Continental Shelf Research 129 (2016) 1–9

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Sediment dynamics and their potential influence on insular-slope mesophotic coral ecosystems

C. Sherman*, W. Schmidt, R. Appeldoorn, Y. Hutchinson, H. Ruiz, M. Nemeth, I. Bejarano, J.J. Cruz Motta, H. Xu

Department of Marine Sciences, University of Puerto Rico-Mayagüez, PO Box 9000, Mayaguez, PR 00681, Puerto Rico

ARTICLE INFO

Keywords:
Sediment dynamics
Mesophotic coral ecosystem (MCE)
Insular slope
Bed load

ABSTRACT

Although sediment dynamics exert a fundamental control on the character and distribution of reefs, data on sediment dynamics in mesophotic systems are scarce. In this study, sediment traps and benthic photo-transects were used to document spatial and temporal patterns of suspended-sediment and bed-load dynamics at two geomorphically distinct mesophotic coral ecosystems (MCEs) on the upper insular slope of southwest Puerto Rico. Trap accumulation rates of suspended sediment were relatively low and spatiotemporally uniform, averaging <1 mg cm^{-2} d^{-1} and never exceeding 3 mg cm^{-2} d^{-1} over the sampled period. In contrast, trap accumulation rates of downslope bed-load movement were orders of magnitude higher than suspended-sediment accumulation rates and highly variable, by orders of magnitude, both spatially and temporally. Percent sand cover within photo-transects varied over time from ~10% to more than 40% providing further evidence of downslope sediment movement. In general, the more exposed, lower gradient site had higher rates of downslope sediment movement, higher sand cover and lower coral cover than the more sheltered and steep site that exhibited lower rates of downslope sediment movement, lower sand cover and higher coral cover. In most cases, trap accumulation rates of suspended sediment and bed load varied together and peaks in trap accumulation rates correspond to peaks in SWAN-modeled wave-orbital velocities, suggesting that surface waves may influence sediment dynamics even in mesophotic settings. Though variable, off-shelf transport of sediment is a continuous process occurring even during non-storm conditions. Continuous downslope sediment movement in conjunction with degree of exposure to prevailing seas and slope geomorphology are proposed to exert an important influence on the character and distribution of insular-slope MCEs.

1. Introduction

Upper insular slopes in the Caribbean are dynamic transition zones between shallow shelves and deep ocean basins that provide conduits through which shelf materials are transported to deeper water. Caribbean slopes are also prime habitats for mesophotic coral ecosystems (MCEs), which are defined as light-dependent corals and associated benthic communities found at depths of ~50–100 m or more, or roughly the base of the photic zone (Hinderstein et al., 2010; Kahng et al., 2010; Lesser et al., 2009). Sediment dynamics exert a fundamental control on the character and distribution of both shallow shelf reefs and deeper mesophotic systems (Bridge et al., 2011; Goreau and Land, 1974; Hubbard, 1986; James and Ginsburg, 1979; Liddell et al., 1997; Liddell and Ohlhorst, 1988; Perry, 2007). Sediment can affect corals and other sessile benthos by burial, abrasion and increased turbidity. On steep insular slopes, MCEs are subject to persistent downslope transport of sediment generated primarily by prolific growth of coral and calcareous algae and associated carbonate production at the shelf-edge. As a result, MCEs are preferentially concentrated on steep-sided buttresses and other topographic highs that effectively shed sediment and are further removed from the influence of downslope sediment movement (Liddell et al., 1997; Liddell and Ohlhorst, 1988; Sherman et al., 2010). Although sediment dynamics play a crucial role in MCEs, quantitative data of spatial and temporal patterns in sediment transport and the primary physical drivers of these processes are scarce (e.g., Hubbard, 1986; Hubbard, 1992; Hubbard et al., 1981).

