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Review

Impacts of global climate change on the floras of oceanic islands – Projections, implications and current knowledge

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ABSTRACT

Recent climate projections indicate substantial environmental alterations in oceanic island regions during the 21st century, setting up profound threats to insular floras. Inherent characteristics of island species and ecosystems (*e.g.* small population sizes, low habitat availability, isolated evolution, low functional redundancy) cause a particular vulnerability. Strong local anthropogenic pressures interact with climate change impacts and increase threats. Owing to the high degree of endemism in their floras, a disproportionally high potential for global biodiversity loss originates from climate change impacts on oceanic islands. We reviewed a growing body of research, finding evidence of emerging climate change influences as well as high potentials of future impacts on insular species and ecosystems. Threats from global climate change are not evenly distributed among the world's oceanic islands but rather vary with intrinsic (*e.g.* island area, structure, age and ecological complexity) and extrinsic factors (regional character, magnitude and rate of climatic alterations, local human influences). The greatest flora vulnerabilities to climate change impacts can be expected on islands of small area, low elevation and homogeneous topography. Islands of low functional redundancies will particularly suffer from high rates of co-modifications and co-extinctions due to climate-change-driven disruptions of ecological interactions. High threat potentials come from synergistic interactions between different factors, especially between climatic changes and local anthropogenic encroachments on native species and ecosystems. In addition, human responses to climate change can cause strong indirect impacts on island floras, making highly populated islands very vulnerable to secondary (derivative) effects. We provide an integrated overview of climate change-driven processes affecting oceanic island plants and depict knowledge gaps and uncertainties. The suitability of oceanic islands and their ecosystems for potential research on the field of climate change ecology is highlighted and implications for adequate research approaches are given.

Contents

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Introduction

Oceanic islands have always been stimulating to scientists as natural showcases of ecology, evolution and biogeographical processes (*e.g.* Darwin, 1859; Wallace, 1880; MacArthur and Wilson, 1967; Carlquist, 1974; Whittaker and Fernández-Palacios, 2007). Their origin from oceanic crust and final erosion beneath sea level has been persistent and characteristic traits during all times of earth history, defining special conditions and time scales for evolution and extinction. Isolation from continental landmasses sets up an efficient filter for the immigration of terrestrial organisms to oceanic islands. Successful colonisers are confronted with novel environments and evolutionary opportunities, leading to unique species and species assemblages (MacArthur and Wilson, 1967; Gillespie and Roderick, 2002; Whittaker and Fernández-Palacios, 2007). Thus, oceanic islands generally have lower overall species numbers per unit area (Whittaker and Fernández-Palacios, 2007) but show higher percentages of endemism than mainland areas (Kier et al., 2009). As a consequence, the extremely limited insular areas host a disproportional high fraction of global biodiversity (Kreft et al., 2008; Kier et al., 2009).

Although most climate change research is focused on continental ecosystems, ocean regions, too, will be affected by global climate change. For many oceanic islands, changing temperatures and precipitation patterns, shifting frequencies and intensities of extreme weather events (*e.g.* droughts, storm surges, hurricanes), as well as altered patterns of seasonal and mid-term weather systems (El Niño Southern Oscillation, monsoon, etc.) and sea level rise can be expected (IPCC, 2012, 2013b). These changes can pose profound and challenging environmental alterations to terrestrial biota in general (*e.g.* Jump and Peñuelas, 2005; Parmesan, 2006; Cahill et al., 2013), but have specific relevance for island biota (Loope, 1995; Mimura et al., 2007; Caujapé-Castells et al., 2010; Fordham and Brook, 2010; Bramwell, 2011).

This specific relevance is due to several aspects of oceanic islands: First, as a consequence of their isolated evolution, oceanic island species are often insufficiently prepared to changing environments (Cronk, 1997; Gillespie et al., 2008; Fordham and Brook, 2010). For plants on oceanic islands, Carlquist (1974) introduced the "island syndrome", meaning (i) a tendency to reduce their dispersability (see also Cody and Overton, 1996; Fresnillo and Ehlers, 2008; Gillespie et al., 2012), (ii) a tendency to be poor competitors in the face of introduced species and (iii) a lack of defensive mechanisms against (non-native) herbivores (see also Bowen and van Vuren, 1997; Vourc'h et al., 2001). Second, the restricted areas of oceanic islands and the surrounding ocean limit the options of island species to migrate and escape potentially deteriorating conditions via range shifts. This requires affected species to either retreat to potential refuge habitats within their island (if available and within reach), adapt rapidly to changing conditions or to become extinct (Gillespie et al., 2008; Levine et al., 2008). Third, due to the restricted size of oceanic islands, the total range of endemics is also comparably small. This is usually connected to a low overall population size, leading to higher vulnerability to stochastic (but also deterministic) threats (Kruckeberg and Rabinowitz, 1985; Gilpin and Soulé, 1986; Frankham, 1998; Gillespie et al., 2008). Especially very narrow endemics, which represent a high percentage of oceanic islands' biodiversity (*e.g.* Sakai et al., 2002), are likely to exhibit low tolerances and a high vulnerability to extrinsic disturbances (Kruckeberg and Rabinowitz, 1985; Lavergne et al., 2004; Hermant et al., 2013). Also, oceanic isolation acts as a very efficient dispersal filter, drastically limiting the potential of species' responses to ecological shifts, such as climate change, by migration to other landmasses.

The imminent sensitivity of many island endemics to rapid environmental changes and extraordinary encroachments is reflected in the disproportionally high numbers of extinctions after human arrival on remote islands (Cronk, 1997; Sadler, 1999; Steadman, 2006; Caujapé-Castells et al., 2010; Fordham and Brook, 2010). Although this pattern is more obvious for animals than for plant species (*e.g.* Sax et al., 2002; Whittaker and Fernández-Palacios, 2007), numerous examples prove novel anthropogenic stressors