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Composition and temporal stability of turf sediments on inner-shelf coral reefs

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ABSTRACT

Elevated sediment loads within the epilithic algal matrix (EAM) of coral reefs can increase coral mortality and inhibit herbivory. Yet the composition, distribution and temporal variability of EAM sediment loads are poorly known, especially on inshore reefs. This study quantified EAM sediment loads (including organic particulates) and algal length across the reef profile of two bays at Orpheus Island (inner-shelf Great Barrier Reef) over a six month period. We examined the total sediment mass, organic load, carbonate and silicate content, and the particle sizes of EAM sediments. Throughout the study period, all EAM sediment variables exhibited marked variation among reef zones. However, EAM sediment loads and algal length were consistent between bays and over time, despite major seasonal variation in climate including a severe tropical cyclone. This study provides a comprehensive description of EAM sediments on inshore reefs and highlights the exceptional temporal stability of EAM sediments on coral reefs.

1. Introduction

The degradation of coastal marine ecosystems associated with terrestrial sediment inputs is the subject of increasing concern and management activity (Erftemeijer et al., 2012; Maina et al., 2013). On Australia's Great Barrier Reef (GBR), many reefs are threatened by sedimentation and decreased water quality (Brodie et al., 2012; Furnas, 2003; GBRMPA, 2014; Macdonald et al., 2013). Coral reef environments are particularly susceptible to the effects of elevated sediment loads as they disrupt coral recruitment (Birrell et al., 2005; Fabricius, 2005), reduce herbivory (Goatley and Bellwood, 2012, 2013; Clausing et al., 2014), restrict light availability (Fabricius, 2005; Flores et al., 2012; Kleypas, 1996), and smother benthic organisms (Fabricius, 2005; Rogers, 1990). Among the reefs of the GBR, inner-shelf reefs are the most impacted and degraded, due to their close proximity to riverine and terrestrial sediment inputs (De'ath et al., 2012; Fabricius, 2005). It is therefore crucial to understand the drivers of sediment loads on near-shore coral reefs and the influence of terrestrial sediments on the GBR lagoon. By quantifying the composition and variability of EAM sediments over extended spatial and temporal scales we may better understand the factors influencing EAM sediments and the potential long-term effects of sediments on coral reef organisms.

Recent studies of sediment dynamics and their ecological effects on coral reef ecosystems have primarily focused on the suspended sediments that cause turbidity (Fabricius et al., 2013; Orpin and Ridd, 2012; Orpin et al., 2004). Extensive monitoring of turbidity and suspended sediment concentrations (SSC) of inshore waters throughout the GBR have shown extreme variability over space and time (Fabricius et al., 2013; Larcombe et al., 1995; Wolanski and Spagnol, 2000; Orpin and Ridd, 2012; Orpin et al., 2004). While seasonal climate patterns and disturbance events are major factors determining SSC variability (Fabricius et al., 2013, 2014; Larcombe et al., 1995; Orpin and Ridd, 2012), due to constant cycles of deposition and resuspension of sediments, it is difficult to relate SSC to benthic sediment loads on reefs (Fabricius et al., 2014; Wolanski et al., 2005), especially sediments in the epilithic algal matrix (EAM), which form part of a composite habitat including microorganisms, filamentous algae and infauna (Wilson et al., 2003). The EAM is the most abundant form of benthic cover on coral reefs (Goatley and Bellwood, 2011) and underpins most trophic pathways (Wilson et al., 2003; Kramer et al., 2013). It also incorporates sediment and nutrients from the water column (Goatley et al., 2016) and is the first reef surface encountered by most reef organisms as they settle onto reefs (Shima, 2001; Birrell et al., 2005). As such, the EAM forms a critical interface between benthic organisms and the water column, and it is here that EAM sediments may pose one of the greatest challenges to ecosystem function (Bellwood and Fulton, 2008; Goatley and Bellwood, 2012, 2013). While previous studies have assessed the distribution of sediment and organic materials across individual reefs (e.g. Purcell, 2000; Purcell and Bellwood, 2001), few have

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examined the nature and variability of benthic sediment loads in EAMs on inshore coral reefs (Gordon et al., 2016; Hughes et al., 2011), or over time scales longer than a few weeks (Goatley and Bellwood, 2013).

Here we present a detailed description of the distribution, composition (grain-size and organic content), and variability of EAM sediments on an inner-shelf reef on the GBR. While previous studies have examined specific biological aspects of inner-shelf EAMs (e.g. algal turfs, fish grazing, or infauna; Bonaldo and Bellwood, 2011; Kramer et al., 2012; Gordon et al., 2016) the current study aims to provide a comprehensive evaluation of both the biological and physical aspects of EAM sediment loads. Importantly, this study examined EAM sediments over an extended period (6 months) that included a tropical wet season and a severe tropical cyclone, allowing the effects of seasonal changes and associated disturbance events on EAM sediment loads to be examined. By focusing on EAM sediments, rather than those in suspension, this study aims to provide insights into the dynamics of reef-based sediments which may directly influence the diverse and abundant organisms that interact with EAMs on coral reefs.

2. Methods

2.1. Study site

Sampling was conducted during February, April and August 2014 on reefs in Pioneer and Hazard Bays, Orpheus Island (18.618°S, 146.494°E), on the inner-shelf of the Great Barrier Reef (GBR). Orpheus Island is located <20 km from the Queensland coast and close to the mouths of the Herbert (20 km) and Burdekin Rivers (150 km; Fig. 1), the latter delivering the highest mean annual runoff of all GBR watersheds (Furnas, 2003). Pioneer and Hazard Bays are situated on the leeward side of Orpheus Island and exhibit clear reef zonation. Both bays possess wide reef flats extending approximately 150 m from shore, a structurally complex crest comprised predominantly of large *Porites* spp., and a reef slope with low structural complexity and decreased light penetration (Fox and Bellwood, 2007; Kramer et al., 2013). Details of the dominant grazing herbivores and algal turf conditions of Pioneer Bay are given in Fox and Bellwood (2007) and Bonaldo and Bellwood (2011).

