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BIODIVERSITY VIEWPOINT

Publishing trends on climate change vulnerability in the conservation literature reveal a predominant focus on direct impacts and long time-scales

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ABSTRACT

Over the past twelve years the number of papers that explore the impacts of climate change on biodiversity in the conservation literature has grown on average by 20% annually. By categorising these papers on their primary research questions, we show that the vast majority of these articles (88.6%) focus only on those impacts that arise directly as a result of climate change, ignoring the potentially significant indirect threats that arise from human adaptation responses. This pattern has remained fairly consistent throughout the review period (2000–2012), with a trend towards more articles considering both direct and indirect impacts towards the end of the period. We also find a bias in the time-frames considered by published articles that project future impacts of climate change on biodiversity, with more than three-quarters (77.9%) of papers only considering impacts after 2031, and almost half (49.1%) only considering impacts after 2051. This focus on long-term, direct impacts creates a mismatch, not only with the life-cycles of species and timescales of many ecological processes, but also with most management and policy timelines and the short-term nature of human decision making processes. The focus on studying the long-term, direct impacts of climate change on biodiversity is likely a function of the lack of availability of climate projections on shorter temporal scales; a perception that short-term impacts will be minor; and, insufficient integration with the social and political sciences. While the direct impact of changes in mean climatic conditions will significantly change the biosphere by the end of the century, near term changes in seasonality and extreme events coupled with human adaptation responses are likely to have substantial impacts much sooner, threatening the survival of species and ecosystems. It is therefore essential that we balance our research efforts to facilitate a better understanding of these more imminent threats.

Keywords

Adaptation planning, climate change, conservation, direct effects, extreme climate, extreme weather, indirect effects, time-scale, vulnerability.

INTRODUCTION

Anthropogenic emissions of greenhouse gases have committed the Earth to higher global temperatures, altered rainfall patterns, sea level rise and increases in the frequency of extreme weather events, among other impacts (IPCC, 2013). The long-term consequences of climate change for biodiversity are likely to be severe with the most conservative estimates suggesting at least 10% of species could face extinction by 2100 (Maclean & Wilson, 2011). Some of the impacts being reported in the literature include: shifting or shrinking species ranges across the globe (Parmesan & Yohe, 2003), changes in phenology leading to reduced fitness (Lane *et al.*, 2012), mass coral bleaching events (Hughes *et al.*, 2003), and complex changes in community composition and species interactions (Thomas, 2010).The effects of climate change on biodiversity are further shaped by complex interactions with other threatening processes such as habitat loss and

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fragmentation, direct exploitation, invasive species, pollution, and disease (Brook *et al.*, 2008; Jackson, 2008; Turner *et al.*, 2010; Hof *et al.*, 2011; Mantyka-Pringle *et al.*, 2012).

Climate change is also reshaping the ways in which people use the landscapes and seascapes they live in (Watson, 2014). Changing precipitation and temperature patterns are reducing the productivity of some arable lands (Parry *et al.*, 2005) and creating new opportunities for cultivation in other areas (Bradley *et al.*, 2012; Wheeler & von Braun, 2013). The impact of these changes will alter the pattern and intensity of managed lands and thus the impact on biodiversity, and opportunity costs of conservation in production landscapes. Other human adaptation responses which are likely to exacerbate threats to species and ecosystems include construction of sea walls to protect against sea level rise, changing patterns of fishing intensity, diversion and large-scale storage of water, and the planting of non-native forestry tree species which are better suited to changed climatic conditions (Mendelsohn, 2000; Grantham *et al.*, 2011; McClanahan & Cinner, 2011). The effects on biodiversity that arise from the efforts of people to respond to climate change, which are ongoing and will only accelerate in the future as the Earth's human population continues to grow and climate change proceeds (IPCC, 2012), are defined here as the 'indirect impacts' of climate change. All other climate change impacts, including those which act through an interaction with another ecological process such as competition or predation from invasive species or trophic mismatches, are defined here as the 'direct impacts' of climate change.

