Global and Planetary Change 146 (2016) 162–178

Contents lists available at ScienceDirect

Global and Planetary Change

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

Invited research article

Multi-scale records of reef development and condition provide context for contemporary changes on inshore reefs

Emma J. Ryan [a,b,*], Stephen E. Lewis [b], Scott G. Smithers [a,b], Tara R. Clark [c], Jian-xin Zhao [c]

[a] College of Science and Engineering, James Cook University, Townsville, QLD 4811, Australia
[b] Catchment to Reef Research Group, TropWATER, James Cook University, Townsville, QLD 4811, Australia
[c] Radiogenic Isotope Facility, School of Earth Sciences, The University of Queensland, Brisbane, QLD 4072, Australia

ARTICLE INFO

Article history:
Received 10 February 2016
Received in revised form 4 October 2016
Accepted 6 October 2016
Available online 8 October 2016

Keywords:
Great Barrier Reef
Reef cores
Chronostratigraphy
U-Th dating
Stone Island
Middle Island

ABSTRACT

Comparisons between historical and contemporary photographs of coral reef flats from the inshore Great Barrier Reef (GBR) have been cited by various authors and agencies as evidence of reef degradation since European settlement and have been presented as proof of widespread reef decline. The diminished condition is inferred from reduced live coral cover and structural diversity depicted in the contemporary photographs. Anthropogenic causes for this deterioration are most often proposed, usually because it is argued to have coincided with modifications to coastal catchments by European settlers. However, changes in reef condition inferred from photographic comparisons have rarely been verified against quantitative assessments of reef geomorphic state or current reef status. Photographs taken in the late 1800s of the reef flat at Stone Island, located in Edgecumbe Bay in the inshore central GBR, have been compared by others with more recent images to interpret significant reductions in coral cover and diversity over the past 120 or so years. We examined the internal structure of fringing reefs at two locations on Stone Island by collecting 14 percussion cores across the reef flats. Sedimentological analyses coupled with uranium-thorium dating allowed for the reconstruction of reef development over the past ~7000 years. Both reefs at Stone Island initiated prior to 7000 calendar years before present (yBP, where present is 1950 AD) and both reef flats were almost entirely emplaced by 4000 yBP. Surveys of the benthic ecology of reefs at Stone Island and at Middle Island, also in Edgecumbe Bay, indicate that coral cover and diversity across reef flats and slopes was patchy and varied spatially within each location and throughout the region. Live coral cover on the Middle Island reef flat reached an average ($\pm 1\sigma$ standard deviation) of $63.1 \pm 20.2\%$. This was much higher than the live coral cover on Stone Island reef flats, where only a few small living coral colonies were recorded. We evaluate the use of photographic records from Stone Island to depict regional changes in reef condition by comparing the trends in reef condition determined from photographic records with underlying reef geomorphic state reconstructed from reef cores. We conclude that inferred changes in reef condition at Stone Island are localised and should not be used as evidence of widespread regional decline on the GBR.

1. Introduction

Major declines in live coral cover have been documented on coral reefs globally over the past four decades (Gardner et al., 2003; Bruno and Selig, 2007; Wilkinson, 2008; De'ath et al., 2012). Anthropogenic stressors such as over-fishing (Hughes et al., 2007), contaminants, and elevated sediment loads exported from modified catchments (Fabricius, 2005) have been linked to ecological phase-shifts on coral reefs, whereby a coral-dominated ecosystem is transformed into a macroalgae-dominated ecosystem with relatively few hard corals (Hughes, 1994; Bellwood et al., 2004). Shifts in the dominant coral taxa on reefs have also been reported, towards dominance of non-framework building corals (Perry et al., 2015) or opportunistic taxa (Green et al., 2008; Alvarez-Filip et al., 2011). However, the global magnitude and regional extent of such phase-shifts is not well documented or understood (Bruno et al., 2009) and some coral reefs have experienced long periods of recovery while being exposed to human influences (Maragos et al., 1985; Kittinger et al., 2011; Gilmour et al., 2013). Furthermore, how shifts in reef condition forced by human activities interplay with those produced by natural disturbances is also poorly understood. On the Great Barrier Reef (GBR) of Australia, inshore reefs (usually defined as those situated within the 20 m isobath and the mainland coast [Hopley et al., 2007]) are considered most susceptible to ecological phase-shifts due to their proximity to modified coastal catchments and river discharge (Fabricius et al., 2005; Browne et al., 2012; Waterhouse et al., 2012). Since European settlement of the

