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Homogeneity of coral reef communities across 8 degrees of latitude in the Saudi Arabian Red Sea☆,☆☆

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ABSTRACT

Coral reef communities between 26.8°N and 18.6°N latitude in the Saudi Arabian Red Sea were surveyed to provide baseline data and an assessment of fine-scale biogeography of communities in this region. Forty reefs along 1100 km of coastline were surveyed using depth-stratified visual transects of fish and benthic communities. Fish abundance and benthic cover data were analyzed using multivariate approaches to investigate whether coral reef communities differed with latitude. A total of 215 fish species and 90 benthic categories were recorded on the surveys. There were no significant differences among locations in fish abundance, species richness, or among several diversity indices. Despite known environmental gradients within the Red Sea, the communities remained surprisingly similar. The communities do, however, exhibit subtle changes across this span of reefs that likely reflect the constrained distributions of several species of reef fish and benthic fauna.

1. Introduction

The Red Sea is located in the northwest periphery of the Indian Ocean and has long been recognized as its own biogeographic region and a hotspot for biodiversity (Goren and Dor, 1994; Randall, 1994; Randall, 1998) with high levels of endemism (Briggs, 1974; Spalding et al., 2007; Briggs and Bowen, 2012; Bowen et al., 2013; Kulbicki et al., 2013, DiBattista et al., in press). Some of the earliest tropical marine expeditions were conducted in the Red Sea, where pioneering naturalists described marine fauna which was also representative of the greater Indian Ocean (Forsskål et al., 1775; Rüppell, 1828; Cuvier, 1828; Ehrenberg, 1834; Klunzinger, 1870). More recently, with the exception of the Gulf of Aqaba, there has been relatively little ecological research in the Red Sea compared to other major tropical reef systems (Berumen et al., 2013). The lack of baseline information on fish populations and species ranges within much of the Red Sea hinders attempts to quantify changes in the local ecology due to environmental fluctuations or increasing anthropogenic influences.

In addition to its unique set of fauna, the Red Sea is also recognized as a mostly thriving coral reef ecosystem coexisting within relatively extreme environmental conditions (Sheppard et al., 1992). Only the Arabian Gulf supports coral reef environments that experience higher temperatures and salinity levels than those located in the Red Sea (Sheppard et al., 1992). However, across this long and narrow body of water, which spans 17 degrees of latitude, the Red Sea is not homogenous. Sea surface temperatures (SST), salinity, and nutrient concentrations exhibit latitudinal gradients and fluctuate seasonally (Acker et al., 2008; Ngugi et al., 2012; Raitsos et al., 2013). Average temperatures increase southward and range from 20–28 °C (north to south) in the winter and 26–32 °C (north to south) in summer. The low rainfall and freshwater influx in this hot, arid region and pronounced evaporation rates result in high salinity levels (~41 psu) which decrease (to 36 psu) near the Bab al Mandeb Strait, the only connection to the Indian Ocean (Murray and Johns, 1997). Nutrient levels in the Red Sea also increase from north (chlorophyll-a = 0.03 [mg m^{-3}]) to south (10 [mg m^{-3}]), with the most oligotrophic northern waters characterized by high visibility in contrast to the more turbid southern region (Sheppard and Sheppard, 1991).

☆ The RES team (SRT, GPJ, MIM, PLM, SN, MLB) conducted these surveys as part of a WHOI-KAUST partnership, with this project specifically aiming to create some form of baseline data for future work at KAUST. The Reef Ecology Lab at KAUST (MBR, VSNR, MLB) is interested in generally understanding Red Sea ecology, particularly in a comparative context to other Indo-Pacific reef systems.
☆☆ Author contributions: SRT, GPJ, MIM, PLM, SN, MLB collected the data. MBR analyzed the data. SRT and MLB provided funding. MBR and MLB wrote the manuscript. All authors contributed to manuscript sections or general editing.
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The Red Sea has recently been described as containing two marine ecoregions (Spalding et al., 2007), with a division in the central Red Sea located near 20°N latitude. This simplified delineation is contentious among some researchers familiar with the region. Nonetheless, it provides a framework for us to test a hypothesis. While levels of endemism are key characteristics for establishing broader biogeographical provinces and realms (Briggs, 1974; Briggs and Bowen, 2012; Spalding et al., 2007), the finer-scale marine ecoregions such as those identified within the Red Sea are defined as "areas of relatively homogeneous species composition, clearly distinct from adjacent systems…[and] determined by a distinct suite of oceanographic or topographic features" (Spalding et al., 2007). However, the available data from this region is focused only on a few taxonomic groups. For example, regional chaetodontid and pomacanthid distributions were explored by Roberts et al. (1992) and Righton et al. (1996) while Sheppard and Sheppard (1991) and DeVantier and Pilcher (2000) have published studies on the distribution of scleractinian assemblages within the Red Sea. While these previous studies provide valuable insight to species- and family-level distributions and patterns, they may not be sufficient to characterize ecoregion boundaries. Large-scale biogeographic trends provide insights into broad ecological processes and relationships to changing environmental conditions; understanding these trends facilitates the establishment of sound management plans. The present study provides an overview of biogeographic patterns of reef communities for this region.

