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Climate-induced change of environmentally defined floristic domains: A conservation based vulnerability framework

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ABSTRACT

Global climate change is having marked influences on species distributions, phenology and ecosystem composition and raises questions as to the effectiveness of current conservation strategies. Conservation planning has only recently begun to adequately account for dynamic threats such as climate change. We propose a method to incorporate climate-dynamic environmental domains, identified using specific environmental correlates of floristic composition, into conservation strategies, using the province of KwaZulu-Natal, South Africa as a case study. The environmental domains offer an approach to conservation that conserves diversity under current and future climates, recognising that the species constituting diversity may change through time. We mapped current locations of domains by identifying their positions in a multi-dimensional environmental space using a non-hierarchical iterative *k*-means clustering algorithm. Their future locations were explored using an ensemble of future climate scenarios. The HadCM2 and GFDL2.1 models represented the extreme ranges of the models. The magnitude of change in each environmental domain was calculated using Euclidean distances to determine areas of greatest and least stability for each future climate projection. Domains occurring in the savanna biome increase at the expense of domains occurring in the grassland biome, which has significant negative consequences for the species rich grasslands. The magnitude of change maps represents areas of changed climatic conditions or edaphic disjunctions. The HadCM2 model predicted the greatest overall magnitude of change across the province. Species with specific soil requirements may not be able to track changing climatic conditions. A vulnerability framework was developed that incorporated climatic stability and habitat intactness indices. The mean magnitude of change informed the potential speed of transition of domains between the vulnerability quadrants. The framework informs appropriate conservation actions to mitigate climate change impacts on biodiversity. The study explicitly links floristic pattern and climate variability and provides useful insights to facilitate conservation planning for climate change.

1. Introduction

Global climate change is having marked influences on species distributions, phenology and ecosystem composition (Chen, Hill, Ohlemüller, Roy, & Thomas, 2011; Parmesan, 2006). Ecosystems and biodiversity are further impacted by other concurrent stressors such as habitat loss, invasive species, overexploitation, pollution and disease (Mantyka-Pringle, Martin, & Rhodes, 2012). Over the next century, climate change as a result of increasing atmospheric CO_2 levels and other greenhouse gases is expected to become one of

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Abbreviations: CCAM, conformal-cubic atmospheric model; CEC, cation exchange capacity; IPCC, Intergovernmental Panel on Climate Change; KZN, KwaZulu-Natal; MAP, mean annual precipitation; MAT, mean annual temperature.

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the greatest drivers of biodiversity loss (Heller & Zavaleta, 2009), especially as climate change progresses towards the extremes.

These changes raise questions as to the effectiveness of current conservation strategies, which tend to focus on static spatial planning based on current conditions (Pressey, Cabeza, Watts, Cowling, & Wilson, 2007). Global change is turning ecosystems into rapidly changing landscapes (Hansen, Hoffman, Drews, & Mielbrecht, 2009). Thus temporal shifts in ecosystems and species need to be incorporated into conservation planning. Sound predictions of future climatic impacts on biodiversity are needed to guide adaptation and conservation planning efforts.

Much research has focussed on understanding climatic impacts on individual species using species distribution models (Erasmus, Van Jaarsveld, Chown, Kshatriya, & Wessels, 2002; Yates et al., 2010). However modelling all species occurring in diverse systems is not feasible and it is suggested instead that models are developed that predict climate effects on the distribution of communities (Yates et al., 2010), ecoregions (Hansen et al., 2009; Watson, Iwamura, & Butt, 2013) or environmental domains (Saxon, Baker, Hargrove, Hoffman, & Zganjar, 2005). Groves et al. (2012) recommend focussing conservation efforts on the geophysical environment (the metaphorical stage with the species as actors), as this maintains species diversity, and similarly, Beier and Brost (2010) recommend the use of land facets. The latter methods offer an approach to conservation that conserves diversity under current and future climates, recognising that the species constituting the diversity may change through time given their capacity to track appropriate conditions, phenological changes or physiological adaptation (Bellard, Bertelsmeier, Leadley, Thuiller, & Courchamp, 2012). Building on these concepts we suggest that by identifying the specific environmental correlates defining current vegetation communities, the environmental domains of these communities may be identified, i.e. the environmental stage is identified. The environmental domains can then be modelled under future climate scenarios to understand how the domains may change and hence how communities are likely to respond, providing useful insights for dynamic conservation planning.

