Forum

Climate change, sea-level rise, and conservation: keeping island biodiversity afloat

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Island conservation programs have been spectacularly successful over the past five decades, yet they generally do not account for impacts of climate change. Here, we argue that the full spectrum of climate change, especially sea-level rise and loss of suitable climatic conditions, should be rapidly integrated into island biodiversity research and management.

Island conservation in the longer term

Conservation of biodiversity on islands is important globally because islands are home to more than 20% of the terrestrial plant and vertebrate species in the world, within less than 5% of the global terrestrial area. Endemism on islands is a magnitude higher than on continents [1]; ten of the 35 biodiversity hotspots in the world are entirely, or largely consist of, islands [2]. Yet this diversity is threatened: over half of all recent extinctions have occurred on islands, which currently harbor over one-third of all terrestrial species facing imminent extinction [3] (Figure 1).

In response to the biodiversity crisis, island conservation has been an active field of research and action. Hundreds of invasive species eradications and endangered species translocations have been successfully completed [4–6]. However, despite climate change being an increasing research focus generally, its impacts on island biodiversity are only just beginning to be investigated. For example, invasive species eradications on islands have been prioritized largely by threats to native biodiversity, eradication feasibility, economic cost, and reinvasion potential, but have never considered the threat of sea-level rise. Yet, the probability and extent of island submersion would provide a relevant metric for the longevity of long-term benefits of such eradications.

The impact of sea-level rise on islands

Recent research suggests that impacts on islands from sea-level rise will be substantial [2,7–9]. Current scenarios for sea-level rise vary from 0.26 to 2.3 m by 2100, whereas a rise of 2 or 3 m might happen in the following centuries (see [2,10] and references therein). Moreover, greater tidal ranges, in particular centennial tides, will lead to periodic floods that will destroy nonsaline habitats. Increased frequency and amplitude of seawater floods are also expected to be more common with global climate change. Sea-level rise will also increase coastal erosion (e.g., in the range of 50–200 times that of sea-level rise) and saline water intrusion [9]. Furthermore, shoreline retreat will also lead to massive displacement of anthropogenic activities from coasts [9], which will lead to additional habitat loss further inland.

Despite clear and imminent risks, the consequences of sea-level rise for island biodiversity remain one of the least studied of all climate-change issues, both locally and globally, which is surprising when one considers both the number of islands concerned (over 180 000 worldwide) and the potential impact. Even with the most optimistic scenario, many low-lying islands will simply be entirely submerged, threatening most of their biodiversity and many benefits from recent conservation actions. A recent analysis focusing on 4500 islands in ten biodiversity hotspots suggested that 6–19% of these islands could be entirely submerged with a 1–6 m sea-level rise, threatening over 300 endemic species with extinction [2]. Given that they represent the largest proportion of the existing islands, most (69%) of the threatened islands are continental. Yet, unsurprisingly, coral atolls, which are believed to comprise almost 15% of all islands, are disproportionately threatened (27%). A similar study in the Pacific and South East Asia predicted that 15–62% of 12 900 islands could be completely inundated [8]. More globally, a recent study of over 1200 islands from all oceans found comparable results, suggesting a possibility of 6–12% of islands worldwide being entirely submerged [7]. This would amount to a total loss of 10 000–20 000 of the 180 000 islands worldwide, with many more suffering partial losses.

The change of climates on islands

Climatic shift is another issue that is particularly pertinent to island conservation. Following climate change, the area of climatic parameters that is suitable for any given species is expected to change spatially, within this century [11]. These shifts will occur predominantly upward

