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A Geomorphic Interpretation of Shoreline Change Rates on Reef Islands

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ABSTRACT

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Recent-past shoreline changes on reef islands are now subject to intensified monitoring *via* remote sensing data. Based on these data, rates of shoreline change calculated from long-term measurements (decadal) are often markedly lower than recent short-term rates (over a number of years). This observation has raised speculations about the growing influence of sea-level rise on reef island stability. This observation, however, can also be explained if we consider two basic principles of geomorphology and sedimentology. For Takú Atoll, Papua New Guinea, we show that natural shoreline fluctuations of dynamic reef islands have a crucial influence on the calculation of short-term rates of change. We analyze an extensive dataset of multitemporal shoreline change rates from 1943 to 2012 and find that differing rates between long- and short-term measurements consistently reflect the length of the observation interval. This relationship appears independent from the study era and indicates that reef islands were equally dynamic during the early periods of analysis, *i.e.* before the recent acceleration of sea-level rise. Consequently, we suggest that high rates of shoreline change calculated from recent short-term observations may simply result from a change in temporal scale and a shift from geomorphic equilibrium achieved over cyclic time toward an apparent disequilibrium during shorter periods of graded time. This new interpretation of short- and long-term shoreline change rates has important implications for the ongoing discussion about reef island vulnerability, showing that an observed jump from low to high rates of change may be independent from external influences, including but not limited to sea-level rise.

ADDITIONAL INDEX WORDS: *Shoreline evolution, sea-level rise, coral islands, Pacific Ocean, atolls, geomorphic equilibria.*

INTRODUCTION

Shoreline change rates express the horizontal displacement of a coastline over time. The calculation of reliable shoreline change rates requires (1) historical shoreline data (*e.g.*, from maps or aerial photographs) and (2) data with sufficient temporal resolution to account for natural shoreline fluctuations. Because the number of earth observation satellites with submeter accuracy is continually increasing, these requirements are gradually being fulfilled for coral reef islands situated in tropical latitudes. Unfortunately, a general lack of available historical remote sensing data is also characteristic of most Pacific islands (Ford, 2013; Ford and Kench, 2014).

Reef islands are sedimentary landforms consisting of unconsolidated or weakly lithified calcareous sands and gravels (Stoddart and Steers, 1977). Because of their particular position on the rims of tropical and subtropical reef environments, the geomorphic development of reef islands is strongly influenced by geological, biological, and hydrodynamic processes in their surroundings (Kench, Owen, and Ford, 2014; McLean and Woodroffe, 1994; Woodroffe *et al*., 1999; Woodroffe *et al*., 2007). Until recently, reef islands were widely regarded as being in geomorphic equilibrium with these processes (Stoddart and Steers, 1977; Webb, 2006), yet debate occurred about the role of high-magnitude low-frequency events in shaping this equilibrium (Bayliss-Smith, 1988; Smithers and Hoeke, 2014; Woodroffe, 2008). There is growing concern, however, that a secular rise of sea level will change the boundary conditions and permanently affect island stability in the near future (Barnett and Adger, 2003; Dickinson, 2009; Khan *et al*., 2002; Mimura, 1999).

To evaluate recent-past island stability during the last decades, several studies have analyzed multitemporal remote sensing data and have found that there is no obvious causal relationship between styles of shoreline change (*e.g.*, ocean shoreline erosion) and sea-level rise (Ford, 2011, 2013; Ford and Kench, 2014; Kench *et al*., 2015; Rankey, 2011; Webb and Kench, 2010; Yates *et al*., 2013); however, a particular finding in some studies was an apparent transition of shoreline change rates toward higher values in recent times (Forbes and Hosoi, 1995; Ford, 2013; Rankey, 2011). This transition is either a deception resulting from the high-resolution documentation of natural shoreline fluctuations, or it represents the beginning of a permanent decrease in shoreline stability. Understanding the nature of the observed change in shoreline change rates is important: The former can be explained as merely the result of a temporal bias in the dataset, but the latter indicates a new secular trend and, consequently, an imminent risk for the people who live on the affected islands (Nicholls and Cazenave, 2010; Nicholls *et al*., 2010).

