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Assessing atoll shoreline condition to guide community management

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ABSTRACT

Resilience assessment allows targeted management, and many low Pacific island atolls have no baseline condition data or monitoring, and are threatened by sea-level rise. Ecological resilience is a useful management concept where an ecosystem risks losing its ability to recover, potentially driving itself to an undesirable state, which for atoll shorelines is beach erosion without recovery, and mangrove dieback. This study used spatial change analysis to assess resilience condition indicators for lagoon shore habitats of an atoll protected area, methods developed in the region to facilitate improved community based assessment and management decision making. The lagoon shore was the focus, being potentially more vulnerable to human impacts owing to higher population densities, and potentially more vulnerable to relative sea level rise owing low gradients and elevations. Results showed mangrove vegetation to be in healthy condition, and spatial analysis of coastal change found that the mangrove area expanded 1998–2013, increasing by 17%, at a rate of 604 m^2 per year. Results from the southern beach coast showed littoral vegetation to be in poor condition, with profile evidence of recent erosion, confirmed by spatial analysis results of loss of a previous progradation trend. Spatial analysis results therefore confirmed the veracity of community methods for assessing mangrove and beach condition, allowing confidence in their use in assessment of resilience state and rehabilitation needs. Sediment supply is helpful to coastal resilience, and analysis of beach sand found it to be 99.9% carbonate, derived from foraminifera and fragmented shell and coral, and continued supply is essential to maintain resilience. Beach sediment from such biogenic sources is derived from offshore reefs, making resilience assessment and monitoring of those habitats a further priority. Suitable timeframes are needed for managers to assess resilience, necessitating a need for longer term monitoring projects in the region.

1. Introduction

Ecological resilience assessment helps prioritise and target management action (Maynard et al., 2015), and in coastal rural areas, a robust ecosystem can provide the best possible resistance to coastal hazards (DasGupta and Shaw, 2015). Ecological resilience is recognised as the capacity of natural systems to absorb disturbance without changing function, structure and identity (Holling, 1973), a concept evolved to apply beyond ecology to socio-ecological systems, and community, urban and disaster resilience (Davidson et al., 2016), and extended applications to environmental management and policy (Müller et al., 2016). Several disturbances on different timescales such as climate change and weather events may be influencing the state of an ecosystem at any one time, leading to challenges in use of indicators to characterise resilience (Müller et al., 2016).

The IPCC Fifth Assessment confirmed the high level of vulnerability of small islands to multiple stressors, both climate and non-climate (Nurse et al., 2014). There is now wide acceptance of their exceptional vulnerability to future climate change (Nunn, 2009; Pala, 2014; Nunn et al., 2014), and sea level rise poses one of the most widely recognised climate change threats to the low lying coastal areas of islands (Nurse et al., 2014). Pacific islanders remain largely dependent on foods obtained from local terrestrial and nearshore resources (Nunn et al., 2014), requiring environmental resilience, and community level management requires the empowering of traditional leaders in making informed decisions (Nunn, 2009; Nunn et al., 2014). It is challenging in the Pacific islands to build resilience or accommodate change given the size of land, reliance on natural resources, and the size and vulnerability of their economics (Jupiter et al., 2014). There are many programs working to build resilience of Pacific island communities, based

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Table 1
Resilience indicators for mangroves and beaches. Sources: Thom and Hall (1991); English et al. (1997); Ellison et al. (2012, 2015); Ellison (2015).

Indicator	Mangroves	Beaches
Vegetation condition	Even canopy of trees with no gaps. All species producing seedlings. Low mortality, high productivity.	Even littoral tree canopy with no gaps. Intact shrub, herb and vine ground coverage of the upper beach.
Topography	Mangrove ground surface profile is level to slightly convex-up. No scarps.	Beach profile surveyed perpendicular to the shore is convex-up. High tides do not reach the vegetation edge. No scarps.
Spatial change analysis	No seaward edge retreat as delineated by the mangrove canopy margin. No reduction in mangrove area.	No seaward edge retreat as delineated by the beach vegetation margin. No reduction in land area.
Sediment supply	Surplus sediment supply. Adjacent coral reefs and seagrass in good condition.	Surplus sediment supply. Adjacent coral reefs and seagrass in good condition.
Human impacts	No or minimal impacts, such as cutting of trees, wetland infill, human infrastructures, sand mining.	No or minimal impacts, such as mining of sand, trampling of ground vegetation cover, pigs digging up tree roots.

on many enabling conditions and the severity of climate impacts experienced.

Compiling and applying resilience indicators will help climate change adaptation decisions, where direction and rate of change in protected areas is a key resilience indicator (Engle et al., 2014). Ecological resilience is a useful management concept where an ecosystem risks losing its ability to recover, potentially driving itself to an undesirable state (Mumby et al., 2014). Resilience may be measured as the probability that a given state persists over a time period (Drever et al., 2006), and in the case of atoll shorelines, an undesirable state is beach erosion without recovery, and mangrove dieback and retreat without recovery. While few efforts exist to operationalise indicators with respect to resilience (Engle et al., 2014), with little focus on the metrics and indices that describe elements of resilience (Van Looy et al., 2016), coral reef resilience assessment has developed indicators and methods (McClanahan et al., 2012; Mumby et al., 2013; Maynard et al., 2015). Reefs are critical components of atoll shores, however, there have been no developments for mangrove and atoll beach shorelines of practical ways to assess resilience which can target appropriate actions.