Halting biodiversity loss in the long-term requires careful formulation of conservation management strategies that are robust to the full range of climate change impacts, both direct and indirect. For adaptation planning and practice to be successful it needs to be informed by science that provides unbiased estimates of which species, in which places, are likely to be at risk and which actions are necessary to try to ensure their persistence (Whittaker *et al.*, 2005; Bellard *et al.*, 2012; Watson *et al.*, 2013). Recent reviews of the vulnerability of biodiversity to climate change have summarised different modelling and methodological aspects of predicting future impacts (Dawson *et al.*, 2011; McMahon *et al.*, 2011; Mokany & Ferrier, 2011; Sieck *et al.*, 2011); and examined the effects of synergies between climate change and other threatening processes (De Chazal & Rounsevell, 2009; Nobis *et al.*, 2009; Yates *et al.*, 2010; Bradley *et al.*, 2012; Mantyka-Pringle *et al.*, 2012). Surprisingly, no study to our knowledge has evaluated the broad foci in the literature in terms of the way in which vulnerability to climate change is being assessed, and crucially, asked whether we are in fact asking the right questions in the first place.

Here we look at two specific issues related to the broader treatment of climate change as a threat to biodiversity in the conservation literature. First, we examine the evidence that research examining the vulnerability of species or ecosystems to climate change is primarily focused on the direct impacts of climatic changes such as increased temperatures or changes in precipitation as opposed to indirect impacts. As described above, for the purposes of this study we defined the 'direct' impacts of climate change to be all those impacts which arise as a result of changes to the climate (e.g. coral bleaching, changes in phenology, habitat loss from sea-level rise etc.), even where those changes act through an interaction with another threat (e.g. habitat loss), or with an ecological process (e.g. fire, predation, invasive species etc.). Impacts which arise from the actions taken by humans to adapt to climate change (e.g. shifting patterns of agriculture, building of coastal defences, etc.), *sensu* Turner *et al.* (2010), were defined as 'indirect impacts'. Second, we examined the time frames of published research to determine if there was a greater focus on predicting impacts in the long term versus shorter, more imminent time frames.

ASSESSING FOCI IN CLIMATE CHANGE VULNERABILITY ASSESSMENT IN CONSERVATION JOURNALS

The level of interest in climate change in the conservation science discipline has grown substantially over the past decade. We conducted a search on the Web of Science Database in February 2013 using the term 'climat* chang*' and refined to the seven highest ranking 'biodiversity conservation' journals by impact factor (*Global Change Biology*, *Diversity and Distributions*, *Conservation Biology*, *Ecography*, *Biological Conservation*, *Conservation Letters* and *Animal Conservation*). In total, 941 articles matching these criteria were published between January 1 2000 and December 31 2012. The number of papers published annually increased from 24 in 2000 to 141 in 2012, an average annual growth rate of 20% (Fig. 1).

To categorise the literature into direct and indirect impacts studies, we first identified 'empirical' articles ($n = 748$; 79%; Fig. 2), defined as those articles which made observational assessments of species and ecosystems responses to climate change, predictions based on observational work, conducted experimental assessments of the likely impacts of climate change or made predictions based on experimental work. The remaining 'others' included policy and philosophical perspectives, opinion pieces and literature reviews ($n = 193$; 21%; Fig. 2). We then further classified the 'empirical' articles to those that assessed the vulnerability of a species, species assemblages or ecosystem to climate change ($n = 402$; 54%; Fig. 2), and those that did not assess vulnerability ($n = 346$; 46%; Fig. 2). The majority of the latter either documented observed climatic change or evaluated a management plan. Finally, using the above definitions, we further classified the 402 articles that assessed vulnerability into three categories (Fig 2): (i) those studies that only dealt with direct impacts ($n = 356$; 89%); (ii) those studies that only dealt with indirect impacts ($n = 0$); and, (iii) those studies that dealt with both indirect and direct impacts ($n = 46$; 11%).

