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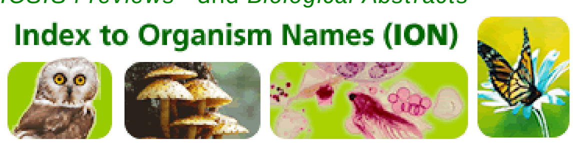

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Caribbean parrotfish density and size inside and outside marine protected area

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Abstract. The direct and indirect impacts of the increase in human population, in particular the growing demand for food, as well as various aspects of climate change pose threats to the abundance of parrotfishes (Scarinae), the main coral reef grazers. One way to reduce fishing is by forming marine protected area (MPA). MPAs tend to increase the abundance of marine fish. Well-managed MPA, with effective protection from fishing, could also benefit sex-changing fish populations. The objectives of this research are to assess effects of MPAs on parrotfish abundance and biomass and how do parrotfish abundance and size in the different life phases differ between sites within MPAs and outside MPAs. Fish surveys were conducted in eight Caribbean countries (Antigua, Bonaire, Barbados, Curaçao, Dominican Republic, Jamaica, St. Lucia and St. Vincent and Grenadines (SVG)) using an underwater visual census technique. The differences between parrotfish density and size within and outside MPAs were assessed. Mean parrotfish numerical density was slightly higher at MPA sites than at non-MPA sites but this was not significant. A significant difference was found between parrotfish biomass within and without the MPAs. The abundance biomass comparison (ABC) results showed that out of 33 MPA sites, 79% had a positive index and 21% a negative W-index value. In contrast, only 49% of non-MPA sites surveyed had a positive W-index. Sites within an MPA generally had higher mean parrotfish sizes than those outside the MPA, except for the juvenile phase. The present results reinforce the belief that parrotfish abundance and biomass, which where depleted by fishing, can be increased through applying significant levels of protection. However further research is needed on the effectiveness and duration of protection which are necessary to produce desired levels of improvement in parrotfish abundance, biomass and size.
Key Words: parrotfish, MPA, carribean, fish density, abundance biomass comparison.

Introduction. The direct and indirect impacts of the increase in human population, in particular the growing demand for food, as well as various aspects of climate change pose threats to the abundance of parrotfishes (Scarinae), the main coral reef grazers (Hughes et al 2003). Fishing is considered a major threat to parrotfish populations or stocks, and in particular overfishing of parrotfishes can lead to the impairment or loss of their functional roles, with negative impacts on tropical coastal ecosystem functions (Bellwood et al 2011).

One way to reduce fishing is by forming marine protected area (MPA). MPAs tend to increase the abundance of marine fish (Roberts 1995; Barrett et al 2007). After four years of protection from fishing, reef fish abundance, size, and biomass were greater in both the Saba Marine Park and Hol Chan Marine Reserve (Belize) than outside these MPAs. In each of the MPAs, the biomass of non-cryptic demersal fish, including parrotfishes, was twice that recorded at fished sites (Polunin & Roberts 1993; Roberts et al 2001). Hughes et al (2007) suggested that the protection afforded by an MPA should increase parrotfish biomass as long as predation inside the MPA is lower than fishing mortality outside the MPA. Marine reserves may also have a negative impact on parrotfish body size due to an increase in the abundance of large predatory fish (Mumby et al 2006). Small-bodied parrotfishes (e.g. *Scarus iserti*) were smaller inside the Exuma Cays Land and Sea Park, Bahama, but there was no discernible difference in density within and outside the MPA. While large-bodied parrotfishes did not differ in size, their density was double inside the reserve (Mumby et al 2006). The effect of MPAs on parrotfish assemblages needs further investigation. The present study will allow us to understand how parrotfish abundance and biomass vary between fished areas and unfished areas, particularly MPAs at large scale.

Well-managed marine protected area (MPA), with effective protection from fishing, could also benefit sex-changing fish populations. A meta-analysis of sex-changing fish from several MPAs around the world showed that abundance was higher inside than outside the MPAs (Molloy et al 2008). Hawkins & Roberts (2003) found that parrotfish terminal phase biomass and size were higher inside an MPA in St. Lucia than in the nearby fishing grounds. They further suggested that since mating success is likely to be influenced by the number of males, the relative density of each parrotfish life phase inside and outside the MPA should be determined.