Jewitt, Goodman, Erasmus, O'Connor, and Witkowski (2015) examined the main environmental gradients correlated to floristic composition in KwaZulu-Natal (KZN) based on detailed vegetation sample plot (relevé) inventories. The study identified 23 major floristic communities in the province. The three primary correlates of floristic pattern were found to be temperature, soil base status and precipitation and can be used to define environmental domains. The study focussed on plant community composition because plants underpin trophic structure and functioning, and have been shown to be the most effective predictor of arthropod assemblage composition, a group which comprises almost two-thirds of the world's diversity (Schaffers, Raemakers, Sýkora, & ter Braak, 2008). Vertebrate species are mobile and thus may respond more readily to climate change compared to plants which are sedentary and thus lack motility other than through seed dispersal, as a means of adapting to climate change. Plant communities thus represent a good starting point to investigate dynamic climate changes.

The ability of species to track changing environmental domains will be hampered by habitat loss and land-cover change, which are recognised as major drivers of biodiversity loss (Jetz, Wilcove, & Dobson, 2007; Millenium Ecosystem Assessment, 2005; Vitousek, 1994). Indeed, in KZN an average of 1.2% per annum of natural habitat was transformed between 1994 and 2011, and it was estimated that by 2011 only 53% of the province remained in a natural state (Jewitt et al., in press). Climate change and habitat loss negatively interact contributing to the loss of biodiversity (Mantyka-Pringle et al., 2012). By considering the degree of habitat loss as well as climate stability (Watson et al., 2013), the vulnerability of environmental domains can be determined. By further considering the mean magnitude of change expected in each domain, the rate of change in each domain can be determined. We present a spatially explicit vulnerability framework using the environmental domains that can inform appropriate conservation actions and indicate where they are most appropriate.

We present an approach for understanding climatic impacts on vegetation communities by using the specific environmental correlates of these communities to define current environmental domains. Using edaphic factors assumed not to change significantly by 2050 and an ensemble of modelled future climates, future environmental domains are tracked and used to identify areas of climatic stability (potential macro-refugia) and instability (potential novel communities). We present a vulnerability framework that incorporates climatic stability, habitat intactness and the potential rate of climate change. These climate-dynamic environmental domains and the vulnerability framework will facilitate conservation planning for climate change. In particular we address the following questions: 1) What and where are the major environmental domains in KZN, determined using the three primary climatic and edaphic correlates of floristic composition in KZN? 2) How will the environmental domains change in KZN by 2050, determined using an ensemble of climatic models based on the A2 emission scenario? 3) Which areas of the province are expected to experience the least and greatest magnitude of change? 4) Which domains are the most vulnerable in terms of climate change, habitat loss and mean magnitude of change?

2. Materials and methods

2.1. Study area

KZN is a province of South Africa occurring on the eastern seaboard of the country (Fig. 1). It has a complex landscape, in terms of both biological and physical diversity. It is species rich having more than 6000 vascular plant species in an area of 93 307 km^2 and endemism levels of 16% (Scott-Shaw, 1999). It contains portions of the Maputaland-Pondoland-Albany biodiversity hotspot and the Drakensberg Alpine, Midlands, Pondoland and Maputaland centres of endemism (Mucina & Rutherford, 2006). KZN has a steep temperature gradient with mean annual temperatures (MAT) ranging between 7.9 °C and 22.9 °C, owing largely to an altitudinal gradient of over 3000 m from the Indian Ocean to the top of the Drakensberg escarpment. Similarly the province has a strong precipitation gradient with mean annual precipitation (MAP) ranging between approximately 450 mm–1900 mm. Cation exchange capacity (CEC) varies between 3 and 112 cmol kg^{-1} (ISRIC, 2013).

2.2. Analysis

The current climatic variables of MAT and MAP were derived from Schulze (2007) at a one arc minute resolution, averaged over a 30 year period (1961–1990). Using a multi-decadal range incorporates the inter-annual variability of the variables. The soil CEC data was obtained from ISRIC (International Soil Reference and Information Centre, 2013) at a 1 km resolution and averaged to a depth of 1 m. The current and future data were standardised to the same projection, resolution (1.8 km × 1.8 km) and normalised to a consistent range. All mapping work was done in ArcMap 10.2 (ArcGIS, 2013).

Future MAT and MAP data specific to KZN was calculated from climate models projected to 2050, averaged over a 20 year period (2041–2060). The future climate data were developed by the