RESEARCH ARTICLE

Parrotfish Body Size As An Indicator of Diurnal Fish Species Richness On Fringing Coral Reefs in Barbados.

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Keywords
Coral reefs: *Tropical and subtropical marine ecosystems containing a wide diversity of life.*
Parrotfish: *An abundant grouping of reef fish found in many different locations, known ecosystem engineers.*
Biodiversity: *the variety of different species in an ecosystem*

Abstract

Background: Coral reefs around the world are host to some of the most condensed and varied ecosystems. However, over the past decades, their biodiversity has alarmingly decreased. A rapid and reliable way of assessing their status is urgently needed to monitor and prevent their decline. The purpose of this study is to assess whether or not family *Scaridae* (common name: parrotfish) body size can be used as an index to evaluate the diurnal fish diversity on coral reefs.

Methods: We selected 6 accessible reefs on the West coast of Barbados and measured the size of parrotfish we encountered, as well as the number of fish species present on the reef; this data was then plotted and statistically analyzed to establish a possible correlation.

Results: Our results show that reef fish species richness is strongly correlated to both the ratio of large to small parrotfish and the average parrotfish size. It is however the large to small ratio that exhibited the strongest relationship. Further analysis revealed that the population size of large parrotfish correlates with reef biodiversity with a Pearson's r coefficient of 0.97.

Conclusion: This relationship could be due to the fact that large parrotfish (greater than or equal to 20 cm) have increased grazing rates compared to smaller ones, this increased grazing promotes coral polyp recruitment, thereby benefiting the diversity observed on coral reefs. Further research is needed to elucidate whether these results can be extended to other areas of the Caribbean and provide conservation efforts with an easy tool to survey and protect coral reef ecosystems.

Introduction

Barbados is an island nation situated in the western part of the North-Atlantic, around 13˚N and occupies 429 km^2. As a seafaring country, fishing has traditionally been an integral source of employment and income for the nation. Mohammed *et al.* (1) found that in recent years the fishing industry has expanded in fleet size, landings, and species targeted. The same study explains that as a result of the heavy reliance on fishing and the small size of the country, many of the fisheries, including the shallow-shelf reef fisheries which target species such as parrotfish, surgeonfish, triggerfish and grunts, are considered over-exploited. Once the top predators are depleted, fishermen proceed to hunt the smaller herbivorous parrotfish. The family *Scaridae* includes over ninety species of herbivorous, day-time active (diurnal) fish that graze primarily on algae-coated corals (2). We encountered 4 species in the sampled area: stoplight parrotfish (*Sparisoma viride)*, princess parrotfish (*Scarus taeniopterus*), redband parrotfish (*Sparisoma aurofrenatum*), and striped parrotfish (*Scarus iserti*). Because this family of fish is widespread and populous throughout the Caribbean it would make a convenient indicator species for the region (2). Parrotfish are also tied to the reef ecosystem through their role as algae grazers (3); in this way their presence can be representative of a healthy, low algae reef system (3). Additionally, if parrotfish are being harvested, this is indicative of overharvesting of larger, commercially valuable fish species (4). The need for an adequate and efficient indicator species is all the more vital given the current abasement of coral reefs worldwide (5). Such an indicator of reef fish diversity would permit a rapid assessment of reefs with abundant diurnal reef fish species, allowing targeted conservation and preservation efforts.

It has already been shown by Vallès and Oxenford (4) that parrotfish size can be used as an index to estimate the fishing pressure and species abundance of large piscivorous fish, such as groupers and snappers upon which pelagic fisheries depend. They demonstrated that *Scaridae* body size and both fishing pressures and the secondary consequences of harvesting (ie. fewer piscivorous fish) are consistently negatively correlated (4). Since parrotfish are typically only fished after the piscivorous fish are depleted, their decline can be seen as a larger indicator of overall fish decline (4). Building on this, we are interested in determining if parrotfish body size structure within a population can be more broadly used as an indicator of the richness of diurnal fish species on a particular reef. Previous studies claim that as the parrotfish size exceeds 20 cm, its grazing rate drastically increases (3). If the overall grazing rate of a parrotfish community is be reduced, the result will likely be a growth in algal cover over reefs, reduced coral polyp recruitment, less reef growth, and fewer reef systems to support fish species (3). This threshold was the basis of our large to small analysis.