Here we present for a remote atoll in the western tropical Pacific a comprehensive dataset of multitemporal shoreline

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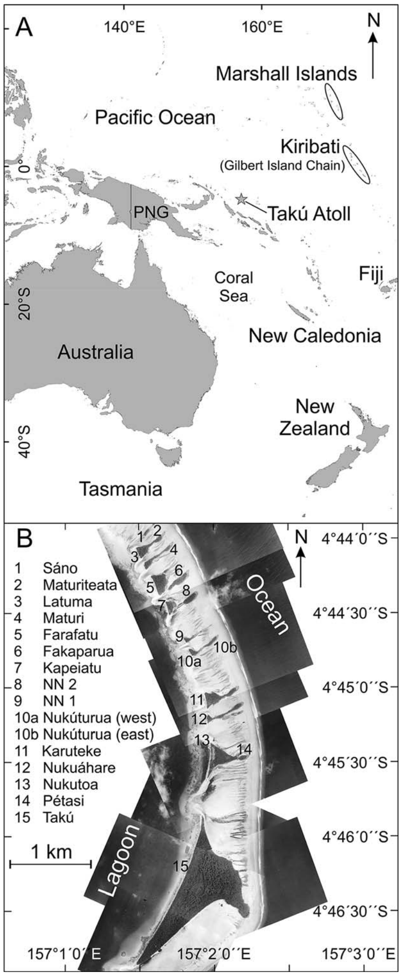

Figure 1. General setting and detailed view of the study site within the western Pacific region. (A) Location of Takú Atoll SW of Kiribati (Gilbert Island Chain) and the Marshall Islands in the western tropical Pacific; PNG: Papua New Guinea. (B) Georeferenced mosaic of aerial photographs illustrating the island setting on the eastern rim of Takú Atoll in 1943. Islands are numbered consecutively from 1 to 15 beginning in the north, and the corresponding names are listed beside. Unnamed islands are assigned with the acronym NN.

change rates over the period from 1943 to 2012. This study site was chosen because it provides the rare opportunity to analyze short-term rates of shoreline change from the early study period, and we want to compare these with short-term rates calculated over the satellite era. The aim of this paper is to show that elevated rates of shoreline change calculated from short-term measurements are not surprising when considered in the context of generally accepted geomorphological and sedimentological principles. This insight has implications for how we interpret the observations that will be generated by remote sensing studies to reliably evaluate reef island vulnerability with respect to changing boundary controls.

Study Setting

We analyzed multitemporal shoreline change rates on 14 islands on Takú Atoll, Papua New Guinea (4°45′ S, 157° E; Figure 1). The atoll is located outside the cyclone belt but has been affected by storm waves in December 2008 that caused severe erosional impacts on the islands vegetation line (Smithers and Hoeke, 2014).

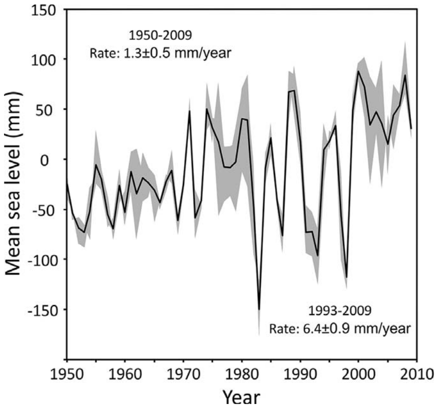

Figure 2. Recent-past sea-level reconstruction for Takú Atoll.