Most studies of sediment dynamics in reef systems have examined shallow fringing and inner shelf reefs and have typically focused on the delivery and transport of terrigenous sediment (Bothner et al., 2006; Hernandez et al., 2009; Ogston et al., 2004; Sherman et al., 2013; Storlazzi et al., 2009; Storlazzi et al., 2004). These studies generally employ vertically oriented tube traps to capture the settling of suspended sediment along with, in some cases, instrumental arrays

* Corresponding author.

http://dx.doi.org/10.1016/j.csr.2016.09.012
Received 27 January 2016; Received in revised form 22 September 2016; Accepted 28 September 2016
Available online 29 September 2016

recording water column dynamics, such as waves, currents and turbidity. In these relatively shallow settings, tides and wind-generated waves/currents are the primary drivers of sediment dynamics (Kench and McLean, 2004; Storlazzi et al., 2004). Episodic storms are known to exert tremendous impacts on shallow reef systems and account for major transport of sediment (Hubbard, 1992). Still, sediment transport is a chronic process affecting reef systems even in the absence of major storms (e.g., Storlazzi and Jaffe, 2008). Although critically important in shaping benthic communities (e.g., Yoshioka, 2009; Yoshioka and Yoshioka, 1989) as well as accounting for a major portion of total sediment fluxes in reef ecosystems (e.g., Hubbard et al., 1990; Hughes, 1999), direct measurements of bed-load transport are relatively rare (e.g., Hubbard et al., 1986; Hubbard et al., 1990; Hubbard et al., 1981; Kench and McLean, 2004; Morgan and Kench, 2014) and measurements in mesophotic systems are rarer still.

Previous work in southwest Puerto Rico documented a systematic relationship between orientation of the insular shelf margin with respect to prevailing seas and geomorphology of the upper insular slope (Sherman et al., 2010). Southeast-facing slopes, more exposed to prevailing seas, have a gentler gradient and lower relief than more sheltered southwest-facing slopes, which are steep and irregular. It was proposed that these differences in exposure and geomorphology affected the nature of downslope sediment transport which, in turn, influenced the distribution of MCEs. MCEs tend to be better developed on steeper more sheltered slopes where irregular topography funnels downslope sediment transport into narrow chutes. This paper provides a preliminary assessment of sediment transport within MCEs occurring in two different geomorphic settings on the insular slope of southwest Puerto Rico. The aim is to establish spatial and temporal patterns in sediment transport and discuss potential linkages between geomorphology, sediment transport and the character and distribution of MCEs.

2. Study area

Puerto Rico lies in the northeast Caribbean Sea where prevailing Trade Winds result in dominant winds and waves from the east. Based on data from the National Buoy Data Center (NDBC) Station 42085/ Caribbean Coastal Ocean Observing System (CariCOOS) Data Buoy A, along the south coast of Puerto Rico, winds are predominantly easterly with average speeds of ~5–6 m s^{-1} (Fig. 1). Accordingly, coastal currents are generally westward in the upper-most part of the water column (< 3 m), averaging ~0.5 m s^{-1} (Schmidt, 2010; Schmidt, 2011). Deeper depths experience a tidally-driven flow, dominantly east-west, but exhibiting a distinct net offshore (south-southwest) component in response to northward Ekman transport. Near-bottom (1–2 m) currents regularly exceed 0.25 m s^{-1} and can be over 0.5 m s^{-1} (Schmidt, 2010; Schmidt, 2011). Waves approach almost exclusively from the southeast with average heights of ~1 m and periods of ~6 s (NDBC Station 42085; Fig. 1). Tides are diurnal with a mean tidal range of < 30 cm (Kjerfve, 1981), although the nearby west coast experiences semi-diurnal tides of a similar range.

The study area lies off the southwest coast of Puerto Rico where a broad insular shelf extends ~8–9 km offshore before dropping abruptly to oceanic depths. The shelf contains two roughly shore-parallel tracts of emergent reefs and shoals that lie 1–2 km (inner reefs) and 2–4 km (mid-shelf reefs) offshore, some capped by well-developed mangrove stands. These are separated from each other by open sandy areas that reach depths of up to ~15 m. The open outer shelf reaches depths of ~25 m and separates the mid-shelf reefs from a band of submerged reefs that form a variable and discontinuous elevated rim along the shelf edge at depths of 15–25 m (Ballantine et al., 2008; Hubbard et al., 1997). The upper insular slope extends from the shelf break at a depth of ~20 m down to a depth of ~160 m where there is a pronounced change in geomorphic character and the basal slope begins (Sherman et al., 2010). The upper slope has been divided into two geomorphic zones on the basis of slope gradient. Zone I extends from 20 to 90 m water depths and has gradients that range from 25 to 45°, with an average of 34°. Zone II consists of a steep wall with a gradient of ~70° or more that drops precipitously from ~90 down to ~160 m water depths (Sherman et al., 2010).

