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Can coral reef islands survive sea level rise?

by Eddie Beetham[1] | Coastal Scientist; Gerd Masselink[2] | Professor of Coastal Geomorphology; Paul Kench[3] | Professor of Earth Science

[1]: Tonkin and Taylor International Ltd., Auckland, New Zealand
[2]: School of Biological and Marine Sciences, University of Plymouth, Plymouth, UK
[3]: Department of Earth Sciences, Simon Fraser University, Burnaby, Canada.

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Coral reef islands are widely perceived as being vulnerable to erosion and flooding from sea-level rise and storms. This perception has led to a global debate about whether some atoll nations will be uninhabitable at the end of this century. Our research shows that reef island landforms are more resilient than previously assumed and provides a more encouraging outlook for adaptive management.

Image credits: Eddie Beetham

Sea-level rise will expose coastal communities around the world to increasingly destructive coastal erosion and flooding. This is especially true for coral reef islands, which are low elevation accumulations of loose sand and gravel that have become populated throughout the tropics. For atoll nations like Tuvalu, Kiribati, the Marshall Islands and the Maldives, coral reef islands provide the only habitable land. Sea-level rise is a serious threat for these countries and may result in mass migration if flooding and erosion cannot be managed.

Coral reef islands sit on top of shallow coral reefs that act as a breakwater for ocean waves. This breakwater effect has allowed islands to form reasonably stable shorelines that have become increasingly developed in recent decades. A key impact of sea-level rise is that reefs will be less effective at causing the ocean waves to break and lose energy, and this is expected to result in more frequent and more destructive erosion and flooding events. Existing models predict sea-level rise will reach a point when the recurrence of these hazard events will prevent recovery and compromise prolonged habitation. However, these models assume that island will simply erode without considering the possibility of changes to their shape or elevation.

Like all sand and gravel beach systems around the world, the loose materials that form reef islands are subject to movement during storms and higher-than-normal tides. Therefore, an important research question is: how will sea-level rise modify the coastal

profile, or shape, of reef islands? To answer this, we validated a computer modeling tool and used it to explore how reef islands will adjust to sea-level rise. This modeling approach accounted for changing wave processes, sediment movement and adjustments in island topography in a way that has not been done before. As expected, model results indicate that waves will surge over the island crest and cause flooding as sea level increases, in a process called overtopping (or overwashing).

A less expected finding was that most overtopping events deposited a layer of sediment that incrementally added elevation to the island crest. This feedback has been documented on other coastal landforms and is called roll-over, where material eroded from the beach accumulates on the crest. The effect is that islands will become taller but narrower with sea-level rise. This is an important phenomenon that can either increase or decrease natural resilience to sea-level rise, depending on its intensity. Results found that islands exposed to periodic low-volume overtopping will build vertically at nearly the same rate as sea-level rise. In contrast, episodic high-volume overtopping can flatten islands and increase hazard exposure.

Implications of this research are that some coral reef islands may naturally adjust and persist when exposed to higher sea levels. However, the process of vertical island building requires sediment to be relocated from the shoreline and waves to wash over the island. Therefore, erosion and flooding hazards will still occur and are critical to the natural resilience of these landforms. Communities on coral reef islands will be required to manage the risk associated with periodic flooding on a moving island. Approaches to hazard management will vary according to the level of development and existing shore protection. On highly urbanized islands, development at the shoreline will prevent any natural adjustment and more traditional engineering methods, such as the construction of seawalls, may be required. On less developed islands, communities may have greater potential to work with nature and integrate hazard management with the way island landforms will naturally evolve. This can be achieved by identifying areas of natural resilience and stability, while adapting infrastructure and agriculture resources to accommodate occasional flooding and sediment movement. This natural process of island adjustment can also be encouraged by nourishing the islands with sediment, for example dredged from atoll lagoons.

Modeling the evolution of coral reef islands with future sea-level rise has allowed us to explore the future vulnerability of these landforms in a new way. Our findings show that natural reef islands have the capacity to grow vertically at the same rate as sea level, which provides a positive outlook for some islands persisting into the future. However, the area available for development will decrease and therefore communities will need to manage erosion and flooding hazards.