The aims of this study were: 1) to determine if and to what degree offshore reef communities change along a latitudinal gradient within our study area, 2) to explore the presence of a within-Red Sea ecological boundary at 20°N as described by Spalding et al. (2007), and 3) to provide baseline data on the biogeography of coral reef communities for future comparative studies in the Red Sea. To achieve these goals, surveys were conducted on coral reefs in the Saudi Arabian Red Sea spanning 1100 km of latitudinal coastline. Surveys assessed the abundance of reef fish species as well as benthic cover at 40 coral reefs. In addition to providing a valuable dataset of distributions and abundances, this data lays the foundation for investigations of the mechanisms underlying regional biogeography.

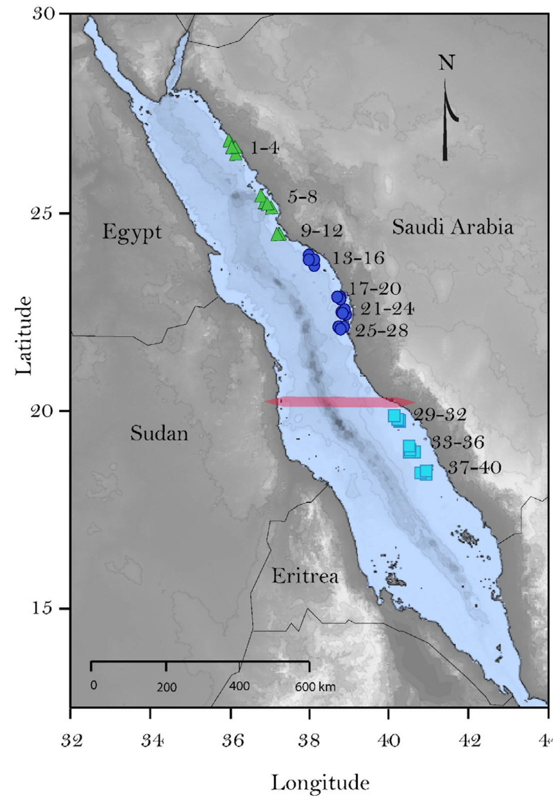

Fig. 1. Reef sites surveyed in the Red Sea for fish abundance and benthic cover, with northern (green triangles), central (dark blue circles), and southern (cyan squares), groupings of survey sites. Reefs were numbered (shown next to reefs) in order of latitude and these correspond to the numbers in Table 1. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

2. Methods

2.1. Ecological survey data collection

Our study area consisted of 40 offshore reefs along the Saudi Arabian coastline between 26.8°N and 18.6°N latitude (Fig. 1). Survey sites were selected to reduce the confounding effects of reef type, reef slope, and within-reef location of transects. Reefs were chosen based on their position at the edge of the Arabian shelf and near deep drop-offs, with survey sites located near the outer reef slope on the leeward side of the reef (given predominant northwesterly winds in the Red Sea, this meant that our surveys were conducted on the southern ends of the reefs). Reef sites varied between 7 and 81 km from shore, representing the variable width of the continental shelf in the Red Sea (Fig. 1). The lack of any significant rainfall (yearly average less than 70 mm (DeVantier and Pilcher, 2000)), the near absence of freshwater runoff, and minimal coastal development (especially in the north) greatly reduces the confounding effects of varying reef distance from shore. We define the terminology used in this study as follows. "Sub-region" refers to the subdivisions of the Red Sea that we surveyed (i.e., the northern, central, or southern sites within the Red Sea), "section" to refer to the groupings of reefs, and finally, we refer to each individual reef site as "reef". We surveyed four reefs per section with a total of 10 sections that were further grouped into three sub-regions (Table 1). These sub-regions were defined as: "northern" ($n = 12$ reefs; 26.8°N–24.4°N), "central" ($n = 16$ reefs; 23.8°N–21.8°N), and "southern" ($n = 12$ reefs; 19.8°N–18.6°N) (see Fig. 1 and Table 1). The groupings by sub-region were used to identify differences within our study area for a biogeographic context, while the sections were used to investigate finer-scale spatial variation in community indices.

At each reef, four replicate transects were laid at each of four depths: the reef crest (~0 m), 2 m, 6 m, and 10 m, for a total of 16 transects per reef (as per Jones et al., 2004). All species (Appendix S1) were counted on 50 m × 4 m belt transects with the exception of the damselfishes (family Pomacentridae) which were surveyed within a 2 m belt transect, as well as the gobies (family Gobidae), blennies (family Blennidae), and dottybacks (family Pseudochromidae), which were surveyed within a 1 m belt due to their small size and abundance. For each transect, three divers (MIM, PLM, and either GPJ or MLB) observed and recorded the abundance of specific groups of fishes based on their expertise. Prior to other analyses, count densities were standardized to 200 m^2 (hereafter referred to as 'abundance'). A fourth diver (SN) conducted point-intercept benthic surveys along the same 50 m transects, recording the benthos at 100 random points selected by a random number generator that allowed for at least two points to be within the bounds of each meter of the transect to space the points out across the entire transect. The substratum under each point was identified to the lowest taxonomic group and morphotype where possible (Appendix S2).

2.2. Statistical analyses

2.2.1. Community indices

Several community indices were assessed among the three latitudinal sub-regions in our study. As each reef had the same number of transects, total abundance of all fishes surveyed within a reef were used to calculate the average total abundance of fishes in each of the three sub-regions ($n = 12$ or 16 reefs per sub-region). Total richness (S) was calculated at the reef level by tallying the number of fish species recorded on all of the 16 transects (i.e., if a fish was seen on any transect it