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# **An Evaluation of Grand Cayman MPA Performance: A Comparative Study of Coral Reef Fish Communities**

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## **ABSTRACT**

Much is now known about the coral communities of the Cayman Islands; however few studies have been carried out on reef fish assemblages. Though there are no commercial fisheries to-date in the archipelago, however recreational fishing pressure has increased considerably with the growing population over the past decade. Marine Protected Areas (MPAs) were established in 1986, with the main objectives of protecting coral reefs and their associated organisms (including fish communities), restoring fish stocks, and replenishment of fish to surrounding areas. In this study, important fish species of reef health status and species most commonly targeted by fishers have been compared between protected areas and non-protected fished areas. A fish census was carried out by Underwater Visual Census (UVC) around Grand Cayman during the months of January through to April 2009. For 53 target species, biomass, size and density were investigated for comparison between MPA and non-MPA. In addition, the occurrence of "rare species" (abundance < 1% of the total number of fish), the relationship between the different trophic groups were explored. Furthermore, the exportation of individuals by spillover effects were measured over a 5 km distance from each boundary using linear regression of the mean biomass per site. Reserve effect, evaluated for the first time in Grand Cayman after 23 years of MPAs, was significant ( $p < 0.01$ ). However, spillover effect was only evident on the north boundary of the MPA ( $R = 0.9158$ ,  $p < 0.01$ ), no spillover effect was apparent on the south boundary.

KEY WORDS: Marine Protected Area, coral reef fish, reserve effect, spillover

## **Una Evaluación de Gran Caimán MPA Rendimiento: Un Estudio Comparativo de las Comunidades de Peces de Arrecifes De Coral**

A pesar de que se conoce bastante sobre las comunidades arrecifales de la Islas Caimán, pocos estudios sobre las comunidades de peces han sido realizados. Hoy en día no existen pesquerías comerciales en el archipiélago pero la pesca recreacional se ha incrementado significativamente junto con el crecimiento poblacional de las últimas décadas. En 1986 se establecieron Areas Marinas Protegidas (AMPs) con objetivos como proteger los arrecifes coralinos y los organismos asociados (incluyendo las comunidades de peces), la restauración de las poblaciones de peces, y la recuperación de las áreas circundantes. En este estudio, las especies más pescadas se compararon entre áreas protegidas y no protegidas de la pesca. El censo se hizo con el "Underwater Visual Census (UVC)" mientras se buceaba alrededor de Gran Caimán. Varias variables se midieron para cada especie, incluyendo biomasa, tamaño y abundancias, la ocurrencia de especies, las relaciones entre los grupos tróficos y la migración de individuos (efecto de desbordamiento) a áreas cercanas a la zona protegida. El efecto de las reservas, por primera vez estimado en Gran Cayman, fue evidente y significativo alrededor de la isla ( $p < 0.01$ ). Sin embargo, migración de la zona protegida a las áreas aledañas solo fue evidente en el borde del norte de las AMPs ( $R = 0.9158$ ,  $p < 0.01$ ).

PALABRAS CLAVES: Islas Caimán, biomasa, peces de arrecifes de coral, reservar el efecto, efecto de desbordamiento

## **Evaluation des Performances de l'Aire Marine Protégée de Grand Cayman: Étude Comparative des Communautés de Poissons Récifaux**

Bien que de nombreuses études aient été menées sur les communautés coralliennes des Iles Cayman, peu de travaux se sont intéressés aux communautés de poissons récifaux. La pêche commerciale n'est pas autorisée dans l'archipel, cependant la pêche récréative s'est largement amplifiée au cours des dix dernières années avec l'augmentation de la population. Les Aires Marines Protégées (AMP) des Iles Cayman, ont été établies en 1986, avec pour objectifs la protection des récifs coralliens et de leurs peuplements associés (dont les communautés de poissons), la restauration des stocks de poissons et l'exportation des individus aux abords des réserves, dans les zones pêchées. Dans cette étude, les espèces de poissons les plus représentatives de l'état de santé des récifs ainsi que les espèces les plus communément ciblées par les pêcheurs ont été comparées entre les sites protégés et les sites non protégés. Le recensement des espèces a été effectué par observation directe sous marine (UVC) autour de Grand Cayman, de janvier à avril 2009. Pour les 53 espèces de poissons récifaux ciblées, la biomasse, la taille et la densité des individus ont été prises en compte pour comparer les communautés localisées dans l'AMP et les sites extérieurs à l'AMP. De plus, l'occurrence des « espèces rares » (abondance < 1% de l'effectif total) ainsi que les relations entre les différents groupes trophiques ont été étudiées. Par ailleurs, l'exportation des individus par effet spillover a été mesurée sur une distance de 5 km en partant de la limite de la réserve, en utilisant une régression linéaire de la biomasse moyenne par site en fonction de la distance de ces sites par rapport à la réserve. L'effet réserve, évalué pour la première fois à Grand Cayman, après 23 ans de mise en place, s'est avéré significatif ( $p < 0.01$ ). Cependant, l'effet spillover n'a été démontré qu'à la limite nord de l'AMP ( $R = 0.9158$ ,  $p < 0.01$ ), aucun effet spillover n'a été remarqué au sud de la réserve marine.