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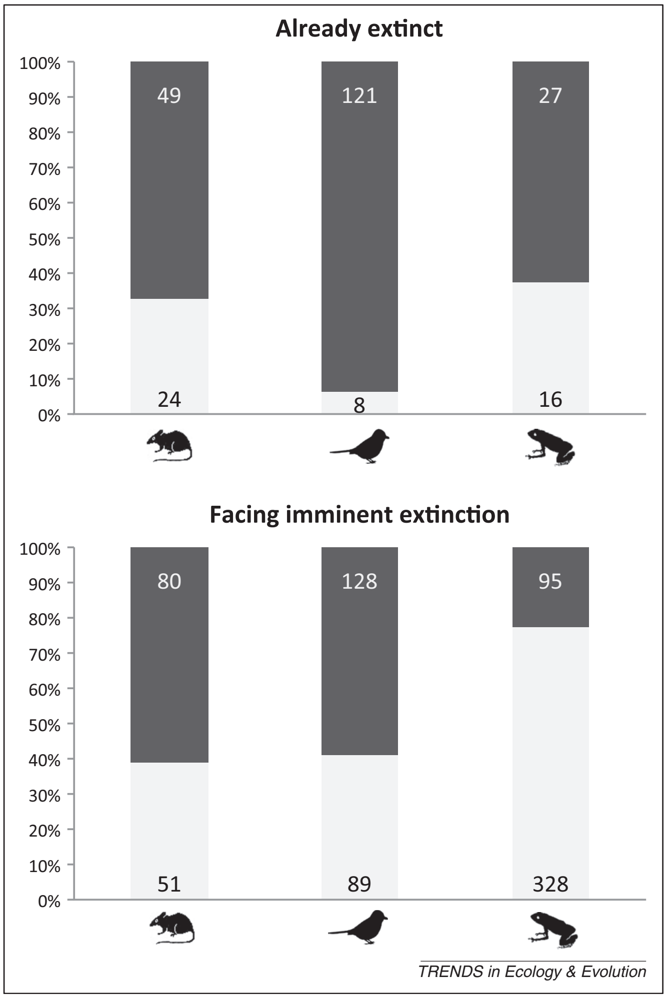

Figure 1. Proportion of extinct and threatened species on islands (dark gray) and the mainland (light gray). Numbers are species and represent mammals (), birds (), and reptiles and amphibians (), showing that terrestrial vertebrate biodiversity is generally more threatened on islands. Data from [3].

(in altitude) and poleward (in latitude). On small islands, this shift may project suitable climates hundreds of kilometers beyond island limits. Consequently, small islands are likely to have a complete change of climatic parameters over their entire surface and many species on those islands will potentially face unsuitable climatic conditions. Whereas continental species can avoid extinction by migrating to follow the climate shift, many insular species cannot. Thus, because such species will be unable to disperse from their original island, they would have to adapt rapidly or will become extinct.

Where not already done so, climate change should immediately be integrated into research and management programs for island biodiversity. Here, we highlight two approaches for doing just that, which will identify solutions that will help safeguard biodiversity and protect conservation investments against future global climate change.

Account for sea-level rise when prioritizing island restoration

Over 900 successful eradications of alien invasive vertebrates have been conducted on islands worldwide (http://eradicationsdb.fos.auckland.ac.nz). In most cases, such as the Surprise Island project, restoration was conducted without a consideration of climate change (Box 1), resulting in some suboptimal choices for long-term conservation benefits. In January 2010, rat eradication led by one of us (J.C.R.) on the 28-ha island of Honuea (in Tetiaroa, an atoll in the Windward group of the Society Islands of French Polynesia) failed because it was completely flooded by tropical cyclone Oli the day after final baiting occurred throughout the island. Increased frequency and amplitude of cyclones following climate change are indeed increasingly likely to flood low-lying islands and interfere with conservation programs.

Of 604 islands where invasive vertebrates have been eradicated and for which elevation data are available [2,12], 26 are predicted to be completely inundated with a 1 m increase in sea level, and many more will be impacted by partial habitat loss (Figure 2). Researchers are increasingly developing prioritization frameworks to help guide decision-making on which islands should be targeted for restoration via invasive species removal. Quite simply, the anticipated level of island submersion should become one of the primary factors to consider for restoration prioritization, so that conservation gain is further optimized, and over longer time horizons. To do so, geographic data, such as island area and elevation profile, and a variety of inundation models at local, regional, and global scales [13], will need to be explicitly incorporated into prioritization frameworks. Consequently, islands with greater elevations may become a priority for invasive species eradication, which will require further research to increase the scale of island eradications, because islands with greater elevations are also often larger. Such islands will also suffer complex exposure to climate change.