Pacific island countries that submitted National Communications to the UN Framework Convention on Climate Change highlighted their gaps in knowledge regarding responses of coastal ecosystems such as mangroves to climate change effects (Gilman et al., 2006a). Limited capacity was identified for information on mangrove monitoring and assessment, mangrove rehabilitation, and spatial analysis of mangrove loss or advance (Gilman et al., 2006a, 2006b). The Secretariat of the Pacific Regional Environment Program (SPREP) subsequently developed guides to facilitate the condition assessment of mangroves and beaches, allowing identification of rehabilitation and management needs (Ellison et al., 2012, 2015), with the objectives of enhancing resilience. These are directed at community levels, to facilitate improved local area management and adaptation capacity, which is an increasing need in traditional communities facing climate change (Adger et al., 2013; Nunn et al., 2014). Effective adaptation requires that community-level decision makers are given the knowledge and the right tools to make informed decisions about environmental management (Nunn, 2009).

While vulnerability and ecological resilience measure fundamentally different properties of a system (Mumby et al., 2014), vulnerability can be more readily quantified through identification of dimensions, components and their respective measurements (Ellison, 2015). Low vulnerability ranking indicates high resilience (Ellison, 2015), particularly in dimensions of potential system sensitivity and descriptors of pristine or unimpacted mangroves and beaches. Resilience indicators for beaches and mangroves, as complied from sources, are summarised in Table 1.

The aims of this study were to use spatial change analysis to assess the veracity of resilience condition indicators for lagoon shore habitats of an atoll protected area, to facilitate improved community based assessment and management decision making. The lagoon shore was the focus for the study, being potentially more vulnerable to human impacts owing to having higher population densities, and potentially more vulnerable to relative sea level rise owing low gradients and elevations. Poor mangrove condition as a result of human impacts results in area loss and seaward edge retreat, a trend recently prevalent for mangroves worldwide (Valiela et al., 2009), and good mangrove condition is shown by spatial area stability or increase (Ellison, 2015). Poor beach condition as a result of impacts results in beach erosion and concave profiles, whereas good beach condition brings accretion and convex profiles (Thom and Hall, 1991; Bird, 2008; Johnston and Ellison, 2014). We assessed mangrove and beach condition, and sediment characteristics of the beach to allow identification of sediment sources and capacity for continued sediment supply, and compared results with long term change analysed from spatial analysis of the shoreline over the previous 15 years.

2. Methods

2.1. Study area

The Republic of Kiribati has a land area of 811 km^2 in an ocean area of over 3.5 million km^2. The capital atoll, Tarawa has 48% of the population living on South Tarawa (Duvat et al., 2013) on a land area of 15.6 km^2 (Fig. 1). The more isolated North Tarawa has an area of 10.4 km^2 (Duvat, 2013), with 13% of the national population (Duvat et al., 2013). All of the country is <10 m above sea level, and furthermore the majority is <3 m (Duvat, 2013).

Kiribati has a mangrove area of 2.58 km^2 (Spalding et al., 2010), only found in the western islands of the Gilbert group. Mangroves are one of the worlds' most critically threatened ecosystems, with extensive losses due to direct human impacts (Valiela et al., 2009). Mangrove areas in the Pacific islands are of high proportions relative to total land areas, such as 12% of the Federated States of Micronesia, and 10% of PNG and Palau. Mangroves provide significant benefits for Pacific people including shoreline stabilisation, improvement of lagoon water quality, a protective buffer to wind and waves, and a source of resources for local communities (Ellison, 2009a). The associated fishery resources of mangrove ecosystems provide a major source of daily protein (Seidel and Lal, 2010).

On South Tarawa, mangroves have been lost to development (Duvat et al., 2013), though recent planting of *Rhizophora stylosa* in sheltered waters of the lagoon's eastern shore has been successful (Suzuki et al., 2009; Baba, 2011). Other mangrove planting sites have failed, where shallow pools of water at low tide may become overheated, causing propagules to die (Baba et al., 2009). After Kiribati became a signatory to the Ramsar Convention in 2013, its first Ramsar site was gazetted at Nooto in North Tarawa (Fig. 1). This 1033 ha site includes windward and leeward coasts of the atoll, with mangrove and beach shorelines, and is habitat to a num-