Of the 402 articles that were classified as a vulnerability assessment, we extracted those which projected future

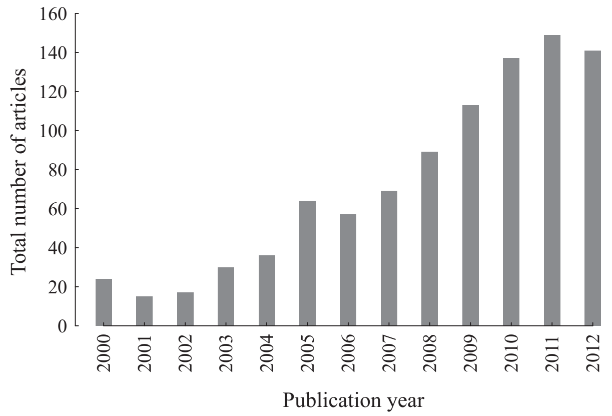

Figure 1 Number of studies in the published literature on the impact of climate change on biodiversity between January 1st 2000 and December 31st 2012, based on a Web of Science search using the term 'climate chang*' and refined to the seven highest ranking 'biodiversity conservation' journals by impact factor (*Global Change Biology*, *Diversity and Distributions*, *Conservation Biology*, *Ecography*, *Biological Conservation*, *Conservation Letters* and *Animal Conservation*).

impacts of climate change on species or ecosystems over a defined time period (n = 177; 44%; Fig. 2). The remaining articles (n = 225; 56%) either used an unknown time-frame in their projections, or only considered impacts which had already occurred up to the present day. We then defined six time horizons over which projections were made (Fig. 2) and categorised the articles accordingly: present – 2030 (n = 3; 2%); present – 2050 (n = 6; 3%); present – beyond 2051 (n = 30; 17%); 2031–2050 (n = 22; 12%); 2031 – beyond 2051 (n = 29; 16%); and 2051 onwards (n = 87; 49%). For clarity, we collapsed these to three categories (Table 1): short-term only (pre-2030 only; n = 3); short and long term (a time period between the present and beyond 2051; n = 36); and long term only (beyond 2031 only; n = 138). Two papers considered a time-frame that began prior to the present day, to beyond 2051. These papers were included in the category present – beyond 2051.

Once all articles had been assigned to categories, the first 60 articles were re-examined and re-classified to ensure the classification had not changed over the course of the research. This is similar to the method used by Heller & Zavaleta (2009), who periodically re-shuffled and re-classified articles in their review to ensure the classification did not differ based on when the articles were read.

A DOMINANCE OF STUDIES THAT ASSESS DIRECT IMPACTS

The vast majority (n = 356, 88.6%) of the papers that assessed vulnerability considered only the direct impacts of climate change, while 46 (11.4%) papers considered both direct and indirect impacts. We found no papers that only addressed indirect impacts (Table 1; Fig. 2). While no papers considered both direct and indirect impacts between 2000 and 2003, between 2004 and 2012 between 3 and 20% (mean = 12.8%) of papers each year considered both types of impact.

Thus, the focus of vulnerability research to date has principally been on the ecological responses of species and ecosystems to changes in direct climatic drivers, as opposed to taking a more holistic approach which also incorporates how the human response to climate change will also impact species and ecosystems. These indirect impacts, however, may be as much, if not more, of a threat to species and ecosystems, than the direct impacts of climate change (Paterson *et al.*, 2008; Turner *et al.*, 2010; Watson & Segan, 2013). For example, Wetzel *et al.* (2012) examined the potential change in habitat availability for selected mammal species as a result of both direct effects of future sea-level rise and indirect effects through the relocation of urban areas and intensive agricultural land as people are displaced from the coast, for islands in Southeast Asia and the Pacific. They predict that the indirect impacts of sea level rise could be equal to or greater than the direct impacts (Wetzel *et al.*, 2012). This is not an isolated example; most biodiversity is already impacted by multiple threatening processes aside from the direct impacts of climate change (Hoffmann *et al.*, 2010), and ignoring how these threatening processes will change due to climate change is likely to grossly underestimate the risk (e.g. Jetz *et al.*, 2007).

The bias these results show in the way that conservation scientists are assessing the impact of climate change on species and ecosystems likely arise in part from the predominance of ecologists in the field of conservation science with little or no background in the social sciences (Knight *et al.*, 2008) as well as the relative ease with which direct impacts can now be modelled owing to the range of bioclimatic models that relate species distributions to aspects of climate (Keith *et al.*, 2008; Kearney & Porter, 2009).