Consider translocations to save island species from climate change

For many island species that cannot adapt or migrate to a suitable nearby island, practitioners will eventually be faced with a decision to either let them go extinct by doing nothing or to attempt to save them by actively moving them to suitable habitat. Species translocations have long been a powerful conservation tool, especially for island conservation, but are controversial, because they can also lead to biological invasions. Many translocations were originally to islands, to alleviate impacts of alien invasive species [6]; however, in the future, translocations may have to be from islands to mitigate climate loss [5]. Thus, the assisted migration of threatened species from islands will require a framework that considers not only the probability of success and lack of impacts in the new introduced range [14], but also the more intractable value issues that emerge when deciding how to manage species [15], such as which species to move, when, and to where.

Concluding remarks: securing long-term conservation benefits

Currently, the removal of invasive species from islands is one of the most powerful tools for preventing extinctions and restoring ecosystems. To safeguard the biodiversity benefits secured through these restoration programs and to maximize future benefits, implications of climate change

Box 1. The restoration of Surprise Island

In the coming decades, thousands of low-lying coral atolls around the world will be vulnerable to sea-level rise, predominantly due to expansion of ocean water and mass loss of mountains glaciers and ice sheets. Tropical atolls of some island nations are already experiencing inundation. Importantly, sea-level rise is predicted to be heterogeneous: due to spatial heterogeneity of surface temperatures and other complex, interacting sets of factors, sea levels in some oceanic areas will rise more than in others. Thus, the persistence of atoll islands will depend strongly on location, local conditions, and geomorphology. Therefore, on some of these islands, the conservation benefits of important restoration efforts may be lost in the long term.

Surprise Island (Figure I), located in the Entrecasteaux reef off New Caledonia, provides one example of island conservation research and action that did not integrate climate change. Only a few meters above sea level, the small and remote island was the focus of a research program that ended in 2009 with the eradication of introduced rats (*Rattus rattus*), mice (*Mus musculus*), and an invasive plant (*Cassytha filiformis*). The eradication of alien invasive species from Surprise Island was a positive conservation action. It has undoubtedly helped protect the local species for the coming decades, possibly preventing some of them from local extinction. In addition, it provided a wealth of knowledge necessary for island conservation that can be applied to other islands. Notably, research investigating species interactions helped mitigate unexpected ecological chain reactions during eradications, which has been observed during other eradication programs. Research and conservation actions were a result of substantial investment in resources, lasting over a decade. Despite careful planning and long-term commitment, it did not occur to those of us involved in this program (F.C.) that expected sea-level rise would threaten the benefits from our conservation actions.

Many other alien species eradication programs have taken place on islands that are doomed in the long term by sea-level rise. Of course, most of these eradication efforts occurred before current understanding of climate change and an ability to measure its impacts. Also, on some of these islands, a rapid conservation response was required despite the long-term threat of climate change. Nonetheless, future conservation programs must take the full breadth of climate change into account, by prioritizing islands according to threats from sea-level rise and climate shifts, and by considering translocation of island species that will be lost to climate change.

Figure I. Surprise Island (24 ha), 230 km north of New Caledonia.

must become a priority for research and conservation agendas. Research should focus on better understanding and predicting the impacts of sea-level rise and climatic shifts at both the organismal and ecosystem levels on islands. Researchers and practitioners should rapidly integrate these effects of climate change into the planning and prioritizations that are currently taking place. They also should begin to assess island species that are most likely to be at risk from future climate change and the options for preventing their extinction.