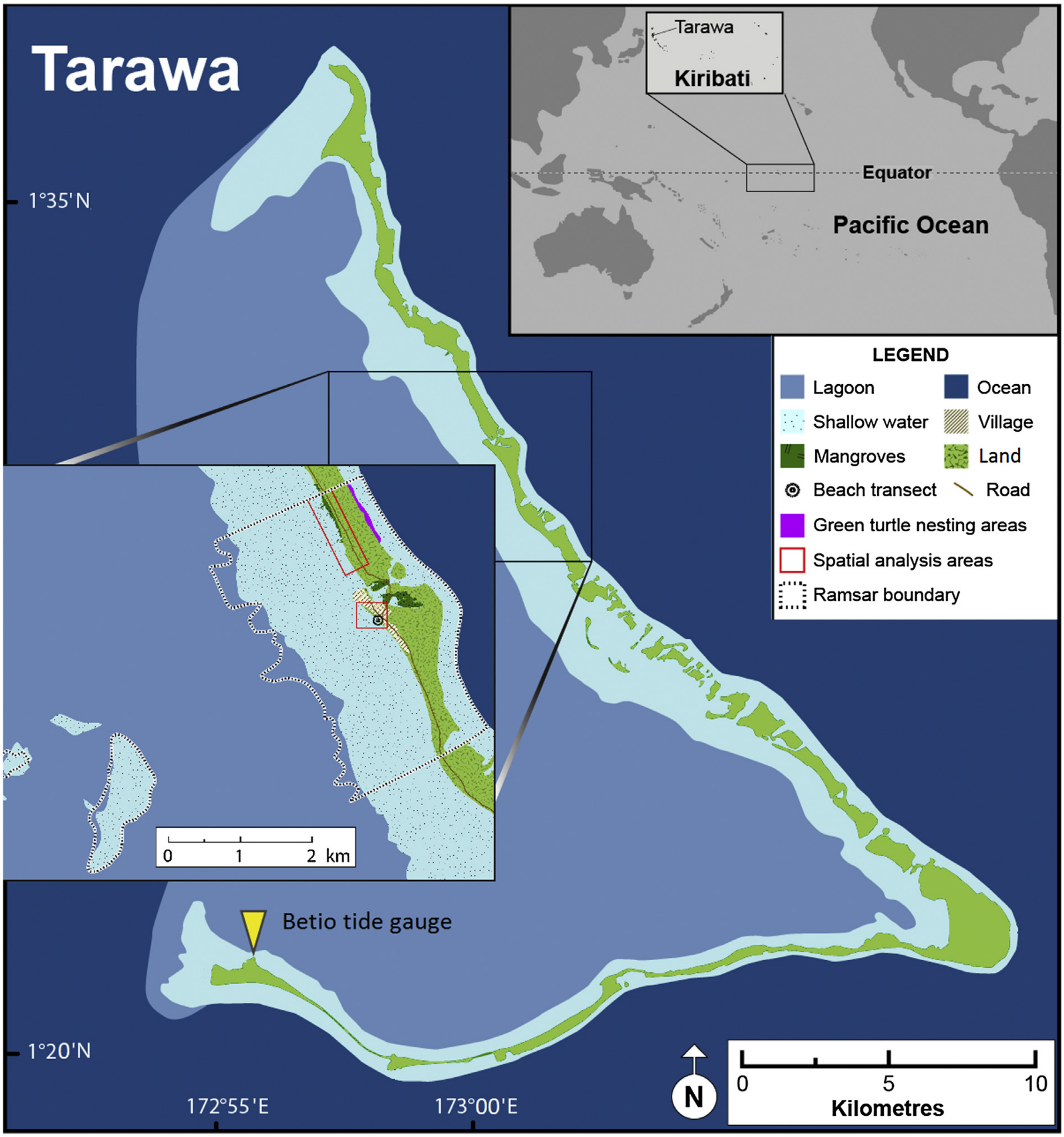

Fig. 1. Map of Tarawa atoll, Kiribati, locating the Nooto Ramsar site, and locations of spatial analysis areas and beach survey transect.

ber of rare and threatened wetland species (Teariki-Ruatu, 2013). Beaches have important values for local communities, such as for fishing, tourism, recreation, and low tide gathering and gleaning. Pacific island communities have traditionally maintained a vegetation fringe along the shoreline, to protect village infrastructure from the sea, and where this is maintained shoreline erosion issues have been lower relative to locations where it has been lost (Mimura and Nunn, 1998).

2.2. Spatial analysis

Spatial analysis of coastal change was conducted for the northern mangrove lagoon shoreline, and the southern beach adjacent to Nooto village (Fig. 1), to evaluate historical change of the shoreline over a fifteen year period spanning 1998–2013. Three datasets were used for the analysis (one of aerial photography and two of satellite imagery) including the earliest and the most recently available data (Table 2). Satellite images were selected based on image resolution and lack of cloud cover, to optimise accuracy during the rectification and digitising processes.

Analysis was conducted using ArcGIS, with the 2013 image used as the base image, having the highest resolution and being most recent. Ground Control Points (GCP) were chosen for the rectification process based on features present in the 2013 imagery that were persistent throughout the fifteen year period. A shapefile was generated in ArcGIS and cultural features that remained stable over the full period, such as building edges and fish trap corners as found useful by other atoll spatial change studies (Ford, 2011; Yates et al., 2013), were digitised as GCP reference points. In some areas where no persistent features existed, GCP points were chosen based features such as the centre point of beachrock outcrops, as used for spatial analysis of other atolls (Ford, 2013). At least 6 control points

Table 2
Datasets used for spatial analysis.

Imagery	Year	Scale/resolution	Transformation	Ground Control Points	Root Mean Square error values
Aerial photographs	1998	1: 2500	1st Order Polynomial	6	0.76394
Ikonos-2	2003	<1–4 m	1st Order Polynomial	11	1.13253
Worldview-2	2013	<1–2.6 m	Base image		

were used in each image, to minimise effects of distortion and error (Biribo and Woodroffe, 2013), and the 1998 and 2003 images were rectified to the 2013 image using the GCP shapefile. Although positional accuracy was reduced due to errors introduced through the use of a variety of images captured at different resolutions and angles, and the use of GCP's based on variably permanent features, the georeferencing Root Mean Square error values (Table 2) were however adequate for the scope of this analysis (Federal Geographic Data Committee, 1998).

The seaward edge of vegetation was used to define the island shoreline, being the most reliable long term indicator of beach stability (Ford, 2011). The shoreline was digitised as new line-based vector layers for each of the time series within ArcGIS, with additional digitisation of mangrove area coverage as polygon-based vector layers, resulting in multiple vector map layers within the dataset. A tolerance of ten metres between mangroves was selected based on mangrove density and distribution in order to determine the area included within a singular polygon. The shoreline maps were then converted to polygons so that land area within an arbitrarily defined map extent, consistent over the three time series, could be calculated to indicate shoreline change.

2.3. Mangrove and beach surveys

In the Pacific Regional Wetlands Action Plan for the Pacific Islands (SPREP, 2011) endorsed by the 26 member countries, three actions identified the need for scientific monitoring of mangroves in the region. Mangrove condition assessment was carried out using methods of the subsequently developed SPREP Mangrove Monitoring Manual (Ellison et al., 2012), based on the ASEAN-Australia Manual (English et al., 1997), allowing reconnaissance and re-survey by community groups to identify impacts and prioritise management objectives. Criteria include mangrove canopy cover, recruitment evidence of seedlings and young trees, and evidence of mortality and human impacts. Transects were surveyed perpendicular to the coast, mangrove zone width measured, and mangrove condition assessed on a 6 point scale from none to severe impacts (Ellison et al., 2012).

