Western Indian Ocean JOURNAL OF Marine Science

Volume 15 | Issue 1 | Jan – Jun 2016 | ISSN: 0856-860X

Chief Editor José Paula

Western Indian Ocean JOURNAL OF Marine Science

Chief Editor **José Paula** | Faculty of Sciences of University of Lisbon, Portugal

Copy Editor **Timothy Andrew**

Published biannually

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ISSN 0856-860X

Cover image: Fisherman pushes his boat along the channels around Inhaca Island, Mozambique (© José Paula)

Temporal and Spatial variability in Reef fish Density and Biomass within the Dar es Salaam Marine Reserve System, Tanzania

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Abstract

This study was conducted within the Dar es Salaam Marine Reserve System with the aim of investigating temporal and spatial variations in reef fish biomass and density. Benthic cover which is a key factor for fish distribution was also estimated. Sampling was conducted from August 2014 to April 2015. Underwater Visual Census (UVC) techniques were used for the assessment of reef fish density and biomass, and line intercept transect (LIT) was used for the estimation of benthic cover. Results showed that there was a significant seasonal and temporal variation in fish density and biomass at both Mbundya and Bongoyo Islands. Benthic cover of live coral was significantly higher at Mbudya than at Bongoyo. It was concluded that Mbudya Island has less seasonal variation than Bongoyo due to the existence of a larger fraction of live coral cover. These results have implications for the management of marine reserves with regard to destructive fishing practices, a key factor impacting the stability and biomass of reef fish populations.

Keywords: Reef fish density, reef fish biomass, seasonal variation, Marine Reserves, Tanzania

Introduction

Identifying the scales of spatial and temporal variation relevant to patterns of distribution and abundance of species is a first step in the process of understanding the forces that govern their community structure (Underwood *et al*., 2000). Size structure of fish populations are related to seascape structure, including water depth, suggesting that non-linear variations exist in secondary production, seasonal variation, and biomass turnover rates across spatial and temporal scales (Fowler, 1990; Malcolm *et al*., 2007). Ecological processes such as predation risk and foraging success/food availability are considered among the core factors underpinning fish population dynamics in putative nursery habitats (Kimirei, 2012). Coral reef fishes often exhibit a high degree of structure in their distribution and abundance, but the factors that influence their spatial and temporal arrangement are poorly understood (Lecchini *et al*., 2003; Malcolm *et al*., 2007; Tuya *et al*., 2011). Despite considerable research effort, particularly in recent decades, the processes that determine such characteristics are still contentious and a source of debate (Fowler, 1990; Akin, 2003; Borges *et al*., 2007). Patterns in reef fish abundance, diversity and assemblage structure remains largely unexplored; even less understood is the extent to which any spatial and temporal pattern remains consistent through time (Tuya *et al*., 2011; Huijbers, 2015). There have been no previous studies on temporal and spatial variability of reef fish density and biomass within the Dar es Salaam Marine Reserve system (DMRs) on which this study is focussed.

DMRs has two sections. The Northern Dar es Salaam Marine Reserve system (NDMRs) was gazetted in June 1975 due to the high biodiversity found there and its high aesthetic, recreational, and educational and research value, as stipulated under the Fisheries Act No. 6 of 1970 and in the General Management Plan (GMP). The Southern Dar es salaam Marine Reserves (SDMRs) was gazetted in 2007 and lacks a GMP. Earlier studies in the NDMRs indicated that some parts had significant live coral cover and were important tourist attractions, while some areas were already degraded as a result of dynamite fishing (Hamilton, 1975; Wagner, 2000; 2004). In general, the DMRs were characterized by unregulated fishing, including the widespread use of beach seines, spear fishing and dynamite, prior to the Marine Parks and Reserves Unit (MPRU) taking over their management and the introduction of a GMP in 2005. Benno (1992) also observed that the natural systems within the DMRs had been degraded due to the widespread use of dynamite and destructive fishing techniques prior to the MPRU taking control.

