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Habitat and water quality variables as predictors of community composition in an Indonesian coral reef: a multi-taxon study in the Spermonde Archipelago

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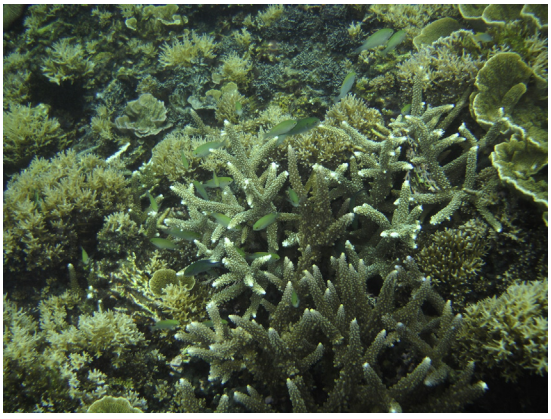
HIGHLIGHTS

- Taxa sampled: corals, sponges, foraminifera, bacteria, archaea
- Goal: relate variation in composition to habitat and water quality variables
- There were marked differences among taxa in the explanatory variables selected.
- Habitat variables generally explained more variation in composition.
- CDOM, Chlor-a and Rrs_645 were the most important satellite-derived variables.

GRAPHICAL ABSTRACT



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ABSTRACT

Assemblages of corals, sponges, foraminifera, sediment bacteria and sediment archaea were assessed at two depths in the Spermonde Archipelago. Our goal was to assess to what extent variation in composition could be explained by habitat and water quality variables. The habitat variables consisted of depth, substrate type and scleractinian coral cover while water quality variables were derived from ocean color satellite imagery, including the colored dissolved organic matter index (CDOM), chlorophyll-a (Chlor-a) and remote sensing reflectance at 645 nm (Rrs_645). Together, habitat and water quality variables explained from 31% (sediment bacteria) to 80% (forams) of the variation in composition. The variation in composition of corals, sponges, forams and sediment archaea was primarily related to habitat variables, while the variation in composition of sediment bacteria was primarily related to water quality variables. Habitat and water quality variables explained similar amounts of variation in the composition of corals and sediment bacteria. CDOM (sponges, sediment bacteria and sediment archaea), Chlor-a (corals and forams) and Rrs_645 (sponges and forams) proved significant predictors of

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variation in composition for the studied taxa. In addition to water quality variables, all taxa responded to a range of habitat variables including depth and the percentage cover of various benthic life forms including coral cover variables, rubble and sand. Sand cover was the most important habitat variable for corals, sponges, sediment bacteria and sediment archaea. Coral life forms including the cover of branching and tabular corals were important habitat variables for sponges and forams. These results show marked differences in how various taxa respond to variation in habitat and water quality in the Spermonde Archipelago. Moreover, our results indicate that variables estimated from ocean color satellite imagery proved to be better predictors of variation in marine community composition than commonly-used proxies such as the distance offshore or distance to the nearest river.

1. Introduction

Coral reefs are among the most diverse and economically important marine ecosystems in the world (Hughes et al., 2010). They provide coastal protection, food, building materials and areas of recreation (Costanza et al., 2014; Burke et al., 2002). Additionally, they also function as marine hatcheries and refugia for a wide variety of marine organisms, many of which are commercially important (e.g., fish, shrimp, crabs, clams; Burke et al., 2002; Buddemeier et al., 2004; Mora et al., 2011; Hoeksema et al., 2012). Coral reefs are often located in areas of ongoing coastal development and subject to relatively high population growth rates (Bryant et al., 1998). This combination of factors threatens their existence and, as a result, the services they provide. Indeed, a majority of coral reefs are now considered vulnerable or have been seriously degraded (Burke et al., 2011). The latter includes the loss of reef structure, species, and shifts in community composition (Bellwood et al., 2004). For example, many fish species depend on the three dimensional structure provided by mature coral reefs (Pratchett et al., 2008). Losses of key structural components, such as branching *Acropora* species, can lead to the local extirpation of numerous dependent species (Pratchett et al., 2008). Some studies have shown that biodiversity loss can, in turn, adversely affect ecosystem functioning (Worm et al., 2006) while others have shown that, even the functional diversity of coral reefs with high species diversity is vulnerable to the loss of species (Mouillot et al., 2014). Hence, it is important to understand how individual taxa respond to changes in reef environmental conditions.