MOTS CLÉS: Aires Marines Protégées, poissons récifaux, effet réserve, spillover

## INTRODUCTION

The ability to maintain a vibrant and sustainable marine ecosystem has been the main objective of Marine Protected Areas (MPAs) globally. They represent a durable solution for the conservation of marine ecosystems, in view of problems such as over fishing and the degradation of marine habitats. Prohibiting all anthropogenic impacts (anchoring, fishing, extractions), increased reproductive potential. Enhanced production of eggs and larvae inside MPAs are predicted to lead to net export and increased settlement of juveniles outside their boundaries (Bohnsack 1998, Gell and Roberts 2003).

In the last decade, several studies have demonstrated the “reserve effect”, based on comparisons of biomass, abundance or density and size classes between protected areas and outlying non protected fished areas (Dugan and David 1993, Polunin and Roberts 1993, Roberts 1995, Wantiez *et al.* 1997, Harmelin-Vivien *et al.* 2008). In a review (Halpern, 2003) of 112 independent empirical measurements of 80 marine reserves, it was found that average values of all biological measures were strikingly higher inside MPAs when compared to non protected areas; 63% had higher density, 90% higher biomass, 80% had larger organisms and 59% of had higher species diversity.

Measures of gradients (biomass or abundance) are used to access the “Spillover” effect (export of individuals), around MPAs, and evaluate the distance of marine reserve influence (Ratikin and Kramer 1996, Abesamis *et al.* 2006, Ashworth and Ormond 2005, Russ and Alcala 1996, McClanahan and Mangi 2000).

Many comparisons have been made between MPAs and fished areas, where fishing pressure is exerted by artisanal and or commercial fishers, but few have examined the effect of recreational fishing on fish assemblage in coral reef habitats (Westera *et al.* 2003). However, this kind of fishing, principally using lines and spears, can have a severe negative impact because of the inherent selective nature towards certain fish species.

Though many studies have been carried out on coral communities in Grand Cayman, few involved fish assemblages (Burgess 1978, 1994, Pattengill-Semmens and Semmens 2003) and no study, to date, has showed any potential benefits of the Grand Cayman MPA on fish communities, after 23 years of protection. This study represents the first analysis of Grand Caymans fish communities and will constitute a baseline for future studies, especially on a temporal scale.

The objective of this study is to assess the effects of the Grand Cayman MPA system on coral reef communities by comparing fish populations between protected and non protected areas. Reserve effect and Spillover effect were studied, and two hypotheses were proposed in order to test if there are differences in 53 species of targeted fish between protected areas (inside MPA) and recreationally fished areas (outside MPA):

- i) Biomass, size of fish, and carnivore to herbivore ratio does not change with level of protection (MPA vs. non-MPA), and
- ii) There is no export of individuals from MPA to adjacent areas around the reserves, by Spillover effect.