The impact of MPA on fish assemblages can be assessed using the abundance biomass comparison (ABC) method. Originally proposed by Warwick (1986) to detect the impact of pollution on macrobenthic communities, it was subsequently improved to detect effects of other disturbances, either physical or biological, on benthic invertebrates (Warwick et al 1987). The ABC method was also successfully applied to investigate disturbance on fish communities in Namibia (Bianchi et al 2001), in the Bay of Biscay, France (Blanchard et al 2004), and in South Africa (Yemane et al 2005). The applicability of ABC method to assess effects of fishing on parrotfish is needed.

The objectives of this research are to assess effects of marine protected areas (MPAs) on parrotfish abundance and biomass and how do parrotfish abundance and size in the different life phases differ between sites within MPAs and outside MPAs.

Material and Method

Description of the study sites. Fish surveys were conducted in eight Caribbean countries (Antigua, Bonaire, Barbados, Curaçao, Dominican Republic, Jamaica, St. Lucia and St. Vincent and Grenadines (SVG)). The Caribbean region is a semi-enclosed sea bounded to the north by the Gulf of Mexico and to the east by the Atlantic Ocean, surrounded from north to south by the North American mainland, the east coast of Central America and north coast of South America. There are over 700 islands in this region, which are divided among 13 sovereign states and 17 dependent territories, including overseas territories of the United Kingdom, France, the Netherlands, and the United States of America (Figure 1). The Caribbean marine environment includes some of the most productive and biologically complex ecosystems in the world, such as coral reefs, sea-grass beds, mangrove forests, and coastal lagoons. These tropical coastal ecosystems provide food, habitat, and nurseries for many marine and coastal species, including commercially valuable fishes and marine invertebrates. These ecosystems are vital to the economy of many communities and states in the region due to their association with activities such as fishing and tourism (Miller 1996).

Fish survey. Parrotfish abundance and size were recorded using an underwater visual census technique. At each site, four 10 x 4 m transects were placed to record fish < 20 cm and eight 30 x 4 m transects for fish > 20 cm total length. Data were gathered between October 2010 and December 2011. Parrotfish biomass was calculated using length-weight relationships between size and counts (Bohnsack et al 1988) with species-specific values from www.fishbase.org (Froese & Pauly 2013). In addition, fish life phase (juvenile (JP), initial (IP), and terminal (TP)) was determined *in situ* during the survey based on their coloration. JP is generally characterized by drab colouration, the IP by dull colouration, and the TP by bright colours.

