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A detrital sediment budget of a Maldivian reef platform

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ABSTRACT

Sediment dynamics are an important control on the morphology and development of reef systems by actively removing and redistributing excess detrital sediment. This study presents quantitative data from direct point measurements of sediment transport on the platform surface and fore-reef slope of Vabbinfaru reef, North Malé Atoll, Maldives. A suite of sediment traps were used to construct actual rates of platform sediment fluxes and off-reef export over different spatial and temporal (seasonal) scales to establish key sediment transport pathways. Findings showed that high sediment fluxes occur on Vabbinfaru platform in the absence of major storm activity (up to 1905 g m^{-1} d^{-1}), with 95% of annual transport occurring during the southwest monsoon as a result of increased wave energy. Climate-driven changes in the platform process regime caused a reversal of net sediment transport pathways between each monsoon season. Off-reef export rates were high, reaching a maximum of 12.58 kg m^{-1} y^{-1} for gravel and 407 g m^{-1} d^{-1} for sand-sized sediment. An estimated 127,120 kg is exported from the platform annually equating to a significant loss from the reef sediment budget and contributing to the long-term geomorphic development of the fore-reef slope and atoll basin. Detrital sediment reservoirs on Vabbinfaru are not purely depositional carbonate sinks, but rather temporary stores that are important in the transfer of sediment between reef zones.

1. Introduction

Coral reefs are highly productive ecological systems that represent the end product of a variety of constructive and destructive processes (Chave et al., 1972; Stearn et al., 1977; Scoffin, 1992). As living reefs breakdown through mechanical and biological erosion, reef-derived sediments are produced as a by-product. Continued and excess sedimentation on reefs (from either carbonate or non-carbonate sources) is known to have adverse impacts on the ecological health of reef communities (Bak, 1978; Rogers, 1983, 1990; Fabricius, 2005) and as a consequence, the ecological maintenance of reefs is partly dependent on the redistribution of detrital sediment, either internal to the reef system or export from the reef platform.

Sediment transport is an important component of coral reefs as it controls the movement and residence time of sediment in a number of sediment stores and mediates the development of geomorphic features on coral reef platforms. Sediments generated on coral reefs can be redistributed to a number of depositional sinks, including: (1) re-incorporated into the reef structure to contribute to the development of the reef internal fabric (Hubbard et al., 1990; Perry and Hepburn, 2008), (2) used to construct and maintain reef islands (Woodroffe et al., 1999; Yamano et al., 2005; Hart and Kench, 2007; Perry et al., 2011), (3) transferred to infill lagoons (Kench, 1998a; Kennedy and Woodroffe, 2000), (4) stored in deposits on the reef surface (Harney and Fletcher, 2003; Storlazzi et al., 2009), or (5) exported from the reef system representing a loss to the reef carbonate budget (Hine et al., 1981; Hughes, 1999). Despite recognition of the importance of sediment transfers to and between ephemeral sediment stores, only a few studies have resolved the detailed sediment transport pathways and produced contemporary rates of sediment flux for modern reef systems. Several notable studies have used direct measurements of sediment transport to construct actual rates of sediment flux on reefs (Land, 1979; Hubbard et al., 1981; Sadd, 1984; Hughes, 1999; Harney and Fletcher, 2003).

Existing studies on reef sedimentation have typically focused on the response of reef organisms to terrigenous sediments as a result of changes to land use practices (Ogston et al., 2004; Storlazzi et al., 2009), provided case studies of transport and deposition of sediment during high energy events (Hubbard, 1992; Keen et al., 2004; Harris and Heap, 2009), and examined the role of biologically-mediated processes in the transport of sediment (Bellwood, 1995, 1996; Goatley and Bellwood, 2010; Krone et al., 2011). Such studies have typically examined reefs associated with high islands that yield terrigenous sediment inputs and have been conducted within a narrow geographic range on inner shelf or fringing reefs in the Caribbean (Land, 1979; Hubbard et al., 1981; Sadd, 1984; Hoskin et al., 1986; Hubbard, 1986; Hubbard et al., 1990; Li et al., 1998), Hawaii (Eversole and Fletcher, 2003; Ogston et al., 2004; Storlazzi et al., 2004, 2009; Presto et al.,

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2006), or Australia (Hughes, 1999; Harris and Heap, 2009), with few transport studies conducted within the Indian Ocean.

Quantitative estimates of sediment flux and off-reef export derived from direct field measurements are rare for atoll reef systems. Kench (1998a) and Kench and McLean (2004) provided a detailed budget of bedload sediment transport through inter-tidal channels on Cocos (Keeling) Island, eastern Indian Ocean. Findings showed that sediment transport occurs during non-storm conditions but significantly increases during episodic high-energy events which accounts for the majority of total annual sediment transport. Understanding temporal and spatial reef sediment dynamics is necessary for determining patterns of sediment deposition (Li et al., 1998; Yamano et al., 2000), to predict changes in reef sedimentary landforms in response to shifts in environmental conditions (Perry et al., 2011), and in understanding the long-term evolution of reef structures (Hughes, 1999; Rasser and Riegl, 2002).

