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Long-term effectiveness of a multi-use marine protected area on reef fish assemblages and fisheries landings

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ABSTRACT

The Loreto Bay National Park (LBNP) is a large, multi-use marine protected area in the Gulf of California, Mexico, where several types of small-scale commercial and recreational fishing are allowed, but where less than 1% of the park is totally protected from fishing. The LBNP was created in 1996; its management plan was completed in 2000, but it was not effectively implemented and enforced until 2003. Between 1998 and 2010, we monitored reef fish populations annually at several reefs inside and outside the LBNP to measure the effects of the park on fish assemblages. We also evaluated reported fisheries landings within the LBNP for the same time series. Our results show that reef fish biomass increased significantly after protection at a small no-take site at LBNP relative to the rest of the park. However, the multi-use part of LBNP where fishing is allowed (99% of its surface) has had no measurable effect on reef fish biomass relative to open access sites outside the park boundaries. Reported fisheries landings have decreased within the park while increasing in nearby unprotected areas. Although the current partial protection management regime has not allowed for reef fish populations to recover despite 15 years as a "protected area," we conclude that LBNP's regulations and management have maintained the conditions of the ecosystem that existed when the park was established. These results suggest that community livelihoods have been sustained, but a re-evaluation of the multi-use management strategy, particularly the creation of larger no-take zones and better enforcement, is needed to improve the reef fish populations in the park in order to ensure sustainable fisheries far into the future. These recommendations can be applied to all multi-use MPAs in Mexico where ecosystem recovery is not occurring despite maintenance of fish stocks.

1. Introduction

In response to the perceived failure of traditional, species-specific management tools to restore most fisheries, marine protected areas (MPAs) have been established as a means to conserve biodiversity and help sustain fisheries (Pikitch et al., 2004) within the context of ecosystem-based management (Halpern et al., 2010). The term "marine protected area" encompasses many differing management schemes and a gradient of protection levels that may restrict all extractive practices ("no-take marine reserves"), limit gear types, or restrict fishing temporally or via zonation (Ward et al., 2001). Marine reserves need to be used as a complement to fisheries management, particularly in developing countries where other institutionalized regulations may not exist. Benefits of marine reserves may be dampened in multi-use MPAs that lack sufficient no-take area and proper zonation.

MPAs have been established throughout Mexico in the last 15 years, including the Gulf of California (Sea of Cortés), a global marine biodiversity hotspot (Roberts et al., 2002) that has been of particular focus by conservation organizations and scientific groups, and gained UNESCO World Heritage Site status in 2005. The majority of these MPAs are multi-use, with typically small no-take areas surrounded by "buffer" zones where fishing effort and/or certain gear types are limited or restricted. Despite the

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establishment of several MPAs in the Gulf of California, the efficacy of these multi-use MPAs as both conservation and fishery management tools has seldom been assessed (but see Cudney-Bueno et al., 2009; Espinoza-Tenorio et al., 2010). There is concern that these MPAs may suffer from the "paper park" syndrome, where MPAs are established, but without the proper regulations, management plan, and resources to be effective in allowing for fish stock recovery (a common MPA objective). Rather, these areas only maintain the status quo of degraded ecosystems with no or very low benefits for the community and local fisheries.

The Gulf of California supports a large fishing community, producing 50–70% of Mexico's annual catch (Carvajal et al., 2004; Ulloa et al., 2006), of which 15% is captured by small-scale fishers (SEMARNAT, 2006; Ulloa et al., 2006). Fisheries management in Mexico is largely permit-based, limiting fishing effort by permitting skiffs (*pangas*) to harvest a number of target species (SAGARPA, 2007). For the majority of species, no quotas exist and management is dependent on this limited entry system. This strategy of a moratorium on entry into the fishery for preserving fish stocks has been recognized as an inefficient management measure as it does not create the right incentives to reduce fishing effort (Townsend, 1990; Wilen, 1988). Furthermore, it has generally been unsuccessful in maintaining fisheries stocks (CONAPESCA, 2010) and has been deemed to be unsustainable in the Gulf of California (Sala et al., 2004). Cinti et al. (2010) argue that this permit-based system does not provide the incentives for a sustainable fishery in Mexico, and MPAs may be one way to effectively fill this gap.

We used Loreto Bay National Park (LBNP) as a case study for the effectiveness of a multi-use MPA in meeting both its objectives (detailed below) and in allowing for fish stock recovery. The total no-take area is less than 1% of the park, and while prohibiting industrial-scale fishing, the park allows small-scale fisheries to operate within its borders. The stated goal of the park is to preserve fish biomass in order to maintain fisheries. Here, we assess whether the LBNP has met its objectives using a 13-year time series of data on fish abundance in multiple sites inside and outside the park, from before to after effective protection, and fisheries catch statistics.