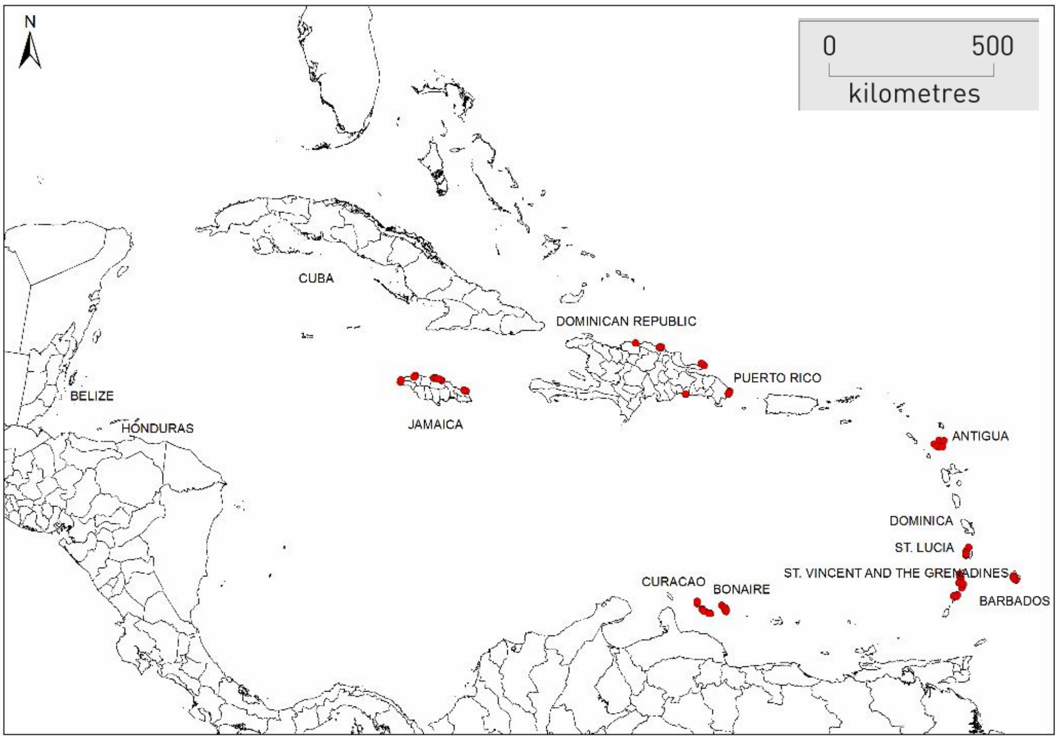

Figure 1. Map of the Caribbean showing the extant countries or territories. Red dot shows the study locations and number of sites.

***Marine protected areas**.* MPA data were obtained from the World Database of Protected Areas (UNEP-WCMC & IUCN 2012). The shapefile with coordinates of the surveyed sites was overlaid onto the map of the MPA using ArcGIS v.10.1. The sites were classified as being within an MPA when they were within the boundaries of a legally designated MPA. Proposed MPA sites and the areas outside the legal MPAs were classified as non-protected areas. Due to lack of information on the effectiveness of each MPA, all designated MPAs were assumed to have a significant level of management.

***Statistical analysis**.* The differences between parrotfish density and size within and outside MPAs were assessed using the two-sample permutation test since data was not normal even after transformation, conducted within the *perm* package (version 1.0-0.0) in the R environment (R Core Team 2013). Prior to the analysis, parrotfish abundance and biomass were fourth-root transformed to reduce the effect of extreme values. The potential impact of MPA was assessed using the ABC analysis for all sites. The ABC plots and the calculation of the W-index were carried out using the *forams* package (version 2.0-4) in the R environment (R Core Team 2013).

Results. Mean parrotfish numerical density was slightly higher at MPA sites than at non-MPA sites but this was not significant (Permutation t-test, Z = 1.0259, p = 0.3049; Figure 2a). A significant difference was found between parrotfish biomass within and without the MPAs. Sites within an MPA had significantly higher parrotfish biomass than non-MPA sites (Permutation t-test, Z = 2.2429, p = 0.0059; Figure 2b).

Scarus numerical density was significantly different (Permutation t-test, Z = 2.7518, p = 0.0059, Figure 2c), while *Sparisoma* numerical density was no different between sites within and those outside MPA (Permutation t-test, Z = -0.8381, p = 0.4020, Figure 2e). *Scarus* and *Sparisoma* biomass were significantly different between sites within and outside MPA (Permutation t-test, Z = 2.4301, p = 0.0151 (*Scarus*), Figure 2d; Z = 2.1766, p = 0.0295 (*Sparisoma*), Figure 2f).

