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Coral morphology and sedimentation

Alan Duckworth, Natalie Giofre, Ross Jones*

Australian Institute of Marine Science (AIMS), Townsville, QLD, Australia
Australian Institute of Marine Science (AIMS), Perth, WA, Australia
Western Australian Marine Science Institution, 35 Stirling Highway, Crawley, WA 6009, Australia

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ABSTRACT

The sediment rejection ability of 8 coral species of 5 families and 3 morphologies were assessed in a series of short term exposure tests over a sedimentation range of 0.5–40 mg cm^{-2} d^{-1} and one longer term exposure test of 235 mg cm^{-2}. Sediment accumulation rates on live corals and dead (enamel-covered) skeletons varied between morphologies, with branching species often more adept at self-cleaning. Flow rates (0–17 cm s^{-1}) significantly affected sediment-shedding ability as did differences in particle sizes, with coarse silt rejected faster than fine silt, but only at very high (235 mg cm^{-2}) deposition rates. Siliciclastic sediment was rejected faster than carbonate sediments and smothering for many days by mms of low organic content carbonate sediment resulted in bleaching, but no mortality. The findings are discussed with respect to turbidity generated in natural and dredging-related resuspension events and in the context for impact prediction for dredging projects.

1. Introduction

Dredging and dredging related activities (such as dredge material disposal in offshore disposal grounds) release sediments into the water column. The increased turbidity (water cloudiness) can negatively impact the local marine environment, especially sensitive marine habitats such as coral reefs, seagrass beds and mixed filter feeder assemblages (Foster et al., 2010; McCook et al., 2015; Jones et al., 2016). The need for dredging is predicted to grow associated with the trends of increasing cruise and container ship sizes and maritime transport (Asariotis et al., 2010; Ports Australia, 2014). An accompanying need is to improve the ability to make scientifically sound predictions of the likely extent, severity, and persistence of environmental impacts associated with dredging (McCook et al., 2015; EPA, 2016). This is predicated upon establishing a relationship between changes in water quality and the health of the underlying communities. Once established, it can be used together with coupled hydrodynamic and sediment transport models to predict the likely spatial extent of any possible effects at the environmental impact assessment stage e.g. Gailani et al. (2016); Nelson et al. (2016), and also used with water quality monitoring during dredging to inform adaptive management.

Elevated sedimentation is one of the key cause-effect pathways that can result in damage to adult and recently settled juvenile corals at sites close to excavation activities (Dodge and Vaisnys, 1977; Bak, 1978; Jones et al., 2015b; Jones et al., 2016). High sedimentation rates require corals to self-clean, i.e. to keep their surfaces sediment-free and prevent sediment accumulation and 'smothering' of the underlying tissue (Philipp and Fabricius, 2003; Weber et al., 2006; Weber et al., 2012). If smothering occurs (see Fig. 1), sediments could build up on a coral over successive days, decreasing solute and metabolite exchange and feeding. It will prevent light from reaching the symbiotic dinoflagellates in the coral tissue (Riegl and Branch, 1995; Weber et al., 2006). Once smothering has occurred, partial mortality (lesion formation) can sometimes occur in a few days (Philipp and Fabricius, 2003; Weber et al., 2006; Piniak, 2007; Weber et al., 2012). Estimating the sedimentation rate where the self-cleaning ability of corals is exceeded is a priority for impact prediction assessment during dredging programs.

Corals routinely experience periods of increased sedimentation associated with storms and natural resuspension events (Larcombe et al., 1995; Ogston et al., 2004; Storlazzi et al., 2004; Verspecht and Pattiaratchi, 2010). They have a range of different mechanisms for shifting sediments, primarily involving mucus entrapment and ciliary action (muco-ciliary transport), hydrostatic inflation and tentacle movement (Duerden, 1906; Marshall and Orr, 1931; Hubbard and Pocock, 1972; Rogers, 1983; Rogers, 1990; Stafford-Smith and Ormond, 1992). These 'active' (energy-requiring) processes work in combination with 'passive' forces associated with gravity. Both the macroscale morphology (growth form, branch thickness and spacing) and microscale morphology (corallite size and shape) affect how sediments settle, collect and are cleared from the surface (Hubbard and Pocock, 1972; Stafford-Smith and Ormond, 1992).

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* Corresponding author.
E-mail addresses: aduckworth1@gmail.com (A. Duckworth), n.giofre@aims.gov.au (N. Giofre), r.jones@aims.gov.au (R. Jones).

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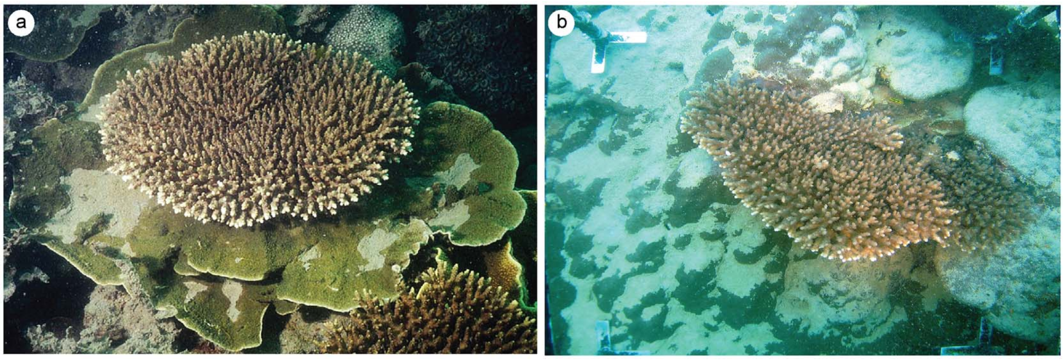

Fig. 1. Smothering of corals during dredging projects (a) near Magnetic Island (Central Great Barrier Reef, Queensland, Australia) in January 2001 at depth of 5–6 m (Jones et al., 2004; Jones, 2008) and (b) near Barrow Island (Pilbara coast of Western Australia, Australia) in April 2011 at a depth of ~11 m (Fisher et al., 2015; Jones et al., 2015a) showing a build-up of sediment on foliose *Montipora* spp. corals and massive *Porites* spp. but no sediment build-up on the branching *Acropora* spp. Corals were located < 100 m from (image a) and 1.5 km (image b) from dredging activities.