The NDMRs comprises a chain of small islets (Bongoyo, Mbudya and Pangavini) and the Fungu Yasini sand bank. The SDMRs comprise inner and outer Sinda and Makatube Islands, and Kendwa Island. Both areas are located close to Dar es Salaam City, being separated from the mainland by the main entrance of Dar es Salaam harbour. The islands are surrounded by diverse and unique habitats including coral reefs, seagrass beds, sandy beaches and rocky shores, and lie within waters of less than 20 m depth.

Various studies have been carried out in the DMRs. Hamilton (1975) described the coral fauna of the East African Coast, Kamukuru (1997) carried out an assessment of the biological status of the DMRs, and McClanahan *et al.* (1999) assessed the effect of Marine Parks and fishing on coral reefs. Most studies in the DMRs have investigated the status of coral reefs (Kamukuru, 1997;

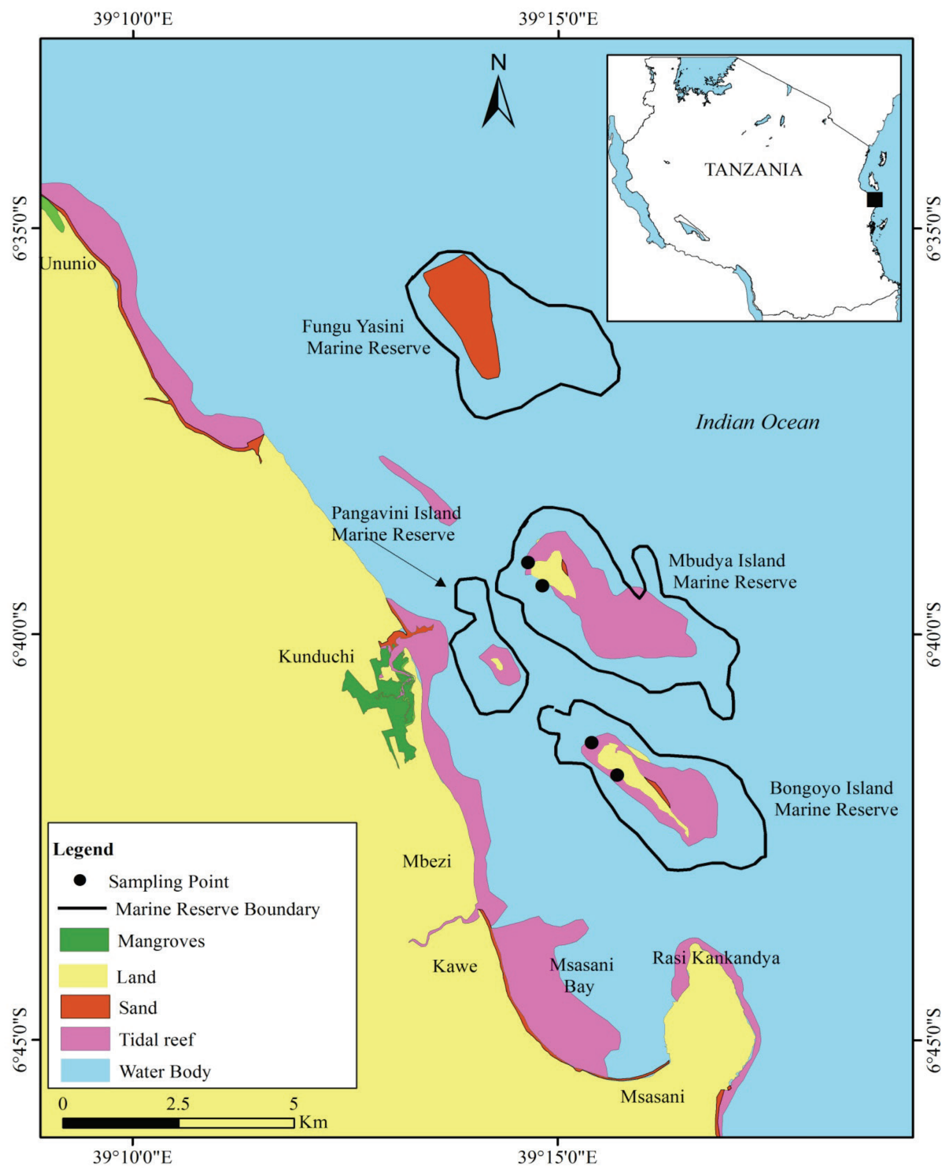

Figure 1. Map of Dar es Salaam Marine reserve showing study sites

Muhando and Francis, 2000; Mohammed *et al.*, 2000; Wagner, 2004; McClanahan *et al.,* 2009). However, information on fish biomass and density within the DMRs is not exhaustive. Kamukuru, (2009) studied the trap fishery and reproductive biology of the white spotted rabbit fish *Siganus sutor* (Siganidae) within NDMRs.

Tuya *et al.* (2011) reported that, at small spatial scales (>10 <100 km), the physical structure of the reef plays a key role in the organization of fish assemblages by providing protection from predators and accessibility to food. The relationship between reef habitat and fish population structure is becoming a major tool for the sustainable management of fisheries and marine park planning (Anderson and Millar, 2004; García-Charton *et al.*, 2004). This study aimed to investigate temporal and spatial variation in coral reef fish biomass and density within the DMRs, and was replicated in the dry season (August and September, 2014), intermediate rainy season (January and February, 2015) and wet season (April, 2015) in order to capture seasonal variations.

Methodology

This study was conducted within the DMRs located 26 km from Dar es Salaam City centre (Fig. 1). Sampling sites details are shown in Table 1. Rapid assessment using the manta tow technique was conducted in the shallow waters around Mbudya and Bongoyo Islands for the general description of sampling sites. At each Island two sites were established based on coral health status. Eight belt transects (50m x 10m) with three