* Corresponding author at: School of Environment, The University of Auckland, Auckland 1010, New Zealand.
E-mail address: e.ryan@auckland.ac.nz (E.J. Ryan).

http://dx.doi.org/10.1016/j.gloplacha.2016.10.007
0921-8181/

Queensland coast in the early-mid 19th Century, sediment, nutrient and pollutant loads exported to the GBR lagoon have increased two- to tenfold (McCulloch et al., 2003; Kroon et al., 2012; Waters et al., 2014) and high floods in coastal rivers have become more frequent, increasing from 1 in 20 years prior to European settlement to 1 in 6 years (Lough et al., 2015). However, direct evidence of the impact these changes have on inshore reefs is lacking and whether they are localised or system-wide is contested (see Sweatman et al., 2011; Hughes et al., 2011; Sweatman and Syms, 2011).

Evidence for coral loss on inshore reefs of the GBR is largely derived from reef monitoring studies undertaken across a wide range of reefs on the GBR since the 1980s (*e.g.* Done et al., 2007; Thompson and Dolman, 2010; De'ath et al., 2012). These ecological data collected over decades are enormously valuable for informing management, but nonetheless provide very restricted temporal records of reef condition compared to those preserved in historical sources (Thurstan et al., 2015) and the fossil record (Pandolfi and Kiessling, 2014), which for most inshore reefs on the GBR may encompass several millennia (Smithers et al., 2006). Historical and contemporary photographs of reef flats have been compared to determine changes in coral cover and structure on inshore reefs over a 'longer-term' centennial-scale period (Wachenfeld, 1997). In 1994, Wachenfeld (1997) attempted to replicate the historical photographs of Stone Island reef flat taken by Saville-Kent (1893) at low tide (shown in Fig. 1); Wachenfeld's 1994 photographs depict a conspicuous change from a coral-dominated reef flat in the late 1800s/early 1900s to a macroalgae- and sediment-dominated reef flat. More recent photographs taken in 2012 by Clark et al. (2016) and those in Fig. 1 show this condition persists (see also Electronic Supplementary Materials 1). The sequence of photographs from Stone Island have been broadly used as evidence of widespread reef degradation in the inshore GBR (Hughes et al., 2010; Bell et al., 2014; GBRMPA, 2013, 2014; Hoegh-Guldberg, 2014), despite Wachenfeld (1997, pp. 147) concluding that the results from the historical photograph project "…throws doubt on the proposition that the GBR is subject to broad scale decline". Of the 14 reefs examined by Wachenfeld (1997) just 4 reefs displayed major change between the late 1880s and 1994, including Stone Island and nearby Bramston Reef. Interestingly, a recent study by Ryan et al. (2016a) suggested that the reef flat condition at Bramston Reef in 2013 was not dissimilar to descriptions of Bramston Reef given by Saville-Kent (1893). This raises concerns with the validity of the photographic comparison that were originally emphasised by Wachenfeld (1997) and remain unresolved today, including: 1) a single photograph from one location on a reef flat may not be representative of the entire reef flat; and 2) each photograph captures just one point in time and does not provide sufficient temporal resolution, given the dynamic nature of coral cover across reefs, and especially across reef flats. Furthermore, it is likely that the original photographs taken by Saville-Kent were deliberately taken in areas of high benthic cover. Indeed, Saville-Kent (1893) stated intentions for the photographs to be used to monitor future coral growth. In addition, the elevation of the reef flat at the location where the historical and contemporary photographs were taken is not properly referenced to a tidal datum (with the exception of recent work by Clark et al. [2016]) and thus the possible influence of the elevation of these commonly emergent reef flats cannot be determined. Accordingly, firm conclusions about regional-scale inshore reef condition should not be drawn from historical photographic evidence alone and quantitative baseline data on contemporary and past (centennial-millennial scale) reef condition (which do not currently exist at Stone Island) are required. When used together with quantitative data about past and present reef state, historical and contemporary photographs may provide additional supplementary evidence of changes in reef condition.