In this study, we assessed the body size of parrotfish, the structure of that body size within the community (proportion of the population to occupy different size classes) and the total number of diurnal reef fish species; the latter being the most widely used diversity measure in literature (6). This was done on 6 reefs along the West coast of Barbados to determine the presence or absence of a relationship between these variables. In order to capture variation in fish body size, we sampled three sites in a marine protected area (MPA) and three located in non-protected marine areas, this protected area was found to have a reduced fishing effort of 70% or greater compared to the surrounding non-protected areas (7). We expected larger and more populous parrotfish communities to reside in the protected areas due to the lack of or reduced fishing stressor (8). Ultimately, we predict that the larger the size of the parrotfish on the reef, the higher the species richness of fish will be. Two different measures for parrotfish size are used: 1) mean parrotfish body size, and 2) the ratio of large to small parrotfish, with the cutoff for large being greater than or equal to 20 cm. The two models were compared to determine which metric is a more rigorous predictor of biodiversity on the reef.

Methods

The 6 chosen sites were sampled over four days from May 17-20th, 2013. They had to be accessible using snorkeling gear, which restricted sampling to fringing reefs on the West coast of Barbados. Sites were chosen in an effort to survey areas with different amounts of fish species yet similar physical composition. We chose to assess 6 sites, three of which were located in the Folkestone Marine Reserve (hereinafter referenced to as Bellairs South, Bellairs North and Discovery Bay) and three in unprotected areas (Gibbes Beach, Sandy Lane and Batts Rock Beach).

Fish Sampling

We randomly and continuously snorkeled throughout each reef at a pre-practiced speed. One person assessed the *Scaridae* body size, another counted the number of fish species, while the last person held a watch and signaled every minute to the two others. This design was repeated thrice on each reef in order to have every person play all roles once and mitigate for possible observer bias.

Encountered parrotfish were identified according to species. Four different species were counted in our observations. These were: the redband parrotfish, the princess parrotfish, the spotlight parrotfish and the striped parrotfish. To estimate *Scaridae* body size, we first trained ourselves to evaluate the length of 30 and 60 centimeter sticks underwater. This was done to help account for the 33% magnification of objects under water (9). Once on the reef, we evaluated the length of each parrotfish we encountered and recorded it on an underwater slate, as the number of fish found per 5 cm fish length intervals. Each person scanned for Scaridae size on each reef for a set total time of ten minutes.

To assess the fish diversity on the reef, one person would record on a slate the number of new fish species seen every minute. This was done to establish a saturation curve of species richness. The biodiversity count would end after having assessed zero new species per minute, three times in a row or five times cumulatively, for a minimum sampling time of 10 minutes. The sites sampled for the longest periods were Bellairs North and South reefs which were both surveyed for 23 minutes, the shortest was Gibbes at 13 minutes, in between Discovery was 16 minutes, Sandy Lane and Batts were both 17 minutes.

Statistical Analysis

We calculated Pearson's r correlation coefficient between species richness variables and the ratio of large to small parrotfish, as well as the correlation coefficient (r) between species richness and average parrotfish size. We then calculated the significance of the results with α set at 0.05. Coefficients of determination (R^2) for our two models were also determined. This was done in order to establish which metric (the large-to-small ratio or the average size) would best describe general fish richness on a reef. Lastly, a one-way analysis of variance with α equals 0.05 was used to determine if there was a statistical significant difference in mean parrotfish abundance, average parrotfish size, diurnal reef fish species richness and large to small parrotfish ratio between protected and non-protected sites.

Results

Our parrotfish population size measurements showed relatively uniform distributions at all six sites. We also found a diminishing rate of discovery of new species over time (Fig. 1). Table 1 shows the variation in species abundance, average parrotfish size and other measured variables over the surveyed sites. The protected reefs possessed substantially greater parrotfish population than their non-protected counterparts. The non-protected sites showed smaller parrotfish abundance [$F(1,16)=18.04$, $p=0.001$)], lower large-to-small parrotfish ratios, smaller parrotfish size on average [$F(1,16)=15.80$, $p=0.001$)], and lower diurnal species richness [$F(1,16)=14.55$, $p=0.002$] all in comparison to the protected sites using a one-way ANOVA, $\alpha = 0.05$ (Table 2). The difference in parrotfish size, parrotfish abundance, and species diversity between the non-protected sites in the south (Batts Rock Beach and Sandy Lane) and the non-protected site in the north (Gibbes Beach) was not significant at $\alpha=0.05$ (ANOVA).