As reference for the local sea-level trend, we use the mean of an ensemble comprising three reconstructions developed by Meyssignac *et al*. (2012) based on satellite altimetry and data from two different Ocean General Circulation Models (DRAKKAR and SODA). Reconstructions indicate a rate of sea-level rise for the area around Takú Atoll of 1.3 ± 0.5 mm year^{-1} between 1950 and 2009 (Figure 2). Local sea level rose at a lower rate of 0.6 ± 0.8 mm year^{-1} between 1950 and 1993. From 1993 to 2009, the local rate of sea-level rise increased to 6.4 ± 0.9 mm year^{-1}. Superimposed on the rates of sea-level rise is a strong interannual variability of sea level (Becker *et al*., 2012). Higher average annual rates of sea-level rise in the tropical western Pacific since around 1990 are consistent with observations from satellite altimetry data (Cazenave and Le Cozannet, 2013; Nicholls and Cazenave, 2010) and may be influenced by a strengthening of trade-wind intensity (Merrifield and Maltrud, 2011).

METHODS

Planform shoreline changes have been identified by superimposing vertical aerial photographs from 1943 and satellite images from 1967, 2003, 2005, 2008, 2010, and 2012 (Table 1) using the software ArcGIS 9.3 (ESRI, 2009). The temporal sequence of this dataset includes multiple historical aerial photographs from 1943 that enable the calculation of short-term rates of shoreline change before the rate of local sea-level rise increased. The aerial pictures were available as a photo mosaic and were scanned at a resolution of 800 dpi. The digital files have been assigned with the coordinate system WGS 84 (UTM Zone 57S). Scanned aerial photos and the satellite image from 1967 were georeferenced according to uniformly dispersed natural and artificial ground control points visible on the remote imagery by a second-order polynomial transformation (Mann and Westphal, 2014). We used the edge of vegetation as datum for shoreline positions following the approach of several earlier studies (Ford, 2011, 2013; Webb and Kench, 2010; Yates

Table 1. *Summary parameters of remote sensing data used in this study.*

Aquisition Date	Image Type	Imaging Bands	Focal Length (in)	Altitude (ft)	Scale
18 September 1943	Aerial photograph b/w		6	2360	1:4720
			6	5000	1:10,000
11 December 1943	Aerial photograph b/w		24	10,000	1:5000
17 August 1967	CORONA		24		
20 September 2003	QuickBird	three bands pansharpened			
21 July 2005	QuickBird	three bands pansharpened			
13 May 2008	WorldView-1	Panchromatic			
30 October 2010	WorldView-1	Panchromatic			
10 November 2012	WorldView-2	three bands pansharpened			

et al., 2013). The shorelines were digitized manually by an individual operator, adopting the approach from Ford (2011, 2013) and Ford and Kench (2014).

Data Processing

For processing with the Digital Shoreline Analysis System (DSAS), a baseline was drawn onshore at a constant distance to the edge of vegetation. We then added the required columns (date, uncertainty) to the attribute fields of the shoreline vectors and converted the shapefiles (shorelines, baseline) to feature classes stored in personal geodatabases for each island (Thieler *et al*., 2009). DSAS casted transects perpendicular to the baseline, intersecting all shorelines for each island at an interval of 1 m. This close transect spacing was chosen because it is known from other studies that atoll islands can display highly dynamic planform changes in shoreline position (Ford, 2013; Webb and Kench, 2010; Yates *et al*., 2013). Thus, a larger spacing may have led to an undersampling of some sections. In total, we analyzed shoreline change rates along 12,258 transects.

Data Evaluation

Shoreline analysis from remotely sensed data comprises uncertainties related to natural influences and measuring inaccuracies (Fletcher *et al*., 2003; Moore, 2000; Thieler and Danforth, 1994). Thereby, errors are related to tidal fluctuations, seasonal variations, georeferencing, image resolution, and shoreline digitization. When we calculated the positional uncertainty of the shorelines, we adopted the method from Ford (2011, 2013) and included potential error sources attributable to georeferencing, image resolution, and shoreline digitization. Georeferencing errors are provided by ArcGIS, and the personal error related to shoreline digitization was determined by calculating the standard deviation in shoreline positions after the same shoreline section was repeatedly vectorized. The total positional uncertainty was calculated by extracting the square root of the sum of the squared values (Ford 2011, 2013) and ranged from 0.7 m to 5.2 m (Table 2).

