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Variation in the composition of corals, fishes, sponges, echinoderms, ascidians, molluscs, foraminifera and macroalgae across a pronounced in-to-offshore environmental gradient in the Jakarta Bay–Thousand Islands coral reef complex

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ABSTRACT

Substrate cover, water quality parameters and assemblages of corals, fishes, sponges, echinoderms, ascidians, molluscs, benthic foraminifera and macroalgae were sampled across a pronounced environmental gradient in the Jakarta Bay–Thousand Islands reef complex. Inshore sites mainly consisted of sand, rubble and turf algae with elevated temperature, dissolved oxygen, pH and chlorophyll concentrations and depauperate assemblages of all taxa. Live coral cover was very low inshore and mainly consisted of sparse massive coral heads and a few encrusting species. Faunal assemblages were more speciose and compositionally distinct mid- and offshore compared to inshore. There were, however, small-scale differences among taxa. Certain midshore sites, for example, housed assemblages resembling those typical of the inshore environment but this differed depending on the taxon. Substrate, water quality and spatial variables together explained from 31% (molluscs) to 72% (foraminifera) of the variation in composition. In general, satellite-derived parameters outperformed locally measured parameters.

1. Introduction

A central aim in ecology is to explain the spatial and temporal variation in biodiversity (Mora et al., 2003). Understanding the causes of this variation is an important issue in ecosystems such as coral reefs, particularly those that have been severely affected by over-harvesting, pollution, disease and coral bleaching (Roberts et al., 2002; Walther et al., 2002; Mora et al., 2003; Bellwood et al., 2004). Evidence over the last 40 years has revealed a widespread loss of coral cover in tropical coastal waters of the Indo-West Pacific and the western Atlantic. In some areas, entire coral reefs have been overgrown and killed by fast-growing species of macroalgae, leading to 'coral–algal shifts' (Raffaelli et al., 1998; Bellwood et al., 2004; Schaffelke et al., 2005). This kind of reef degradation has been attributed to a decline in herbivory as top-down mechanism and an increasing supply of nutrients as bottom-up mechanism (Burkepile et al., 2013; Bruno et al., 2014). In addition to this, corals may also undergo mortality as a result of mass bleaching events, which impacts some species more than others (Carpenter et al., 2008) and therefore may also have a selective effect on coral communities.

The community composition of coral reef taxa is structured by often pronounced in-to-offshore gradients in parameters including depth, salinity, nutrient concentrations and sedimentation (Cleary et al., 2005, 2008, 2014; Fox and Bellwood, 2007). Coral reef communities have also been structured by infrequent past events (e.g., hurricanes) and chronic stress related to human activities such as fishing and the release of heavy metals and other contaminants. Many of these pressures also have a pronounced spatial component (Goatley and Bellwood, 2013). Taxa also interact and can have important effects on the community composition of other taxa (Bellwood et al., 2004; Berumen and Pratchett, 2006; Hughes et al., 2010). Herbivory is considered to be a

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significant selective factor structuring macroalgal assemblages (Littler and Littler, 1984) and can increase species diversity by removing dominant spatial competitors (Menge and Farrell, 1989), by clearing substrate for new individuals (Menge and Lubchenco, 1981), and by maintaining the equilibrium between competing species (Gleeson and Wilson, 1986). Herbivory can also reduce diversity by selectively removing preferred food items (Lubchenco and Gaines, 1981) and altering rates of succession (McClanahan, 1997). Major grazers include fishes, molluscs and sea urchins (Hay, 1981a, 1981b, 1981c).

The crown-of-thorns starfish, *Acanthaster planci*, a ferocious coral predator, has also caused widespread damage to Indo-Pacific coral reefs (Baird et al., 2013; Pratchett et al., 2014; Plass-Johnson et al., 2015). Other taxa such as sponges, ascidians and benthic algae in contrast may not prey on corals, but compete with corals for habitat space (Jackson and Buss, 1975; Lirman, 2014), which may be more problematic for some corals than others (van der Ent et al., 2015). In addition to studying communities of coral, it is important to understand how the various coral reef communities vary spatially and in relation to environmental conditions in order to assess management strategies and the exploitation of natural products (Tuomisto et al., 2003).