Beach assessment was undertaken using methods of the SPREP Beach Rehabilitation Guide (Ellison et al., 2015), using criteria of ground, shrub and canopy vegetation condition, beach profile shape, where convex-up indicates accretion and concave-up indicates erosion (Thom and Hall, 1991; Bird, 2008), and evidence of human impacts. This guide helps local communities to understand the pressures people may place on beaches, such as by vegetation trampling, and other activities that exacerbate erosion, and condition is assessed on a 6 point scale from none to severe impacts (Ellison et al., 2015).

The beach adjacent to the Nooto village was <1 km in length, and with uniform characteristics, and a profile was surveyed in the centre (Fig. 1) (N 01°30.898 E 173°00.438), using an automatic level, secured to a permanent point. Water level at a recorded time at the seaward end of the survey was incorporated into the survey. This elevation was compared with the tidal level recorded at that time on the tide gauge at Betio (Fig. 1, c. 16 km to the south), in order to adjust the beach profile to mean sea level datum. For the Betio tide gauge, the Seaframe Tide Gauge Zero 1992 (STGZ92) is MSL −1.637 m (Tonkin and Taylor International Ltd, 2013).

2.4. Sand analysis

To investigate sediment sources, sand samples were collected at regular distances from the upper beach to the lower beach across the narrow beach section of the surveyed profile. Replicated surface samples were collected at 10 points on each side of the profile, each 10 cm apart.

Samples were gamma irradiated on entry to Australia, then oven dried at 60 °C. Cascade sieves with apertures ranging from 0.063 to 4.00 mm were used to separate size fractions. Each fraction was weighed and a frequency distribution histogram and cumulative frequency curve were constructed for each sample. Grain size was described using log transformation to the phi scale, which simplifies statistical descriptions (Krumbein, 1938), and particle size dimensions were classified according to the sediment textural classifications and statistics of Folk (1966, 1980).

The mineral composition of the beach sand was analysed from the proportion of dissolution of a 100 mg sub-sample in concentrated HNO_3 acid, followed by the filtration and weighing of any residue, following Pilkey et al. (1967) and the APHA method 208.D: Total non-filterable residue dried at 103–105° (Rand et al., 1976). Sources of the sediment grains were identified from microscopic observation of samples using an Olympus SZ40 microscope, at magnifications ranging from X6.7-40, and the percentage of foraminifera, coral, gastropod and bivalve shells and shell fragments determined by comparison with reference sources (Carpenter and Niem, 1998; Wilson, 2013) and a reference collection.

3. Results

3.1. Spatial analysis

GIS results showed the northern lagoon mangrove area to have expanded and prograded seawards 1998–2013 (Fig. 2A). The mangrove area increased by 16.7% over that period, to 6.32 ha in 2013. Some sections that were previously mangroves become littoral forest, indicating the sediment accretion functions of mangroves. Mangroves extended offshore to increase mangrove area at a rate of 604 m^2 a^{-1}, gaining an average of over 1 m^2 per day 1998–2013.

The beach shoreline behind the mangroves in the north of the Ramsar site prograded over the 15 year period in the central section of the area analysed (Fig. 2B), and remained stable to the north and south. Near to the southern margin of the major area of mangroves at N 01°31.663 E 173°00.046, beach progradation seawards was at a rate of about 3 m a^{-1}.

Spatial change analysis results from the village lagoon beach showed that this section of the coast was overall stable in the last 15 years (Fig. 3), with a 0.88% land loss 1998–2003, and a 1.01% gain 2003–2013, to total just an 0.39% overall gain 1998–2013.

3.2. Mangrove condition

The north-western section of the Ramsar site (Figs. 1 and 2) featured mangrove and beach habitats, with occasional beachrock on the shore. Results from north to south are shown in Table 3. The wetland consists of *Rhizophora stylosa* of up to 6 m in height, with denser trees extending 20– >60 m from the beach. Offshore man-