Shoreline change rates are calculated from weighted linear regression (WLR) analyses for time intervals of 69 years (1943–2012) and nine years (2003–12). Linear regression analysis was processed at a 2σ confidence interval. For shorter time periods of two or three years (2003–05, 2005–08, 2008–10, and 2010–12), shoreline change rates are calculated from end-point measurements (EPRs). A number of reef islands on Takú Atoll provide the special opportunity to calculate shortest term shoreline change rates for a period of several months during 1943. These rates are also expressed as EPRs. The confidence intervals for the EPR values were calculated as the square root of the sum of the total positional uncertainties squared and then divided by the time difference between the two incorporated shorelines (Ford, 2013). Significant data, both WLR and EPRs, are characterized by confidence intervals with the higher and lower limits, positive and negative, respectively (Ford, 2011). In this study, only statistically robust data have been used for further analysis and interpretation.

RESULTS

Results present characteristic patterns of shoreline change that are illustrated exemplarily for Kapeiatu Island (Figure 3). Further attention is given to the respective rates of shoreline change calculated from observation intervals of different lengths. The personal geodatabases comprising shoreline data for all analyzed islands and time periods are available at the Data Repository PANGAEA (PANGAEA, 2015).

Table 2. *Summary of shoreline uncertainties.*

Image	Georeferencing (root mean squared; m)	Resolution (m)	Shoreline Digitzation (m)	Total (m)
18 September 1943	1.82–2.77	0.13–0.29	0.53–1.15	1.90–3.00
11 December 1943	0.61–2.57	0.24	0.51	0.83–2.63
17 August 1967	2.96	3.96	1.55	5.18
20 September 2003	0.63	0.60	1.06	1.37
21 July 2005	0.38	0.60	1.06	1.27
13 May 2008	0.37	0.50	0.53	0.81
30 October 2010	0	0.50	0.53	0.72
10 November 2012	0.26	0.50	0.53	0.77