2. Material and methods

2.1. Study site

LBNP was decreed in 1996; its management plan was finished in 2000, published in 2002, and implemented in 2003. LBNP was created as a result of stakeholder requests to exclude shrimp trawlers and purse seiners from local fishing grounds (CONANP, 2000). Its management plan was created through an open process that included input from user groups. The park encompasses 1837 km^2 and is zoned into different areas that allow various activities and degrees of extraction, with 1.27 km^2 as no-take, centered around two shallow seamounts (CONANP, 2003, 2000) (Fig. 1). Although only 0.07% of the park is no-take, some gear restrictions do exist (CONANP, 2003, 2000): beginning in 2000, the presence of industrial-scale boats (trawlers and purse seiners) was prohibited; the use of gillnets is prohibited half of the year; harpooning is banned; and north of Montserrat Island, only hook-and-line fishing is permitted (Fig. 1). LBNP adjoins several towns,

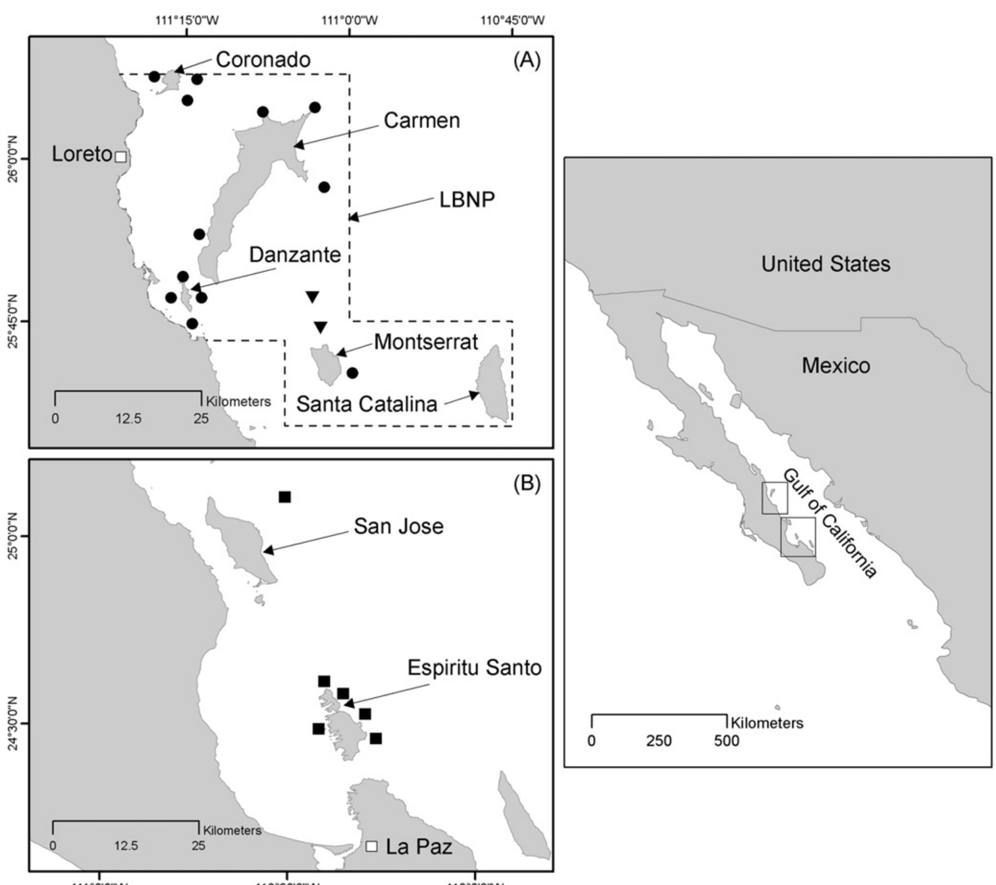

Fig. 1. Location of study sites. Loreto Bay National Park boundary depicted by the dotted line. Circles are MPA sites. Inverted triangles indicate no-take and restricted gear sites within the MPA (restricted sites). Open access (unprotected) sites are depicted by squares.

including Loreto, with a population of approximately 15,000 people. About 10% of the total population of these communities is involved in commercial fisheries as their primary livelihood (CONANP, 2003, 2000).

Stated objectives of the park include “to preserve renewable and nonrenewable natural resources” and “restore critical habitats, promoting the social development of the communities within the region” (CONANP, 2000). Specifically, the park seeks to establish guidelines to orient the development of the many activities that occur within the park, including commercial fishing, sport fishing, and other tourism activities (e.g., bird and whale watching, recreational diving) while ensuring that these activities are compatible with conservation and maintain community livelihoods. An assessment of the park must take into account these objectives: a preservation of environmental conditions and sustainable fisheries.

In general, the status of fish populations and the spatial distribution of fishing effort within the LBNP boundaries are not well known. The Gulf of California is impacted by the El Niño Southern Oscillation, which has been shown to affect fish assemblages and fisheries (Aburto-Oropeza et al., 2007; Sala et al., 2003) and further complicates management and recovery efforts. The park has, in recent years, been going through the evaluation and revision process of its management plan, including an increase in the no-take areas within the LBNP.