Different coral species have different inherent abilities to clean themselves of sediments (Stafford-Smith and Ormond, 1992) with some species, such as *Turbinaria mesenterina* known to be particularly hardy (Sofonia and Anthony, 2008). Other factors which could influence the ability of corals to self-clean include sediment type, particle size and water movement, with the latter factor not only affecting the particle settling velocity, but also providing an additional force to compliment the active and passive removal processes.

In nearshore locations, corals can be exposed to different types of sediment particles, from primarily calcium carbonate (i.e. the skeletal remains of animals and plants), to more terrestrially-derived siliciclastic sediment (Larcombe and Carter, 1998). It is most likely corals will be exposed to a mixture of the two depending on location, distance from shore and proximity to river mouths (Furnas, 2003; Piniak, 2007). The different types of sediments will vary in their density, sphericity and angularity. In addition to different geochemical properties, the sediments will also differ in their organic and nutrient-related properties, which can mediate effects once smothering has occurred (Piniak, 2007; Weber et al., 2012).

A number of studies have examined the difference in sediment rejection ability of corals in response to fine and coarse sediment. However, as noted in Jones et al. (2016), these studies have frequently used sands, whereas even close to a working dredge the particle sizes are typically in the silt range ($< 62\ \mu m$). Many studies examining the sediment shifting ability of corals have also used silicon carbide (carborundum) (Yonge, 1930; Bak and Elgershuizen, 1976; Stafford-Smith and Ormond, 1992; Junjie et al., 2014; Browne et al., 2015) and as with the use of sands the relevance of these studies for impact prediction with dredging is uncertain.

As part of a sequence of experiments examining the effects of dredging pressures (i.e. suspended sediments, light reduction sedimentation) on corals, alone and in isolation, and over different time periods, in this study the short-term self-cleaning capabilities of a range of coral species was examined. The species included different families and morphologies and were tested with different sediment types (carbonate and siliciclastic and mixed sediments) and different particle sizes (median diameter 10–60 μm), sedimentation rates ($0.5–40\ mg\ cm^{-2}\ d^{-1}$) and flow rates ($0–17\ cm\ s^{-1}$), while a long-term (16 d) experiment examined the consequences of sediment smothering on survival. One of the problems of relating coral health and sedimentation is accurately measuring sedimentation rates at scales that are physiologically relevant i.e. $mg\ cm^{-2}\ d^{-1}$. In this study, two new measuring techniques were used that can provide better estimates of net sedimentation rates — SedPods which are flat, cement filled PVC pipes with a roughened surface (Field et al., 2012), and optical back scatter (OBS) sensors (Ridd et al., 2001; Whinney et al., 2017) which are autonomous in situ instruments capable of measuring deposition over periods of minutes to weeks.

2. Materials and methods

2.1. Coral species

Experiments were conducted with 8 common Indo-Pacific coral species, representing 5 families and 3 morphologies (see Table 1), although not all species were used in each experiment (see Table 3). *Porites lobata* and *Porites lutea* are morphologically similar and difficult to identify underwater due to their small and variable corallites (Veron, 2000), and therefore a mixture of species were used and referred to as *Porites* spp.

For the branching and foliose species, up to 10 colonies were collected and fragmented into replicates using a mallet and cold chisel. The *Porites* spp. cores were removed from > 10 large *Porites* spp. colonies using a pneumatic drill. All coral species were collected between depths of 4–10 m from the lagoon at Davies Reef (a mid-shelf reef of the central (18°S) Great Barrier Reef). *M. aequituberculata* is reported as occurring at Davies Reef, but could not be located during collections, and instead was collected from a coastal fringing reef at Magnetic Island (in Cleveland Bay (18°S), inshore, central GBR) at depth of 4 m. Corals were collected separately for each experiment, with an average of 30

Table 1
Coral species, family, morphology and size, used in the clearance and smothering experiments.

Species (author)	Family	Morphology	Size
Pocillopora damicornis (Linnaeus, 1758)	Pocilloporidae	Branching	Small 4–5 cm (width) fragments containing ≥ 3 branches from 10 + colonies
Acropora millepora (Ehrenberg, 1834)	Acroporidae		
Montipora aequituberculata (Bernard, 1897)		Foliose	Small $\sim 50\ cm^{-2}$ (area) fragments collected from 10 + colonies
Montipora capricornis (Veron, 1985)			
Turbinaria reniformis (Bernard, 1896)	Dendrophylliidae		
Goniastrea retiformis (Lamarck, 1816)	Merulindae	Massive	Small $\sim 50\ cm^{-2}$ whole colonies
Porites lutea (Milne Edwards & Haime 1851)	Poritiidae		Small $\sim 50\ cm^{-2}$ whole colonies and 50 mm diameter cores.
Porites lobata (Dana, 1846)			