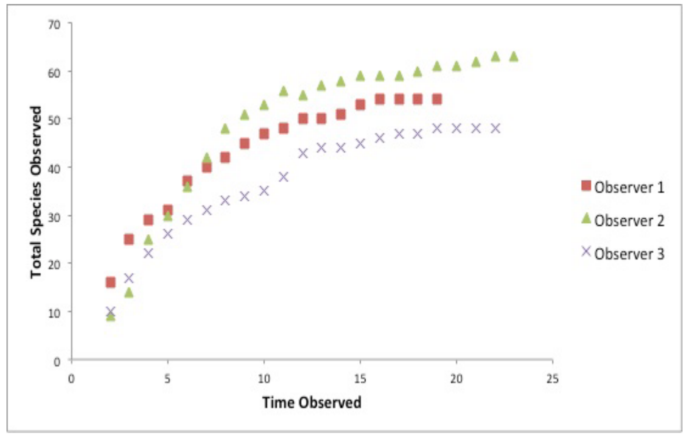


Fig. 1
Saturation curve from Bellairs North Reef, demonstrating the diminishing rate of discovery of species over time.

Site	Average Dirunal Reef Fish Species Richness	Parrotfish Average Length (cm)	Average Parrotfish Abundance	Average Number of Large	Average Number of Small	Large-Small Ratio	Average Proportion of Small Parrotfish	Average Proportion of Large Parrotfish
Bellairs South	54.33	23.35	34.33	53.00	24.00	2.21	0.31	0.69
Bellairs North	54.67	29.29	26.00	56.00	22.00	2.55	0.28	0.72
Discovery Bay	35.00	23.73	17.00	24.00	27.00	0.89	0.53	0.47
Gibbes Beach	21.67	11.00	8.33	1.00	24.00	0.04	0.96	0.04
Sandy Lane Bay	37.00	23.96	16.00	25.00	23.00	1.09	0.48	0.52
Batts Rock Beach	30.67	10.56	3.00	1.00	9.00	0.11	0.90	0.10

Table 1
Summary of general results obtained from the 6 sampled sites. This includes measurements like species richness, average parrotfish length and ratios of small to large and large to small parrotfish.

a) Parrotfish Abundance

	Protected	Non-Protected	
Mean	25.78	9.11	
Standard Deviation	10.08	6.07	
Degrees of Freedom		ANOVA	
Between Groups	1	P-Value	0.00061
Within Groups	16	F	18.04

b) Parrotfish Size

	Protected	Non-Protected	
Mean	27.56	15.99	
Standard Deviation	4.31	7.59	
Degrees of Freedom		ANOVA	
Between Groups	1	P-Value	0.00108
Within Groups	16	F	15.80

c) Diurnal Reef Fish Species Richness

	Protected	Non-Protected	
Mean	48.00	29.78	
Standard Deviation	10.84	9.38	
Degrees of Freedom		ANOVA	
Between Groups	1	P-Value	0.00153
Within Groups	16	F	14.55

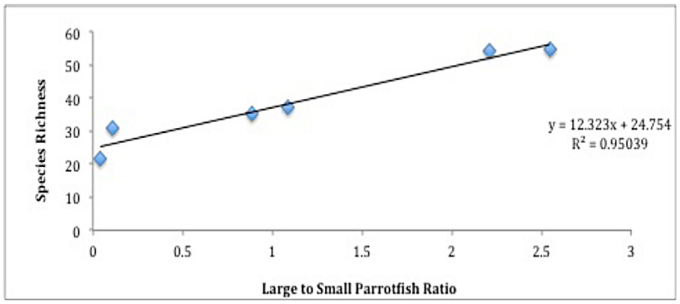
d) Large to Small Parrotfish Ratio

	Protected	Non-Protected	
Mean	2.17	0.51	
Standard Deviation	1.69	0.70	
Degrees of Freedom		ANOVA	
Between Groups	1	P-Value	0.02067
Within Groups	16	F	6.59

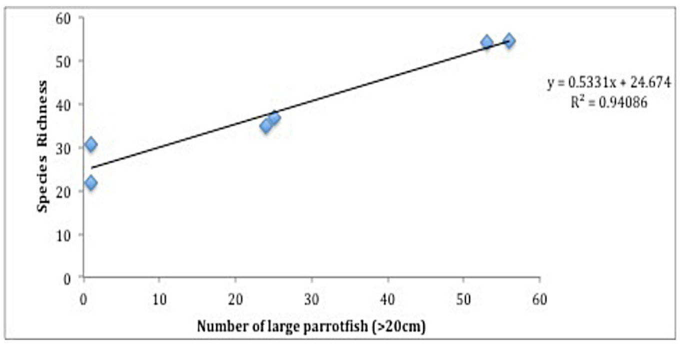
Table 2
One-way analysis of variance (ANOVA), α = 0.05 for:
a) parrotfish abundance
b) parrotfish size
c) diurnal reef fish species richness
d) large to small parrotfish ratio