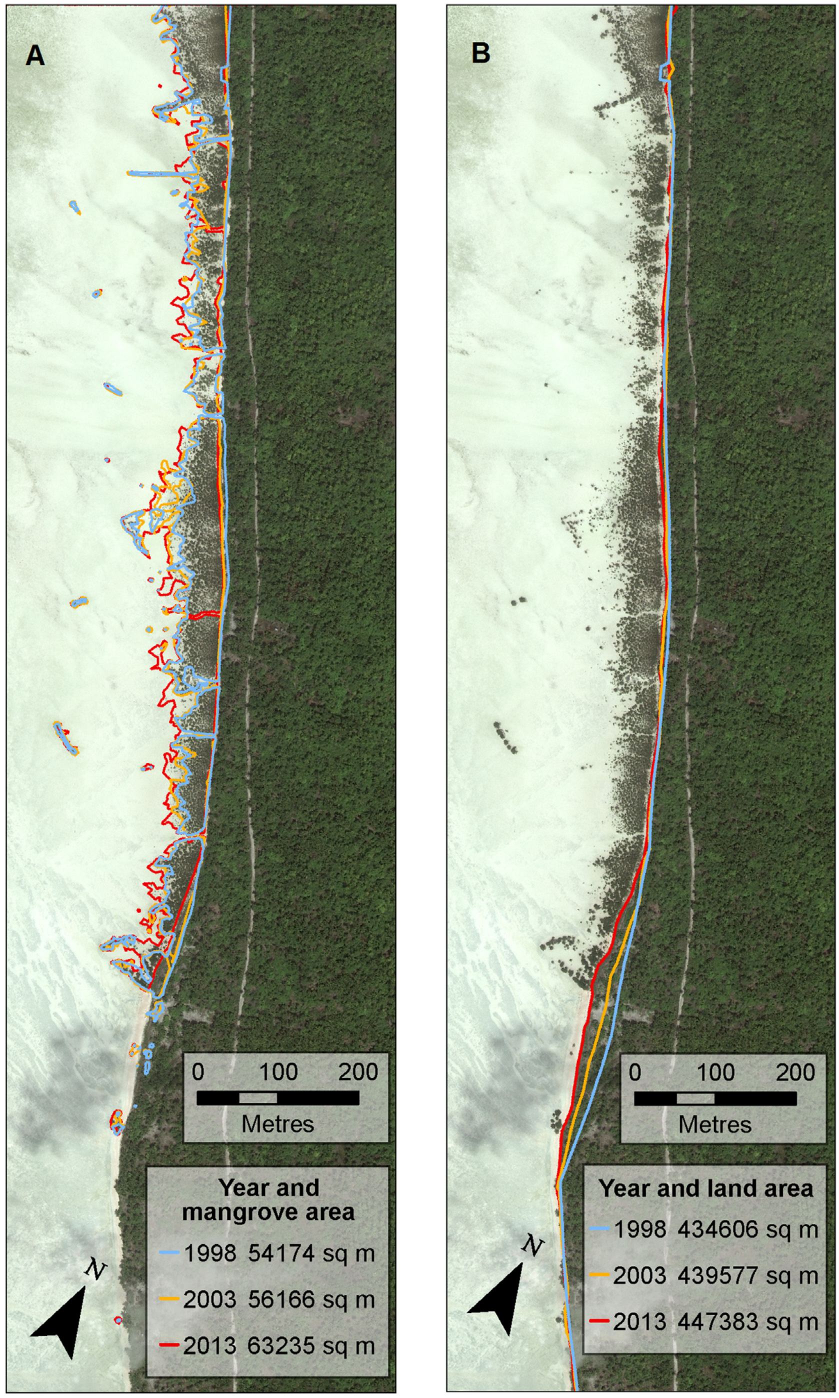

Fig. 2. Spatial analysis results of shoreline change 1998–2013 of the northern lagoon shore of the Nooto Ramsar site (Fig. 1). The background image is from 2013 (Worldview-2), and the land area calculations are based on the land area shown in each image. A) Change over time of the mangrove area. B) Change over time of the beach shoreline.

groves feature narrow lines perpendicular to the shore, or in curved polygonal shapes, which may be owing to mangrove colonisation of former fish traps (Fig. 2; Table 3). At the southern margin of this mangrove wetland, about 1000 seedlings of *R. stylosa* were planted at the initiative of a family in 2008, having learned from the mangrove planting to the south in 2007, and successfully planted and maintained mangrove seedlings to assist in coastal protection.

3.3. Beach condition

Along the beach shoreline behind the northern mangroves (Fig. 2B), beaches showed good condition, with an even littoral canopy, intact herb and vine coverage of the upper beach, and the profile convex-up in shape. There was no evidence of human impacts in terms of disturbance to littoral vegetation.

By contrast, beach condition on the southern lagoon (Figs. 1 and 3) showed moderate human impacts, including human trampling of vegetation, pigs tied to trees causing disaggregation and erosion, sand mining hollows, and solid waste. The beach littoral canopy was broken, and herb and vine coverage of the upper beach was patchy. The beach shape showed flat to concave-up profiles (Fig. 4), and was narrow, with the high tide mark close to the top of the beach slope. Offshore was evidence of previous mangrove planting efforts, with 4000 hypocotyls planted

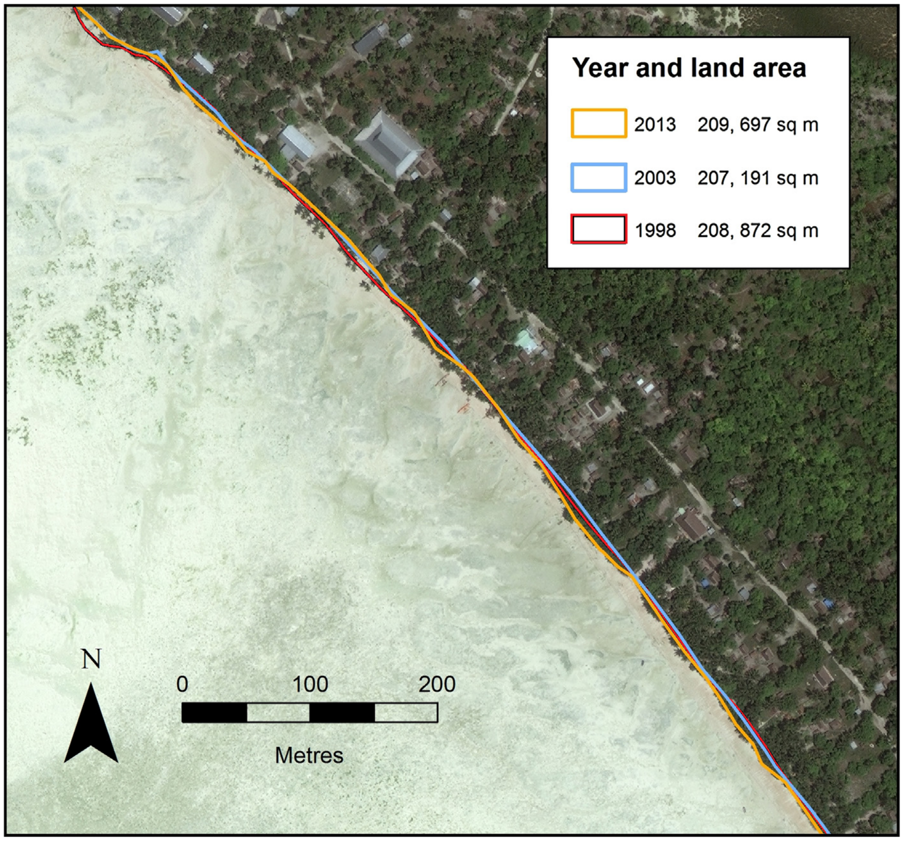

Fig. 3. GIS analysis of shoreline change 1998–2013 at the Nooto Ramsar site southern lagoon shore beach, of the southern area shown in Fig. 1. The background image is from 2013 (Worldview-2), and the land area calculations are based on the land area shown in the image.