2.2. Biological monitoring

We surveyed 22 sites between Loreto and La Paz, in Baja California Sur (Fig. 1) annually in August–September from 1998 to 2010. All research was conducted under research permits (DAPA/2/110808/1990, DGOPA/07191/060907/3623, DGOPA/05356/140710/3457, SGPA/DGVS/06821/08, and DAN-03651), and LBNP managers were informed prior to conducting surveys. Fourteen of the survey sites lie within the LBNP, and eight open access sites south of the park were used as controls. All sites are in shallow, rocky reef habitats. Monitoring sites within the LBNP are located around the four main islands within the park – Coronado, Carmen, Montserrat, and Danzante. One of the LBNP sites is located within the current no-take zone and one within the restricted gear use area (Fig. 1). The restricted gear use site was not surveyed in 2003 due to unfavorable ambient conditions.

Surveys at each site involved underwater visual fish surveys censuses using SCUBA. Censuses followed standard belt transect methodology described in previous studies (Aburto-Oropeza et al., 2011; Sala et al., 2002), with each transect covering an area of 250 m^2 (50 m long $\times$ 5 m wide). Up to seven transects were surveyed per site, with divers swimming along an isobath of reef and making two passes along the same transect. Divers identified and counted all actively swimming fishes on the first path and sedentary, benthic, or territorial fishes on the second to account for observer effects and estimated their total length within 5 cm. Fishes that passed divers from behind were omitted to avoid counting the same fish multiple times. The censuses focused on reef fishes, those that use the hard substrata for protection, shelter, feeding, or reproduction (Thomson et al., 2000). However, we also included the epipelagic species that regularly visit reefs in search of food, cleaning services, and reproduction (Mascareñas-Osorio et al., 2011). We concentrated our efforts on conspicuous fishes species rather than cryptobenthic species, small fishes of less than 5 cm in length that are behaviorally cryptic and difficult to quantify by visual surveys due to their close association with the substratum. To calculate fish biomass we used length–weight allometries from Fishbase (Froese and Pauly, 2011). The surveyors are experienced at and trained in visually surveying fish assemblages and estimating fish lengths accurately (Aburto-Oropeza and Balart, 2001; Sala et al., 2002).

Detecting the impact of an MPA on fish assemblages may not be as straightforward as it appears. The commonly used single comparison of an MPA with nearby unprotected sites after the creation of the MPA may be confounded by spatial differences in fish biomass that are independent of reserve effects (Guidetti, 2002). Furthermore, these snapshot comparisons do not allow us to determine the rate of recovery of fish assemblages (Russ et al., 2005). An additional problem is the intrinsic variability in fish populations. In order to detect changes in fish biomass resulting from MPA establishment, these changes must be greater than natural variability. The optimal method to evaluate the efficacy of an MPA is to survey several sites in the MPA and multiple unprotected sites nearby and/or in the same biogeographic area, several times before and after the creation of the MPA. We used this design, called a Beyond-BACI (Before-After Control-Impact) (Underwood, 1992, 1994), to test the effect of the MPA on total fish biomass and the biomass of major fish trophic groups. The eight open access sites outside the park were the “control” sites and the 14 sites within the MPA were the “impact” sites. The impact sites are expected to show a positive temporal change in fish biomass following the implementation of management. Monitoring began in 1998, which is technically after the park was decreed; however, the management plan was not created until 2000 and not published in the Official Gazette of the Mexican Federation until January of 2003 and thus not official until 2003. Therefore, we assume that no significant change in fishers’ behavior occurred until 2003, leaving 1998–2002 as five years of “before” and 2003–2010 as eight years of “after” treatment. In 2007, some of the open access, control sites were decreed as part of a new MPA (Espiritu Santo Archipelago National Park). As no management plan has been published or implemented, these sites are still considered open access in our analysis.

We first compared the no-take area and the line fishing-only area within LBNP. There were no statistically significant differences in fish biomass between the two sites from before to after protection (see Results). Hence we included these two sites in a ‘restricted’ protection category and compared them with the rest of sites within LBNP. This comparison was intended to test whether the greater protection north of Montserrat has produced an effect on fish populations that is different from the rest of the park where fishing is less restricted. There were statistically significant differences in fish biomass between these two different levels of protection (restricted and rest of park) within LBNP (see Results). Therefore we decided to compare all sites within the park (except the restricted area) with the unprotected areas nearby in order to test any effect of the multi-use park as compared to open access areas.