## METHODS

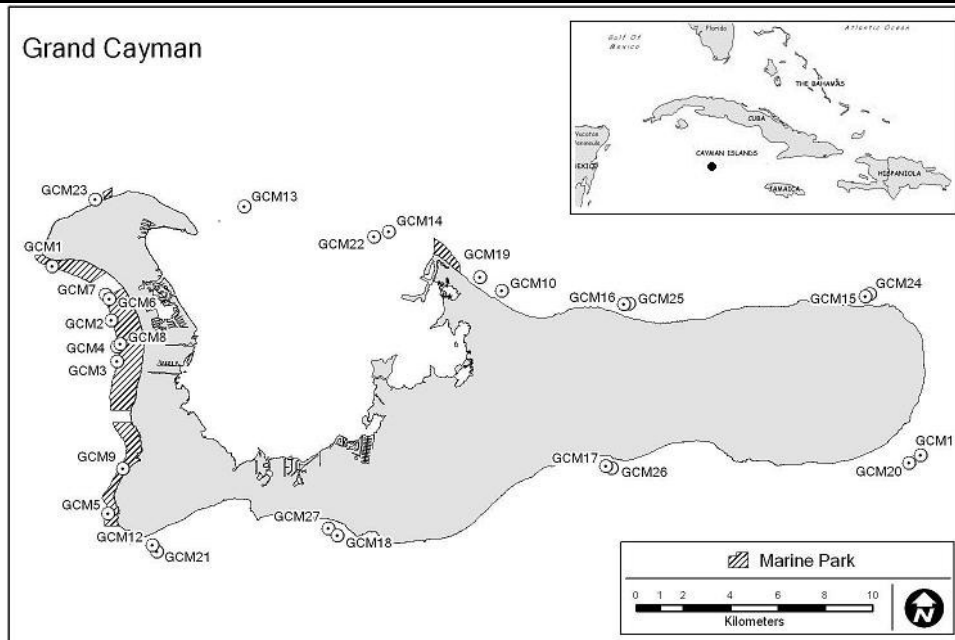
### Study Site

The Cayman Islands consist of three islands, Grand Cayman, Little Cayman and Cayman Brac, located between 19°15' and 19°45' N latitude and between 79°44' and 81°27' W longitude. They are the peaks of a submerged ridge, which runs westwards from the Sierra Maestra mountain range of Cuba. These three Overseas Territories of the United Kingdom are the most arid and isolated of West Indian islands unusually flat and formed entirely from calcareous marine deposits (Davies and Brunt 1994). The study was carried out at Grand Cayman, the largest and the most populous island (197 km<sup>2</sup> and 60,000 inhabitants). There are two distinct reef terraces: the shallow terrace reef (5 - 12 meters), associated with two environments, lagoons and a fringing-reef complex, and the deep terrace reef (16 - 25 meters), plunging vertically into the abyssal depths of the ocean. The narrow insular reef-shelf measure 1.5 kilometers maximum in width and the structure of the reefs, principally constituted by “spur and groove” formations, greatly differ according to the exposure of the coast. The easterly approach of storm and fair-weather wave fields results in three margin types: a high energy exposed-windward margin (east and south coast), a moderate energy protected-windward margin (north coast), and a low energy leeward margin (west coast).

The MPA in Grand Cayman was established in 1986, and is located on the western part of the island (Figure 1). This Marine Park covers 9 km<sup>2</sup> of coast which is 18 % of the total shelf area of Grand Cayman. Residents of the Cayman Islands can fish in this area provided that they do so from the shore or beyond the 25 m depth contour.

### Method of Visual Census

Sampling was carried out during the months of January through to April 2009, between 0900 hours and 1500 hours. In order to study the reserve effect, 27 sites were chosen around Grand Cayman with 9 of them inside the MPA and 18 outside the MPA (Figure 1). Fish counts were made at two depths: one on the deep terrace reef (16-18 meters) and one on the shallow terrace (10 - 12 meters). In addition, 10 sites were added to the list of sampling sites, to test the Spillover effect; 5 sites in the north of the MPA and 5 sites in the south of the MPA, each in 1 km increments for a total distance of 5 kilometers from the boundaries of the MPA. These sites were all located on the shallow terrace reef.



**Figure 1.** Location of the sites studied around Grand Cayman. Hatched zone corresponds to the Marine Protected Area.

Data were collected by Underwater Visual Census (UVC), using belt transects, (Samoilys and Carlos 2000). At each site, fish were censused along three transects 50 m x 5 m sampling 750 m<sup>2</sup> of reef per site. The diver swam along transects with a graduated PVC T-bar and recorded the number of individuals, species and total length of fish (in 9 size classes of 5 centimeter increments), within 2.5 meters on either side of the transect line and 5 m above it. Target fish crossing the transect belt were identified and counted, with 53 coral reef species, belonging to 16 fish families, constituting the list of targeted fish species (Table 1). However, five species never appeared during census: *Epinephelus itajara*, *Mycteroperca bonaci*, *Caranx latus*, *Anisotremus surinamensis* and *Chaetodon acuelatus* (Table 1).

Census began 15 minutes after the deployment of the transect line at the bottom and the time of census was limited to 15 minutes per transect for consistency. The collection of data began after a training period to familiarize species recognition. Fish models were used to estimate size classes, mean standard error of size estimates was; - 1.09 cm.

#### Data Analysis

Length estimates (TL) of fish from surveys were converted to weight per unit area of reef by using the allometric length-weight conversion (Bonhsack, 1988) and expressed in (g/m<sup>2</sup>) using surface area sampled:

$$W=aTL^b$$

Were  $W$  is weight in grams, parameters  $a$  and  $b$  are

**Table 1.** List of the fish families and species censused and their respective trophic group. HB: Herbivores, OM: Omnivores, P: Predators, C1: carnivores 1 (inverts feeders) and C2: carnivores 2 (inverts and fish feeders).

Species	Trophic groups	Species	Trophic groups
<b>Serranidae</b>		<b>Acanthuridae</b>	
<i>Epinephelus striatus</i>	C1	<i>Acanthurus coeruleus</i>	HB
<i>Epinephelus cruentatus</i>	C1	<i>Acanthurus chirurgus</i>	HB
<i>Epinephelus guttatus</i>	C1	<b>Scaridae</b>	
<i>Cephalopholis fulvus</i>	C1	<i>Sparisoma viride</i>	HB
<i>Mycteroperca tigris</i>	P	<i>Scarus vetula</i>	HB
<b>Lutjanidae</b>		<i>Scarus taeniopterus</i>	HB
<i>Lutjanus mahogoni</i>	C2	<i>Scarus iserti</i>	HB
<i>Lutjanus analis</i>	C2	<i>Sparisoma aurofrenatum</i>	HB
<i>Lutjanus jocu</i>	C2	<b>Pomacentridae</b>	
<i>Ocyurus chrysurus</i>	C2	<i>Holacanthus ciliaris</i>	C1
<i>Lutjanus apodus</i>	C2	<i>Holacanthus tricolor</i>	C1
<b>Labridae</b>		<i>Pomacanthus paru</i>	C1
<i>Lachnolaimus maximus</i>	C1	<i>Pomacanthus arcuatus</i>	C1
<i>Bodianus rufus</i>	C1	<b>Chaetodontidae</b>	
<i>Halichoeres radiatus</i>	C1	<i>Chaetodon striatus</i>	C1
<i>Thalassoma bifasciatum</i>	C1	<i>Chaetodon capistratus</i>	C1
<b>Haemulidae</b>		<i>Chaetodon ocellatus</i>	C1
<i>Haemulon flavolineatum</i>	C1	<b>Balistidae</b>	
<i>haemulon sciurus</i>	C1	<i>Balistes vetula</i>	C1
<i>Haemulon plumieri</i>	C1	<i>Melichthys niger</i>	OM
<i>Haemulon macrostomum</i>	C1	<i>Cantherhines macrocerus</i>	C1
<b>Aulostomidae</b>		<i>Aluterus scriptus</i>	OM
<i>Aulostomus maculatus</i>	C2	<b>Muraenidae</b>	
<b>Sphyrnidae</b>		<i>Gymnothorax funebris</i>	P
<i>sphyrna barracuda</i>	P	<i>Gymnothorax moringa</i>	P
<b>Kyphosidae</b>		<b>Carangidae</b>	
<i>Kyphosus sectatrix</i>	HB	<i>Caranx ruber</i>	P
<b>Sparidae spp</b>	C1	<b>Mullidae spp</b>	C1