Table 3
Mangrove extent and condition at the Nooto northern lagoon shore, from north to south, assessed using methods of the SPREP Mangrove Monitoring Manual (Ellison et al., 2012).

Location	Species present	Mangrove width (m)		Condition	Impact type Observations
		Dense	Scattered		
N 01°32.571 E 172°59.657	*Rhizophora stylosa*	62	0	0: No impact	North of the Ramsar site boundary
N 01°32.231 E 172°59.743	*Rhizophora stylosa*	30	55	2: Moderate impact	Cut pathway, c. 30% mortality of seaward edge mangroves
N 01°32.161 E 172°59.820	*Rhizophora stylosa*	20	35	1: Slight impact	c. 10% mortality of seaward edge mangroves
N 01°31.750 E 172°59.917	*Rhizophora stylosa*	24	131	0: No impact	Group of taller *Rhizophora* Trees 100 m offshore of the dense mangrove margin
N 01°31.663 E 173°00.046	*Rhizophora stylosa*	20	60	0: No impact	Successful mangrove planting to the south

in 2007-8. These developed into seedlings with leaf growth, but then suffered near 100% mortality (Fig. 4).

3.4. Beach sand analysis

Grain size results showed beach sand to have biomodal distributions on the lower beach profile (Fig. 5, Table 4), and was poorly sorted throughout. The finer upper beach samples showed a smoothly arched cumulative frequency curve (Fig. 5B), whereas the lower beach samples show a mid-curve hollowing, which is indicative of a mixture of two different sediment types (Spencer, 1963). This trend therefore represents a sudden change to another dominant size class, as shown in the bimodal distributions of these two samples (Fig. 5B).

The beach sand was shown by acid dissolution to be over 99.9% carbonate with <0.01% filtered residue after treatment. The beach sand was identified to be 60–80% foraminifera, which dominated the smaller size fractions of <1 mm, with proportions increasing to over 90% at dimensions of <0.125 mm. Coral fragments, shells and shell fragments dominated larger size fractions of over 1 mm, with intact shells of gastropods and bivalves increasing in proportion towards the coarsest texture sizes of 4 mm and over.

4. Discussion

4.1. Mangrove condition and spatial change

Spatial analysis results of the northern Nooto lagoon shore (Fig. 1) 1998–2013 showed mangrove area increase and seawards progradation (Fig. 2A), in association with progradation of the beach behind the mangroves at a lower rate. Earlier trends 1968–1998 also showed progradation of this shore at a rate of

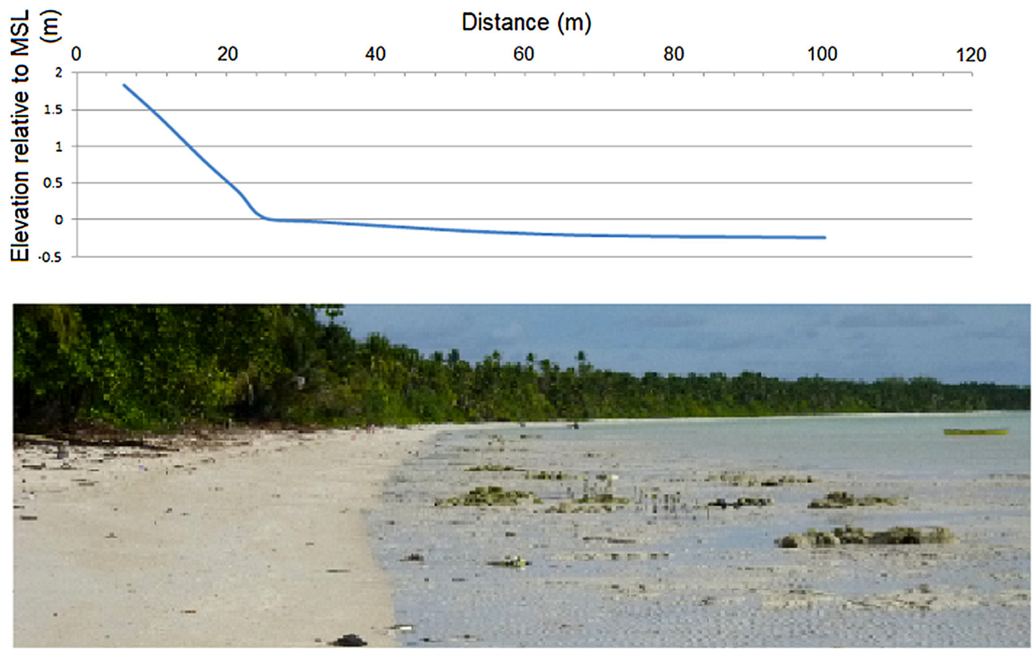

Fig. 4. Surveyed beach profile on the lagoon shore at the Nooto village.