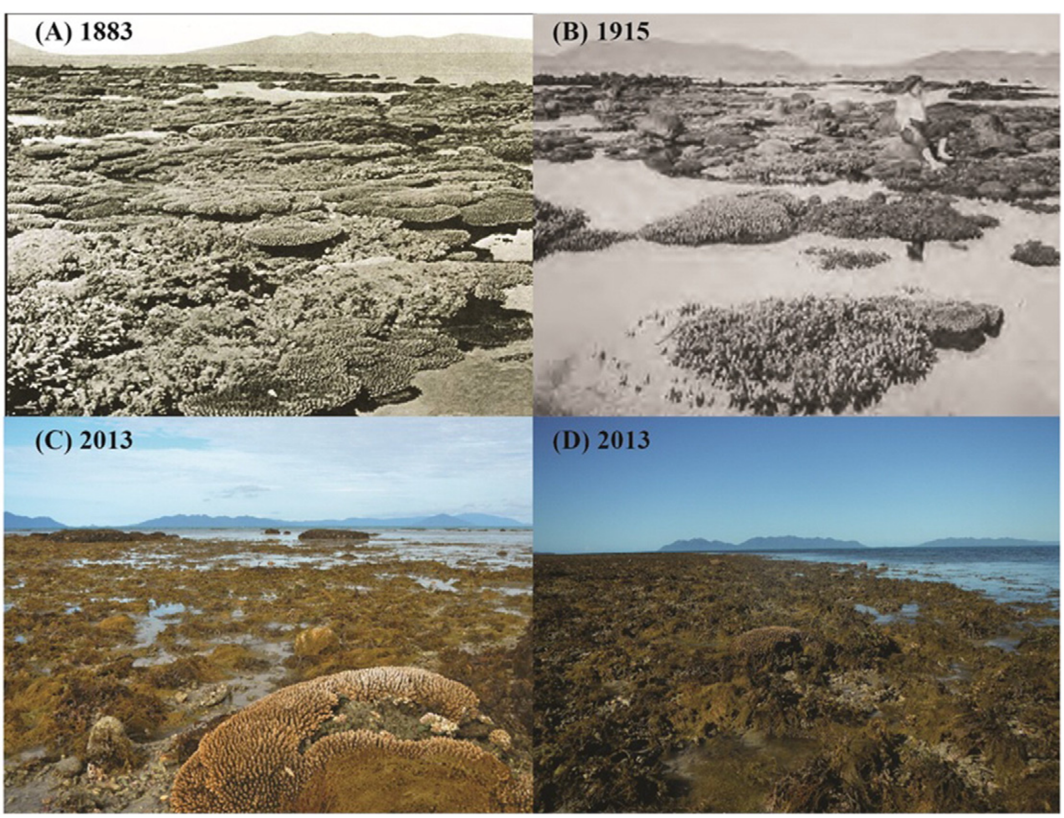

Fig. 1. Photographs of the Stone Island reef flat: (A) taken by Saville-Kent (1893) in 1883, (B) taken in 1915 by an unknown photographer, (C) and (D) taken by E. Ryan at spring low tides (0.13 and 0.23 m above lowest astronomical tide on 22 (C) and 21 (D) July 2013, respectively). Note the high standing fossil microatolls at the water's edge in (C). For additional photographs and elevations of the reef flat surface where photographs were taken see Electronic Supplementary Materials 1.