2.2. Sampling procedure

To characterise EAM sediment loads, initial sampling was conducted in February in Pioneer and Hazard Bays. In each bay, two sites were selected at least 400 m apart (Fig. 1b). At each site three reef zones were examined: the reef flat (1.5–2 m deep), the crest (3–4 m), and the slope (6–8 m). Eight replicate sediment samples were collected from EAMs in each reef zone at each site (n = 96 samples in total). To examine temporal variation, additional samples were collected during April and August from the reef crest and flat in the two previously sampled sites in Pioneer Bay. In each of these subsequent periods, five replicate sediment samples were collected (n = 20 in each period). The three sample periods covered the beginning and end of the tropical wet season in 2014 (February and April respectively) and the middle of the dry season (August). They also spanned a major climatic event, being two months before (February), one week before (April) and four months after (August) Severe Tropical Cyclone Ita (STC Ita), a category 3 storm, which passed close to Orpheus Island on the 12th–13th of April 2014 (Bureau of Meteorology, 2014) (Fig. 1). STC Ita resulted in gale force winds and damaging wind gusts at the nearest coastal town, Lucinda, as well as widespread rainfall and flooding throughout North Queensland (Bureau of Meteorology, 2014).

Sediment samples were collected on SCUBA using a submersible 12 V electronic vacuum sampler (adapted from Kramer et al., 2012). The replicate samples were collected from random points along a 50 m transect line, laid parallel to the reef crest. EAM sampling locations were flat with very low structural complexity and free from sediment-retaining pits, macrophytes, or encrusting organisms (following Purcell 2000). Sampling areas were delineated by a PVC ring (55.87 cm^2) placed onto the EAM. Following sample collection, algal turf length was measured using Vernier calipers at four haphazardly selected points within the sampling area (adapted from Bonaldo and Bellwood, 2011; Goatley and Bellwood, 2013). Sediment samples were immediately fixed with 20 mL of 10% buffered formalin and transferred into 9 L containers to settle. After 24 h, samples were decanted and transferred into 120 mL sample jars for analyses. February samples were analysed to determine mass and particle size (five samples for mass analysis and three for particle size); April and August samples were used for mass analysis only.

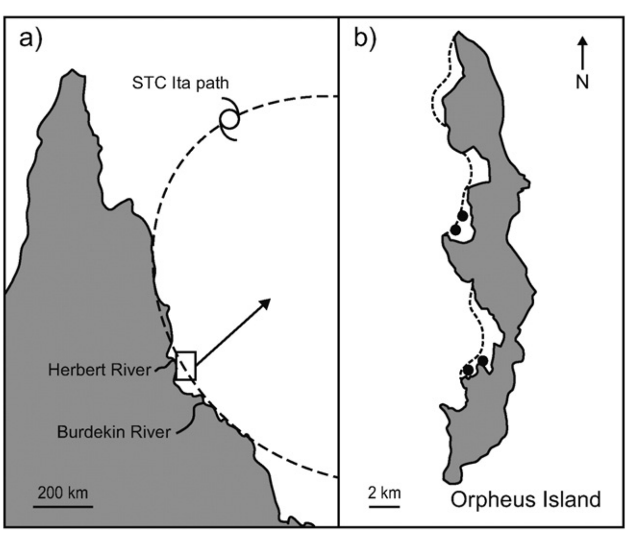

Fig. 1. Map detailing: a) the approximate track of Tropical Cyclone Ita on the 12th–13th April 2014 (Bureau of Meteorology, 2014) and its relative position to the study sites b) around Orpheus Island. Each site is indicated by a black dot, Pioneer Bay to the north and Hazard Bay to the south.

2.3. Sediment depth

Sediment depth is not just related to mass and is affected by properties including particle size, biochemical composition and interactions with organic materials (DeMaster, 1981; Mayer, 1999). The depth of all samples was therefore measured in identical 120 mL sample jars prior to analyses. Measurements were taken using Vernier calipers 24 h after decanting, to allow adequate time for material to settle out of suspension. All measurements were standardised by the sampling area to estimate the potential depth of particulate loads within the EAM.

2.4. Mass analysis

Sediment samples for mass analysis were rinsed three times with fresh water to remove salts prior to analysis (allowing a minimum of 24 h to settle between rinses). The samples were then dried to a constant weight at 60 °C and the total sediment mass (organic material and inorganic sediment) recorded. To remove organic material, samples were bleached with 30% hydrogen peroxide (H_2O_2) for a minimum of 7 days, or until no bubbles evolved within a 24 h period (following Cortés and Risk, 1985). The bleached sediments were dried and weighed to provide the inorganic sediment mass (carbonates and silicates). To remove the carbonates, samples were acidified with 5% hydrochloric acid (HCl) until no bubbles were produced in 24 h (following Brown-Saracino et al., 2007), then rinsed with fresh water on dried, pre-weighed, acid-resistant filter paper to remove salts before being dried and weighed. After subtracting the mass of the paper, this yielded the mass of silicate sediments. Subtracting the mass of silicate sediments from the inorganic sediment mass also revealed the mass of carbonate sediments lost during acidification.