We used asymmetrical analysis of variance (ANOVA) to test for two different types of impact: change in mean biomass after protection and change in temporal variance (e.g., Currie and Small, 2005; Francini-Filho and Moura, 2008; Skilleter et al., 2006). Protection can be considered a “press disturbance” since its effects are continuous and can cause a sustained increase in mean fish biomass. In addition, protection may dampen temporal variance in fish abundance relative to unprotected areas (e.g., Francour, 1994). Both effects can be detected as significant interactions. Increased biomass after protection would cause an increased interaction between the difference from impacted to control locations before, compared with after, protection (B $\times$ I in Tables 1 and 2) (Underwood, 1992, 1994). An effect on temporal variance can be detected as a significant interaction between the impacted and control locations in their temporal changes after the disturbance (T(Aft) $\times$ I in Tables 1 and 2) (Underwood, 1992). Since the same sites were monitored each year, reefs were nested within the control-impact treatment and randomized. To fulfill assumptions of normality and heteroscedascity, data on fish biomass were ln-transformed.

2.3. CONAPESCA catch data

We analyzed the reported fisheries catch databases from 1999 to 2009 from the Loreto and La Paz CONAPESCA offices. Generally, fishers fishing at our control sites report to the La Paz office, while fishers in the LBNP and outside the park near Loreto report to the Loreto office. Based on the reported capture sites, we determined if the catch came from the MPA or open access area, and used these location categories to compare catch trends under the two treatments as above (2.2). We eliminated the few capture sites whose location we could not determine as well as those outside the immediate area around LBNP in order to accurately measure and distinguish between catch in the MPA and open access treatment.

CONAPESCA fisheries statistics are too limited to evaluate the status of individual fish stocks for multiple reasons including lack of data on or assessment of fishing effort, lack of adequate spatial resolution, misidentification and lumping of species, and lack of data on fish sizes (Aburto-Oropeza et al., 2006). However, these databases have been used to identify general catch trends for "species groups" harvested in the Gulf of California (Erisman et al., 2011).

We eliminated all inconclusive and uncertain catch data (e.g., labeled as "other") within the database, as well as reports for ornamental and aquarium fishes. It is difficult to measure the level of fishing conducted by outsiders from the region and not reported in the local CONAPESCA office, so we did not attempt to account for this in the analysis. Reported catches were divided into family groups and species groupings (e.g., cabrillas and groupers as Serranidae and Epinephelidae) but identified to the species level when possible, which allowed us to determine the trophic groups in the catch. We used an ANCOVA model to test for differences in catch trends between the MPA and open access areas.

3. Results

3.1. Biological monitoring data

We studied if the data for the sites with fishing restrictions (no-take site, fishing-line only site) could be pooled into a single "restricted fishing" category. We tested for normality (Shapiro–Wilks test) of the Before, After, and combined samples for each site, and we compared the variances (Levene test) and means (Welch two-sample *t*-test) between the two Before and the two After samples (Romeu, 2004). The Before, After, and combined samples did not deviate statistically from normality (No-take Before: $W = 0.899$, $p = 0.409$; Fishing-line Before: $W = 0.920$, $p = 0.530$; No-take combined: $W = 0.975$, $p = 0.932$. No-take After: $W = 0.858$, $p = 0.145$; Fishing-line After: $W = 0.899$, $p = 0.327$; Fishing-line combined: $W = 0.0.911$; $p = 0.165$). In addition, there were no statistically significant differences in the variances (Before: $L = 0.010$, $p = 0.919$; After: $L = 1.741$, $p = 0.212$) and means (Before: $t = -1.439$, $p = 0.188$; After: $t = -0.186$, $p = 0.858$), so we pooled the data for the two sites in a single "restricted area" category.

Total fish biomass in the restricted area of LBNP was greater than in the other sites within LBNP from before to after the implementation of the management plan in 2003 (ANOVA, $p < 0.001$), despite the high degree of variability in biomass over time in the restricted zones (Table 1, Fig. 2). This difference was explained by the significantly greater abundance of herbivorous fishes ($p < 0.05$) and zooplanktivorous fishes ($p < 0.001$) (mostly *Abudefdful troschelli*) in the restricted sites relative to other sites in the park. There were no statistically significant differences in biomass of apex predators and carnivores between the restricted sites and the rest of the park from before to after 2003. Temporal variance among zones in the park did not change significantly before and after 2003 (Table 1, Fig. 2).

There was no statistically significant difference in total fish biomass and the biomass of fish trophic groups from before to after protection between the MPA (12 sites within LBNP, not including the restricted area sites) and open access sites (Table 2, Fig. 2). Temporal variance between the park and unprotected areas nearby did not change significantly before and after 2003. In both settings, zooplanktivores and herbivores compromised approximately 70% of the total biomass while piscivores and carnivores constituted the remaining 30% (Fig. 2).

