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How robust are global conservation priorities to climate change?

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ABSTRACT

International conservation organisations have identified priority areas for biodiversity conservation. These global-scale prioritisations affect the distribution of funds for conservation interventions. As each organisation has a different focus, each prioritisation scheme is determined by different decision criteria and the resultant priority areas vary considerably. However, little is known about how the priority areas will respond to the impacts of climate change. In this paper, we examined the robustness of eight global-scale prioritisations to climate change under various climate predictions from seven global circulation models. We developed a novel metric of the climate stability for 803 ecoregions based on a recently introduced method to estimate the overlap of climate envelopes. The relationships between the decision criteria and the robustness of the global prioritisation schemes were statistically examined. We found that decision criteria related to level of endemism and landscape fragmentation were strongly correlated with areas predicted to be robust to a changing climate. Hence, policies that prioritise intact areas due to the likely cost efficiency, and assumptions related to the potential to mitigate the impacts of climate change, require further examination. Our findings will help determine where additional management is required to enable biodiversity to adapt to the impacts of climate change.

1. Introduction

International conservation organisations aim to mitigate the rate of species extinctions (Halpern et al., 2006; Brooks et al., 2006), which currently exceeds the background rate by two to three orders of magnitude (Pimm et al., 1995). These organisations are entrusted to spend funding from governmental and non-governmental monetary resources such as the Global Environmental Facility (Mittermeier and Bowles, 1993; Ferraro, 2001). A number of global schemes for identifying priority areas for investment have been created to support decisions of where to invest these vast, albeit inadequate, funds (Halpern et al., 2006; Brooks et al., 2006; Wilson et al., 2009). For example, the Biodiversity Hotspots developed by Myers *et al.* (2000) influences the distribution of US$ 750 million annually to local conservation projects around the world (Myers et al., 2000; Brooks et al., 2006). Considering their influence on conservation interventions around the world (Mittermeier and Bowles, 1993; Ferraro, 2001; Halpern et al., 2006; Brooks et al., 2006; Wilson et al., 2009), it is important to assess the effectiveness of global conservation priorities in the context of climate change.

There are at least twelve sets of widely-known global priority schemes (Brooks et al., 2006; Wilson et al., 2009). Most international conservation organisations have created an organisation-specific scheme because they have different objectives (Halpern et al., 2006; Wilson et al., 2009). None of the decision criteria that underlie these schemes, however, account for the impacts of climate change. This is a problem because climate change is impacting species distributions and ecological processes (Hughes, 2000; Parmesan and Yohe, 2003) and is predicted to cause significant biodiversity loss at the global scale (Thomas et al., 2004). Along with predictions of species range shifts in the future (Thuiller, 2004; Araújo et al., 2004; Hannah et al., 2007), an unstable climate may force species to seek climatic refugia (Williams and Jackson, 2007; Loarie et al., 2009; Davison et al., 2012). Furthermore, there are increasing concerns as to whether current protected areas will retain suitable climates for existing ecosystems into the future (Lee and Jetz, 2008; Hole et al., 2009). Thus priority areas that are less robust to the impacts of climate change will require implementation of additional adaptation and mitigation strategies (McClanahan et al., 2008).

Past assessments of the impacts of climate change on conservation priorities often have been performed through predictions of species range shifts (Thuiller, 2004; Araújo et al.,

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2004; Hannah et al., 2007) based on many species distribution models (Guisan and Zimmermann, 2000; Guisan and Thuiller, 2005; Elith et al., 2006). However, responses to climate change are highly area and species specific (Broennimann et al., 2006; Dawson et al., 2011). Therefore, unless researchers include species representing most taxonomic groups, such analyses will result in an assessment biased towards well-studied and well-modelled taxonomic groups (Rondinini et al., 2006). Furthermore, conducting such analyses at regional or global scales is limited by the availability of fine resolution species distribution data over extensive areas (Murdoch et al., 2010) and species distribution predictions can yield large errors and uncertainties (e.g. Thuiller, 2004; Pearson et al., 2006; Araújo and Rahbek, 2006; Garcia et al., 2012), potentially impacting conservation decisions (Rondinini et al., 2006). One way to reduce these limitations considerably is to determine the robustness of a region based on a single index measuring the overlap of climatic envelopes (Warren et al., 2008; Iwamura et al., 2010; Broennimann et al., 2012).

Here, we take this single index approach to evaluate the robustness of eight sets of global priority areas to future climate change. We estimate the similarity between the current and future climates of each priority area (herein referred to as the 'climate stability') by applying a measure of niche overlap (Warren et al., 2008; Iwamura et al., 2010; Broennimann et al., 2012). We also examine the decision making criteria underlying each prioritisation scheme and create a categorical framework for identifying schemes likely to be most robust to the impacts of climate change.

