

Darwin's atolls revisited: lagoon infilling and closure has ecological consequences to North Keeling Atoll

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Charles Darwin's seminal theory of atoll formation was developed during his epic voyage on the *Beagle*. The Cocos (Keeling) Islands (12°12' S, 96°54' E) were the only atolls Darwin visited and comparisons with his 1836 observations reveal sediment-infilling of the south-east lagoon entrances at the southern atoll (Smithers et al. 1992). Here, we report that the same processes have caused the closure of the only lagoon entrance (south-east) at the northern atoll in 2005.

In 2014 the lagoon entrance remained closed and had been colonised by plants. Prior to closing, the lagoon contained coral, seagrass, sand, and mud flats, which were inhabited by turtles, mud crabs (*Scylla* sp.), blacktip sharks, and at least 20 other fish species. The closure caused significant changes to the lagoon community. In 2008, we observed extensive

cyanobacteria mats (10–50 cm thick) smothering the lagoon substrate. Removing this mat released a sulfur-like smell and revealed a thin layer (1–2 cm) of black sand covered in dead gastropod shells (1–2 cm in length). No seagrass was seen and the only animals observed were milkfish (*Chanos chanos*) and small glass shrimp. Similar changes in habitat and community composition occurred at Clipperton Atoll following the lagoon closure, and were linked to three changes in water condition: desalination of surface water, a deeper water layer of anoxic H₂S, and high nutrient input from seabirds (Charpy et al. 2010). It is likely that these changes also occurred at North Keeling Atoll, given its moderate rainfall, abundant nesting seabirds, and benthic layer of lagoon water smelling like H₂S.

We conducted detailed snorkel surveys around the entire outside of the atoll (at 1–15 m depth) and did not locate any seagrass, bonefish or juveniles of fishes previously reported from the lagoon. Species reliant on seagrass or lagoonal habitats may have become locally extinct. The endemic endangered buff-banded rail may also be affected because it forages on seagrass-associated crustacea (Cochrane 2004). The northern atoll was declared a national park in 1995 to protect the unique biodiversity, with the lagoon, considered an important nursery habitat, also listed as a Ramsar Wetland (Cochrane 2004). The Ramsar listing criteria are still met because it is a rare and unique natural wetland, and the surrounding

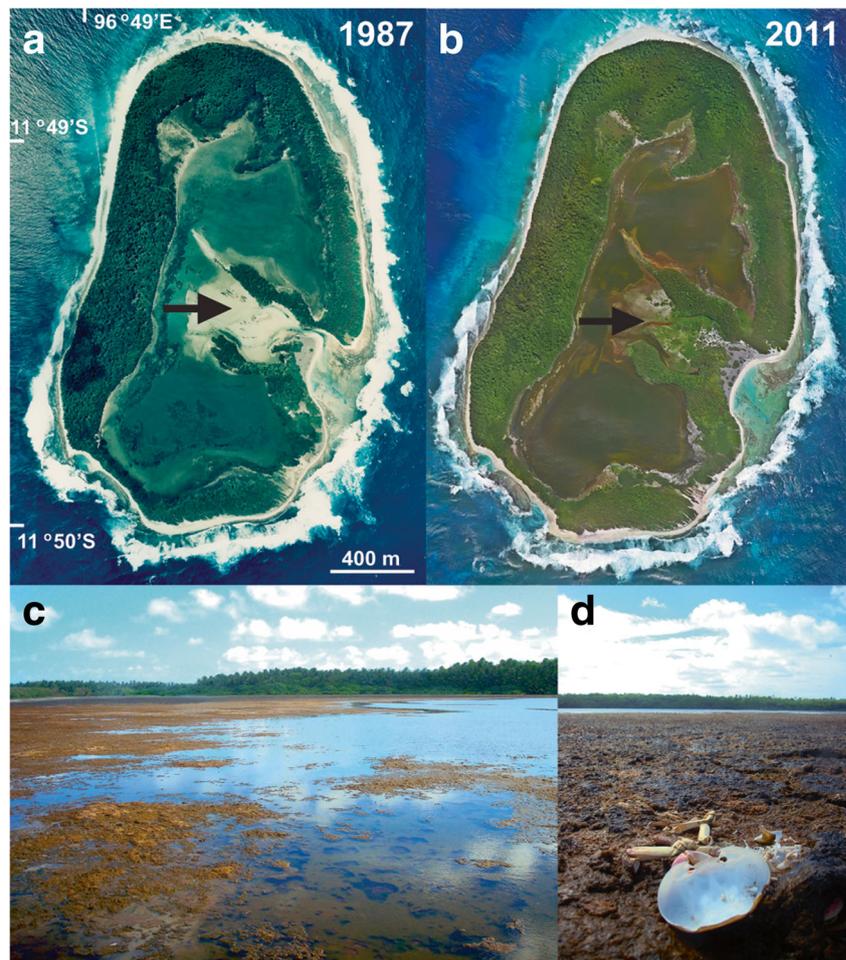
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Fig. 1 The northern atoll (**a** 1987, **b** 2011) lagoon entrance closure (*arrow*). **c, d** Cyanobacteria mats covering the lagoon floor, with dead gastropod and crab shells (*Cardisoma carnifex*) in 2008



vegetation still supports large, unique, and vulnerable populations of waterbirds. This lagoon closure provides an interesting example of how an isolated and highly protected atoll can experience habitat and biodiversity loss due to natural processes (Fig. 1).

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