3.2. CONAPESCA catch data

The top species groups caught in the LBNP varied in order of importance from year to year, but always included snappers (Lutjanidae), cabrillas and groupers (Serranidae and Epinephelidae), tilefish (Malacanthidae), and sharks and rays (not identified to the family level in the CONAPESCA reports). Herbivores and zooplanktivores made up less than 10% of the total catch combined. Piscivores and carnivores heavily dominated the catch. Mean

Table 1
Beyond-BACI analysis to detect the effects of the Loreto Bay National Park on fish populations. Comparison between the restricted area [a no-take site and a site where only hook-and-line is permitted (MPA1)] and 12 other sites in the park where both line and nets are allowed (MPA2). The degrees of freedom and the Mean Square are shown only for the residual of the B × I test.

Source of variation	df	Total biomass		Top predators		Carnivores		Zooplanktivores		Herbivores	
		MS	*F*	MS	*F*	MS	*F*	MS	*F*	MS	*F*
Year = T	12	0.024		0.005		0.014		0.011		0.002	
Before vs. After = B	1	0.001		0.001		0.001		0.002		0.001	
Among locations = L	13	0.024		0.015		0.013		0.033		0.017	
MPA1 vs. MPA2 = I	1	0.001		0.008		0.006		0.016		0.001	
Among MPA2 = C	11	0.028		0.017		0.014		0.036		0.020	
T × I	11	0.008	1.340	0.002	0.597	0.001	0.428	0.005	0.726	0.005	1.562
B × L	13	0.009		0.002		0.001		0.009		0.005	
B × I	1	0	**8.374****	0.001	0.381	0.001	0.034	0.032	**5.026***	0.035	**10.666****
B × C	11	0.004	0.657	0.002	0.919	0.001	0.351	0.006	1.322	0.002	1.128
T(Aft) × L	88	0.005		0.002		0.003		0.004		0.002	
T(Aft) × I	6	0.004	0.730	0.002	0.847	0.002	0.632	0.002	0.265	0.003	0.874
T(Aft) × C	76	0.005		0.002		0.003		0.004		0.002	
Residual (B × I)	174	0.007		0.003		0.004		0.006		0.003	

Significant interaction terms are in bold. *$p < 0.05$, **$p < 0.001$.

Table 2
Beyond-BACI analysis to detect the effects of the Loreto Bay National Park on fish populations. Comparison between 12 sites in the park where both line and nets are allowed (MPA2), and unprotected areas nearby. The degrees of freedom and the Mean Square are shown only for the residual of the B × I test.

Source of variation	df	Total biomass		Top predators		Carnivores		Zooplanktivores		Herbivores	
		MS	*F*	MS	*F*	MS	*F*	MS	*F*	MS	*F*
Year = T	12	0.031		2.141		0.014		0.012		0.004	
Before vs. After = B	1	0.057		0.004		0.000		0.054		0.010	
Among locations = L	21	0.019		0.034		0.012		0.032		0.012	
MPA2 vs. unprotected = I	1	0.001		0.080		0.017		0.019		0.001	
Among unprotected = C	7	0.012		0.060		0.008		0.032		0.005	
T × I	12	0.009	1.367	0.005	0.996	0.003	0.920	0.006	0.954	0.003	1.030
B × L	19	0.005		0.003		0.002		0.006		0.002	
B × I (a)	1	0	2.805	0.005	1.028	0.002	0.406	0.014	2.199	0.001	0.368
B × C	7	0.005	0.559	0.004	0.996	0.003	0.729	0.005	1.018	0.002	0.498
T(Aft) × L	130	0.007		0.003		0.003		0.004		0.003	
T(Aft) × I (b)	7	0.011	1.435	0.004	0.844	0.003	0.825	0.006	0.882	0.002	0.513
T(Aft) × C (b)	47	0.009		0.004		0.004		0.004		0.003	
Residual (B × I)	249	0.008		0.004		0.002		0.015		0.001	

No statistically significant statistical relationships were found, meaning that p was not <0.05.

annual landing per year by trophic group, common group, and family are shown in Table 3. Reported landings for each year of data and including Spanish common and species names are included in Supporting information (S1). Overall reported catch in the open access areas was larger, as expected given the industrial-scale fishing effort, and increased over time relative to catch in the LBNP (ANCOVA, $F = 50.84$, $p < 0.001$), as was the case for catch of carnivorous fishes ($F = 16.12$, $p = 0.001$) (Fig. 3).

4. Discussion

The trophic group distribution of fishes at LBNP is representative of a system with a high level of human impact (Sandin et al., 2008). Zooplanktivores and herbivores make up the bulk of the biomass within LBNP and do not reflect the apex predator-dominated structure of a healthy reef system (DeMartini et al., 2008). This has been the situation in LBNP since the park was first established and has not changed in 13 years of monitoring. Total fish biomass and biomass of trophic levels targeted by commercial fisheries have not increased significantly in the LBNP after protection relative to open access, unprotected areas nearby. Only the biomass of herbivorous and planktivorous fishes increased in the restricted areas of LBNP relative to the rest of the park, although it is unclear whether this increase was due to protection. Despite the lack of recovery, our temporal monitoring shows that biomass did not decrease significantly over time for reef fishes within LBNP. Catch of higher trophic groups may indicate a higher presence than our monitoring data suggest, but we doubt that this is the case as fishers specifically target these groups, our monitoring sites are located in piscivore and carnivore habitat, and we regularly see these fishes while monitoring in other sites (e.g., Cabo Pulmo, Aburto-Oropeza et al., 2011). While catch has fallen, in numerous conversations with fishers, managers, and residents, loss of livelihood was never expressed as a concern (A. Rife unpublished data).

