and fishery responses to marine reserves. *Ecological Applications, 22*, 322–335.

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Kellner, J. B., Tetreault, I., Gaines, S. D., & Nisbet, R. M. (2007). Fishing the line near marine reserves in single and multispecies Fisheries. *Ecological Applications, 17*, 1039–1054.

Lester, S. E., & Halpern, B. S. (2008). Biological responses in marine no-take reserves versus partially protected areas. *Marine Ecology Progress Series, 367*, 49–56.

López-Carr, D., Davis, J., Jankowska, M., Grant, L., López-Carr, A. C., & Clark, M. (2012). Space versus place in complex human–natural systems: spatial and multi-level models of tropical land use and cover change (LUCC) in Guatemala. *Ecological Modelling, 229*(24), 64–75.

Maunder, M. N., & Punt, A. E. (2004). Standardizing catch and effort data: a review of recent approaches. *Fisheries Research, 70*, 141–159.

McClanahan, T. R., & Mangi, S. (2000). Spillover of exploitable fishes from a marine park and its effect on the adjacent fishery. *Ecological Applications, 10*, 1792–1805.

Murawski, S. A., Wigley, S. E., Fogarty, M. J., Rago, P. J., & Mountain, D. G. (2005). Effort distribution and catch patterns adjacent to temperate MPAs. *ICES Journal of Marine Science, 62*, 1150–1167.

NRC. (2001). *Marine protected areas: Tools for sustaining ocean ecosystems*. Washington, DC: National Academy Press.

Parrish, R. (1999). Marine reserves for fisheries management: why not. *CalCOFI Reports, 40*, 77–86.

Rassweiler, A., Costello, C., & Siegel, C. (2012). Marine protected areas and the value of spatially optimized fishery management. *Proceedings of the National Academy of Sciences of the United States of America, 109*.

Roberts, C. M., Bohnsack, J. A., Gell, F., Hawkins, J. P., & Goodridge, R. (2001). Effects of marine reserves on adjacent fisheries. *Science, 294*, 1920–1923.

Roberts, C. M., & Polunin, N. V. C. (1993). Marine reserves – simple solutions to managing complex fisheries. *Ambio, 22*, 363–368.

Sanchirico, J. N., Malvadkar, U., Hastings, A., & Wilen, J. E. (2006). When are no-take zones an economically optimal fishery management strategy? *Ecological Applications, 16*, 1643–1659.

Smith, M. D., & Wilen, J. E. (2003). Economic impacts of marine reserves: the importance of spatial behavior. *Journal of Environmental Economics and Management, 46*, 183–206.

Stein, A., Riley, J., & Halberg, N. (2001). Issues of scale for environmental indicators. *Agriculture, Ecosystems & Environment, 87*(2), 215–232.

Stevenson, T. C., Tissot, B. N., & Walsh, W. J. (2013). Socioeconomic consequences of fishing displacement from marine protected areas in Hawaii. *Biological Conservation, 160*, 50–58.

St. Martin, K., & Hall-Arber, M. (2008). The missing layer: geo-technologies, communities, and implications for marine spatial planning. *Marine Policy, 32*, 779–786.

White, C., & Kendall, B. E. (2007). A reassessment of equivalence in yield from marine reserves and traditional fisheries management. *Oikos, 116*, 2039–2043.

Wilcox, C., & Pomeroy, C. (2003). Do commercial fishers aggregate around marine reserves? Evidence from Big Creek Marine Ecological Reserve, Central California. *North American Journal of Fisheries Management, 23*, 241–250.

Withy-Allen, K. R., & Hovel, K. A. (2013). California spiny lobster (*Panulirus interruptus*) movement behaviour and habitat use: implications for the effectiveness of marine protected areas. *Marine and Freshwater Research, 64*(4), 359–371.

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