Pronounced on-to-offshore environmental gradients, including gradients in salinity, depth, nutrients, sedimentation and pollution (Fox and Bellwood, 2007; Cleary et al., 2005, 2008) determine community structure throughout the reef ecosystem. In addition to the above, community structure of coral reefs is also determined by storm damage, thermal stress, and overexploitation of grazers and predators, to mention just a few (Szmant, 2002). All of these stressors have distinct spatial components (Goatley and Bellwood, 2013).

Following the widespread ecological changes to Caribbean reefs and the realization that benthic community structure is to a great extent determined by the interplay between corals, algae, and herbivorous fishes, more scientific attention has been paid to these groups (e.g., Bellwood et al., 2004; Hughes et al., 2010; Berumen and Pratchett, 2006). The conservation of coral reefs also tends to rely on indicators from these taxa. Yet, there has been far less focus on other groups inhabiting the same reefs.

Bacteria and archaea, for instance, are abundant members of the vast marine microbial community and are important players in processes such as the geochemical cycling of carbon, nitrogen and sulfur, transformation and degradation of nutrients and organic matter derived from both surface ocean production and terrestrial runoff (Webster et al., 2004). For oligotrophic coral reefs, this cycling activity is of crucial importance in order to degrade organic matter and maintain high levels of primary production (Schöttner et al., 2011). According to Sneed et al. (2014) biofilm bacteria also play an important role in inducing the larval settlement of some corals. Coral reef carbonate sands due to their complex surface structure and highly porous matrix present a high abundance of prokaryotes (Wild et al., 2006). Coral reef sponges, in turn, have also been shown to harbor exceptional microbial densities, which can make up from 35 to 40% of sponge biomass (Hentschel et al., 2002, 2012).

In the present study, in addition to sponges and foraminifera studied in previous studies (Cleary et al., 2005; Becking et al., 2006; de Voogd et al., 2006) in the same study area (Spermonde Archipelago; Indonesia), we assessed the composition of bacterial and archaeal communities in sediment and sponges (of critical importance to the biogeochemical nutrient cycles in coral reef ecosystems) and the composition of scleractinian corals (important for maintaining the three-dimensional structure of coral reefs systems). These taxa were selected based on their ecological importance, distinct life-history strategies and on the taxonomic expertise of the research team.

The previous studies conducted in the Spermonde Archipelago (Cleary et al., 2005; Becking et al., 2006; de Voogd et al., 2006) related variation in composition of sea urchins, sponges, mushroom corals and larger foraminifera to offshore distance, depth, exposure, degree of human settlement, distance between sites and substrate type (remotely sensed). In summary, they showed that variation in community similarity of the studied taxa was primarily explained by environmental components with the exception of the sea urchins, for which the spatial component had a greater influence. Additionally, depth was the most important parameter for sponges, corals and foraminifera and human settlement was significantly associated with sponges and foraminifera community composition.

In the present study, our main goal was to investigate how beta diversity (change in species composition of assemblages between sites; Purvis and Hector, 2000) in the Spermonde coral reef system is related to habitat and water quality variables. Important environmental parameters such as coral reef habitat structure and remotely sensed data were used in this study to explain spatial variation in the composition of all taxa sampled. The remotely sensed data focused on four of the most important threats to coastal coral reefs: eutrophication (high nutrients; chlorophyll-a concentrations), bleaching (high-temperatures; sea surface temperature), sedimentation (high-sediments; remote sensing reflectance at 645 nm) and runoff (high-humic and fulvic substances; colored dissolved organic matter index). We compared to what degree habitat and water quality variables were able to explain variation in the composition of different taxa.

2. Material and methods

2.1. Study site

The Spermonde Archipelago (Fig. 1) is situated adjacent to the city of Makassar, capital of the Indonesian province of South Sulawesi and home to more than two million inhabitants (Renema, 2010). This archipelago consists of 160 cay-crowned reefs dispersed over a 40 km wide continental shelf (Moll, 1983; Renema and Troelstra, 2001; Cleary et al., 2005). It lies on a carbonate shelf, which increases in depth with distance from the coast, except for the outer rim consisting of a barrier reef (Renema and Troelstra, 2001; de Voogd et al., 2006; Hoeksema, 2012a). The westernmost islands lie on this rim beyond which the sea floor abruptly drops down to depths exceeding 800 m in the Makassar Strait (Moll, 1983). Its proximity to Makassar leaves these coral reefs exposed to many anthropogenic disturbances including river discharge