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Biodiversity and climate change: Risks to dwarf succulents in Southern Africa

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ABSTRACT

The aim of this study was to explore the effects of anthropogenic climate change on the dwarf succulent genus *Conophytum* (Aizoaceae) within areas recognised for their floral biodiversity, namely the Succulent Karoo, Fynbos, Desert and Nama Karoo biomes of South Africa and Namibia. Niche-based modelling was used to identify the key climatic and geological variables influencing the distribution of members of the genus *Conophytum*. The distribution of the genus is primarily controlled by a small number of environmental variables, notably winter and summer rainfall levels, together with geology. Assuming a zero-dispersal model, the predicted effect of both the A1B and A2 climatic emission scenarios was a severe contraction in the area satisfying the bioclimatic envelope for the genus coupled with significant range dislocation. Reductions of >90% in suitable habitat for 10 of the 16 taxonomic Sections that comprise the genus and represent >80% of taxa under the A2 scenario are predicted. Under A1B the projected effects are ameliorated, but reductions of >50% of habitat can be seen in a majority of Sections. Significant projected reductions in the habitable bioclimatic envelope are very likely to increase risk of extinction of ~80% of taxa even under a partly mitigated emissions scenario.

1. Introduction

Anthropogenic climate change is recognised as one of the main potential threats to biodiversity over the course of this century. Early projections indicated that richly bio-diverse regions including the Succulent Karoo and Fynbos biomes of southwestern Africa would be particularly prone to predicted changes in the climate (e.g., Midgley et al., 2002, 2006; Midgley and Thuiller, 2007). More recently a report by the South African Department of Environmental Affairs (DEA, 2014) has instead predicted a more complex suite of changes across the various biomes of the region, with potential expansion of some (e.g., Desert) and contraction of others (e.g., Fynbos). Contrary to the results of earlier studies, the area that lies within the climatic envelope of the Succulent Karoo biome is now thought to largely persist under all climate scenarios tested, through to 2050, with higher risks of extinction contingent on continued warming. While the inherent richness in floral diversity, especially amongst succulents, is one of the defining elements of the region, such diversity makes the prediction of responses to environmental change (e.g., increasing aridity and thermal stress) challenging. For example, the variability amongst the flora of these biomes in terms of drought tolerance is thought to be especially significant (e.g., Hoffman et al., 2009).

Lying within the southwestern corner of Africa, the Succulent Karoo biome is recognised as one of the most important regions of floral biodiversity globally (Mittermeier et al., 1998, 2004). The biome is an area of approximately 116,000 km^2 lying on the fringes of the Cape Floristic Region. It is characterised by a low winter rainfall (Desmet and Cowling, 1999a; Jürgens, 1991, 1997; Rutherford and Westfall, 1994) and is regarded as one of only two global biodiversity hotspots that are fully arid (Cowling et al., 1998; Mittermeier et al., 2004). The primary climatic factors affecting the biome are temperature and precipitation (rainfall, fog and dew) both in amount and seasonality. Rainfall declines east to west and south to north but is also characterised by its unpredictable nature. Non-rainfall moisture is thought to make a significant contribution

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to make a substantial, and reliable, contribution to total moisture availability (Matimati et al., 2013). Fog is recognised to be especially prevalent on the west coast and along some larger river systems, notably the Orange River. The contribution made by dew to annual precipitation appears to be less pronounced (<20-fold less), although it is much more widespread than the effects of fog (Matimati et al., 2013). The combination of high temperatures, low humidity and low cloud cover is characteristic, especially inland from the coastal strip (where the temperature range is reduced compared to further inland).