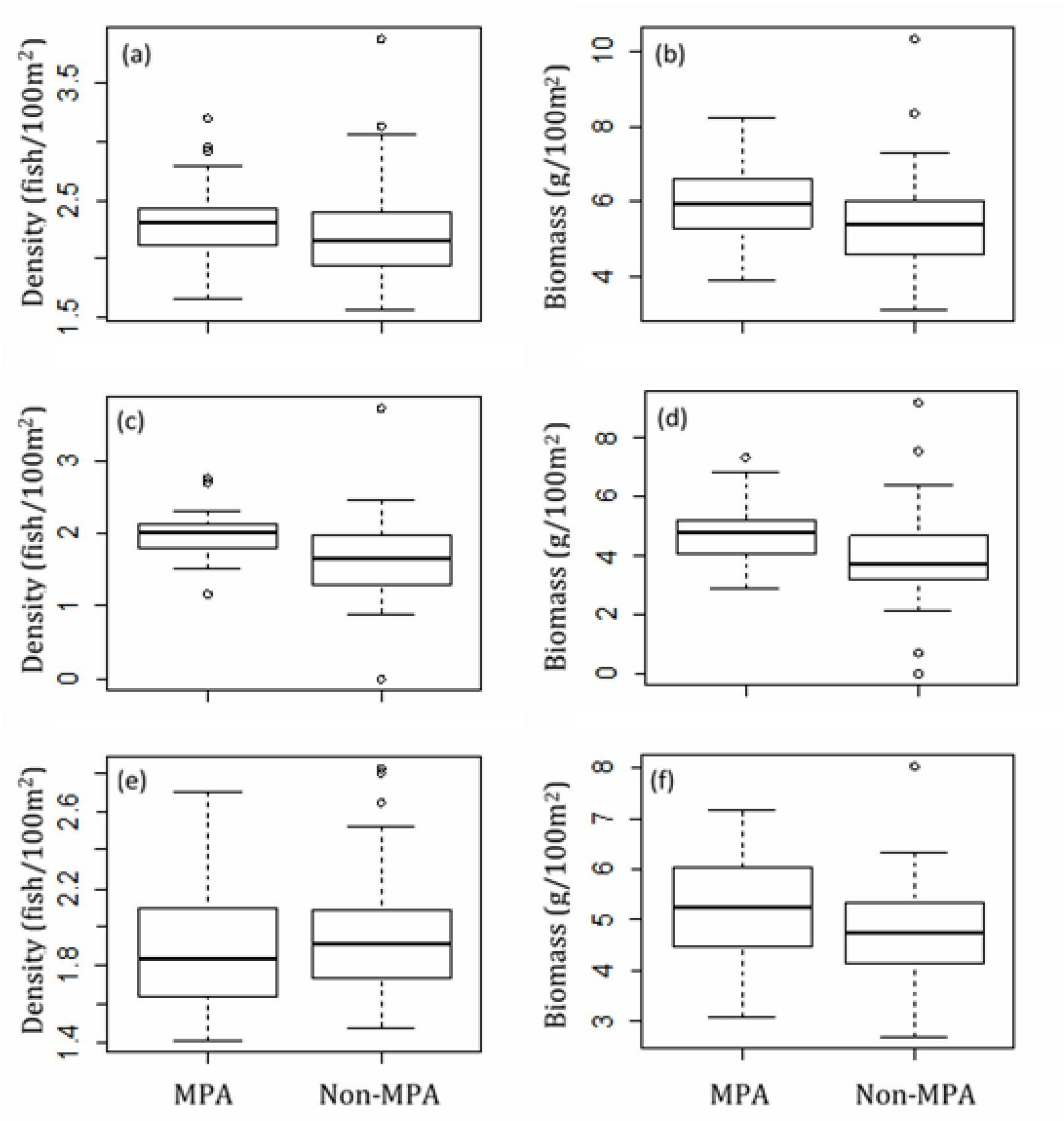

Figure 2. Differences between parrotfish density (a) and biomass (b), *Scarus* density (c) and biomass (d), *Sparisoma* density (e) and biomass (f) across the Caribbean within and outside MPA. Parrotfish abundance and biomass have been fourth-root transformed before plotting.

MPA and abundance biomass comparison. The ABC results showed that 61% of the 84 sites surveyed had a positive W-index. Out of 33 MPA sites, 79% had a positive index and 21% a negative W-index value. In contrast, only 49% (25/51) of non-MPA sites surveyed had a positive W-index (Figure 3).

In general, parrotfish density at each life phase was higher at sites inside MPAs than outside MPAs, except for individual species (Table 1). In the JP, densities were significantly higher in protected than not protected sites for *S. taeniopterus* (Permutation t-test; $\rho = 2.419$, $p < 0.05$; Table 1). In the TP, the combined density of all parrotfishes was significantly different between sites within and outside MPAs (Permutation t-test; $\rho = 2.071$, $p < 0.05$; Table 1). No parrotfish, genus, or individual species initial phase (IP) had significantly different densities between MPAs and areas outside.

