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## Regional variation in the structure and function of parrotfishes on Arabian reefs

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## ABSTRACT

Parrotfishes (f. Labridae) are a unique and ubiquitous group of herbivorous reef fishes. We compared the distribution and ecosystem function (grazing and erosion) of parrotfishes across 75 reefs in Arabia. Our results revealed marked regional differences in the abundance, and taxonomic and functional composition of parrotfishes between the Red Sea, Arabian Sea, and Arabian Gulf. High densities and diversity of parrotfishes, and high rates of grazing (210% year<sup>-1</sup>) and erosion (1.57 kg m<sup>-2</sup> year<sup>-1</sup>) characterised Red Sea reefs. Despite Arabian Sea and Red Sea reefs having broadly comparable abundances of parrotfishes, estimates of grazing (150% year<sup>-1</sup>) and erosion (0.43 kg m<sup>-2</sup> year<sup>-1</sup>) were markedly lower in the Arabian Sea. Parrotfishes were extremely rare within the southern Arabian Gulf, and as such rates of grazing and erosion were negligible. This regional variation in abundance and functional composition of parrotfishes appears to be related to local environmental conditions.

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## 1. Introduction

Herbivory is intense on coral reefs, with rates of herbivory exceeding those measured in any other ecosystem (Carpenter, 1986). Through their feeding actions herbivores have been estimated to remove over 90% of daily algal production on reefs with intact fish populations (Hatcher, 1983; Polunin and Klumpp, 1992). Irrespective of whether they are assimilating or even ingesting the algal material such intense feeding maintains algal communities in a low biomass, but productive, state (Russ, 2003; Wismer et al., 2009), reduces the frequency of competitive interactions between coral and algae (e.g., Bonaldo and Hay, 2014), and provides space for the settlement and replenishment of corals (Hughes et al., 2007). The role of herbivores on coral reefs is becoming increasingly important as a range of chronic and acute stressors are reducing the cover of live coral on reefs globally (Gardner et al., 2003; Bellwood et al., 2004; Atweberhan et al., 2011). These reductions in coral cover are accompanied by increases in other benthic organisms, primarily filamentous algae that rapidly colonise the available space (Diaz-Pulido and McCook, 2002) thereby increasing the abundance and productivity of algal communities. The ability of these impacted, or low coral cover, reefs to recover to a pre-impact configuration may be dependent on the capacity of herbivore populations to compensate

for the increased algal production. Several studies have reported increases in herbivore densities following coral mortality, with such increases likely to be related to increases in food availability (e.g., Adam et al., 2011; Gilmour et al., 2013). However, in areas where herbivore populations have been reduced by fishing activities they are often unable to respond to increased algal production, releasing algal communities from top-down control, and potentially leading to a shift toward macroalgal-dominance (e.g., Hughes, 1994; Graham et al., 2015).

Herbivorous fishes are clearly important for the structure and resilience of coral reefs, however there is considerable diversity in feeding behaviour and diet among individual taxa (e.g., Choat et al., 2002; Hoey et al., 2013; Rasher et al., 2013). Herbivorous fishes may be broadly classified into four functional groups, scrapers, excavators, croppers, and browsers, based on the potential impact of their feeding activities on algal communities (Steneck, 1988; Bellwood et al., 2004). Browsers are those species that consume canopy-forming, typically brown macroalgae (e.g., *Sargassum*), and have been suggested to be important in the reversal of macroalgal-dominated regime shifts (Bellwood et al., 2006; Hoey and Bellwood, 2009). In contrast, scrapers, excavators, and croppers (collectively 'grazers') generally feed on the combination of filamentous algae, macroalgal propagules, detritus, sediment, and microbes that forms the epilithic algal matrix (EAM, Wilson et al., 2003). However, differences in feeding mode among these grazing groups mean they perform complimentary roles in shaping benthic communities. Croppers (predominantly surgeonfishes [f. Acanthuridae] and rabbitfishes [f. Siganidae]) bite or 'crop' the upper portions of the

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algae, leaving the basal portions intact. In contrast, the fused beak-like jaw of parrotfishes (f. Labridae, t. Scarini) allows them to 'scrape' and/or 'excavate' the underlying substratum when feeding (Bonaldo et al., 2014). The distinction between parrotfishes that scrape (*Scarus* and *Hipposcarus*) or excavate (*Bolbometopon*, *Cetoscarus*, and *Chlorurus*) relates to the amount of substratum removed during feeding, with scraping species taking relatively shallow bites (<1 mm depth), whereas excavators take deeper bites and remove a greater volume of material with each bite (Bellwood, 1994). Parrotfishes not only contribute to the removal of EAM, but importantly facilitate the settlement of corals and other benthic organisms through the provision of areas of bare substrata, while also acting as the major conduits of external bioerosion (Bellwood et al., 2003, 2012).