swim tracks were conducted for observation of fish biomass and density for each sampling season. The Underwater Visual Census (UVC) technique (English *et al.,* 1994) was adopted to assess reef fish density, biomass and diversity. A 50m fibreglass tape was laid on the reef flat where reef fish were assessed within a distance of 5m on either side of tape. Three swimming tracks were conducted along each belt transect, with a 20 minute interval between them to allow fish to return to the area. A total of 8 belt transects were conducted at each site per sampling season.

Fish observed along each swimming transect were identified with the aid of laminated colour photographs of reef fish. Fish were counted and the size category estimated and recorded on a plastic slate. The size categories used were named as Juvenile (0-10 cm), Recruit (11-20 cm), and Adult (21cm-above). Fish counts were undertaken by swimming at a slow and constant speed along the transect line while recording fish by size category and species. A 10m transect was laid on the reef to assess the benthic cover based on the Line-Intercept Transect (LIT) technique of English *et al.* (1994). Benthic cover was recorded as live hard coral, rubble, sea grass, sand, rock, and algae.

In addition, a GPS was used for marking the study sites, an underwater camera was used for taking photographs of reef fish for later identification, and a portable multiprobe Horiba instrument was used for measuring temperature, oxygen, turbidity, conductivity, salinity and pH.

Data analysis

Fish density (counts) was computed as individuals/ha. Fish biomass in kg/ha was estimated from published length-weight relationships (See www.fishbase.org) using conversion equations (W = a * Lb) where a and b are constants for each fish. Statistical analysis was carried out using Graph Pad Instant Statistical software,

Table 1. Location of sampling sites.

Site	Sampling Location		Coordinates
mbudya	West	Latitude	06°39′07″ S
		Longitude	39°14′39″E
	South	Latitude	06°39′24″ S
		Longitude	39°14′49″E
Bongoyo	West	Latitude	06°41′20″ S
		Longitude	39°15′24″E
	South	Latitude	06°41′44″ S
		Longitude	39°15′42″E

Version 3.06. Both number of individuals and biomass was tested for normality before data analysis, with the software providing the best option for analysis thereafter. The Kruskal-Wallis test was used to compare data between sampling dates, and the nonparametric Spearman correlation coefficient for relation between fish density and coral cover.