The particular climatic conditions within the Succulent Karoo lead to a unique flora, dominated by a large number of leaf succulents, especially members of the Aizoaceae and Crassulaceae (Cowling and Hilton-Taylor, 1999; Jürgens, 1991, 1997). The biome is strongly species-rich, with approximately 5,000 vascular plant species recorded, and displays high floral endemicity (~40%). The miniaturisation of growth form in leaf succulents (as seen in the genus *Conophytum*) is an adaptation especially evident in the Succulent Karoo (Desmet and Cowling, 1999b). Within the Aizoaceae a high degree of speciation is evident (Klak et al., 2004), no more so than in the miniature or dwarf succulent genus *Conophytum*, which has >160 recognised species and subspecies (Hammer and Young, 2016). Young and Desmet (2016) determined that more than half (96) of all *Conophytum* species and subspecies are endemic to the Succulent Karoo biome alone with >90% of all *Conophytum* taxa found within this single biome. Members of the genus are found in all six bioregions that comprise the Succulent Karoo in South Africa, and display a particularly strong association with the Namaqualand Hardeveld and Richtersveld bioregions. Within Namibia, the genus is also most closely associated with the biome. Within the Succulent Karoo, the highest levels of floral species diversity, especially in dwarf succulents, are often associated with koppies or rocky outcrops (Desmet and Cowling, 1999b). The flora of the biome is also characterised by high levels of point (local/range-restricted) endemism (Cowling and Hilton-Taylor, 1994; Driver et al., 2003; Mucina et al., 2006). Such point endemism is most pronounced amongst succulents, especially members of the Mesembryanthemacae, including *Conophytum* in which more than one fifth of all taxa can be considered point endemics (Young and Desmet, 2016). The range distribution of the genus *Conophytum* lies predominantly within a winter rainfall area with a few taxa extending, through a precipitation transitional zone, east into the Bushmanland and Griqualand Nama Karoo (areas with summer rainfall). The vast majority (93%) of taxa are associated with the Succulent Karoo (especially the Namaqualand Hardeveld and Richtersveld bioregions) and the Desert biomes (Young and Desmet, 2016). Substantially fewer taxa are found within the Fynbos and Nama Karoo biomes. The strongest affinity of the genus is with the Namaqualand Hardeveld bioregion which is home to 84 taxa alone, including 43 that are endemic to that single bioregion.

While predictions of the possible effect of climate change on individual biomes now exist (e.g., DEA, 2014) there are few studies exploring such effects on individual plant genera. Until now one of the major restrictions in performing such analyses has been the lack of accurate locality data for succulents. These represent a key element of the flora of the region, all the more so as they are recognised as amongst the best-adapted plants to the local environmental conditions, especially drought tolerance (e.g., Musil et al., 2010). Utilising a comprehensive location database, the aim of this study was to assess the vulnerability of the dwarf succulent genus *Conophytum* to anthropogenic climate change in this region.

2. Methods

2.1. Vegetation data

This study concerned the dwarf succulent genus *Conophytum* at species and subspecies level as defined by Hammer and Young (2016). The genus consists of 165 recognised species and subspecies, of which the localities of just six are currently unknown (lost or possibly extinct in habitat). Distribution of taxa was represented by the locality data in >2700 points, mainly the result of fieldwork conducted by two of the authors (Young and Desmet, unpublished data). The recorded locality data were carefully assessed for error before using them in the model and where accurate gps recordings were not available, distributions were individually geo-referenced to within 0.5 km of their stated location. When this was not possible or in cases when the identification of the taxon was uncertain, data was excluded from this study. The vast majority of all available data arise from South Africa and much less from Namibia. Nevertheless, all available records were used as long as the accuracy of the record was deemed sufficiently rigorous. In addition to studying the effects on the genus *Conophytum*, the potential effects of the chosen emission scenarios (see below) were modelled on closely related groups of *Conophytum* species and subspecies organised into discrete taxonomic Sections, based on their morphology (as recognised by Hammer, 2002 and Hammer and Young, 2016). The adoption of Sections here allows the combining the locality records for several taxa and therefore permits the inclusion of those species and subspecies for which there are only a limited number of locality records (i.e., where either the number of known localities is low or for taxa which are point-endemics and are severely range-restricted).

2.2. Global emission scenarios

The climate and environmental data used were from the Worldclim database (Hijmans et al., 2005), and from the National Land-cover Project 2006. To examine the possible future climate change impacts on the geographic distribution and potential range shifts for the genus *Conophytum* in southern Africa, projected future (2040–2069) climate data (Ramirez and Jarvis, 2008) were used with the present (1950–2000) climate data, with a resolution of 1 km × 1 km. ECHAM5 is the fifth generation of the ECHAM general circulation model, and it is a global climate model developed by the Max Planck Institute for Meteorology (Roeckner et al., 2003). It was specifically adjusted by modifying global forecast models developed by the European Centre for Medium-Range Weather Forecasts, so that it can be used for climate research. ECHAM5 and other global climate models were recently used in the IPCC Fourth Assessment Report, where it proved to be a reliable global climate model by comparison to others (e.g., Connolley and Bracegirdle, 2007). MIROC (considered to be the wettest global climate change scenario), ECHAM5 (an intermediate rainfall future) and CSIRO (driest) were initially evaluated in our studies. ECHAM5 was chosen as it was seen to be better suited for predictions of Southern Africa climate, with its inherent regions of dryness and wetness. ECHAM5 has also used by the recent analysis of climate change in the studies for the South African Department of the Environment (DEA, 2014).

In this study, the impact of climate change was examined under two different carbon emission scenarios. Potential changes in the future on the distribution area of the 16 Sections that comprise the genus compared to the present distribution were analysed. To explore how sensitive *Conophytum* may be to climate change, the A2 and A1B climate scenarios were used to allow between-model comparison, assuming unconstrained and constrained global