constants obtained from the literature (Froese and Pauly 2005) and TL is total length in centimeters.

The diet of the different trophic groups has been listed (Table 1), according to the data of Randall (1967) and species were classed into five trophic groups: herbivores (HB), omnivores (OM), fish feeders (Predators: P), invertebrate feeders (Carnivores 1: C1), fish and invertebrate feeders (Carnivores 2: C2).

Fish density, size and biomass were tested for normality (Shapiro-Wilks test). Data from within the MPA was compared to data outside the MPA by student T test, when the normality and the number of sampling allowed. Otherwise, non parametric test (Wilcoxon-Mann-Whitney) was used for comparisons. Spillover effect was studied by a linear regression of the mean biomass of each site, and the distance of these sites to the MPA boundary.

## RESULTS

### Fish Density and Biomass

The average density, biomass and mean size of fish on the protected and non protected sites (deep and shallow sites) are presented in Table 2. There were no significant differences in density between the deep terrace reef sites and the shallow terrace reef sites, nor were there any significant differences in density between protected and non protected sites.

Mean biomass for each site and per fish family is displayed in Figure 2. Mean fish biomass was significantly higher inside the MPA ( $p < 0.01$ ), and there was no significant difference of fish biomass between the different non protected sites outside the MPA.

Fish biomass on protected sites and non protected sites were higher on shallow sites, where the biomass of Scaridae was two times higher and biomass of Lutjanidae was five times higher. Only one family had a mean biomass significantly higher on non protected sites: Balistidae (represented principally by *Melichtys niger*). However, on the deep terrace sites, even if the majority of fish family had a biomass higher inside the MPA, only two families had a biomass significantly larger (Carangidae and Pomacanthidae).

### Structure of the Fish Community

Mean biomasses were grouped into the five trophic groups previously established: HB, P, OM, C1 and C2, for the different sites: protected and non protected, deep terrace and shallow terrace sites. Significant differences were investigated (Figure 3). Mean fish biomasses were significantly higher inside the MPA for each trophic group considered. In separating the two studied depths independently, variations of fish biomass did not affect the same trophic group for the depth considered.

On the shallow sites, significant difference of fish biomass was due to two trophic groups: Herbivores, which had a biomass two times higher inside the MPA and

Carnivores 2 which had a biomass four times higher inside the MPA. Omnivores (mostly constituted by the balistid *Melichtys niger*) had a biomass significantly higher outside the MPA.

On the deep terrace, mean biomass of two other trophic groups contributed to increase biomass inside the MPA: Predators and carnivores 1, who had a biomass two times higher inside the MPA.

Proportions between two groups of fish (carnivores and herbivores) allowed us to study the distribution of trophic groups inside and outside the MPA (Figure 4). First group was constituted by the herbivores and omnivores (HB-OM), the second grouped carnivores together: P, C1 and C2 (CA). Grand Cayman reefs are dominated by herbivores and omnivores who constituted the largest biomass of the fish community. Though the proportions of carnivores were close between protected and non protected areas on the deep terrace sites, significant differences were found ( $p < 0.001$ ). The fish community outside the MPA on the shallow reef terrace sites were particularly unbalanced, with carnivores only representing 16% of the fish biomass ( $p < 0.001$ ), which is less than half the biomass of carnivores inside the MPA.

### Size Class Distributions

Nine size classes were established in order to study the distribution of fish size (Figure 5).

Size distributions were quite similar on the deep sites and on the shallow sites; therefore individuals of both terraces were grouped together. We found a significant difference in the distribution between protected sites and non protected sites ( $p < 0.001$ , Wilcoxon-Mann-Whitney) showing that fish resident within the MPA are larger than fish resident at sites outside the MPA. Individuals measured outside the MPA were more represented in the smaller size classes. Additionally, individuals from sites inside the MPA were more represented in the larger size classes.

The fish communities of non protected areas are dominated by fish between 10 and 15 centimeters; 67.5% of these fish were less than 15 centimeters, compared to 52% of the fish community of protected sites within the MPA.

Mean size of individuals was equally compared between protected and non protected sites. We found a significant difference of mean size of individuals ( $p < 0.001$ ), that was 19 cm for the fish measured inside the MPA and 16 cm for the fish measured outside the MPA.

