Ecological Modelling 360 (2017) 343–362

Contents lists available at ScienceDirect

Ecological Modelling

journal homepage: www.elsevier.com/locate/ecolmodel

Bridging the gap between climate science and regional-scale biodiversity conservation in south-eastern Australia

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ARTICLE INFO

Article history:
Received 30 December 2016
Received in revised form 18 May 2017
Accepted 22 June 2017

Keywords:
Terrestrial biodiversity assessment
Climate change impacts and adaptation
Biological communities
Australia

ABSTRACT

Recognition of a trajectory of climate change has raised concerns over implications for the conservation of biodiversity. Quantifying the severity of the issue and informing adaptation measures presents a challenge to ecological modelling.

We undertook a study of biodiversity impacts and adaptation using spatial modelling across south-eastern Australia. The study aimed to (1) forecast future impacts on biodiversity arising from 18 plausible climate futures, and (2) identify places where land management actions including revegetation will maximise expected improvements to projected biodiversity persistence. This work augments well-tested regional-scale biodiversity assessment by considering an uncertain future climate.

Generalised Dissimilarity Models (GDMs) were developed at two baselines (1990 and 2000) to characterise the continuous nature of compositional turnover of vascular plants varying with climate, soils and landform across the region. The classified outputs of the GDM, representing a vegetation-based biodiversity surrogate, were projected using kernel regression to simulate changing distributions for the future epochs 2020, 2030, 2050 and 2070, referred to as Bio-climatic Classes (BCC). BCC distributions were combined with a model of current ecosystem condition and applied to a range of biodiversity assessment methodologies, including the Biodiversity Forecasting Tool, the Spatial Links Tool and a new coupled time-series metapopulation occupancy model.

The BFT evaluation of the BCC distributions and their respective ecosystem conditions, forecasts a reduction in biodiversity persistence across the region of between 3 and 20 percent by 2070 (due to climate change only) adding to a past loss of 20 percent since European settlement (due to land use change only, not other factors such as weeds and pests). Maps of compositional dissimilarity change in vascular plants point to varying degrees of expected change in biodiversity across south-eastern Australia. Conservation benefit analysis indicates a general increase and re-distribution of the relative benefits of undertaking conservation to sustain or enhance biodiversity across the region. Results have been incorporated into novel visualisations, to assist environmental managers and others to interpret the complex concepts and issues associated with the work, and support regional adaptation planning.

1. Introduction

1.1. Modelling biodiversity for a changing climate

To be effective, biodiversity conservation should respond to identified risks, even when complexity and uncertainty places limitations on the ability to predict the outcome (Haag and Kaupenjohann, 2001; Freedman, 1998).

A trajectory of significant climate change is now upon us (Heller and Zavaleta, 2009), although the precise nature and consequences

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http://dx.doi.org/10.1016/j.ecolmodel.2017.06.022
0304-3800/

of that change cannot be known in advance. Climate change threatens biodiversity globally and it confounds system understandings and conservation efforts (Hartvigsen et al., 1998; Noss, 1990; Rissik et al., 2014). Conventional approaches to conservation planning and model-based assessment are built upon a dynamic equilibrium view of ecosystems. These approaches are becoming increasingly ineffective (Fitzgibbon and Mensah, 2012; Funtowicz et al., 1999; Saloranta, 2001) and so it is necessary to move towards alternatives that recognise fundamental change as being inevitable, and design scenarios of actions that are relevant to a range of plausible futures (Game et al., 2014).

1.2. The influence of climate on biodiversity distributions

Climate has always been a key factor influencing the spatial distribution of biological communities (Austin and Van Niel, 2011). Many species are known to have survived and persisted within specific ranges of temperature and precipitation regimes or have depended on other species that do (Aitken et al., 2008). Outside of specific tolerances there is lower colonisation, increased mortality, impaired reproduction and reduced ability to compete with species better adapted to the prevailing conditions. Over long time scales, these processes manifest as spatial heterogeneity or clustering of co-dependent species with associated similar environmental tolerances, evident as ecological communities (Gaston, 2009; Wiens, 2011).

Through exposure to repeated episodes of climate fluctuation spanning millions of years, surviving biota have accumulated an evolutionary legacy of adaptive capacity in relation to climate change (Taylor and Figgis, 2007; Pitelka, 1997; Graham et al., 2010; Dawson et al., 2011). This legacy provides species with a range of biological mechanisms (Hoffmann and Sgro, 2011) that enable persistence in the face of natural fluctuations or instabilities in environmental conditions either by increasing realised niche width (Soberón and Arroyo-Peña, 2017), or through dispersal to places where suitable conditions prevail (Chen et al., 2011). Through a complex of processes, biogeographic range shifts (i.e., the change in location of the physical area occupied by a species) in response to climate drivers are observed over time (Bulleri et al., 2016).