The main objective of the present study was to assess the composition of several abundant coral reef taxa across a pronounced in-to-offshore gradient in the Jakarta Bay–Thousand Islands reef complex. To achieve this objective, we sampled data on reef-dwelling corals, fishes, sponges, echinoderms, ascidians, molluscs, large benthic foraminifera (LBF) and macroalgae. We also measured substrate variables including live coral and algal cover, dead coral, rubble and sand cover and local water quality variables including water transparency, pH and dissolved oxygen content. The water quality variables were supplemented with satellite-derived parameters including chlorophyll-a concentration, remote sensing reflectance at 645 nm (Rrs_645), sea surface temperature (SST) and coloured dissolved organic matter index (CDOM). The satellite-derived parameters were chosen as proxies of potential threats to coral reefs, namely eutrophication (chlorophyll-a concentrations), bleaching (sea surface temperature), sedimentation (remote sensing reflectance at 645 nm) and runoff (colored dissolved organic matter index) (Miller and Mckee, 2004; Chen et al., 2007). In addition to assessing compositional change across the in-to-offshore gradient, we also assessed to what extent spatial, substrate and water quality variables are able to explain variation in the composition of coral reef taxa.

2. Material and methods

2.1. Study site

The Jakarta Bay–Thousand Islands reef complex (hereafter referred to as JBTI) consists of cay-crowned platform reefs that extend from Jakarta Bay to more than 80 km to the north in the Java Sea (Fig. 1). Several rivers transport sewage and storm water over a 2000 km^2 catchment area to the central sector of the bay (Williams et al., 2000; Rinawati et al., 2012), defined by two flanking delta systems, both of which have a large sediment input in a catchment area of 6000 km^2 (Rees et al., 1999; Williams et al., 2000). The river discharge in JBTI also contains pollutants, such as industrial waste and household litter (Willoughby, 1986; Uneputty and Evans, 1997; Willoughby et al., 1997), heavy metals (Hosono et al., 2011), and nutrients (Baum et al., 2015). Annual precipitation averages 1700 mm yr^{-1} with a 'wet' season during the northwest monsoon (November–March) and a 'dry' season during the southeast monsoon (May–September) (Rees et al., 1999).

2.2. Data collection

Sampling took place from September 7th to 23rd 2005, predominantly at the northwestern side of the surveyed reefs with the exception of a single reef (Tikus) where the southern and northwestern sides were sampled. This entailed estimating the cover of coral colonies and other benthic cover categories (algae, dead coral, coral rubble and sand) using the line intercept transect survey method (English et al., 1997). In each site, three 30-m transects were laid out at two depths (3 and 5 m) for a total of six transects per site. A total of 43 sites were sampled that included a core set of 28 sites (Table 1). For certain taxa, some core sites were not sampled due to logistical constraints and additional sites were sampled. Along each transect, we measured the intercept distance of individual live coral colonies and other substrate cover categories.

Consistent with previous studies of the area (DeVantier et al., 1998; Cleary et al., 2006, 2008), all sample sites fell within specific zones along an in-to-offshore gradient. These included an inshore zone (zone 1) to the south of −5.97° latitude, a midshore zone (zone 2) between −5.77° and −5.97° latitude, and an offshore zone (zone 3) to the north of −5.77° latitude (Fig. 1). The offshore zone is largely contained within the Pulau Seribu National Marine Park, the first marine park established in Indonesia (Farhan and Lim, 2012).

2.3. Corals

Scleractinian coral species were visually identified during line-intercept transect surveys (English et al., 1997). Photos of unrecognized specimens were taken for closer examination and identification using Veron (2000). The line-intercept transect data was analysed in order to calculate the percent cover of each coral species and life form surveyed (see below). In each site, we surveyed six transects (30 m long) at each of the two studied depths (3 and 5 m). In total, 28 sites were surveyed for corals.

2.4. Fishes

Fishes were visually assessed along six transects (30 m long) at each of the two studied depths (3 and 5 m). Individuals observed within 5 m on either side of the transect were identified to species, if possible, and recorded. Individuals that left the transect area and re-entered were not counted again (Hoey and Bellwood, 2008; Dickens et al., 2011). In total, 28 sites were surveyed for fishes.

2.5. Sponges

Thirty patch reefs were visually surveyed during a one-hour dive from deep to shallow water (3–25 m) using a presence/absence classification. Smaller (cryptic, boring, and thinly encrusting <4 cm) specimens were excluded from this study. Species were visually identified in the field, and fragments of all species were collected for closer examination. Voucher specimens were preserved in 70% ethanol and deposited in the sponge collection at Naturalis Biodiversity Center, Leiden, the Netherlands.

2.6. Echinoderms

In close proximity of the transects, a visual census was made of asteroids and echinoids (starfish and sea urchins; referred to as echinoderms in the present study for simplicity) using a presence/absence classification. No attempt was made to locate cryptic species. In total, 31 sites were surveyed for echinoderms.

2.7. Ascidians

In the neighbourhood of the transects, a visual census was made of ascidians using a presence/absence classification. In total, 25 sites were surveyed for ascidians. It was not possible to identify all ascidians to species level, as many species have not been described and also because immature specimens of some species lacked diagnostic characters. Following a similar study off Halmahera, Moluccas, Indonesia,