	Large to Small & Population Size	Large to Small & Species Richness	Average Size & Species Richness	Population of Small & Species Richness	Population of Large & Species Richness	Population of Large & Small
Pearson's r	0.92	0.97	0.80	0.20	0.97	0.42
P-value	0.008	0.001	0.052	0.70	0.001	0.42

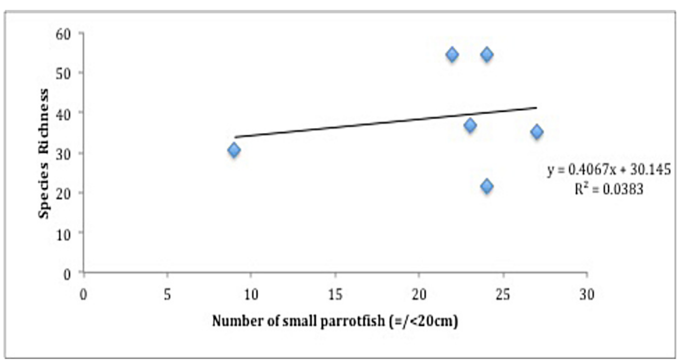
Table 3
Pearson's r values and their associated p-values for all examined variables.



A



B



C

Fig. 2
A) Regression of diurnal reef fish species richness vs. number of large parrotfish.
B) Regression of diurnal reef fish species richness vs. number of small parrotfish.
C) Regression of diurnal reef fish species richness vs. ratio of large to small parrotfish.

When examined with Pearson's r, the variables showed strong correlation values. The strongest of which was the relationship between the large to small parrotfish ratio and the diurnal species richness (r=0.97, p=0.001). Large to small ratio was also highly correlated with parrotfish population (r=0.92, p=0.008) and diurnal species richness was correlated with parrotfish average size but was not considered significant with α set to 0.05 (r=0.80, p=0.052). The number of small parrotfish was not correlated to biodiversity (r=0.20, p=0.7) however the number of large parrotfish was (r=0.97, p=0.001). Finally, the Pearson's r for the abundance of small vs. large parrotfish resulted in a moderate correlation of 0.42 (p=0.42) (Table 3).

The large to small parrotfish ratio vs. diurnal reef fish species richness had a strong correlation with an R^2 value of 0.95 (Fig. 2a). Moreover, the coefficient of determination for population of large parrotfish vs. species richness and small parrotfish vs. species richness was 0.94 and 0.04 respectively (Fig. 2b and 2c).

Discussion

The results showed that the distribution of different size classes in communities of parrotfish, particularly the population of large parrotfish, is a more accurate linear measurement for predicting fish species richness on a particular reef than average parrotfish size or number of small-size parrotfish. We concluded that small parrotfish have a relatively small influence on overall fish species richness, while large parrotfish possess a significant one. Average parrotfish size and overall abundance showed notable relationships as well but were not as powerful as the population of large parrotfish. Secondly, the influence of marine reserves on both parrotfish populations and reef fish diversity was found as highly beneficial with more and larger parrotfish found within the reserve as well as greater numbers of diurnal fish diversity.

The positive correlation between *Scaridae* size and the number of fish species present on the reef was again a highlight of the study. However, such a statistical correlation does not provide any information with respect to the direction of that relationship. It could be thought, for example, that since high fish diversity is positively correlated with coral health (10). A reef with high fish diversity (as a result of good coral health) would be an ideal habitat for parrotfish, enabling them to graze *ad libitum* and allowing different species of large parrotfish to thrive. Nevertheless, the analysis highlighted above suggests a direction to the correlation we have established; larger parrotfish graze more on the algae thus increasing polyp recruitment, which is beneficial to the reef diversity, although behavioral studies are needed to further prove this causal relationship.