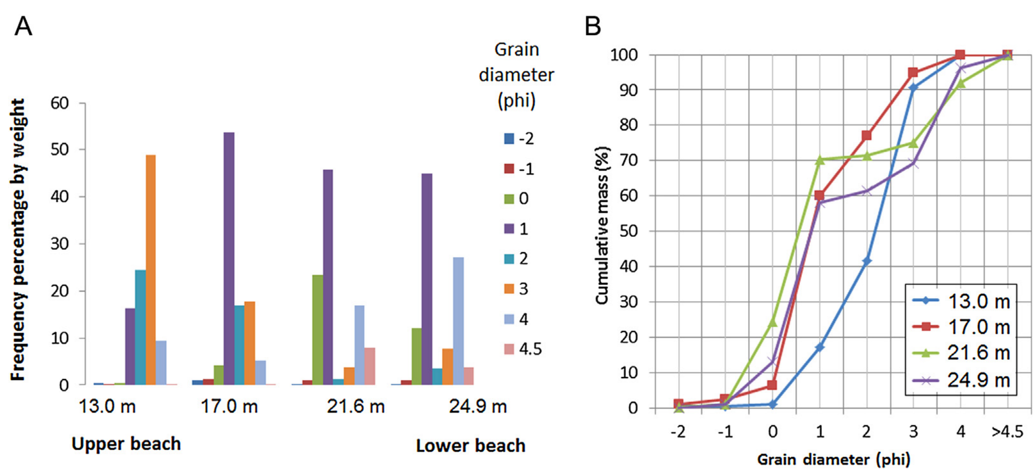

Fig. 5. Sand grain size results A) Histogram showing texture class frequency percentage and B) Cumulative frequency curve, with coarser sand on the left and finer sand on the right.

Table 4
Results from particle size analysis of beach sediment samples.

Distance along transect (m)	Particle Size	Median Grain Size (mm)	Degree of Scatter/Sorting	Skewness	Kurtosis
13.0	Fine sand	0.22	Poorly sorted	Skewed towards coarse particles	Very Platykurtic
17.0	Coarse sand	0.64	Poorly sorted	Strongly skewed towards fine particles	Platykurtic
21.6	Coarse sand	0.75	Poorly sorted	Strongly skewed towards fine particles	Very Platykurtic
24.9	Coarse sand	0.68	Poorly sorted	Strongly skewed towards fine particles	Very Platykurtic

greater than 0.2 m a^{-1} (Biribo and Woodroffe, 2013). Results from mangrove condition assessment (Table 3) showed mangroves to have no impacts and showing good condition on the southern lagoon shore, where spatial analysis showed mangrove area expansion and seawards progradation at the greatest rates (Fig. 2A). The northern section of mangroves rather showed some impacts and recent mangrove mortality (Table 3), and spatial analysis results (Fig. 2A) rather showed coastal stability. Hence the mangrove condition results were supported by long term spatial change data.

Mangrove area expansion is in contrast to global trends, where rates of mangrove loss are 2834 km^2 a^{-1} largely owing to human activities, with sea level rise perhaps having some impacts (Valiela et al., 2009). The Pacific islands' intertidal wetlands contributed to a 17% decline in the Oceania Ramsar region's wetland area 1970–2008, though the majority of records available were from Australia and New Zealand (Dixon et al., 2016).

While seawards progradation and healthy mangrove conditions show resilience, some seaward mortality (Table 3) is indicative of potential vulnerability to relative sea level rise. The 22 year tide gauge record for Tarawa shows an unclear trend (Becker et al., 2012), with high variability from ENSO cycles. The longer term rate of past relative sea level rise is modelled to be +2.2 ± 0.6 mm a^{-1}

(Becker et al., 2012). Relative sea level rise is a critical component of mangrove vulnerability (Ellison, 2015), as well as microtidal range, which can be offset by sediment accretion and root mat growth. Active management for ongoing mangrove accretion may be the best adaptation available (Ellison, 2015), considering also the resilience of biogenic sediment sources. More intensive monitoring of vegetation condition (Ellison et al., 2012), combined with measurement of accretion rates (McLeod and Salm, 2006), would allow improved assessment of resilience.

Ecosystem resilience of the Nooto mangrove area might remain high if measured for the next decade, but with increased sea-level rise become vulnerable if measured over the next 50 years. Resilience timescales differ (Mumby et al., 2014), and there is need for longterm ecological monitoring to allow its confirmation and management (Müller et al., 2016). More intensive ecological monitoring using techniques of permanent plots of the Mangrove Monitoring Manual (Ellison et al., 2012), would allow more quantitative assessment of the health of mangroves and mortality trends. Measurement of accretion rates (Lovelock et al., 2015) would also contribute to mangrove vulnerability assessment, and quantification of below ground carbon accumulation.

4.2. Beach condition and spatial change

The beach shoreline behind the mangroves (Fig. 1) prograded 1998–2013 (Fig. 2B) in the central section analysed, at 3 m a^{-1}, and the beach profile shape was convex-up, indicating accretion trends (Thom and Hall, 1991), verified by the spatial change results. By contrast, the southern village beach remained stable in the 15 year period (Fig. 3). Earlier trends 1968–1998 however, showed progradation of this shore at a rate of greater than 0.2 m a^{-1} (Biribo and Woodroffe 2013), a trend that was lost after 1998. Field survey found results of human impacts, and a flat to concave-up beach profile (Fig. 4), demonstrative of beach erosion (Thom and Hall, 1991; Bird, 2008), unlike convex-up beach profiles observed behind the mangroves to the north.

Hence the beach assessment results of moderate impacts were verified by long term spatial change analysis of the village beach, with loss of a previous progradation trend. Rehabilitation by vegetation planting and reduction of human impacts could enhance accretion and biodiversity, combined with community awareness building (Ellison et al., 2015), to facilitate recovery of beach accretion and biodiversity.