Results

Most of the water quality parameters measured were significantly different along the seasons, except for Dissolved Oxygen and Turbidity (see Figs. 2 and 3). Benthic categories and their cover at Mbudya and Bongoyo are described in Fig. 4 and Table 2. Mbudya displayed the highest percentage of live coral cover (87.3 $\pm$ 1.22%) while Bongoyo had the highest percentage of coral rubble (33.03 $\pm$ 2.02%). Both types of cover differed significantly ($P < 0.0001$) between the study sites.

Reef fish size structure revealed a prevalence of individuals of <10cm in both study sites, signifying a dominance of small-bodied fishes, mainly of the family Pomacentridae (Fig. 5). Very few individuals of >20cm were observed in the study areas; possibly an impact of overfishing.

The mean number of reef fish counted in Bongoyo for each sampling phase was 2419 (August/September, 2014), 3485 (January/February, 2015), and 3607 (April, 2015) ind/ha respectively (Fig. 6). Fish density varied significantly between sampling phases (Kruskal-Wallis Test (Hc) = 23.429, $P < 0.0001$). The mean reef fish biomass at Bongoyo for each sampling season was 65, 170 and 221 kg/ha during phase one (August and September, 2014), phase two (January and February, 2014) and phase three (April, 2015) respectively (Fig. 7). There was a significant difference in fish biomass between the three sampling phases (Kruskal-Wallis Test (Hc) = 27.631, $P < 0.0001$).

The mean number of reef fish counted in Mbudya for each season was 12413, 13988, and 10517 individuals/ha during phase one (August and September, 2014), phase two (January and February, 2014) and phase

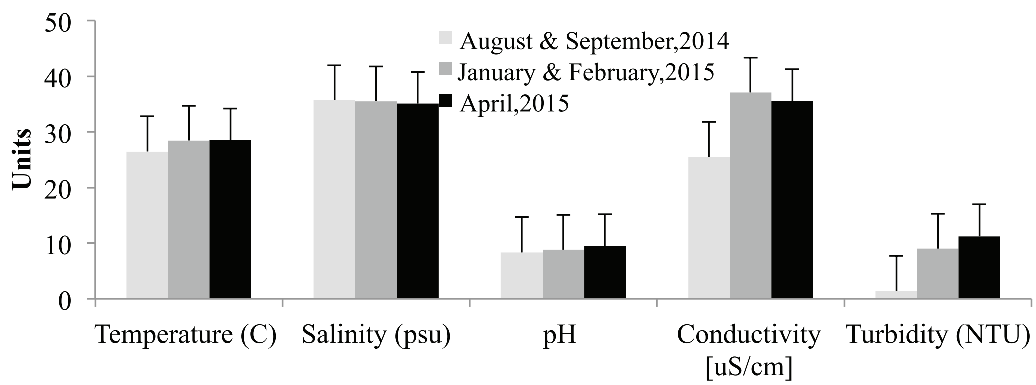

Figure 2. Variation of selected water parameters at the study sites in Mbudya and Bongoyo islands.

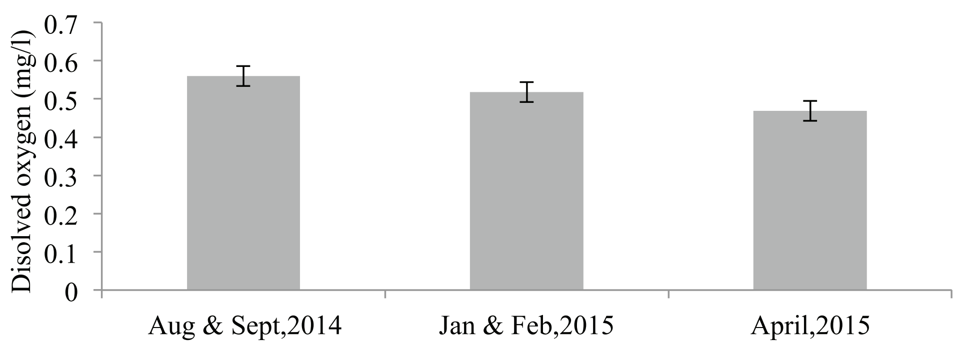

Figure 3. Dissolved oxygen variation at the study sites in Mbudya and Bongoyo islands.