Accounting for the indirect impacts requires dealing with the inherent difficulties in trying to adequately capture and forecast diverse processes including land-use change, human displacement and altered resource utilization patterns (Turner, 2010). The factors that drive land-use change and deforestation are complex and the importance of each driver varies across countries and regions making the patterns hard to predict (Bawa & Dayanandan, 1997). Forecasting indirect impacts also requires an understanding of how government, market forces and other factors affect where and how people live (Turner, 2010). Despite these challenges, recent work has made progress in understanding the complex dynamics of social ecological systems and assessing likely system response. For example, Hein *et al.* (2009) constructed a socio-ecological model for a pastoralist system in the Western Sahel that allowed exploration of how changing precipitation regimes will impact local livelihoods given alternative scenarios for grazing and livestock prices (Hein *et al.*, 2009). They demonstrated that local incomes are likely to suffer from both decreasing rainfall and increased rainfall variability, but that

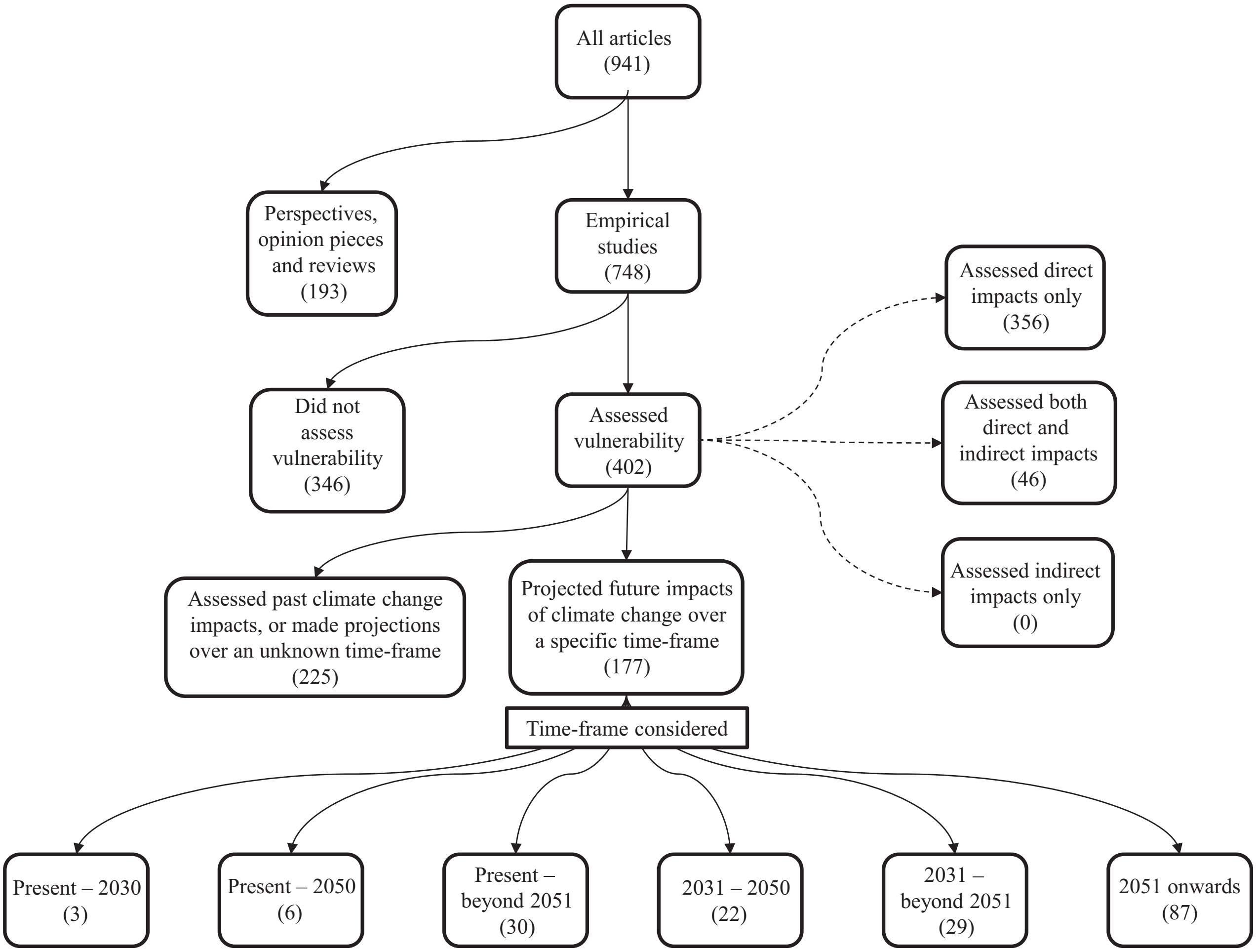

Figure 2 Schematic diagram of the classification criteria used to ascertain the numbers of research papers published in the top seven ranked journals in conservation biology between 2000 and 2012 which considered direct vs. indirect, and long vs. short term impacts of climate change. Papers were first classified based on research methodology, separating empirical from non-empirical studies. Empirical studies were then classified as either a vulnerability assessment of a species or ecosystem to climate change, or other pieces of work. The vulnerability assessments were then classified into three categories: (i) studies that only dealt with direct impacts, (ii) studies that only dealt with indirect impacts, and (iii) studies that dealt with both indirect and direct impacts. We further categorized the articles that undertook vulnerability assessments to those that evaluated future impacts of climate change versus those articles that only evaluated vulnerability up to the current period. For those studies that predicted future impacts, we further classified each study based on the temporal extent of impact considered to three broad time periods (pre-2030, 2031–2050, and beyond 2051). Numbers in parentheses are the number of papers in each category.

Table 1 A matrix of the number of research articles that considered the predicted impacts of climate change on biodiversity, broken up into temporal scale of the research (short, long, and short and long) and types of impact (direct, indirect or both) assessed

	Temporal scale of analysis		
Focus of vulnerability assessment	Short only (now to 2030)	Both short and long	Long (beyond 2031)
Indirect only	0	0	0
Both	2	3	23
Direct only	1	33	115
Total	3	36	138

