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Shoreline and beach volume change between 1967 and 2007 at Raine Island, Great Barrier Reef, Australia

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ABSTRACT

Raine Island is a vegetated coral cay located on the far northern outer Great Barrier Reef (GBR), recognised as a globally significant turtle rookery. Cay geomorphology, specifically the morphology of the beach and swale, dictate the availability of nesting sites and influence nesting success. Understanding short and long-term shoreline change is critical for managers charged with protecting the nesting habitat, particularly as climate change progresses. Historical topographic surveys, a simple numerical model and geographic information system (GIS) techniques were used to reconstruct a 40-year (1967–2007) shoreline history of Raine Island. Results show that significant shoreline change has occurred on 78% of the island's shoreline between 1967 and 2007; 34% experienced net retreat and 44% net progradation during the study interval. Shoreline retreat is mainly concentrated on the east–southeast section of the shoreline (average annual rate of -0.3 ± 0.3 m/yr), while the shore on the western side of the island prograded at a similar rate (0.4 ± 0.2 m/yr). A seasonal signal was detected relating to oscillations in wind direction and intensity, with the southeast and west–southwest shorelines migrating an average of ~17 m from season to season. The volume of sediment deposited on Raine Island between 1967 and 2007 increased by ~68,000 m^3 net, but accretion rates varied significantly seasonally and from year to year. The largest volumetric changes have typically occurred over the last 23 years (1984–2007). Despite the recent concern that Raine Island is rapidly eroding, our data demonstrate net island growth (6% area, 4% volume) between 1967 and 2007. Perceptions of erosion probably reflect large morphological changes arising from seasonal, inter-annual and inter-decadal patterns of sediment redistribution rather than net loss from the island's sediment budget.

1. Introduction

It is projected that global sea level will rise ~0.03 m in the next decade and between 0.18 and 0.79 m by 2100, and that tropical cyclones will become more intense (IPCC, 2007; Church et al., 2008). Low-lying reef islands are widely perceived to be particularly sensitive to these changes (McLean and Tsyban, 2001; Mimura et al., 2007; Woodroffe, 2007), although a number of geomorphologists have argued that rising sea levels do not always cause reef islands to erode. For example, a rise in sea level may promote reef island growth by: i) increasing accommodation space for new sediment; ii) reinvigorating carbonate production on reef flats where further reef growth has been inhibited by a stable sea level; and iii) increasing the efficiency of waves to transport new and stored sediment to an island depocentre (Hopley, 1993; Hopley et al., 2007; Smithers et al., 2007; Woodroffe, 2007). However, many calcifying organisms that produce sediments eventually deposited on reef islands survive within narrow environmental limits, and global climate changes are likely to raise mortality rates (Baker et al., 2008; Veron et al., 2009). At least initially, this may promote island accretion by raising the production of detrital sediments and increasing sediment availability (Smithers et al., 2007), but if community recovery is slow and the frequency of mortality events remains high, reef island sediment budgets will eventually go into deficit. Furthermore, significant and sustained reductions in coral growth may increase the wave energy reaching island shorelines as frictional wave attenuation is reduced, potentially changing shoreline dynamics (Sheppard et al., 2005).

Coral cays are low-lying reef islands formed from sediments derived from the reef on which they sit and swept by refracted waves to a focal point on the reef flat where they are deposited. Seasonal fluctuations in the intensity and dominant direction of wind and wind-driven waves/currents can produce significant changes in island size, shape and position on a reef platform (Flood, 1986; Aston, 1995; Kench and Brander, 2006a). Higher-energy waves and currents produced by tropical cyclones may markedly modify reef island morphology over shorter periods (Scoffin, 1993); cyclones affect much of the Great Barrier Reef (GBR) about once every two and a half years on average (Australian Bureau of Meteorology, 2009). Cyclones can produce major depositional features such as beach ridges

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(Maragos et al., 1973; Chivas et al., 1986; Hayne and Chappell, 2005). Alternatively, cyclonic waves and surge can severely erode shorelines and even completely remove islands (Nott, 2006).

Raine Island is a low reef island located on the outer edge of the far northern GBR, Australia. It is one of the world's most important nesting sites for marine turtles (Limpus et al., 2003). The availability of nesting sites is determined by cay geomorphology, specifically the morphology of the beach and adjacent swale. Understanding short and long-term shoreline change is critical for managers charged with protecting the nesting habitat, particularly as climate change progresses. Raine Island is also geomorphically significant in that it is characterised by geomorphic features that, although not particularly unique in themselves, are rarely found in combination on reef islands (e.g. a phosphate rock cap and intertidal beachrock pavements — see Baker et al., 1998).

Previous geomorphic investigations at Raine Island have focused on wave dynamics and lateral shoreline change (Gourlay and Hacker, 1991), phosphate rock formation (Baker et al., 1998), geomorphological description (Jukes, 1847; Stoddart et al., 1981), and the implications of geomorphology on green turtle nesting (Neil et al., 2000; Limpus et al., 2003). Changes in island size and volume have been estimated using photogrammetry in several studies (Gourlay and Hacker, 1991; Gourlay, 1997), but these analyses focus on a relatively short time period (1984–1990) for which quality imagery is available. This study extends the timescale of investigation to reconstruct 40 years of change (1967–2007) using both historical topographic surveys and additional field data collection. Our results improve the understanding of shoreline dynamics and reef island geomorphology at Raine Island and provide important data on shoreline variability necessary to assess the potential impacts of projected environmental changes.