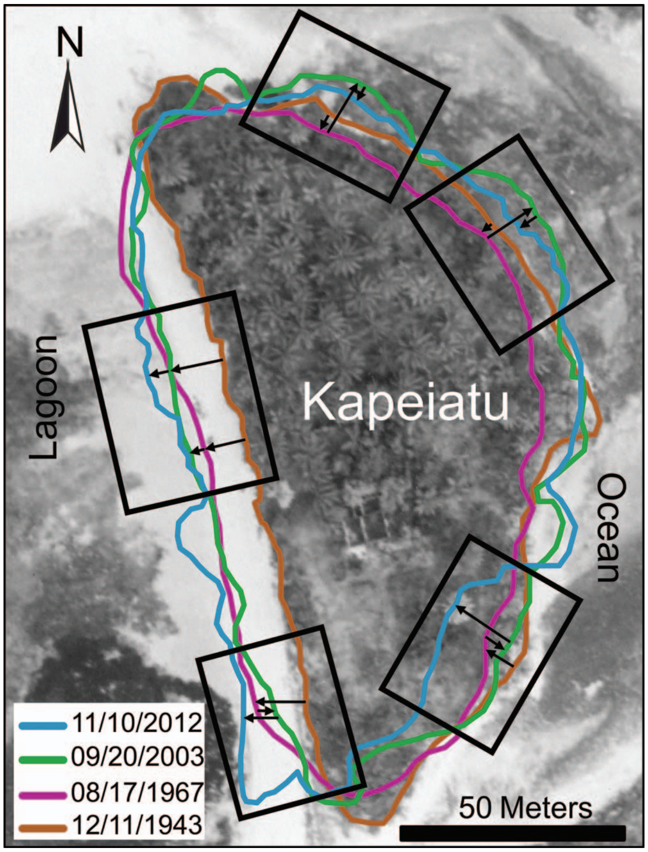

Figure 3. Styles of planform shoreline changes exemplified by Kapeiatu Island (see No. 7 on Figure 1B). The colored lines represent the edge of vegetation from different times (see legend). Note the lagoonward island accretion from 1943 to 2012 and the fluctuating shoreline sections indicated by arrows within the rectangles. For reasons of clarity, not all shorelines are depicted. For details on all shorelines of all islands and positional information on the transects, see Data Repository PANGAEA.

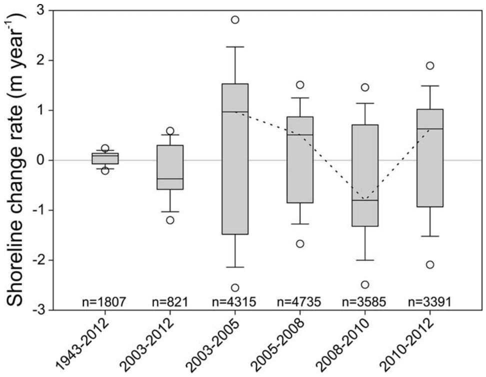

Figure 4. Statistical distribution of significant shoreline change rates for the different study intervals. Circles indicate the fifth and 95th percentile. Note the apparent increase of significant shoreline change rates for shorter time intervals from 2003 to 2012 and the fluctuation of the median shoreline change rate about zero, as indicated by the dashed line.

In the studied shoreline sections, dominant long-term trends such as lagoonward island migration over several decades are visible, but they are largely obscured by small-scale and high-frequency shoreline fluctuations that are superimposed on shorter timescales (Figure 3). Provided that the temporal difference is sufficient, these long-term trends may be identified if two datasets, *e.g.*, one historical aerial photograph and one recent satellite image, are compared. The recognition of shoreline fluctuations, however, requires several datasets over a relatively short period.

Results furthermore show that the magnitudes of shoreline change rates calculated from temporally variable observation intervals are distinctly different. For the longest time interval, in this study from 1943 to 2012, maximum significant WLR rates ranged from –1.04 ± 0.22 m year^{-1} to +0.65 ± 0.15 m year^{-1}, with an average rate of +0.06 ± 0.07 m year^{-1}. For a shorter time period from 2003 to 2012, WLR rates of shoreline change are substantially higher, with maximum values between –2.81 ± 1.04 m year^{-1} and +2.74 ± 1.62 m year^{-1} and an average rate of –0.25 ± 0.37 m year^{-1}. For time intervals of two or three years between 2003 and 2012, EPRs range from –6.92 ± 0.93 m year^{-1} to +7.54 ± 0.53 m year^{-1}. Two images from September 1943 and December 1943 (Table 1) are available for a subset of study islands (Nukutoa, Petasi, and Takú). Statistically significant EPRs for this three-month period of analysis range between –40.74 ± 8.90 m year^{-1} and +38.65 ± 8.90 m year^{-1} ($n = 5401$; 5th/95th percentiles). When all transects from the different time intervals are compared, it becomes clear that the likelihood of generating lower rates of shoreline change is much higher if long time periods in the range of decades are analyzed (Figure 4).