### Occurrence of Species

Due to the fact that a target species list was used, species diversity could not be assessed. Occurrences of species, meaning the percentages of sites wherein we found each species was calculated, based on a presence or absence basis. Comparing the occurrences of all the species, a significant difference is noticeable between

protected areas and fished areas ( $p < 0.01$ ), showing that the distributions of species are more homogenous inside the MPA.

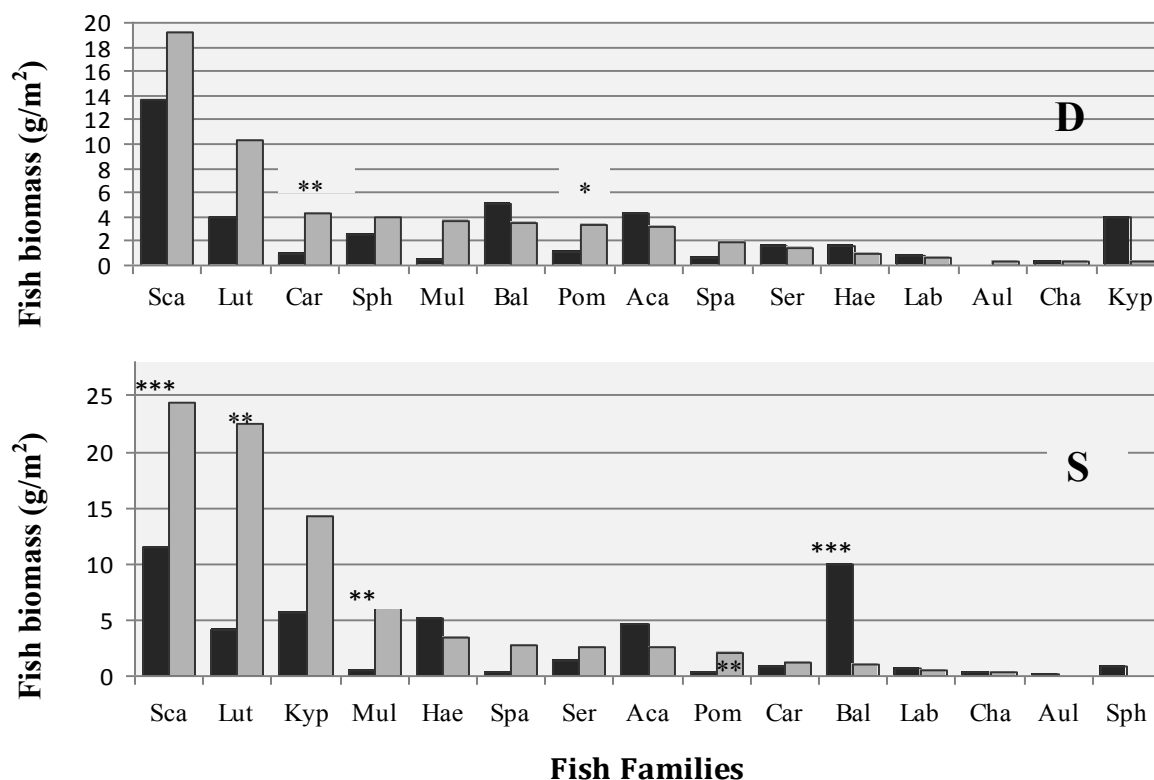
Furthermore, we paid particular attention to those species whose abundance was  $< 1\%$  of the total number of fish, for all sites combined (protected and non protected). These species were called “rare” species (Table 3).

Even though these particular species are considered “rare” amongst the fish community of Grand Cayman, their occurrence is significantly higher inside the MPA. On average, the occurrence of these “rare species” was three times higher in the protected sites within the MPA. The Queen angelfish, *Holacanthus ciliaris* (Linnaeus 1758) was the most striking example. This species appeared in 67% of the protected sites and was counted in only 11% of the non protected sites; a likelihood of being found six times more frequent at sites within the MPA.

### Spillover Effect

At each boundary of the MPA (north and south), five sites were chosen, each approximately 1 km apart to investigate the exportation of individuals from the MPA to outlying fished areas, termed “spillover effect”.