2. Island setting

Raine Island (11°35′28″S 144°02′17″E) is located at the northwest end of a planar reef on the outer edge of the Great Barrier Reef (GBR) (Fig. 1). The reef crest is exposed to high energy Pacific Ocean swells generated by both the southeast tradewinds that prevail during the austral winter (April–October,) and more rarely by episodic cyclones during the summer monsoon (November to March). The typical diurnal mesotidal range is about 1.8 m and much of the reef-flat is ~0.5 m above lowest astronomical tide (LAT), corresponding with the mean low water level. Highest Astronomical Tide (HAT) is 2.75 m above LAT.

The island is approximately 820 m long, 440 m wide and 27.5 ha in area. Maximum elevation is ~8 m above LAT (Fig. 1). The island's long axis is aligned parallel to the southeast tradewinds, as is common for cays of the GBR (Flood, 1986; Frank and Jell, 2006). Beach width ranges from 10 to 25 m and most beaches have relatively steeply sloping beach faces (7–8°) that rise to a berm crest at ~4 m LAT (Fig. 1). Landward of the berm crest is a wide sandy berm and swale zone (hereafter collectively referred to as the swale) that terminates to landward at a prominent 0.5–1.5 m high phosphate rock cliff (Figs. 1, 2A, C). The swale is partially vegetated by a sparse cover of *Lepturus* sp. (thintail grass), which is seasonal but is also disturbed during turtle nesting (November–February). Beachrock outcrops were exposed on the eastern and northeastern shorelines during a field visit in November 2007 (Fig. 1). These outcrops cover ~6800 m^2, and include clear bedding structures that dip seawards at a similar angle to the present day beach (Fig. 2B). Phosphates leached from avian guano have reprecipitated and cemented island sediments

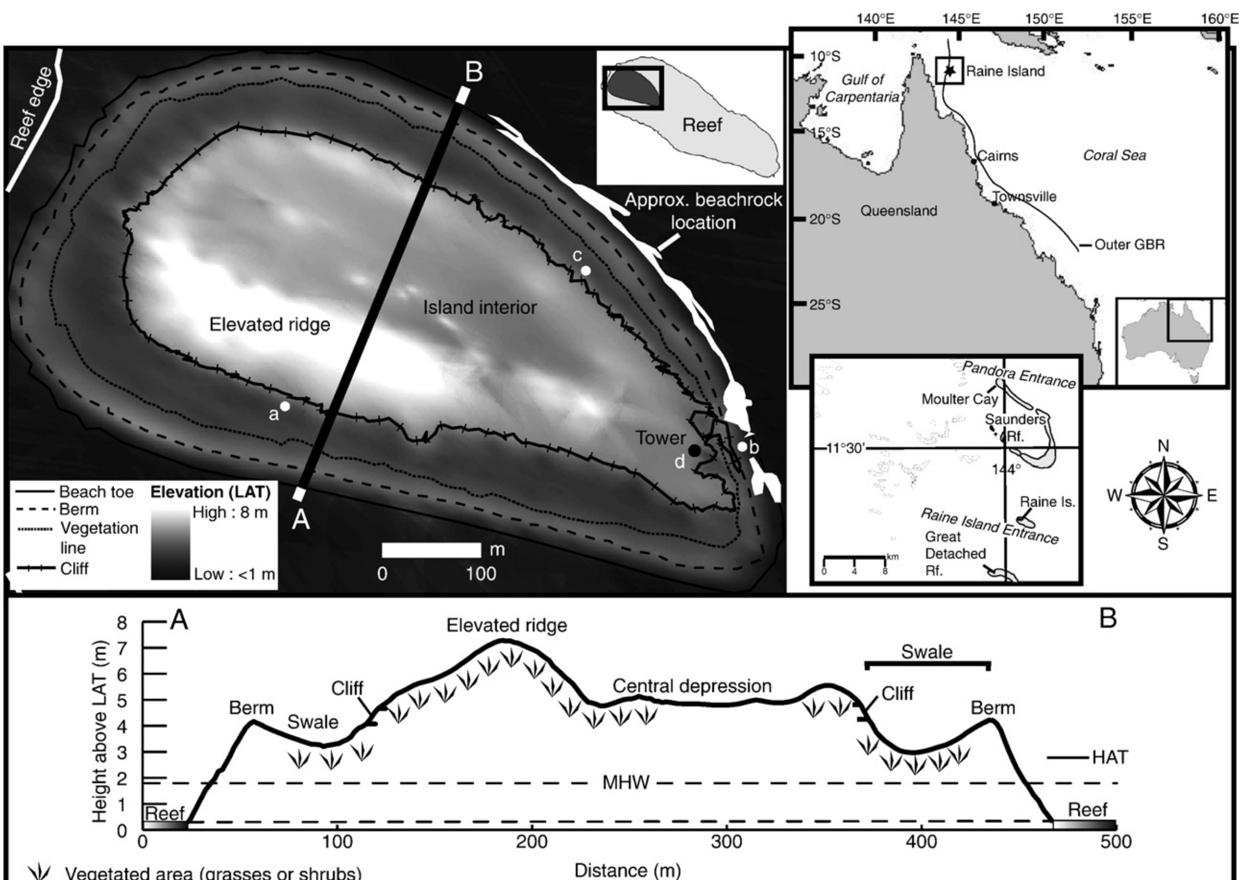

Fig. 1. Location map of Raine Island on the outer northern Great Barrier Reef, Australia. A cross section (A–B) is also included, illustrating beach and central island morphology. Small letters a–d indicate the locations of photographs illustrated in Fig. 2. Note the island's northwest location on the reef-flat as well as the general beach and central island geomorphology. The swale region is defined as the portion of beach between the base of the cliff and the elevated berm crest. MHW = mean high water level (1.8 m above LAT); LAT = lowest astronomical tide; HAT = highest astronomical tide (2.75 m above LAT).