DISCUSSION

Differences between long- and short-term rates of shoreline change are consistent with the results from earlier studies (Forbes and Hosoi, 1995; Ford, 2013; Rankey, 2011). This indicates a systematic variability that is related to the length of the observation interval, assuming that reef islands (1) have not been repeatedly exposed to storm waves over the last decade of analysis and (2) have been equally dynamic over short timescales during the earlier periods of analysis. Recent short-term rates of shoreline change reach maximum values between 2003 and 2005 (Figure 4), a time interval where the atoll was not affected by high-energetic waves (Mann and Westphal, 2014; Smithers and Hoeke, 2014). Testing the second hypothesis requires multiple relatively closely spaced records from the 1940s to 1950s, a difficult prerequisite owing to the limited availability of remote sensing data from the 20th century (Ford, 2011; Ford and Kench 2014); however, our temporal record allows for the detection of (unrealistically) high rates of short-term change from September 1943 to December 1943. The documentation of high-frequency shoreline changes before the recent acceleration of the rate of sea-level rise and the detection of high rates of change that are independent from high-magnitude events strongly corroborate the idea of a systematic variability that is linked to the temporal selection of imagery rather than extrinsic causes. Knowledge about the dynamics of past and present reef-island shorelines (Figure 3) as observed from multiple remotely sensed datasets is necessary to interpret within a geomorphological context the observed variability of shoreline change rates over time.

The Integration of Reef Islands into Geomorphic Systems Theory

Open geomorphic systems are structures of interacting morphologic (landform) and cascading (material and energy flow) components with a permanent supply of energy through external inputs (Chorley, 1962; Chorley, Schumm, and Sudgen, 1984; Schumm and Lichty, 1965). In this way, reef systems are good examples of process-response systems that include morphologic (reef island, reef flat, and reef crest) and cascading (waves, currents, and sediments) components. Each of the morphologic components is itself an open system. Each has its own morphological characteristics, and each characteristic is linked to the surrounding systems by a functional interdependency.

Varying inputs of external energy (*i.e.* fair-weather *vs.* storm conditions) control the cascading components on the reef flat. For example, during a storm, wave energy may be sufficient to break corals from seaward reefs or erode shorelines. Wavelength and -height and current velocity are modified across the reef flat and affect the geomorphic development of reef islands (Kench and Brander, 2006a). Changes in island form can be considered as a morphological response to a change in energy input and the related supply or release of material (sediment). Bayliss-Smith (1988) suggested different styles of island shoreline change depending on the island sedimentary composition and storm frequency. Sediment grain size of reef islands is determined by the mean energy that reef systems are exposed to (*e.g.*, in- or outside the storm belt) (Stoddart and Steers, 1977). Takú Atoll is located outside the major storm belts, and, accordingly, study islands comprise mainly sand-sized sediments (Smithers and Hoeke, 2014). An immediate geomorphic response of the study islands to a low-frequency high-magnitude event was detected by Smithers and Hoeke (2014) and fits well to the conceptual model of sandy reef islands presented by Bayliss-Smith (1988).

Thus, reef islands, like any geomorphic process-response system, are permanently in pursuit of a system state that is (1) in accordance to the prevailing energy input and (2) can be maintained by negative feedback processes interacting between the morphologic and the cascading components, a state that is referred to as geomorphic equilibrium (Chorley, Schumm, and Sudgen, 1984). For reef islands, the equilibrium concept implies that any changes in the cascading components, not necessarily resulting from high-magnitude events but also resulting from any subtle changes, *e.g.*, in the monsoon wave climate on the surrounding reef flat, are morphologically expressed by changes in island size, shape, and location on the reef flat (Bayliss-Smith, 1988; Kench and Brander, 2006a; Kench *et al.*, 2006; McLean and Woodroffe, 1994). Of particular importance, morphologic changes are not necessarily accompanied by net volumetric changes but rather by different rates of change over time (Ford and Kench, 2014; Kench and Brander, 2006b; Kench *et al.*, 2009; Kench, Parnell, and Brander, 2009; Webb and Kench, 2010).