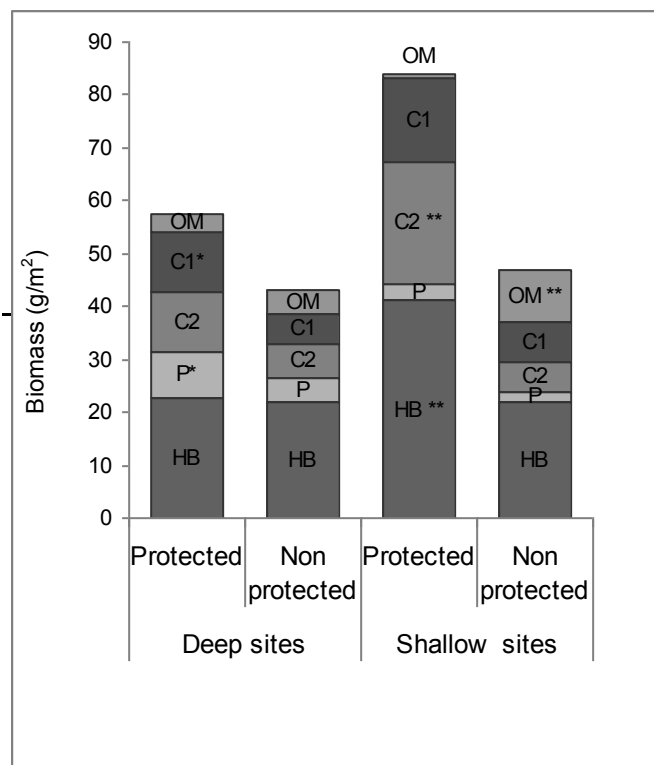
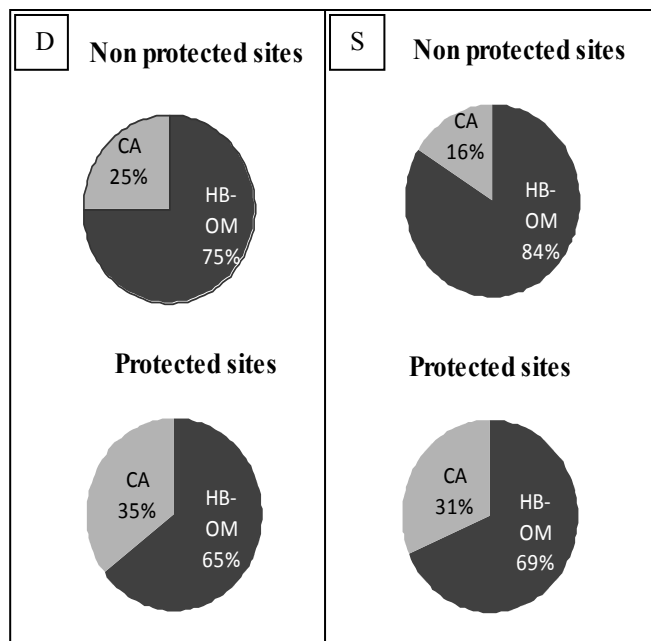
Linear regressions of the mean biomass per site and the distance of these sites from the MPA boundaries, showed a significant negative correlation ( $R = 0.9158$ ,  $p < 0.01$ ) between both variables only at the north boundary of the MPA (Figure 6). No correlation or spillover effect was evident on the south boundary of the MPA.



**Figure 2.** Mean biomass ( $\text{g/m}^2$ ) of Scaridae (Sca), Lutjanidae (Lut), Carangidae (Car), Sphyraenidae (Sph), Mullidae (Mul), Balistidae (Bal), Pomacanthidae (Pom), Acanthuridae (Aca), Sparidae (Sp), Serranidae (Ser), Haemulidae (Hae), Labridae (Lab), Aulostomidae (Aul), Chaetodontidae (Cha) and Kyphosidae (Kyp) on protected sites (gray) and non protected sites (black); on the deep sites (D) and on the shallow sites (S). Wilcoxon-Mann-Whitney test were used to test differences; \*, significant at  $p < 0.05$ ; \*\*, significant at  $p < 0.01$ ; \*\*\*, significant at  $p < 0.001$ .

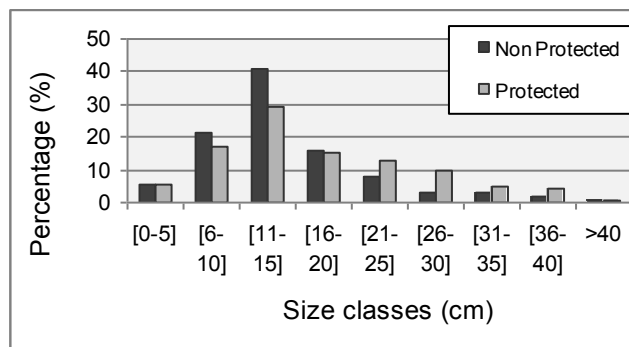
**Table 2.** List of the fish families and species censused and their respective trophic group. HB: Herbivores, OM: Omnivores, P: Predators, C1: carnivores 1 (inverts feeders) and C2: carnivores 2 (inverts and fish feeders).

A Deep Sites	Density (ind/100m <sup>2</sup> )	Biomass (g/m <sup>2</sup> )	Mean size (cm)
Protected	24.27 ± 13.18	57.48 ± 22.74	19.08 ± 0.56
Non protected	25.76 ± 9.6	41.69 ± 23.36	17.12 ± 0.56
Difference	NS	***	*
B Shallow Sites	Density (ind/100m <sup>2</sup> )	Biomass (g/ m <sup>2</sup> )	Mean size (cm)
Protected	28.08 ± 5.90	84.10 ± 46.76	19.66 ± 2.19
Non protected	31.88 ± 11.44	46.89 ± 15.68	16.54 ± 1.26
Difference	NS	*	**
C All Sites	Density (ind/100m <sup>2</sup> )	Biomass (g/ m <sup>2</sup> )	Mean size (cm)
Protected	26.17	71.78	19.01



**Figure 3.** Mean fish biomass (g/m<sup>2</sup>) of Herbivores (HB), Predators (P), Carnivores 1 (C1), Carnivores 2 (C2) and Omnivores (OM), on protected and non protected sites, on deep and shallow sites. A Wilcoxon-Mann-Whitney test were used to test differences; \*, significant at  $p < 0.05$ ; \*\*, significant at  $p < 0.01$ .