The present study generates quantitative data on sediment flux and off-reef sediment export for Vabbinfaru reef, North Malé Atoll, Maldives. The aim is to identify spatial and temporal variations in sediment transport, which sediment constituents are preferentially transported, and examine the role of seasonal variations on net sediment transport pathways. Results are discussed with regard to reef geomorphic

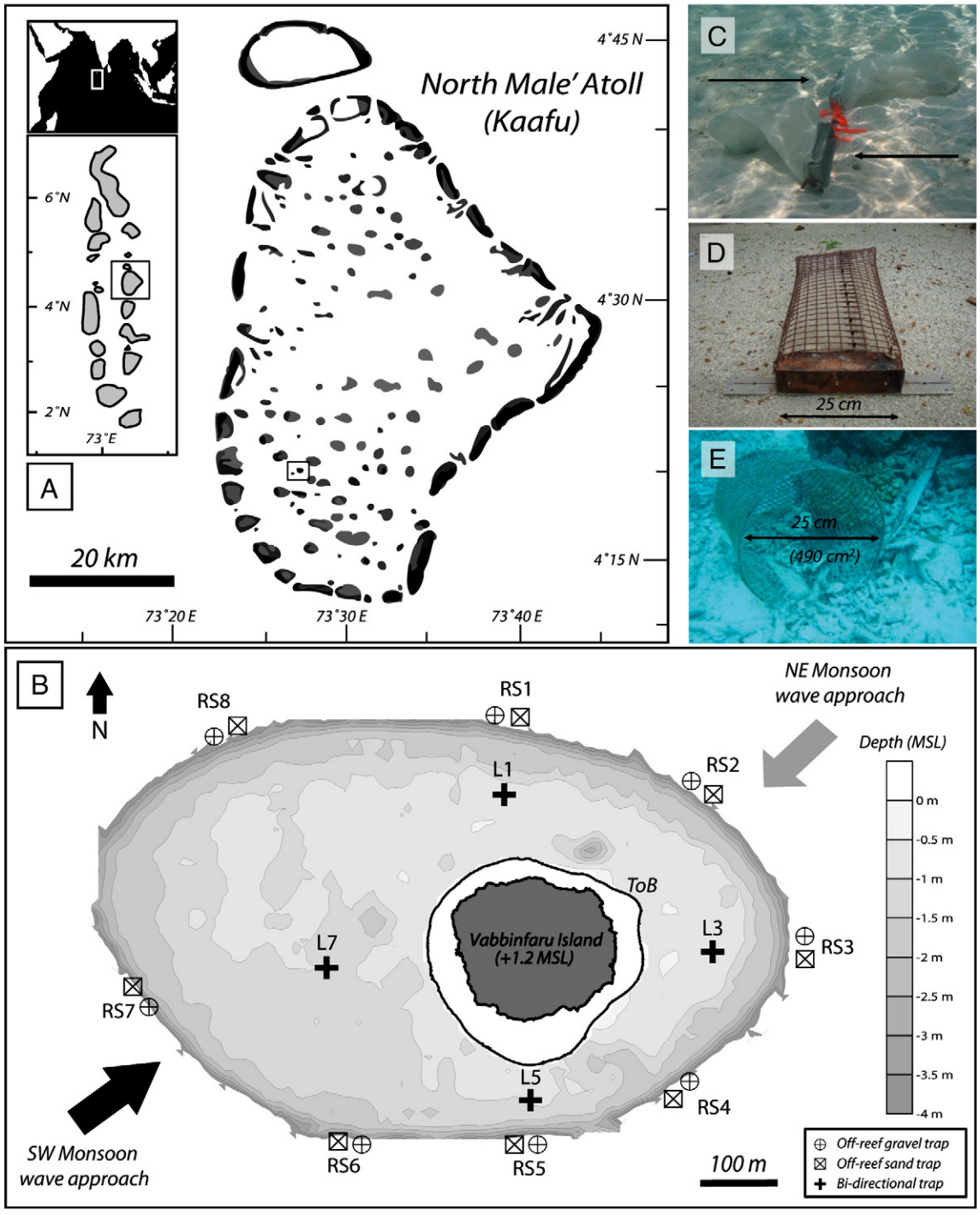

Fig. 1. (A) Location of Vabbinfaru reef platform, North Malé Atoll, Republic of the Maldives. (B) Experimental design and deployment location of sediment traps on the platform surface and fore-reef slope. Photographs of the different sediment trap apparatus used: (C) bidirectional traps, (D) sand export trap, and (E) gravel export trap.