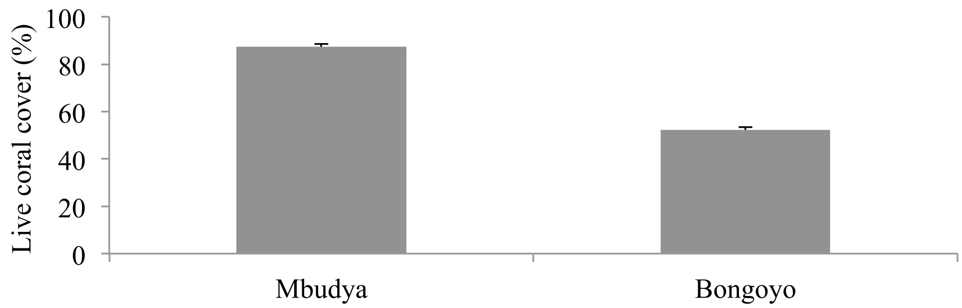

Figure 4. Benthic cover at Mbudya and Bongoyo Islands Marine Reserves.

three (April, 2015) respectively (See Fig. 8), and there was a significant difference in fish density between sampling phases (Kruskal-Wallis Test (Hc) = 42.352, $P < 0.0001$). The mean reef fish biomass at Mbudya for each sampling season was 697, 471 and 934 kg/ha during phase one (August and September, 2014), phase two (January and February, 2014) and phase three (April, 2015) respectively (see Fig. 9). There was a significant difference in fish biomass between sampling phases (Kruskal-Wallis Test (Hc) = 32.957, $P < 0.0001$).

It was found that an almost perfect positive correlation existed between fish density and live coral cover. Nonparametric Spearman Correlation Coefficient for Mbudya was (r) = 0.9971, n = 96, $p< 0.0001$ and at Bongoyo (r) = 0.9963, n = 96, $p< 0.0001$.

Overall, Mbudya displayed higher fish biomass than Bongoyo, mainly composed by members of the family Pomacentridae (27%), followed by Pomacanthidae (10%), and Scaridae (6%). The remaining biomass was made up of several other species. Reef fish of all sizes were observed at Mbudya, as compared to mainly juveniles observed at Bongoyo Island. At Bongoyo, reef fish density is directly correlated to fish biomass. Biomass was made up mainly of individuals of small size, mostly juveniles. This means that the fewer individuals present, the less the biomass, and vice versa, which was the case around Bongoyo Island. A few fish families made up the greatest contribution to biomass, namely the families Kyphosidae (19%), Chaetodontidae (11%) and Blenniidae (11%) (see also Julius, 2015).

Discussion

Water parameters measured were within the required range for coral reef survival, and live coral cover at Mbudya and Bongoyo Islands was significantly different. Benthic cover has a direct link to biomass and density in that those areas with higher live coral cover have higher numbers of juveniles, recruits and adults. The positive correlation between fish density and live coral cover corroborates that coral cover is a key substratum for reef fish.

Table 2. Benthic cover at study sites (%).