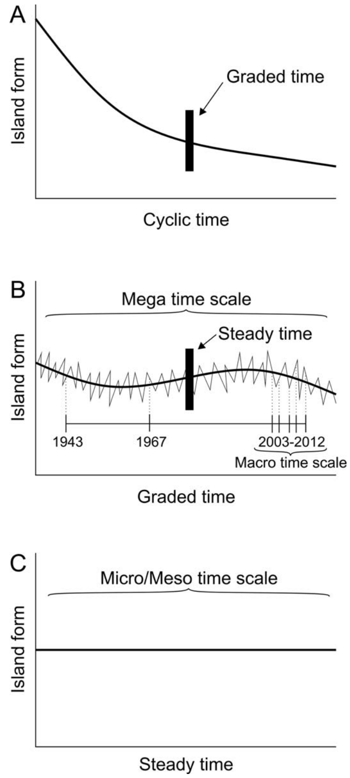

Figure 5. Different types of geomorphic equilibria proposed for changes in reef-island form over (A) cyclic, (B) graded, and (C) steady time spans. Depending on the temporal perspective within graded time, reef islands may display shoreline stability over megatimescales or apparent instability over macrotimescales. Thus, comparative timescales need to be studied to extract whether an increase in erosion is taking place (adopted and modified from Carter and Woodroffe [1994]; Chorley, Schumm, and Sudgen [1984]; Kraus, Larson, and Kriebel [1991]; and Schumm and Lichty [1965]).

Importance of Timescales in Coastal Geomorphology

For a complete interpretation of coastal landform evolution, three time spans of different duration must be considered (Chorley, Schumm, and Sudgen, 1984; Schumm and Lichty, 1965). The longest of these time spans is referred to as cyclic time and comprises a complete cycle of erosion taking place within an extended period of approximate sea-level stability without meter-scale oscillations, for example, the Late Holocene. For coastlines, therefore, cyclic time may encompass a time span in the range of millennia (Cowell and Thom, 1994). Over cyclic time, reef islands may be considered to be in dynamic or dynamic metastable equilibrium with respect to changes in island form over time (Bayliss-Smith, 1988; McLean and Woodroffe, 1994). In a dynamic equilibrium, the morphologic characteristics of the system continuously change, and the island form oscillates about a trending mean value (Figure 5A). The trend itself is caused by external mechanisms perhaps including shifts in wind and wave climate and minor changes in sea level. A continual change in the position of islands on the reef flat (*e.g.*, lagoonward migration) is commonly manifested by the exposure of beachrock (Stoddart and Steers, 1977), which could be considered as the morphological expression of this trend during cyclic time.

During periods of graded time, *i.e.* a shorter period within the cyclic time span, progressive change of landforms is often masked by a series of fluctuations about a mean condition (Chorley, Schumm, and Sudgen, 1984; Schumm and Lichty, 1965). For coastal morphological changes, the graded time is in the range of decades to centuries (*i.e.* megatimescale *sensu* Kraus, Larson, and Kriebel [1991]). This time span is of particular importance for the interpretation of shoreline change rates on reef islands, as it corresponds approximately to the period that is recorded when historical and recent shoreline data are compared. When considered over graded time, reef islands achieve a steady-state equilibrium where the continual change that is seen during cyclic time (*e.g.*, lagoon migration) is largely superimposed by short-term shoreline fluctuations (Figure 5B). Fluctuations in island form over graded time are caused by continuous adjustments of the morphological components of reef systems to the varying supply of external energy and/or material.

Ultimately, during the shortest period of steady time comprising some hours or days, landforms are in static equilibrium (Chorley, Schumm, and Sudgen, 1984). In a static equilibrium, the morphologic components of the geomorphic system do not change provided that the external input of energy and/or material remains constant (Figure 5C). Shoreline positions of reef islands analyzed over a steady time span will show no change in the absence of high-magnitude events such as hurricanes or storms. Rapid changes resulting from such high-magnitude events are followed by progressive adjustments of the morphologic components over graded time (Bayliss-Smith, 1988; Ford and Kench, 2014; McLean and Woodroffe, 1994).

