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Climate change modifies risk of global biodiversity loss due to land-cover change

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ABSTRACT

Climate change and land-cover change will have major impacts on biodiversity persistence worldwide. These two stressors are likely to interact, but how climate change will mediate the effects of land-cover change remains poorly understood. Here we use an empirically-derived model of the interaction between habitat loss and climate to predict the implications of this for biodiversity loss and conservation priorities at a global scale. Risk analysis was used to estimate the risk of biodiversity loss due to alternative future land-cover change scenarios and to quantify how climate change mediates this risk. We demonstrate that the interaction of climate change with land-cover change could increase the impact of land-cover change on birds and mammals by up to 43% and 24% respectively and alter the spatial distribution of threats. Additionally, we show that the ranking of global biodiversity hotspots by threat depends critically on the interaction between climate change and habitat loss. Our study suggests that the investment of conservation resources will likely change once the interaction between climate change and land-cover change is taken into account. We argue that global conservation efforts must take this into account if we are to develop cost-effective conservation policies and strategies under global change.

1. Introduction

Over the past 400 years, human pressures including habitat conversion, hunting, and alien species introductions have increased species extinction rates to as much as 1000 times historical rates (Barnosky et al., 2011; Turvey, 2009), and one quarter of the species assessed so far are at risk of extinction (Hoffmann et al., 2010). In the 21st century, conservationists are becoming increasingly concerned about biodiversity disruption and loss as climate change emerges as another major threat, with impacts at the genetic, species, community and ecosystem levels (Foden et al., 2013; Lawler et al., 2009; Pacifici et al., 2015; Pounds et al., 2006; Thomas et al., 2006). As climate change and land-cover change impacts intensify and interact in the coming decades, the threat to biodiversity may be amplified (Jetz et al., 2007; Sala et al., 2000; Visconti et al., 2015). At present, our understanding of the implications of these interactions for ecological systems are limited, and have generally been based on broad assumptions about what the interaction might look like, rather than empirical data about interactions (Brook et al., 2008; Felton et al., 2009; Oliver and Morecroft, 2014; Vinebrooke et al., 2004).

Climate change can interact with land-cover change by exacerbating the impact of habitat loss and fragmentation on biodiversity through increasing the susceptibility of fragmented biological populations to stochastic extinction risk (de Chazal and Rounsevell, 2009; Jetz et al., 2007; Sala et al., 2000). Climate change can also hinder the ability of species to cope with modified land-cover (Opdam and Wascher, 2004). If climate change depresses population sizes or causes increased stochasticity in population dynamics, for example as a consequence of increased incidents of extreme events (Van De Pol et al., 2010), then habitat networks may require

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larger patches and improved connectivity to maintain populations (Verboom et al., 2010). Loss and fragmentation of habitat may also severely hinder the movement of species and their ability to cope with climate change through tracking of suitable climatic conditions (Brook et al., 2009; Keith et al., 2008; Thomas et al., 2004). Even relatively intact landscapes are at risk, particularly where landscape heterogeneity is low, forcing species to move potentially large distances to track suitable climatic conditions. Spatial heterogeneity may help buffer the impact for some species, however the buffering will vary regionally (Dunlop et al., 2012). Population responses to extreme climatic events, such as fire and flooding, are also likely to be affected by habitat quality, area and heterogeneity (Cochrane and Laurance, 2008; Fischer et al., 2006). Interactions between climate change and land-cover change may therefore be widespread phenomena and have the potential to fundamentally alter the magnitude and spatial patterns of declines in biodiversity (Jetz et al., 2007; Sala et al., 2000). However the degree to which these interactions influence biodiversity is likely to vary regionally (e.g. Cochrane and Laurance, 2008) and by taxon (e.g. Jetz et al., 2007). Not all species will be negatively affected; some will adapt and even benefit from the changes (Warren et al., 2001). But others are likely to suffer catastrophic declines without effective conservation planning and intervention. It is therefore imperative that we assess the consequences of these interactions for declines in biodiversity and identify the implications for conservation priorities.

Here we quantify the degree to which interactions between climate change and land-cover change will drive the extent and patterns of biodiversity loss due to future land-cover change at the global scale. We used a form of risk analysis (Dawson et al., 2011; McCarthy et al., 2001; Turner et al., 2003) to estimate the risk of biodiversity loss from habitat loss while accounting for its interaction with climate change. Our approach allows us to quantify the effect of climate on the probability that habitat loss has a negative effect on a species. This therefore captures the implications of the interaction between climate and habitat loss for species vulnerability to habitat loss. We applied this model globally to map estimates of the risk of terrestrial birds and mammals to future land-cover change across a range of future climate and land-cover change projections. We also assessed the risk to global biodiversity hotspots and demonstrate that conservation priorities may depend critically on the interactions between climate and land-cover change.