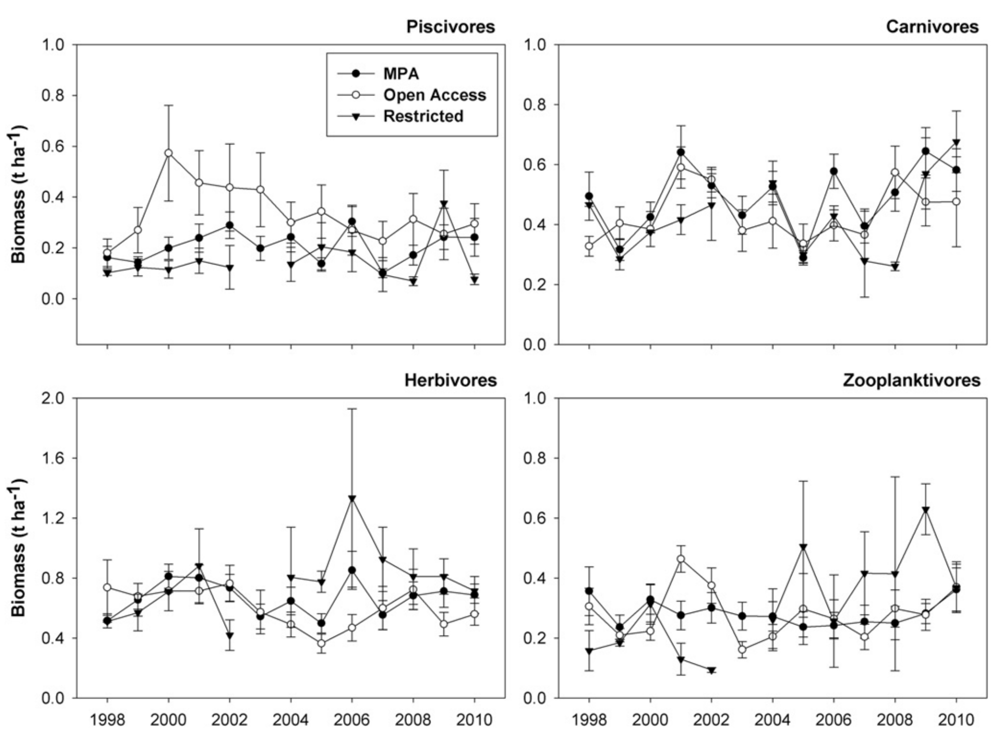

Fig. 2. Reef fish biomass (tonnes ha^{-1}, mean ± S.E.) in the Loreto Bay Marine Park and adjacent areas from 1998 to 2010. Bars indicate standard error.