Availability of Remote Sensing Data and Its Proposed Influence on the Calculation of Shoreline Change Rates

Considerations of the changes in island form during graded time and the temporal distribution of remote sensing data are essential if we are to understand why shoreline change rates based on long- and short-term measurements show apparent variability. A similar scaling variability has been reported in sedimentological studies where a systematic, inversely proportional relationship between sedimentation rates and the time span of observation is obvious (Sadler, 1981; Tipper, 1983). This dichotomic scaling is explained by the pulsating nature of sedimentation that is, in turn, related to geomorphic variables, as, for example, in a fluvial process-response system (*e.g.*, relief, discharge of water, channel gradient). Unsteady and episodic sedimentation processes result in hiatuses, condensed sections, and, when erosion is involved, unconformities. The longer the observation interval, the more likely it is that periods of erosion or nondeposition are included in the analyzed sedimentary succession. If the presence of these lacunae is not recognized (*e.g.*, due to missing biozone markers), the average sedimentation rate automatically decreases (Schlager *et al.*, 1998).

Following this logic, it is therefore obvious that long-term analyses of shoreline change will cover longer periods of naturally occurring shoreline fluctuations. Unfortunately, the limited availability of remote sensing data (*cf.* biozone markers) from the 20th century is often not sufficient to record the high-frequency shoreline oscillations. Consequently, long-term rates of shoreline change (in this study from 1943 to 2012) will reflect the proposed steady-state equilibrium during graded time, which is why they approximate to a value close to zero (Figures 4 and 5B).

Shoreline changes on reef islands are a function of multiple parameters, including sedimentary island composition and storm frequency (Bayliss-Smith, 1988; Stoddart and Steers, 1977), sediment production, transport, and redistribution (Dawson, Smithers, and Hua, 2014; Kench and Cowell, 2000; Yamano, Miyajima, and Koike, 2000) and probably depend on different island evolutionary stages (Perry *et al.*, 2013). The relative importance of each of these parameters likely varies between individual atolls, and, consequently, the frequency and magnitudes of short-term shoreline changes may differ locally. The documentation of recent shoreline changes with high temporal and spatial resolution, however, has been facilitated by the increasing availability of remote sensing data (mainly satellite images) since the 21st century (Ford, 2013) on a global scale. As we have shown, short-term analysis covering a few months or years (*i.e.* macrotimescale *sensu* Kraus, Larson, and Kriebel [1991]) is more likely to document individual displacements of fluctuating shoreline sections, and the resulting rates of change are correspondingly higher (Figures 4 and 5B). Consequently, we hypothesize that the concept of a time-dependent island equilibrium presented herein is valid for other reef islands in different settings, with different primary sediment-producing taxa, and on islands in different stages of their geomorphic development.

CONCLUSIONS

The interpretation of remote sensing data is an effective way, indeed often it is the only way, to reveal potential links between shoreline changes on reef islands during recent decades and sea-level rise. Given the high diversity of natural processes and anthropogenic activities potentially affecting the coastlines of small tropical islands, the Intergovernmental Panel on Climate Change warns that the scope of empirical monitoring needs to be extended to identify (or infer) the type and source of changes observed (Nurse *et al.*, 2014). With the ongoing declassification of historical data and the increasing availability of high-resolution satellite images, remote sensing studies are expected to make the biggest contribution to all future monitoring programs. We point out that such studies are likely to uncover differing rates between long- and short-term measurements. We suggest, however, that these differences can be explained as an outcome of the natural shoreline fluctuations of dynamic reef islands that tend toward an equilibrium state over graded time spans.

The need will soon arise to reconcile rates of shoreline change with increasingly dominant narratives, especially in the media, about the vulnerability of reef islands to both climatic, sea-level, and anthropogenic stressors. Because short-term rates calculated from macrotimescales may also mimic an increase in shoreline erosion, we argue that the temporal perspective is a critical element in any accurate interpretation. Only an explicit awareness of various processes operating over various timescales can prevent major errors in our interpretations of short-term observed changes in coastal (and other) landforms.

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