2. Materials and methods

We developed a model of the risk of species being impacted by habitat loss as

$$\text{Risk} = [\text{Exposure} * \text{Vulnerability}] * \text{Hazard} \quad (1)$$

where *Risk* was an index of the expected number of species of terrestrial birds and mammals negatively impacted by habitat loss from future land-cover change, *Exposure* was defined as the number of terrestrial birds and mammals that are exposed to the effect of habitat loss, *Hazard* was defined as the percent change in natural vegetation through anthropogenic land-cover change, projected for a range of land-cover change scenarios, and *Vulnerability* was defined as the probability that anthropogenic land-cover change has a negative impact on bird or mammal species and it explicitly incorporated how climate influences this probability (Fig. 1). We estimated the dependence of *Vulnerability* on climate using an existing empirical model derived from a global meta-analysis of habitat loss effects (Mantyka-Pringle et al., 2012). The *Vulnerability* model was mapped for the entire globe and then projected under a range of climate and land-cover change scenarios.

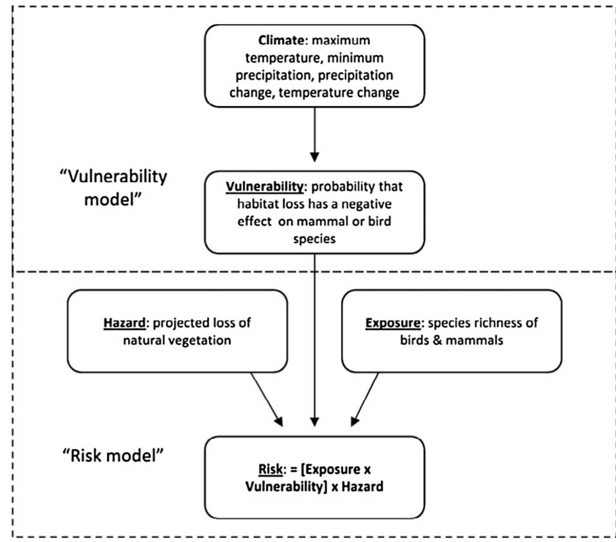

Fig. 1. Schematic representation of the steps taken to calculate the risk of biodiversity loss from habitat loss. The dotted-line boxes indicate the division of the analysis into the two separate components of "Risk" and "Vulnerability" taken from Mantyka-Pringle et al. (2012).

2.1. Future climate projections

Climate projections were downloaded from the Climate Change, Agriculture and Food Security (CCAFS) database (http://www.ccafs-climate.org/) in 2012 by statistically downscaling the outputs of three SRES (Special Report on Emissions Scenarios) climate scenarios for the fourth assessment report of the intergovernmental panel on climate change (IPCC) (IPCC, 2007), A2A, A1B, and B1 (see Table 1 for a description of these scenarios). Based on the data and model availability, three different climate models were selected to downscale the data (delta method) for the period 2050s (1×1 km), MK3.0 (for A1B), HadCM3 (for A2A) and CNRM-CM3 (for B1). For each climate scenario, five variables were

Table 1
Characteristics of the six scenarios used in our analysis. More specific details regarding these scenarios can be found elsewhere (IPCC, 2007; Visconti et al., 2011).

Scenario	Main characteristics regarding environmental sustainability
Land-cover change (MEA[a])	
Order from Strength	Regionalized and fragmented world; reactive approach to ecosystem management (reserves, parks, national-level policies, conservation)
Global Orchestration	Integrated world; reactive approach to ecosystem management (sustainable development, economic growth, public goods)
TechnoGarden	Integrated world; proactive approach to ecosystem management (green technology; eco-efficiency; tradable ecological property rights)
Climate change (SRES[b])	
SRES A2A	Divided world; continuously increasing population; regionally orientated economic growth that is more fragmented and slower than other scenarios
SRES A1B	Integrated world; population threshold of 9 billion; rapid economic growth; rapid introduction of new and more efficient technologies; a balanced emphasis on all energy sources
SRES B1	Convergent world; population threshold of 9 billion; rapid economic growth with reductions in material intensity; introduction of clean & resource efficient technologies

[a] MEA, Millennium Ecosystem Assessment (MEA, 2005).
[b] SRES, Special Report on Emissions Scenarios (IPCC, 2007).