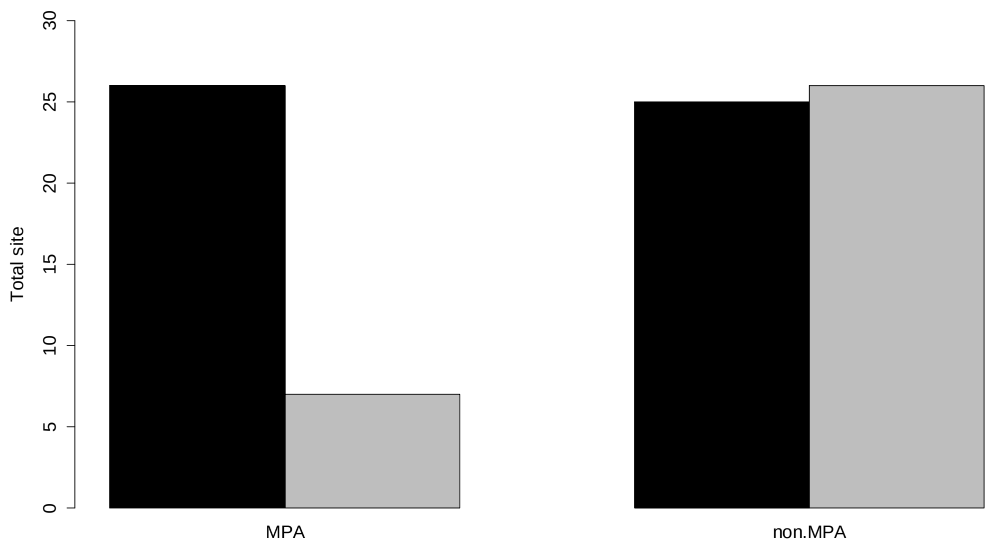

Figure 3. Number of MPA and non-MPA sites with positive and negative W-index values. Black bars represent positive W-index values. Grey bars represent negative W-index values.

Table 1

Differences between parrotfish numerical density between MPA and non- MPA sites in eight countries in the Caribbean

Life phase	*Group*	*Z*	*p*
Juvenile	All	0.9310	0.3519
	Scarus	1.9559	0.0505
	Sparisoma	-1.0181	0.3086
	Scarus taeniopterus	2.4193	0.0156*
	Scarus iserti	-0.1371	0.8909
	Sparisoma aurofrenatum	-0.8418	0.3999
	Sparisoma viride	-1.5945	0.1108
Initial	All	0.1520	0.8791
	Scarus	0.4493	0.6532
	Sparisoma	-0.3508	0.7257
	Scarus taeniopterus	-0.2831	0.7771
	Scarus iserti	-	-
	Sparisoma aurofrenatum	-1.1301	0.2585
	Sparisoma viride	-0.1251	0.9005
Terminal	All	2.0716	0.0383*
	Scarus	0.7777	0.4367
	Sparisoma	1.1293	0.2588
	Scarus taeniopterus	0.6678	0.5043
	Scarus iserti	-0.3620	0.7174
	Sparisoma aurofrenatum	0.9378	0.3483
	Sparisoma viride	-0.2895	0.7722

* indicates significant value < 0.05.

Sites within an MPA generally had higher mean parrotfish sizes than those outside the MPA, except for the JP. The mean sizes of the genus *Sparisoma* in juvenile ($\rho = -2.154$, $p < 0.05$) and TP ($\rho = 2.560$, $p < 0.05$) inside the MPAs were significantly different from those outside MPAs (Table 2).

Table 2

Differences between parrotfish mean size between MPA and non-MPA sites in eight countries in the Caribbean

Life phase	*Group*	*Z*	*p*
Juvenile	All	-0.8530	0.3937
	Scarus	-1.7259	0.0846
	Sparisoma	-2.1542	0.0312*
	Scarus taeniopterus	-1.4467	0.1480
	Scarus iserti	-0.6449	0.5190
	Sparisoma aurofrenatum	-1.7831	0.0756
	Sparisoma viride	-0.2576	0.7967
Initial	All	1.5877	0.1124
	Scarus	0.2663	0.7900
	Sparisoma	1.3333	0.1824
	Scarus taeniopterus	0.5537	0.5798
	Scarus iserti	-	-
	Sparisoma aurofrenatum	1.1841	0.2364
	Sparisoma viride	1.6020	0.1092
Terminal	All	1.3537	0.1758
	Scarus	0.3586	0.7199
	Sparisoma	2.5603	0.0105*
	Scarus taeniopterus	-0.8558	0.3921
	Scarus iserti	0.4564	0.6481
	Sparisoma aurofrenatum	0.6068	0.5440
	Sparisoma viride	1.6526	0.0984

* indicates significant value < 0.05.

Discussion. Parrotfish abundance and biomass were both significantly different between sites within and those outside marine protected areas. These results were similar to those reported from the Western Solomon Islands (Aswani & Sabetian 2010), with observed parrotfish abundance being lower outside than inside MPAs. The establishment of an MPA can enhance ecological processes and fisheries recovery (Roberts & Hawkins 2000) and, over time, has been shown to increase the abundance of many marine fish (Roberts 1995; Barrett et al 2007).