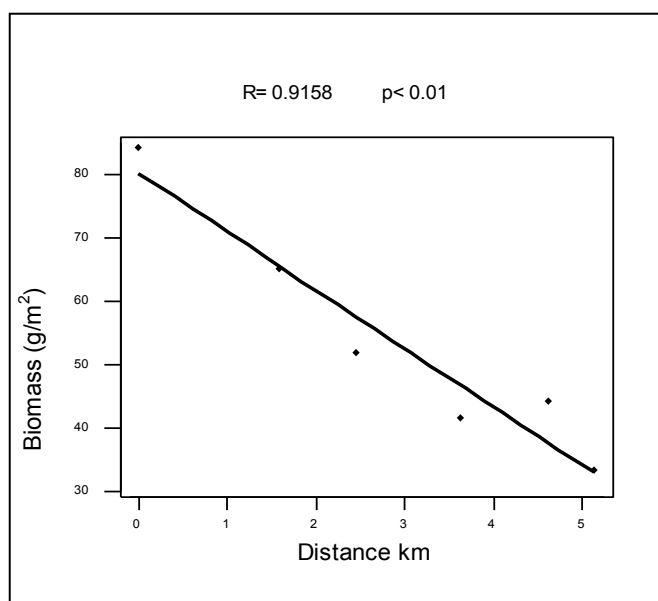
**Figure 4.** Proportions of Herbivores-Omnivores and of Carnivores (C1, C2, P), inside and outside the MPA, on deep sites (D) and on shallow sites (S).



**Figure 5.** Distribution of individuals inside and outside the MPA, grouped into nine size classes.

**Table 3.** Occurrences of the less abundant species inside MPA (P sites: Protected sites) and outside the MPA (NP sites: Non Protected sites).

Species	Abundance (%)	Occurrence (%)	
		NP sites	P Sites
<i>Lutjanus analis</i>	0.21	33	44
<i>Lachnolaimus maximus</i>	0.09	17	22
<i>Scarus vetula</i>	0.56	56	89
<i>Aulostomus maculatus</i>	0.29	33	56
<i>Bodianus rufus</i>	0.38	44	78
<i>Chaetodon ocellatus</i>	0.07	6	11
<i>Aluterus scriptus</i>	0.07	6	11
<i>Pomacanthus paru</i>	0.21	17	44
<i>Calamus sp</i>	0.31	22	67
<i>Lutjanus jocu</i>	0.07	6	22
<i>Mycteroperca tigris</i>	0.21	17	67
<i>Pomacanthus arcuatus</i>	0.17	11	56
<i>Holocanthus ciliaris</i>	0.19	11	67

**Figure 6.** Linear regression of the mean biomass of sites and their distance from the MPA boundary. The first point corresponds to the mean biomass of all the protected sites (inside the MPA).

In the north of the MPA, mean biomass of each site decreased with increasing distance from the boundary of the MPA, decreasing from 84.1 g/m<sup>2</sup>, the mean biomass of shallow sites inside the MPA, to 33.29 g/m<sup>2</sup>, 5 km from the boundary of the MPA. At the 5 km distance, this value becomes equal to the mean biomass measured for all non protected sites around Grand Cayman of 44.93 g/m<sup>2</sup>.

A positive impact of the protection given by the marine park on fished areas around the MPA is evident. Specific analysis allowed us to highlight which species contribute principally to this exportation. Lutjanidae participate highly in this movement of fish from the MPA to outlying areas ( $R = 0.839$ ,  $p < 0.01$ ), in particular, the species *Ocyurus chrysurus*.

## DISCUSSION

The sustainability of fisheries and marine ecosystems is of a global concern. Despite the MPA being on the leeward west side of Grand Cayman only, it is irrefutably efficient in what it was designed to accomplish, protecting coral reefs and their associated organisms (including fish communities), restoring fish stocks, and replenishment of fish to surrounding areas. The variables assessed and compared according to their location, show significant differences between protected sites and fished sites, with total mean biomass 1.6 times higher inside the MPA. Furthermore some sites located within the MPA had biomass  $> 100$  g/m<sup>2</sup> (GCM7: 102.23 g/m<sup>2</sup> and GCM8: 106.49 g/m<sup>2</sup>).

Additionally specific biomass of fish families was also higher inside the MPA; showing two times higher for the Scaridae, four times higher for the Lutjanidae, and three times higher for the Carangidae. The MPA is dominated by herbivores, which is very important for ecological health, considering the absence of the echinoid, *Diadema antillarum*, in large numbers on Caribbean reefs, a major herbivore which suffered almost concurrent mass mortality throughout its entire geographic range in 1982 - 1983 due to a species-specific pathogen (Hughes, 1993).