2. Material and methods

2.1. Global conservation priorities

Eight major schemes of global priorities for identifying the most important areas for terrestrial biodiversity were examined (Table 1). We excluded schemes whose priority areas are too small for a global scale analysis or for which digitised information on spatial extents is not publicly available (e.g. Important Bird Areas). We summarised the underlying decision criteria of each scheme into five categories, based on publicly available information on each scheme (Table 1). The irreplaceability criterion, *IRR*, indicates whether the organisations prioritise irreplaceable areas to protect biodiversity (Cowling et al., 1999). An irreplaceable area is defined as one that cannot be replaced due to its high complementarity to other areas (Margules and Pressey, 2000). This criterion can be based on species and/or other ecological features and is determined in relation to other areas that are selected. The vulnerability criterion, *VUL*, indicates whether areas more vulnerable to land conversion due to human development are prioritised (Cowling et al., 1999). The scale criterion, *SCALE*, indicates whether the minimum size of each priority area is larger than the mean extent of ecoregions (>163,892 km^2). The endemism criterion, *ENDM*, reveals whether areas with a large number of endemic species are prioritised and the fragmentation criterion, *FRAG*, indicates whether fragmented landscapes are prioritised (Wilson et al., 2009).

2.2. Spatial units (ecoregions)

We employed 803 ecoregions as spatial units of analysis as opposed to equal sized grid cells (Williams et al., 2007; Loarie et al., 2009). Ecoregions are defined as "relatively large units of land containing a distinct assemblage of natural communities and species, with boundaries that approximate the original extent of natural communities" (Olson et al., 2001). We chose ecoregions as a spatial unit because it is the most detailed ecological boundary available at a global scale and is used most commonly for global scale conservation assessments (Olson et al., 2001; Ferrier et al., 2010). Ecoregions form the basis of the Global 200 and Crisis Ecoregions prioritisation schemes, while the Biodiversity Hotspot and High Biodiversity Wilderness Areas schemes use boundaries derived from ecoregions. Endemic Bird Areas, Frontier Forests and Last of the Wild prioritisation schemes are not aligned with the boundaries of ecoregions. We also calculated the climate stability index for hypothetical regions of uniformly gridded map consisted from 781 rectangle cells with area size of 310,844 km^2 (Fig. S2, see Supporting Information for details) to evaluate whether the underlying spatial unit of analysis impacts our conclusions.

2.3. Climate dataset

We used a downscaled spatial dataset for climate variables at the resolution of 2.5′ (approximately 4.6 km cell size at the equator), equating to 8.5 million data points across 803 ecoregions. Spatial data for bioclimatic variables (Nix, 1986) for 1950–2000 were obtained from the *WorldClim* database (Hijmans and Graham, 2006). Previous research has shown that the indiscriminate use of bioclimatic variables produces poor results (Beaumont et al., 2005). Hence we chose six climate variables (annual mean temperature, mean diurnal temperature range, mean annual temperature range, annual precipitation, precipitation seasonality

Table 1
Global conservation priority schemes and categorical axes.

Global cons. priorities	Prioritising criteria				
	Irreplaceablity	Vulnerability	Endemism	Scale	Fragmented
Biodiversity Hotspots	Yes	Reactive	Yes	Small	Yes
Endemic Bird Areas	Yes	Neutral	Yes	Small	No
Global 200	Yes	Neutral	No	Small	No
Crisis Ecoregions	No	Reactive	No	Small	Yes
Megadiverse Countries	Yes	Neutral	No	Large	No
Frontier Forests	No	Proactive	No	Small	No
Last of the Wild	No	Proactive	No	Small	No
High Biodiversity Wilderness Areas	Yes	Proactive	No	Large	No

The Biodiversity Hotspot has been adopted by Conservation International. It prioritises the most important areas for endemic vascular plant species and areas that have been extensively cleared (Myers et al., 2000). Endemic Bird Areas were developed by Birdlife International to prioritise important areas for endemic bird species (Stattersfield et al., 1998). Global 200 is used by World Wildlife Fund (WWF) to prioritise important areas for terrestrial vertebrates (Olson and Dinerstein, 1998). Crisis ecoregions were adopted by The Nature Conservancy and WWF to prioritise the most threatened ecoregions (Hoekstra et al., 2005). Megadiverse Countries are defined as countries which, when combined, contain a disproportionate fraction of the world's biodiversity (Mittermeier et al., 1998). Frontier Forests are defined by the World Resource Institute to identify the most intact forests with high biodiversity values (Bryant et al., 1997). Last of the Wild identifies areas still untouched by human development (Sanderson et al., 2002) and High Biodiversity Wilderness Areas prioritise the worlds' largest intact areas with high biodiversity values (Mittermeier et al., 2003). The table states which of decision making criteria are used to define the priorities. Note: In this paper, we class High Biodiversity Wilderness Areas as "Neutral" with respect to vulnerability, as it does not explicitly incorporate land conversion rate.