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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-