Are ocean-exposed fringing coral reefs worthy of protection? Insights from size-abundance distribution

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Background
Ocean-exposed fringing coral reefs show high fish biomass of up to 1,100 kg/ha; however, they are often ecologically underrepresented in Marine Protected Areas (MPAs). These reefs transcend between photic and mesophotic zones and provide a wide range of habitats for fish movement and habitat use. Information on fish and habitat types found in such reefs can play a crucial role in conservation planning and zoning of MPAs, which protect coral reefs from anthropogenic disturbances, thereby increasing coral reef resilience to climate change.

Examining the size-abundance distribution of fishes can be informative when comparing marine areas with different levels of protection e.g. fished (open access) and unfished (protected) areas. Distributions can be compared by determining the types of size-abundance distributions that dominate (i.e. monotonically decreasing, unimodal or multimodal); or evaluating the size-abundance relationships and comparing the size spectra slope in relation to the “Biomass Equivalence Rule” (BER). The rule states that on logarithmic scale, the slope of body size and density is close to -1. The aim of this study was to use fish size-abundance distributions to assess effectiveness of area-based protection within ocean-exposed fringing reefs of the western Indian Ocean (WIO).

Research questions
What fish size-abundance distributions and dominant species characterise levels of protection found at ocean-exposed fringing coral reefs?
What fish sizes characterise the levels of protection found at ocean-exposed fringing coral reefs?
Which level of protection has a slope close to BER?

Material and methods
Data were collated from benthic and fish surveys carried out on ocean-exposed fringing coral reefs between 2009 and 2015 at 24 sites across four WIO countries: Tanzania, Mozambique, Comoros and Madagascar. Each site was assigned a level of protection depending on level of management and enforcement of the management rules, which ranged from Fished sites (F) - no management in place at all; Moderate Protection (MP) - MPA gazetted and established though effectiveness weak due to poor enforcement; and Protected (PR) - MPA gazetted or tourism zone with informal rules, and enforcement good. Multivariate analyses on density and biomass data were used to examine fish community structure in relation to levels of protection and benthic characteristics. Species contributing most to the observed pattern of similarity
were identified using SIMPER and BEST analysis in PRIMER. Differences in the level of protection were assessed from fish length-density distribution for all species and each of the BEST species, which also helped determine the dominant distribution types. Further, length and density data were log transformed and the slopes of three protection levels were compared to BER.

**Results**

MDS results of biomass data showed a significant but weak grouping of sites based on the levels of protection (ANOSIM Global R = 0.297; \( p=0.002 \)). The pattern in fish density was not significant. A total of 33 species out of 147 species were found to drive the patterns of similarity in these reefs. These included species from 9 families, with 60% of the species drawn from Acanthuridae, Lutjanidae and Scaridae.

Length-abundance distributions of the three levels of protection showed unimodal distributions with a clear peak at 13cm total length (TL). However, fish densities at this peak length were significantly higher in Protected sites at 1853.7 ind./ha followed by Fished at 1356.6 ind./ha and Moderate Protected sites at 742 ind./ha. Higher densities of larger fish (25-35 cm TL) and (90-105 cm TL) were found in Moderate Protected sites compared to Fished.

SIMPER identified four species that were consistent in showing the differences in the levels of protection: bullethead parrotfish (Chlorurus sordidus), big-eye emperor, Monotaxis grandoculis, dory snapper (Lutjanus fulviflamma) and bluespine unicornfish (Naso unicornis). These species showed higher densities in Protected sites compared to other management sites except Lutjanus fulviflamma, which were more abundant in Moderate Protection sites.

Linear regression of log transformed fish length and density data showed highly significant relationships (\( r^2 > 0.69 \)) with negative slopes ranging from -0.0265 to -0.0605, all far from -1 as expected in BER.

**Conclusion**

Protection of ocean-exposed fringing reefs has the likelihood of increasing fish densities of 10-15cm and 55-60cm size classes by 1.5 and 13 folds respectively. Moderate Protection is associated with higher densities of dory snapper (Lutjanus fulviflamma) further suggesting the importance of connectivity between mangroves and coral reefs since their juvenile phase is in mangroves.

Lack of large sized fish meant that the biomass equivalence rule did not apply at the sites examined in this study. However, size spectra analysis offers alternative and additional evidence to support an increase in the protection of currently underrepresented ocean exposed fringing coral reefs.

**Keywords**: Marine Protected Areas, size spectra, unimodal distribution, coral reefs