However, giving all MPA sites a similar protection status may have led us to underestimate the differences in parrotfish abundance and biomass between fished and unfished locations. Due to the difficulty in discriminating between sites based on the effectiveness of protection afforded by each MPA, all sites within MPAs were grouped together and considered as essentially unfished regardless of truly effective MPAs. It should be noted that because the MPA classification was extremely coarse, MPA sites might not have the same levels of protection and in addition reserve age varied substantially. Aswani & Sabetian (2010) found that parrotfish abundance in Nusa Hope, Western Solomon Islands (an effective MPA) was significantly higher than at Kida (a moderately effective MPA). The age of the reserve may also significantly enhance the abundance of fish (Molloy et al 2008), increasing with the length of time for which there has been (effective) protection. For example, Molloy et al (2008) found that after protection for at least a decade fish abundance within MPAs was 3 times greater than abundance outside them, however when all MPAs were included in the analysis, regardless of their age, they found no significant difference overall between MPA and non-MPA sites.

The ABC results suggest that most MPAs in the Caribbean are or could be effective to protect parrotfish assemblages and to maintain them in a healthy status. Sites within an MPA were more likely to have parrotfish positive W-index values than non-MPAs which had equal numbers of sites with positive (undisturbed) and negative W-index values (disturbed), the former indicating significant number of larger parrotfish in the MPA sites compared to small ones. This is in keeping with the results from other studies; for example small-bodied parrotfish (e.g. *S. iserti*) density was not significantly different, while large-bodied parrotfish density was double inside the Exuma Cays Land and Sea Park, Bahamas (Mumby et al 2006).

There was a tendency for initial and terminal phase fish to have lower size at phase change. This represents a threat to parrotfish population resilience, the effectiveness of their ecological role and their value as fishery resources. This threat could be addressed by effective management intervention either using site protection such as MPAs or by regulation of fishing seasons to allow stock recovery (Roberts & Polunin 1994; Roberts et al 2001; Barrett et al 2007; Molloy et al 2008; O'Farrell et al 2016). The need for management, either by MPA or fishing regulation is indicated by the greater density and mean size of terminal phase fish within MPAs, consistent with the results of Hawkins & Roberts (2003), in which parrotfish biomass in St. Lucia increased after the creation of an MPA. Mean density of terminal phase *S. vetula* and *S. viride* doubled in the Exuma Cays Land and Sea Park (ECLSP, Bahamas; Mumby et al 2006), while after a decade of protection, abundance of sex-changer fish within MPAs was higher than outside (Molloy et al 2008).

MPAs are one method which has been proven potentially effective in providing protection and increasing fish density and biomass (Roberts 1995; Barrett et al 2007; Lester et al 2009; Molloy et al 2008; Graham et al 2011; Edgar et al 2014; Bonaldo et al 2017). This reseach result indicates that protection, in the form of an MPA, should at least be able to increase the density of large fish, which in turn is expected over time to increase recruitment, even though it is very likely that predation will have a substantial effect on population dynamics and size/age structure. Further research on the interaction between predator and parrotfish population abundances and structures inside MPAs is necessary.

Well-managed MPAs, however, appear to have a negative effect on small parrotfish. Mumby et al (2006) also found more small *S. iserti* and *S. aurofrenatum,* although not significant, in the ECLSP that was attributed to greater predator abundance inside the reserve. While larger-bodied parrotfish were released from fishing pressure and much less vulnerable to predation than the smaller-bodied species, fishing pressure was generally lower on the latter while they are a natural prey for the groupers and other large carnivorous fishes becoming much more abundant within the reserve. *Epinephelus striatus* in the reserve are able to consume between 60-90% of adults of *S. iserti* (Mumby et al 2006).

The present results reinforce the belief that parrotfish abundance and biomass, which where depleted by fishing, can be increased through applying significant levels of protection. However further research is needed on the effectiveness and duration of protection which are necessary to produce desired levels of improvement in parrotfish abundance, biomass and size.

Conclusions. Parrotfish biomass was significantly higher within Caribbean MPAs, while parrotfish density did not differ significantly. The present study also found that juvenile parrotfish density did not differ significantly between sites inside and outside of MPAs, the density of terminal parrotfish was significantly different. Most MPAs in the Caribbean were more likely to have parrotfish positive W-index values than non-MPAs. While MPAs are believed to have positive effects on parrotfish abundance, it is suspected that there are often indirect effects due to increasing predators and competitors that may prevent parrotfish recovery. In this context, the extent to which predators and competitors affect parrotfish abundance, population structure (within species) and parrotfish community composition within an MPA is a matter which warrants further attention.

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