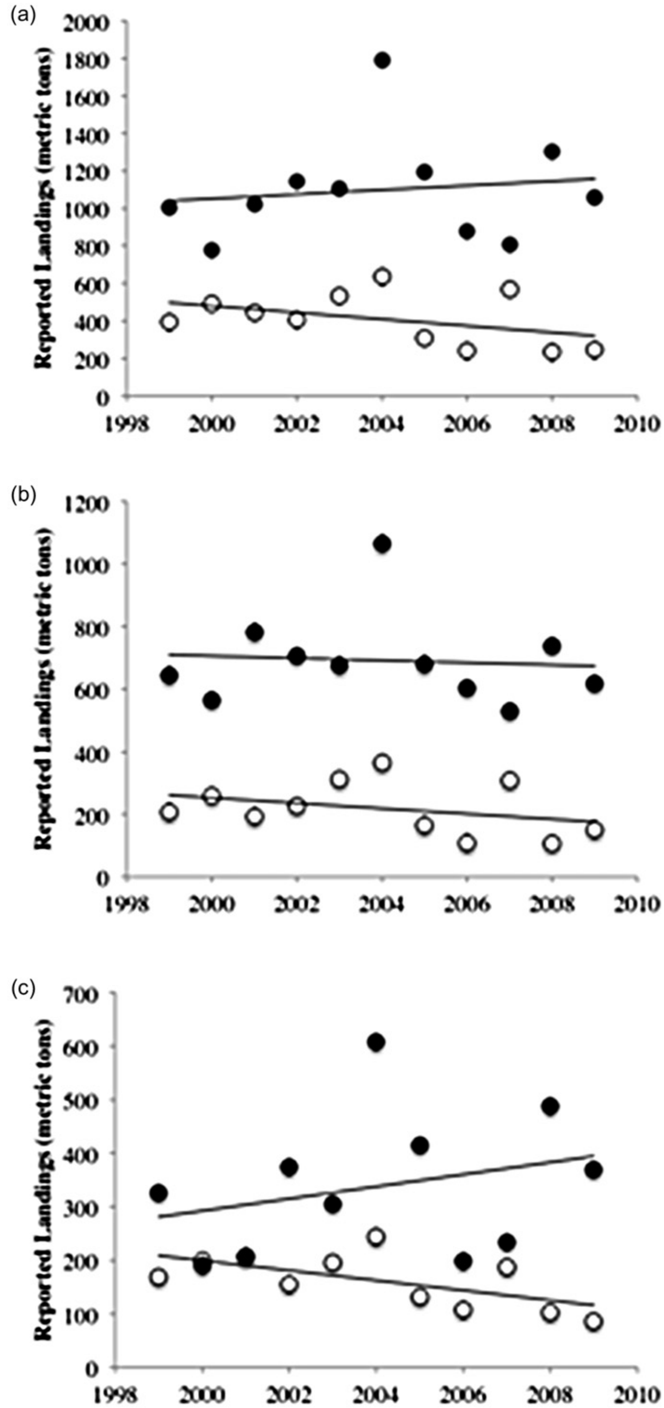

Fig. 3. Catch (metric tonnes) of (a) Total (b) Piscivore (c) Carnivore in MPA (open circles) and open access sites (closed circles). Lines depict linear regression used in ANCOVA analysis.

Table 3
Average fisheries landings per year in LBNP by trophic group, common group, and family (metric tons). Supporting Information (S1) includes Spanish common and species names as well as per year landing.

Trophic group	Common group	Family	Mean total landing/year	Standard deviation
Piscivore			**218.85**	**113.71**
	Barracudas	Sphyraenidae	0.14	0.45
	Halibuts	Paralichthyidae	1.54	1.30
	Groupers	Epinephelidae, Serranidae	40.27	19.04
	Jacks	Carangidae	41.69	25.30
	Palometas	Carangidae	1.42	1.42
	Rooster Fishes	Nematistiidae	0.02	0.07
	Sharks	Alopiidae, Carcharhinidae, Sphyrnidae, Others	15.79	15.89
	Sierras	Scombridae	7.17	6.01
	Snappers	Lutjanidae	110.64	43.92
	Snooks	Centropomidae	0.17	0.30
Carnivore			**162.39**	**50.36**
	Corvinas	Sciaenidae	1.19	2.10
	Croakers	Sciaenidae	0.03	0.06
	Cusk eels	Ophidiidae	2.92	5.00
	Goatfishes	Mullidae	0.07	0.23
	Groupers	Epinephelidae, Serranidae	30.95	11.48
	Grunts	Haemulidae	12.38	6.03
	Guitarfishes	Rhinobatidae	0.92	1.03
	Jacks	Carangidae	0.05	0.12
	Mackerels	Scombridae	3.07	2.16
	Mojarras	Gerreidae	9.68	5.17
	Porgies	Sparidae	2.23	2.37
	Pufferfishes	Tetraodontidae	0.13	0.31
	Rays	Rajiformes	13.01	9.76
	Rockfishes	Sebastidae	3.98	3.86
	Scads	Carangidae	0.00	0.01
	Sharks	Triakidae, Squatinidae	29.59	15.49
	Tilefishes	Malacanthidae	30.53	11.74
	Triggerfishes	Balistidae	14.81	6.50
	Wrasses	Labridae	6.84	6.87
Zooplanktivore			**4.96**	**6.09**
	Groupers	Epinephelidae	3.61	6.20
	Sardines	Engraulidae	0.82	0.99
	Pampanos	Carangidae	0.53	0.56
Herbivore			**22.61**	**16.49**
	Chubs	Kyphosidae	0.16	0.31
	Mullets	Mugilidae	0.14	0.45
	Parrotfishes	Scaridae	22.31	15.73

The Beyond-BACI analysis is a rigorous way to compare an MPA with adjacent unprotected sites in an area with interannual environmental changes (Underwood, 1992, 1994). Our results indicate that some reef sites had significantly higher biomass than others, but this was accounted for because the Beyond-BACI analysis tests for differences from before to after protection between levels of protection, regardless of the absolute biomass at each site.