The mangrove planting that failed was likely due to low elevation (Fig. 4), that increases inundation and wave action, in combination with the ceased progradation at the site over time shown by the spatial analysis results. The tidal flats offshore of the beach were surveyed to be c. 0.3 m below MSL (Fig. 4), which is a marginal seaward elevation for *Rhizophora stylosa* as shown from low islands on the Great Barrier Reef (Ellison, 2009b). Successful mangrove planting could otherwise utilise recent demonstrations of innovative techniques of gabion breakwaters and geo-textile tubes to alleviate wave velocity striking the shore (Stanley and Lewis, 2009; Hashim et al., 2010). Active enhancement of mangrove sediment accretion rates, such as by use of coastal structures, has been shown to be successful in mangrove restoration along a higher energy eroding coastline in Malaysia (Hashim et al., 2010; Kamali et al., 2010; Tamin et al., 2011). There is potential for such combined approaches to be used at higher energy and lower elevation shores in Kiribati, and other island groups.

4.3. Resilience provided by sediment supply

Resilience includes the capacity to absorb disturbances (Holling, 1973), hence managing for resilience concerns the environmental set of conditions that represent a threshold for regime shifts (Anthony et al., 2015). Reduced resilience increases the vulnerability of a system to smaller disturbances that it could previously cope with (Brown, 2007), resulting on atolls in undesirable states of beach erosion or mangrove loss without recovery. Unlike coral reefs, for mangrove and beach shorelines a key factor is sediment supply, which is critical to atoll shoreline stability and progradation (Bird, 2008), hence our attention to assessment of its sources. Grain size results from Nooto showed beach sand to be poorly sorted and mostly positively skewed (Fig. 5, Table 4), indicating quiet water and slow deposition (Stewart, 1958). Strongly skewed sediment grain size distributions have been found from zones of environmental mixing (Folk, 1966), and the platykurtic kurtosis results (Table 4) supported this interpretation, with increase in grain sizes down the beach and a tendency also towards a bimodal distribution (Fig. 5, Table 4), indicating a mixture of two sediment types (Folk and Ward, 1957).

Skewness and kurtosis can indicate a degree of mixing of two lognormal populations (Spencer, 1963), which in the case of Nooto results from the beach sediment being derived from both smaller foraminifera and larger coral fragments/shells. On South Tarawa, beach sand is also 100% carbonate, with a high proportion of foraminifera, shells and coral fragments (Forbes and Hosoi, 1995; Forbes and Solomon, 1997). These findings further increase impetus to conserve coral reef habitats in order to maintain sand supply to atoll beaches, especially with risks of ocean acidification and coral bleaching impacts on reefs (Hoegh-Guldburg et al., 2007).

Loss of resilience for an atoll shoreline would be caused if such sediment supply were reduced or sediment losses increased, lowering the threshold of storm events at which erosion is not subsequently recovered from, resulting in shoreline retreat. Beach erosion in the Pacific islands region, particularly on inhabited shorelines, has been widely documented (Forbes and Hosoi, 1995; Gillie, 1997; Mimura and Nunn, 1998; Duvat, 2013; Duvat et al., 2013; Donner, 2013), with impacts to coastal communities. Immediate erosion challenges are occurring on populated islands (Nurse et al., 2014), where human activities that cause coastal erosion include sand extraction, and the impacts of structures and causeways on sediment supply (Gillie, 1997; Biribo and Woodroffe, 2013; Duvat et al., 2013). This is not the case for the unimpacted mangrove shoreline of Nooto (Table 3), but the moderately impacted village beach (Fig. 4) showed that this threshold is closer. Recovery could be helped by enhancing the sediment supply and reducing sediment losses, through reduction of human impacts.

5. Conclusions

Resilience building in biophysical systems of atolls, with practical steps and indications made clear to local community managers, can allow communities to make informed decisions about management of their environments. This study undertook baseline surveys of mangrove and beach condition using methods recently developed by the Secretariat of the Pacific Regional Environment Program to allow Pacific island communities to assess condition and identify rehabilitation needs. Longer term spatial analysis results confirmed the effectiveness of these community methods for assessing mangrove and beach condition, with results of good mangrove condition where spatial analysis showed expansion over time, and results of poor beach condition where spatial analysis showed loss of beach progradation that had occurred up to 15 years ago.

Resilience indicators for mangroves and beaches (Table 1) could guide further applications of these methods, along with the SPREP Mangrove Monitoring Manual and Beach Rehabilitation Guide (Ellison et al., 2012, 2015). Tools have been developed to enhance mangrove resilience (McLeod and Salm, 2006), such as greenbelt planting and monitoring. Recommendations for future efforts to conduct resilience assessments in beach systems include repeated beach profile measurement, such as periodic repeat of the shore-perpendicular survey shown in Fig. 4. Erosion and accretion are vertical volumetric changes in sediment, and spatial change analysis for beaches is a proxy that assumes that vegetation retreat equates to beach surface lowering, and vegetation advance equates to beach surface raising. Measurement of the beach profile gives a more direct assessment. For mangrove habitats, resilience assessment could include more quantitative assessment of the health of mangroves and mortality trends using permanent plots that are remeasured over time. Measurement of accretion rates would also contribute to understanding of mangrove resilience.

Suitable timeframes are needed for managers to assess resilience, such as >5 year's data (Mumby et al., 2014), and long term datasets are shown to be useful in evaluating resilience and contributing to management conceptions (Müller et al., 2016). Lack of investment has been provided to environmental monitoring frameworks of small islands (Nurse et al., 2014), causing gaps in the ability to improve empirical understanding of climate change impacts. This hampers the level of confidence with which adaptation responses can be designed and implemented (Nurse et al., 2014), necessitating a need for longer term projects in the region. Ongoing monitoring could support these endeavours, and comprehensive survey of the coral reef and seagrass communities remains a gap that needs addressing, given these habitats are the primary source of sand to atoll shorelines.

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