Only Balistidae had a biomass conspicuously higher outside the MPA. This observation is due to the fact that the Marine Park, at Grand Cayman is entirely located on one side of the island: the west side, which represents the leeward margin. Moreover, one particular species was directly responsible for this high biomass, *Melichthys niger*, (Black Durgon) whose planktivorous diet requires stronger water currents which are found more on the north, east and south coast. Having said that, this particular species density is very low on the leeward side within the protected MPA area; additionally this species is particularly established in the south side of Grand Cayman, perhaps due to the prevailing north east trade winds which have a tendency to agitate the waters in that particular location.



Therefore, this difference in biomass for this species can be considered bias, due to the location and the exposure aspect of the MPA.

Another salient point that lends weight to the efficiency of the MPA system of Grand Cayman is that there are no significant differences in the density of fish when protected sites within the MPA are compared to non protected sites outside the MPA, indicative of an efficient MPA design. The MPA allows the development of higher biomass by means of allowing individuals to grow to a larger size class as well as the specific composition of sites, not by the density of individuals. Furthermore, the mean sizes classes showed that individuals were 3 cm larger inside the MPA when compared to individuals outside the MPA. One could say that fish are comparatively distributed in the “big” size classes inside the MPA, and in the “small” size classes outside the MPA.

The data suggest that when all species are considered, there is a more homogenous distribution within the protected MPA sites which again adds weight to the effectiveness of the MPA. When the “rare” species (abundance lesser than 1%) are considered, *Holocanthus ciliaris* (Linnaeus, 1758) was six times, *Pomacanthus arcuatus* (Linnaeus, 1758) five times, *Mysteroperca tigris* (Valenciennes, 1833) four times, and *Lutjanus jocu* (Schneider, 1801) is 3.6 times more likely to be found at the protected sites, within the MPA.

When the ratio of biomass between herbivores and top predators (carnivores) are compared, sites within the protected MPA sites show a much higher biomass of top predators. This is indicative of a much better balanced ecosystem. The biomass of top predator is two times higher within the MPA. The imbalance between the biomass of the trophic groups (herbivores and predators), in the fished areas, confirm the fact that fishing, though recreational puts immense pressure on the fish communities, in particular the top predators. Additionally, because recreational fishing takes place mostly in and around coastal areas, it has the capacity to impact all reef fish species negatively, as survival after catch and release is largely unknown. The decrease of biomass progressively away from the northern boundary of the MPA authenticates the exportation of individuals from the marine reserve to the surrounding fished areas. However, the last site which exhibits the lowest biomass (33.29 g/m<sup>2</sup>) is located at the mouth of a lagoon and represents a different habitat. The four first sites are characterized by “spur and groove”, whereas the last site is more of a scattered, “patchy”, distribution of coral reef with more turbid water due to sediments exiting the lagoon. This disruption in habitat continuity limits individual’s movement along the reef (Forcada *et al.* 2008). However exportation is possible and remarkable because this hindrance to movement is 5 km from the boundary. If we considering only the first four first, the biomass decreases to 44.17 g/m<sup>2</sup>, the mean biomass outside the MPA, and all around Grand Cayman

(44.93 g/m<sup>2</sup>). Spillover effect was not evident on the southern boundary of the MPA, quite possibly due to the fact that the lagoon opens up at < 300 m from the boundary and is over 500 m wide. Biomass measured at the 1km location was 34.04 g/m<sup>2</sup>, which corresponds to the biomass measured in the same kind of habitat in the north at the 5 km location (33.29 g/m<sup>2</sup>), whereby again limiting individual’s movement in the south of the MPA, and possibly preventing exportation to the adjacent fished areas.

## CONCLUSION

The Marine Park of Grand Cayman plays an important role in the restoration of fish stocks; in increasing mean biomass, and mean size of individuals, and balancing the proportions between the different trophic groups. The results of this study add empirical evidence that MPAs promote biomass within their boundaries and provide net export of individuals to adjacent non protected areas. Though spillover effect is only evident in the north boundary of the Grand Cayman MPA, the Marine Park of Grand Cayman has a beneficial impact outside in the fished areas, especially for Lutjanidae, the major export species. The lack of Spillover effect in the south of the MPA does not controvert reserve impacts and is explained by the characteristic geomorphologic make up of the sites, in particular a disruption of the continuity of “spur and groove” habitat.

The effectiveness of an MPA depends on several factors, such as age and size (Claudet *et al.* 2008). The optimum size of a MPA has been debated for decades (Aswani and Hamilton, 2004). It is difficult to say what constitutes the ideal size of an MPA but it is possible to conclude that the MPA of Grand Cayman contributes empirical evidence towards that argument in terms of minimum size to be effective.

It was also determined that seemingly benign recreational fishing does have a negative impact on the fish communities on the reefs of Grand Cayman, reducing their size and contributing to an imbalance of carnivore to herbivore ratio similar to the findings of (Koslow 1988, Russ and Alcala 1989) that fishing pressure reduces the size of carnivores and herbivores. Additionally, it lends support to the findings of (M. Westera *et al.* 2003), in that recreational fishing alone may, in some cases be enough to alter the composition of target fish.

In summary, this study provides evidence that the MPA of Grand Cayman is resolutely efficient in that biomass is higher within the MPA, the size of fish are larger, the proportion of carnivores and herbivore are more balanced, and it is effective in the exportation of individuals to surrounding areas.

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