Benthic cover	Mbudya (Mean + SE)	Bongoyo (Mean + SE)	Islands' comparison
Live coral cover	87.28+ 1.22	52.23 + 1.27	Two sample t-test. $P < 0.0001$
Rubble	5.95 + 0.60	33.03 + 2.02	Two sample t-test $P < 0.0001$
Seagrass	4.25 + 0.57	8.09 + 0.69	Two sample t-test $P = 0.0024$
Sand	1.83 + 0.18	5.16 + 0.38	Mann-Whitney Test. $P < 0.0001$
Rock (RCK)	0.39 + 0.16	0.75 + 0.17	Mann-Whitney Test. $P = 0.0480$
Algae (soft & Turf)	0.28 + 0.11	0.76 + 0.14	Mann-Whitney Test. $P =0.0041$

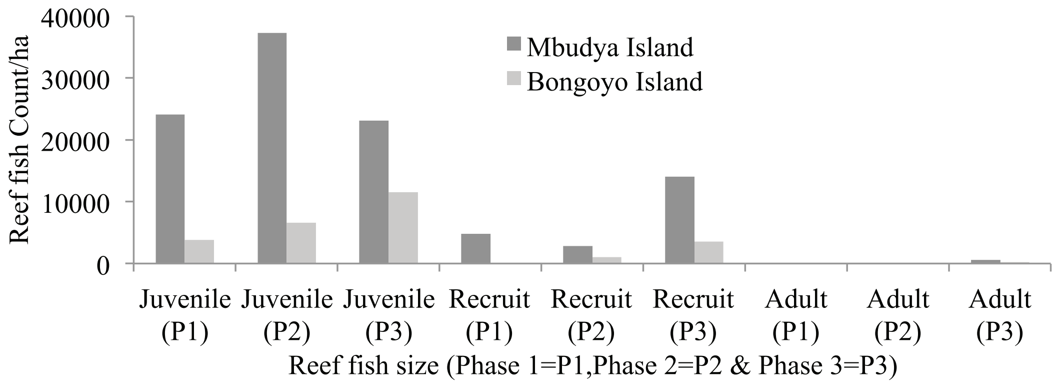

Figure 5. Reef fish population size structure in Mbudya and Bongoyo islands.

The dominant fish size class was juvenile reef fishes. The possible reason for this observation is displacement of juveniles by adults from the adjacent coral reef at Mbudya Island Marine Reserve, perhaps as a mechanism for juveniles to avoid predation. The density of reef fishes is often influenced by the availability of potential shelter sites (Steele, 1999). Juvenile, recruit and adult reef fish have specific habitat requirements that determine spatial size distribution. The separation of juveniles in nursery habitats from the adults on the coral reef implies migration from nursery habitats (such as seagrass beds and mangroves) to the coral reef. Further, these migrations may be related to diet shift with size (Cocheret de la Morinie`re *et al*., 2003).

Lugendo *et al*. (2005), Igulu *et al.* (2013), and Kimirei *et al.* (2013) all reported that the presence of seagrass is a potential component for juvenile settlement among reef fish, and Bongoyo Island has a large occurrence of seagrass cover. Various factors, including microhabitat and physical structures that may provide shelter from predators (such as corals, rocks and macroalgae) influence the spatial and temporal pattern of reef fish density (Jones, 1991; Hixon and Beets, 1993; Caley *et al*., 1996). In such habitats predation of juveniles may be reduced and migration to alternative habitats could be an important defence mechanism. This indicates strong linkages between adjacent habitats at a local spatial scale, and emphasizes the importance of the inclusion of a diversity of habitats in Marine Protected Areas (Beets *et al.,* 2003).

Reef fish density at Mbudya showed an increase from phase one to phase two, with a decline in phase three. This decline was possibly attributed to an increase in the abundance of adult fish observed during this last phase, which reduced the abundance of juveniles due to predation or migration to safer habitats. Biomass declined from phase one to phase two when mostly small individuals were present on the reef. However, in phase three, where adult fish were dominant, the decrease in density coincided with an increase in biomass.