Given the diversity of feeding modes and diets, spatial (e.g., among regions) and temporal variation (e.g., due to sustained and ongoing depletion of some taxa) in composition of herbivorous fish assemblages can have important implications for ecosystem function. Numerous studies on Indo-Pacific and tropical Atlantic reefs have reported variation in the abundance, and taxonomic or functional composition of herbivorous fishes across a range of spatial scales, including among latitudes (Floeter et al., 2005; Cheal et al., 2012), position across the continental shelf (e.g., Russ, 1984; Cheal et al., 2012, 2013; Johansson et al., 2013), between areas of different fishing pressure (e.g., Hay, 1984; Campbell et al., 2012; Rasher et al., 2013), among habitats within a reef (e.g., Hay, 1981; Hoey and Bellwood, 2010; Nemeth and Appeldoorn, 2009), and among sites within a reef zone (Cvitanovic and Bellwood, 2009; Hoey et al., 2011). In contrast, studies within the Red Sea and adjacent areas have been largely restricted to relatively localised among-habitat scales (e.g., Bouchon-Navaro and Harmelin-Vivien, 1981; Brokovich et al., 2008, 2010; Alwany et al., 2009; Afeworki et al., 2011; Khalil et al., 2013). To our knowledge there are no studies examining variation in composition and abundance of herbivorous fishes across regional scales on Arabian reefs (Berumen et al., 2013). The aims of this study, therefore, were to (i) quantify the distribution and abundances of parrotfishes along >2000 km of coastline including the Red Sea, the Arabian Sea and Sea of Oman, and the southeast Arabian Gulf, (ii) estimate the roles of parrotfish in grazing and eroding the

reef substrata throughout this region, and (iii) determine how these roles varied across a range of spatial scales.

## 2. Materials and methods

### 2.1. Distribution of fishes

To quantify the abundance and composition of parrotfishes, visual surveys were conducted with 19 locations encompassing three regions (the Saudi Arabian Red Sea, the Arabian Sea, and the southeast Arabian Gulf; Fig. 1) during 2008–2011. Within each location 2–10 reefs were surveyed (mean = 3.9 reefs, 75 reefs in total) during 2008–2011. Locations in the central Red Sea (Seven Sisters – Jeddah) were surveyed in 2008, the southern Red Sea (Al-Lith – Ablo) in 2009, the northern Red Sea (Wahj – Umm Lujj) in 2011, and the Arabian Sea and Arabian Gulf in 2008 (Fig. 1). Further details of sampling in the Red Sea are provided in Roberts et al. (in press). As well as the large-scale regional sampling, a cross-shelf gradient was sampled at Al-Lith in the southern Red Sea, with two inner-shelf, two mid-shelf, two outer-shelf, and four offshore reefs surveyed.

At each reef, the abundance and composition of parrotfishes was quantified using four replicate belt transects. All surveys were conducted in the same reef zone (i.e., the seaward aspect of the reef at a depth of 5–6 m), with adjacent transects being separated by a distance of 5–20 m. Parrotfishes were surveyed along 50 × 4 m transects at the Red Sea sites, and 60 × 5 m belt transects within the Arabian Sea and Arabian Gulf. To account for differences in transect dimensions between regions the numbers per transect were converted to densities per 100 m<sup>2</sup> prior to analyses. Each survey consisted of a diver swimming parallel to the reef contour and identifying and recording all parrotfishes greater than 10 cm total length (TL) within a 4 (or 5) m wide belt that extended from the reef substratum to the surface of the water. Transect tapes were either deployed simultaneously by the observer when conducting the surveys (Arabian Gulf and Arabian Sea), or deployed approximately 10 min before surveys were conducted (Red Sea). These procedures minimised disturbance prior to the survey and allowed a specific area to be surveyed. Care was taken not to re-census fishes that left and subsequently re-entered the transect area.

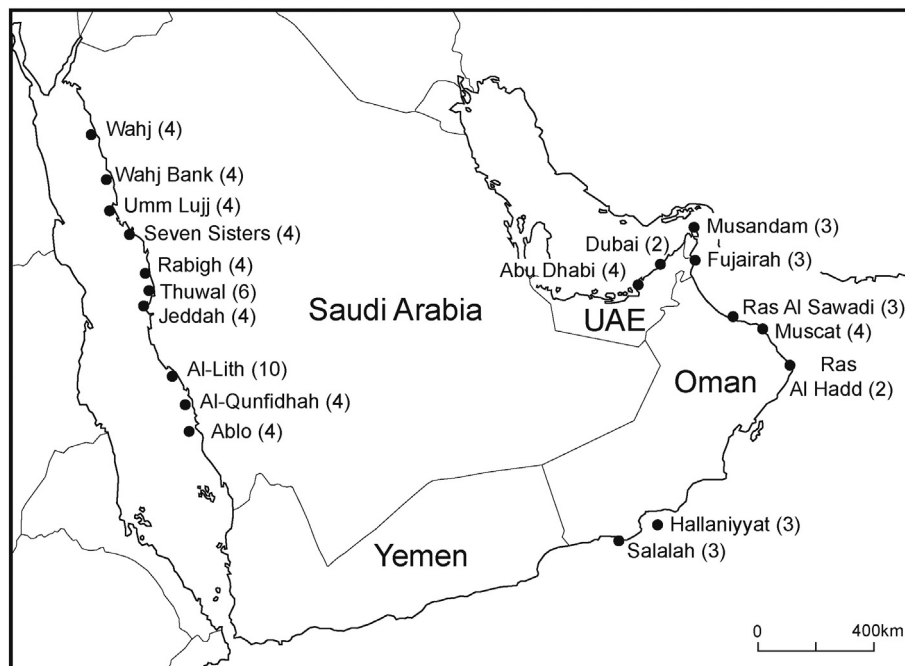


Fig. 1. Map of Arabian region showing location of study sites in the Arabian Gulf, Arabian Sea, and Red Sea. Numbers in parentheses indicate the number of reefs that were surveyed in each location.

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