1.2.1. Climate migration

Even during periods of stable climate, organisms or their propagules move between habitats to access food and other resources and to seek conditions favourable to their physiology. This applies to plants as well as animals (e.g., see Pitelka, 1997). Movements are often driven by seasons, weather events and other facets of climate variability and extremes (Reside et al., 2010).

As climates change, a proportion of species are expected to persist *in situ*, rapidly adapting to environmental change by utilising suitable habitats near or within their past distributions, or by drawing on genetic variability contained within their gene-pools (Franks and Hoffmann, 2012; Franks et al., 2014; Kremer et al., 2012; Sgrò et al., 2011; Dawson et al., 2011). Within their dispersal abilities, and where sufficient habitat connectivity and habitat opportunities exist, species can also migrate or disperse via propagules to areas that become more suitable – generally higher latitudes and altitudes in a warming environment. There is already clear evidence that this process has begun in response to recent realisations of climate change, often evident as biogeopraphic 'range-shifts (Vos et al., 2008; Parmesan and Yohe, 2003; Heller and Zavaleta, 2009) which can be complex and nonconforming (Wen et al., 2017; Seabra et al., 2015). However, habitats for many species, especially those relying on cool and wet climates, are generally expected to contract and in some cases completely disappear (Thomas et al., 2004; Wake and Vredenburg, 2008).

A species' ability to range-shift, unassisted by human agency, relies on the timely emergence of sufficient new habitat supporting successful establishment, within the species' dispersal range and subject to the species' life history (Chen et al., 2011; Burrows et al., 2014). Migrations and dispersal-establishment processes will need to keep pace with the velocity of change and access suitable pathways, both spatially and temporally (i.e. habitat corridors, or stepping stones of suitable habitat) (Taylor and Figgis, 2007; Vos et al., 2008).

Range-shifting strategies can be blocked by natural barriers, such as water bodies, mountain ranges; by unsuitable habitats; or by areas permanently cleared of native habitat for urbanisation, mining or agriculture (Hoegh-Guldberg et al., 2008; Pitelka, 1997). The persistence of many species will also be affected by changing or mismatched interactions with other species in their current or newly colonised areas, including both competition and facilitation (Sinclair et al., 2010; Bulleri et al., 2016). In addition, species will face increased frequency of extreme events, such as storms, droughts and heatwaves, causing more intense and extensive disturbances than they may have adaptions to deal with (Intergovernmental Panel on Climate Change, 2015).

1.3. Managing biodiversity through climate change

Given the complexities outlined above, precise prediction of future biodiversity distributions is well beyond the reach of ecological models, even with increasing elaboration (e.g. see Bush et al., 2016; Dawson et al., 2011). Maximising adaptive capacity is therefore seen as an appropriate management response (Hoffmann et al., 2015; Prober et al., 2015). Adaptive capacity at the landscape level is largely achieved through networks of undisturbed, diverse and connected habitats, able to support biodiversity across a range of plausible futures (Funtowicz et al., 1999; Heller and Zavaleta, 2009; Watson et al., 2012).

Conservation reserve establishment has long been the central tenet of conservation strategies (Margules and Pressey, 2000). Climate change both challenges and highlights the role of reserves in maintaining biodiversity. Until recently, based on prevailing ecological paradigms, ecosystems within reserves were considered relatively stable, albeit within a dynamic equilibrium (Perry, 2002; Thompson et al., 2009). Despite the disruptive influence of shifting climatic envelopes putting pressure on species' adaptive capacity locally, conservation reserves will continue to play a central role in biodiversity conservation, although not necessarily in the ways previously understood or anticipated (Prober and Dunlop, 2011; Rannow et al., 2014). By virtue of their size and generally undisturbed state, reserves are well equipped to enable ecosystems to adaptively self-organise, providing new habitats for displaced species; as well as corridors and stepping stones for species undergoing climate migrations (Dunlop et al., 2012; Dunlop and Brown, 2008; Heller and Zavaleta, 2009; Mackey and Hugh, 2010; Thomas et al., 2004; Skøien et al., 2013). However, with changing conditions, reserves may not be able to support all the species they have in the past (and in some cases for which the reserves were established). Given that there is generally limited capacity to address this problem through the creation of ever more reserves, integrated 'whole-landscape' biodiversity conservation is increasingly seen as the logical way to complement biodiversity conservation (Ferrier and Drielsma, 2010; Scott et al., 2001; Bengtsson et al., 2003; Drielsma et al., 2016). Whole-landscape conservation seeks to build resilience and adaptive capacity across all tenures through systems of functionally connected habitat networks (Fahrig and Merriam, 1985; Merriam, 1984; Taylor et al., 1993; Hanski, I., 1999; Williams et al., 2012b).