Observations on the spawning seasons of East African reef fishes show that most species are characterised

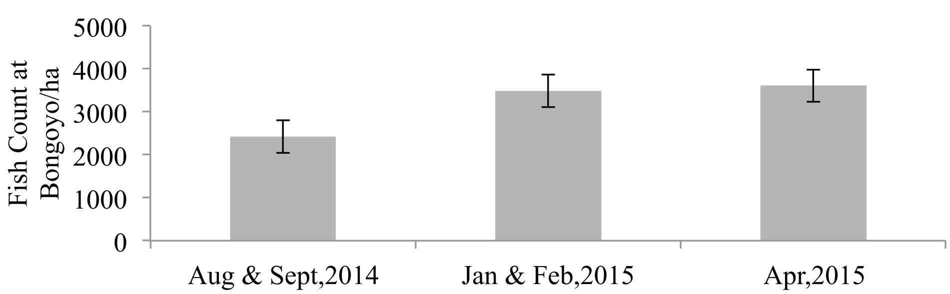

Figure 6. Reef fish density at Bongoyo Island.

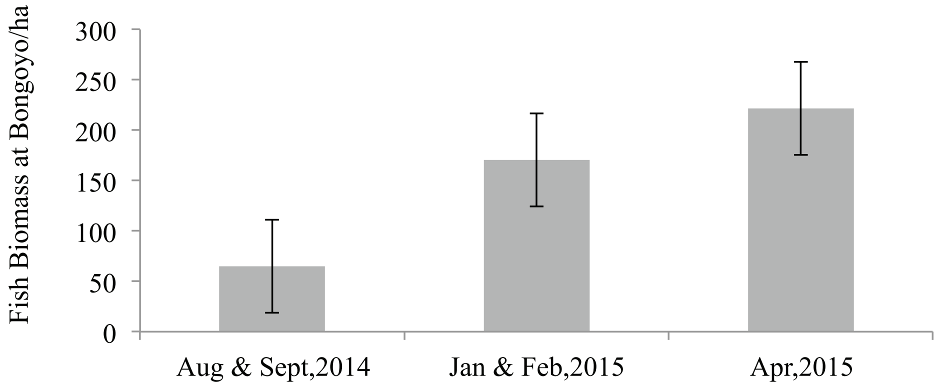

Figure 7. Reef fish biomass at Bongoyo Island Marine Reserve.

by protracted spawning periods during the northeast monsoon, with two peaks in January to March, and September to November (Nzioka, 1979). The increase in adult reef fish observed during phase three (April) in this study may reflect the aggregation of reef fish for spawning at that time. Kamukuru (2009) reported that *Siganus sutor* exhibits a protracted spawning season in the DMRs, extending from December to May, and peaking in March, which coincides with observations during phase three (April) in the present study. It was reported by Ntiba and Jaccarini (1990) that *S. sutor* in inshore Kenyan waters exhibits two sharply defined spawning seasons occurring in January/February and May/June. Further, it was reported by Bwathondi (1981) that Siganids breed throughout the year in Tanzanian coastal waters. The above information is somewhat contradictory and further investigation is needed to conclusively link spawning behaviour to the temporal and spatial variation of reef fish in the present study.

As in this study, it was found previously (1996/7; 2004/5) that Mbudya supports a higher reef fish biomass than Bongoyo (McClanahan *et al.,* 1999; McClanahan *et al.,* 2009). These earlier studies found that fish biomass increased at both Mbudya (214.kg/ha to 298.6kg/ha) and Bongoyo (129.1kg/ha to 159.1kg/ha) between the survey dates, probably linked to more effective management. These results reflect those found in other MPAs in the region which are effectively protected, such as Kisite Marine National Park in Kenya. In Kisite, biomass almost doubled after seven years of effective protection (McClanahan *et al.*, 2009). However, the above studies at Mbudya and Bongoyo did not account for possible seasonal variation, possibly resulting in an under estimate of biomass. Effective management began in the DMRs in 2002 and in 1978 at Kisite. The current study adds to the body of evidence that effective management has led to an increase in biomass over time in most MPAs of the Western Indian Ocean.

The current study has also shown that high live coral cover is directly linked to high fish biomass. With similar conditions and coral diversity, it is likely that fish biomass in the DMRs can increase further to the levels found in Kisite with effective management over time.