For this study, two locations on the upper slope, referred to as Hole-in-the-Wall (HW) and El Hoyo (HY), were chosen because they are geomorpically distinct from each other and essentially represent end members in the geomorphic spectrum of the upper slope (Fig. 2). These sites have also been the subject of other related studies as part of the University of Puerto Rico-Mayagüez (UPRM) multidisciplinary MCE research program. Hole-in-the-Wall is a more sheltered south-southwest-facing slope with a steep average gradient from 20 to 90 m water depth of ~44° (range of 33°–64°) and an irregular topography consisting of steep-sided buttresses separated by narrow sand chutes. The buttresses support a lush cover of mesophotic corals, algae and other benthos. In contrast, El Hoyo is a more exposed southeast-facing slope with a gentler average gradient from 20 to 90 m water depth of ~25° (range of 18–34°) and a lower relief topography consisting of broad, low-gradient buttresses separated by open slopes. The substrate here consists of a sparsely colonized hardground with lower coral cover and thin, discontinuous sheets of unconsolidated sand.

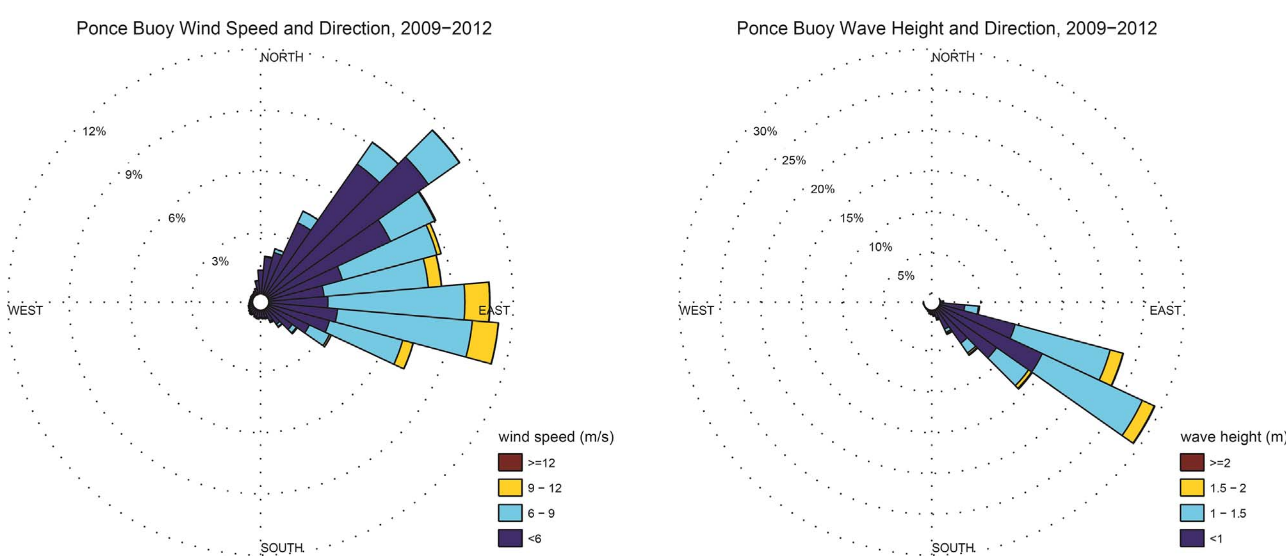

Fig. 1. Wind and wave roses for the south coast of Puerto Rico based on data from NDBC Station 42085/CariCOOS Data Buoy A located off the south-central coast of Puerto Rico.