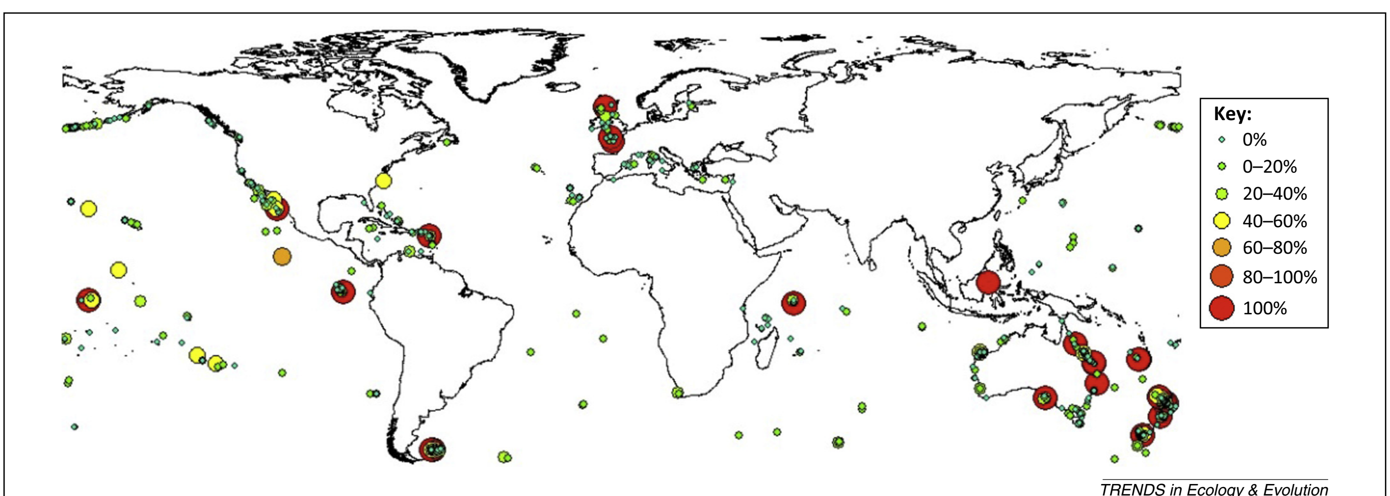

Figure 2. Predicted area submersion on islands with an invasive vertebrate eradication program. The size and color of points represent the percentage of surface immersion. With a 1-m sea-level rise, 4% (26) of the 604 islands with an eradication program would be entirely under water and many more would lose a large part of their habitat. Islands and their elevations come from the Database of Island Invasive Species Eradications [4], which is combined with the island sea-level rise model from [2].

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References
1 Kier, G. *et al.* (2009) A global assessment of endemism and species richness across island and mainland regions. *Proc. Natl. Acad. Sci. U.S.A.* 23, 9322–9327
2 Bellard, C. *et al.* (2013) Impact of sea level rise on the 10 insular biodiversity hotspots. *Global Ecol. Biogeogr.* 23, 203–212
3 Ricketts, T.H. *et al.* (2005) Pinpointing and preventing imminent extinctions. *Proc. Natl. Acad. Sci. U.S.A.* 102, 18497–18501
4 Veitch, C.R. *et al.* (2011) *Island Invasives: Eradication and Management*, IUCN
5 Thomas, C.D. (2011) Translocation of species, climate change, and the end of trying to recreate past ecological communities. *Trends Ecol. Evol.* 26, 216–221
6 Armstrong, D.P. and Seddon, P.J. (2008) Directions in reintroduction biology. *Trends Ecol. Evol.* 23, 20–25
7 Bellard, C. *et al.* (2013) Impact of sea level rise on the french islands worldwide. *Nat. Conserv.* 5, 75–86
8 Wetzel, F.T. *et al.* (2013) Vulnerability of terrestrial island vertebrates to projected sea-level rise. *Global Change Biol.* 19, 2058–2070
9 Wetzel, F.T. *et al.* (2012) Future climate change driven sea-level rise: secondary consequences from human displacement for island biodiversity. *Global Change Biol.* 18, 2707–2719
10 Levermann, A. *et al.* (2013) The multimillennial sea-level commitment of global warming. *Proc. Natl. Acad. Sci. U.S.A.* 110, 13745–13750
11 Mora, C. *et al.* (2013) The projected timing of climate departure from recent variability. *Nature* 502, 183–187
12 Bellard, C. *et al.* (2012) Impacts of climate change on the future of biodiversity. *Ecol. Lett.* 15, 365–377
13 Mcleod, E. *et al.* (2010) Sea-level rise impact models and environmental conservation: a review of models and their applications. *Ocean Coast. Manag.* 53, 507–517
14 Rout, T.M. *et al.* (2013) How to decide whether to move species threatened by climate change. *PLoS ONE* 8, e75814
15 Redpath, S.M. *et al.* (2012) Understanding and managing conservation conflicts. *Trends Ecol. Evol.* 28, 100–109