These results reinforce the paradigm of using MPAs to safeguard and nurture marine ecosystems. Parrotfish alter coral reefs in one of two ways: through eroding corals and feeding on the algae covering these corals (12). The detrimental impact of parrotfish predation of coral polyps on reefs is a source of mortality for reefs but rarely results in the death of entire coral colonies. This is because their beneficial role as grazers greatly outweighs the negative impacts they impose from predation (12). Extensive algal coverage can have a suite of deleterious effects on coral reefs like the inhibition of juvenile coral growth, potentially leading to their death in addition to decreasing growth and fecundity of adult corals (12). Parrotfish graze on the algae and this function significantly increases beyond a length of 20 cm (3). Such a function is beneficial to coral health and has been shown to increase total density of coral recruitment 2-fold (13). While biodiversity has been established as a pertinent marker of coral reef health (14), it has also been shown that population size of a species such as parrotfish can override the biodiversity as a signal for coral reef health given their functional role in the ecosystem (14). Given these findings and prior knowledge, the province of parrotfish in coral reefs should be considered an essential one and be thoroughly examined when assessing reef fish diversity and inferentially, coral reef health.

There are several limitations associated with our study. The largest assumption is that the other factors of reef habitat quality (besides algal cover) are equivalent among sites. Factors such as reef complexity (15), water quality (16), nutrient input (16), and environmental variables such as temperature, salinity, and pH (17) all play a role in determining reef health and-or biodiversity. While large scale parameters like temperature, pH, and salinity could be considered constant over the small scale of the study (less than 15 km); the local scale variables could not be and were not accounted for in our study, further research should aim to control for this.

The sampling procedure relies on the fact that the species are evenly distributed amongst the reef and that they are equally visible to the observers. Visibility depends upon the water turbidity, time of day and cloud cover in the sky, which we could not control for. Spotting was also influenced by swimming rate, and as a result area covered; this was held fairly constant but could have been influenced by currents or individual fatigue. Misidentification of species would create an inaccurate count but it is assumed that improperly designated species such as juveniles that are aesthetically different from their terminal phase would be misclassified at each sites and the relative population would not be skewed. Due to time and equipment restrictions, we were limited to daytime measurements and 6 sampling sites all of which needed to be accessible by snorkeling from the shore. Due to the limited sample sites the values found to be insignificant have the possibility to be significant given more sampling sites. As such, the results are representative of the diurnal life on reefs located on the west coast of Barbados and not necessarily applicable in other regions containing parrotfish and coral reefs. It is possible that parrotfish exude a large presence on nocturnal biodiversity, which could be a matter for additional analysis. Finally, it is also assumed that the parrotfish are larger in MPAs due to reduced fishing stressors and that the parrotfish put no pressure on the biodiversity (i.e. predation) of the reef other than coral and algae grazing. Given the current literature these are reasonable assumptions.

There exist other indicators of diversity and health of coral reefs such as average parrotfish size and piscivorous fish (4), and other fish species such as the link between butterfly fish and coral reef health (18). That said they are not widespread and those mentioned focus on a specific group of fish and the other is positioned as healthy corals giving rise to healthy fish, not fish giving rise to healthy corals. Our results then provide several unique characteristics. Given the ubiquitous presence of parrotfish on coral reefs worldwide our measure is potentially applicable in many different locations as the mechanics are not unique to Barbados. The assessment is easy to apply in low budget scenarios or with non-scientifically trained personnel. If it can be assumed that reefs with higher fish diversity are indeed healthier this provides a crude tool to simply monitor reef health across time by observing abundance of large parrotfish, again with little time or money required. Lastly it provides yet another indication that marine reserves have positive and measurable effects on marine ecosystems.

Conclusion

The Caribbean is home to some of the most diverse and productive reef systems in the world. An easily measured indicator of fish species richness is an important asset in evaluating the state of coral reefs in Barbados in the face of mounting fishing pressures. We have successfully determined that the ratio of large to small parrotfish is an accurate linear measure of diurnal fish species richness at six sites. Primarily, our results demonstrate that the abundance of large parrotfish (cut-off criteria of > 20 cm) is strongly correlated with species richness but small parrotfish do not. Consequently, this measure can provide a useful tool that can be used to rapidly quantify species richness.

We were only able to sample 6 sites and reef complexity and quality was not assessed which may limit the results of the study. We speculate that the main variations in parrotfish size arose from differences in fishing pressures. In order to test that our indicator can be used in a variety of environments, future research should aim to sample different coral reefs throughout the Caribbean. Coral reefs in different locations are likely to be exposed to a multitude of environmental stressors such as nutrient input from groundwater, pollution and deviations in ocean currents and experimenting at varied sites would enable the testing of the validity of our indicator. Overall, our results provide a novel concept that builds upon previous studies though it still demonstrates a tangible result, which, ideally, could be extended spatially, and serve to preserve the unique yet endangered ecosystems that are coral reefs.

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