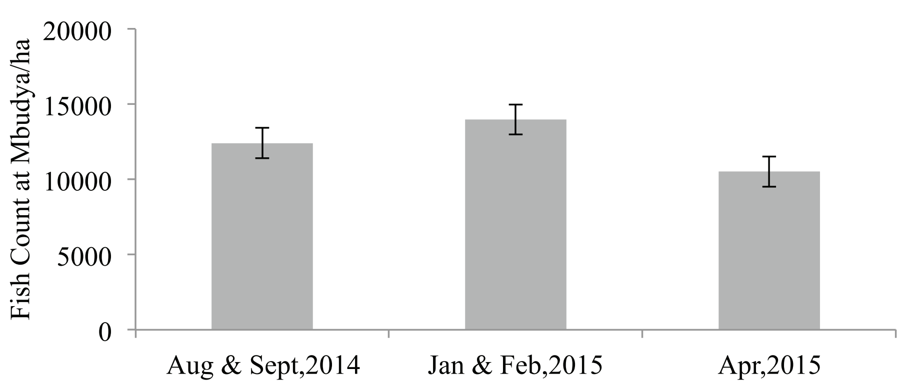

Figure 8. Reef fish density at Mbudya Island Marine Reserves.

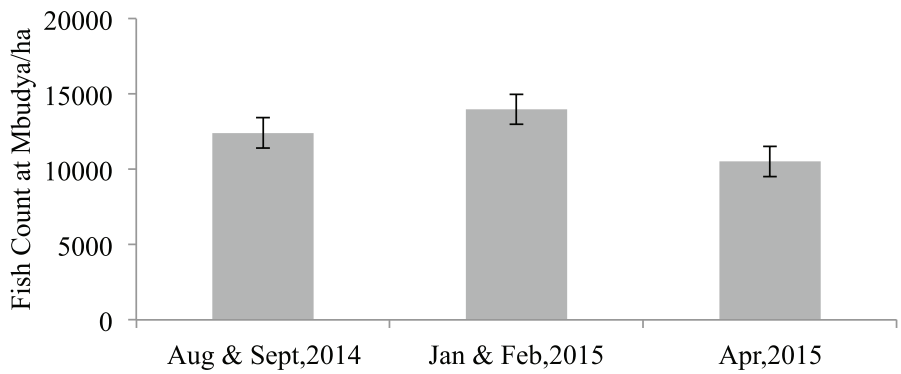

Figure 9. Reef fish biomass at Mbudya Island Marine Reserves.

Based on the information presented here on reef fish density and biomass at Mbudya and Bongoyo Islands within the DMRs, the following conclusions can be drawn:

1. Mbudya Island Marine Reserve has a higher reef fish biomass during all seasons attributable to fish populations comprising juveniles, recruits and adults, while Bongoyo Island has lower biomass comprising mostly juveniles and recruits.
2. Reef fish size structure and biomass was significantly different between seasons at both Islands.
3. Live coral cover is higher at Mbudya as compared to Bongoyo.

This study recommends the following:

4. Efforts to ensure the effective management of the DMRs need to be continued, with the GMP as the primary guidance document, as per the existing Marine Park and Reserve Act, No 29 of 1994 directives.
5. Demarcation buoys need to be placed at least at the corner points and buffer zone of the Marine Reserves.
6. Review and strengthen the enforcement for the DMRs and ensure that surrounding communities are effectively involved.
7. Further investigation on spawning aggregations of highly-targeted fish species such as the Siganids and Serranids is needed to assist with management decisions aimed at protecting spawning aggregations.

Acknowledgements

We acknowledge the Western Indian Ocean Marine Science Association (WIOMSA) for financial support of this research through a Marine Research Grant (MARG) Programme. We appreciate the support from the University of Dar es Salaam for providing SCUBA diving facilities and other equipment for our research. We further acknowledge the assistance from the Marine Park and Reserve Unit (MPRU) for support and permission to conduct this study in the Marine Reserves. We acknowledge the contribution for Dr AT Kamukuru for valuable input in preparation of this manuscript.

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