In other locales it has been shown that fish biomass can increase significantly in no-take reserves within a few years of implementation (Halpern and Warner, 2002; Lester et al., 2009), significantly so within a decade (McClanahan et al., 2007). This is not the case in MPAs which suffer from paper park syndrome (e.g., Rogers and Beets, 2001). Based on evidence from 155 no-take reserves worldwide (Lester et al., 2009; Micheli et al., 2004), we would expect target species (chiefly apex predators and carnivores) to account for most of the fish biomass increase in reserves. The sergeant major, *A. troschelli*, which was the major contributor to fish biomass at the restricted area of LBNP, is not a fishery target. This indicates that the stronger regulations at these sites have not been effective in allowing for recovery of commercially important apex predators and carnivores. This may be due to the small size of these no-take areas (Halpern, 2003; Vandeperre et al., 2010) which are insufficient to affect fish biomass throughout the MPA or the ineffective enforcement of regulations. In any case, the only positive change in fish biomass at LBNP occurred in the restricted site. In Cabo Pulmo National Park, the only well-enforced no-take reserve in the Gulf of California, fish biomass increased 460% within a decade and was dominated by apex predators (Aburto-Oropeza et al., 2011). This is a stark contrast with LBNP, where the partial protection management scheme has not been effective in allowing the recovery of fish assemblages in the park.

The decline in catch may be evidence of commercial fishers switching to other livelihoods. The CONAPESCA database does not include catches from recreational fisheries, which are generally not monitored. Many former commercial fishers have switched to providing sport-fishing services to tourists as it is seen as a more lucrative and steady income (anonymous personal communication). Recreational fishing has increased more than 400% within the LBNP since its creation (López-Sagástegui, 2006). As fishers switch, they continue to catch higher trophic groups, but no longer report these catches, potentially resulting in an unmeasured impact on piscivore and carnivore biomass (Cooke and Crowx, 2006; Lewin et al., 2006; Schroeder and Love, 2002). The decline in catch may also be explained by the presence of fishers from outside the Loreto region within the park, who do not report their catch to the Loreto CONAPESCA office (Erisman et al., 2011). It is well known that fishing vessels from Guaymas fish at LBNP and land and sell their catch on the mainland side of the Gulf (illegally) (B. Erisman pers observations). These possibilities are ways in which fishing may be continuing within the park without regulations or any means to monitor them. With the many caveats associated with the CONAPESCA database, and without the ability to account for fishing effort, we cannot identify the reason why catch has decreased beyond these speculations.

The underlying causes of the lack of recovery of fish assemblages at LBNP may include weak fishing regulations and lack of enforcement of such regulations. It is also possible that some of the legal fishing methods used within the park are detrimental, particularly to spawning aggregations caught in gillnets (Erisman et al., 2010). Gillnets are already restricted temporally and prohibited in one area, but their continued use may be impeding the recovery of apex predators, particularly since known spawning sites of targeted groupers are not included in the restricted areas of the LBNP (Carvajal et al., 2004; Erisman et al., 2007; Ulloa et al., 2006). Our results add to previous examples showing that partial protection does not result in significant recovery of fish populations (Denny and Babcock, 2004; Di Franco et al., 2009; Francour et al., 2001; Shears et al., 2006).

5. Conclusions

The goal of LBNP's management plan is to "preserve the natural resources", not explicitly to restore them, and to ensure "the social development of the communities", which we interpret as safeguarding livelihoods. The LBNP has met these objectives. We remain, however, concerned that this success is in the preservation of an already degraded environment, virtually indistinguishable from the unprotected areas nearby. This is not a positive outcome in any respect, nor is it how the LBNP is promoted publicly. One would hope to detect a significant recovery, especially in higher trophic groups that are the focus of fisheries in the area. We believe that in order to have sustainable fisheries and increase the benefits (ecological and economical) to the local community, recovery of depleted fish assemblages is essential and should be a focus for park managers in the future. Otherwise, one could also claim that the unprotected areas nearby have been as successful as LBNP in "preserving the natural resources" – which could render management of LBNP as irrelevant.

The revised management plan expands the total no-take area and incorporates areas known to harbor spawning aggregations, which may facilitate fish assemblage recovery. Interviews with fishers in Loreto suggested that fishers believe that MPAs are beneficial for tourism in the region, but that they see little benefit to their fisheries (A. Rife unpublished data). However, the groundwork has been laid by local NGOs and CONANP to engage user groups in a dialogue regarding LBNP. These efforts have contributed to a belief among local fishers on the need for better management in providing for sustainable fisheries.

The creation of more and larger no-take marine reserves in LBNP is likely to be a necessary step to restoring populations of targeted fishes, as well as other species (Aburto-Oropeza et al., 2011; Wielgus et al., 2008). This should be associated with an increase in both the CONANP and CONAPESCA staff and resources. The CONAPESCA database on fish landings should be revised to include some measure of effort and information regarding the number and size of fish caught and both logbooks and port monitoring should be required for commercial and sport fishers. There is also a need for revising fishing regulations, management, and enforcement are conducted, since fisheries management and enforcement should be an integral part of the management of any multi-use MPA. Involvement of the local community in enforcement efforts should be pursued in order to increase effectiveness (Cudney-Bueno and Basurto, 2009). Finally, monitoring of the fish assemblages in the park should continue in order to inform management and measure success of the above suggestions.

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Appendix A. Supplementary data

Supplementary data related to this article can be found at http://dx.doi.org/10.1016/j.jenvman.2012.12.029.

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