altered stocking patterns could offset some of the loses. This type of research that focuses on understanding both the vulnerability and likely response of people provides information that is likely critical for identifying and mitigating these changing impacts on local conservation objectives (Watson, 2014).

A number of recent studies have begun to incorporate indirect impacts into conservation vulnerability assessments. For example, Bradley *et al.* (2012) recognized that reduced crop suitability and food scarcity in subsistence areas in South Africa may lead to the exploitation of protected areas for food and fuel. By investigating how crop and maize suitability will change under different climate scenarios, they showed that 328 protected areas in the country are likely to be hotspots for future conflict between human adaptation and conservation. At more regional scales, models like IMAGE (which provide spatially explicit scenarios for future land cover based on forecasted changes in demography, resource utilization and climate change) have been integrated into vulnerability assessments of species and ecosystem services to account for indirect impacts (Jetz *et al.*, 2007; Metzger *et al.*, 2008; Visconti *et al.*, 2011). Visconti *et al.* (2011), for example, used models of forecasted habitat suitability under climate change for 5086 terrestrial mammals and four scenarios for future land cover sourced from the IMAGE model to identify areas where mammals are most likely to lose habitat to either human induced land-use change or change in climatic suitability. They found that when both drivers of habitat loss were considered the countries identified as future conservation priorities varied considerably from those identified as current conservation priorities.

A FOCUS ON THE LONG-TERM

More than three quarters of articles that forecast future impacts of climate change (n = 177; Fig 2) only considered impacts after 2031 (n = 138; 77.9%; Table 1), and approximately half only considered impacts after 2051 (n = 87; 49.1%; Fig. 2). This pattern was consistent over the publication years considered by this study.

These results show that as a scientific community we have focused primarily on the continuous, long-term impacts of climate change and are ignoring the short-term, discrete impacts (Watson *et al.*, 2011). While the long-term impacts of climate change on species and ecosystems will be severe, including the possible extinction of many plant and animal species (IPCC, 2007; Maclean & Wilson, 2011), focusing mostly on these impacts is likely to be inadequate to understand, manage and mitigate the impacts of climate change, which are both discrete and continuous and can have devastating consequences for biodiversity (Corlett, 2011). For example drought events are linked with population die-offs of large mammals (Young, 1994; Foley *et al.*, 2008) while extreme flood events have been found to shape the distribution of riparian plant species (Vervuren *et al.*, 2003) and species habitat utilization (Sarma *et al.*, 2012), and can result in changes in population structure (Heinen & Kandel, 2006). The temporal resolution of most long term studies, often 30 year mean climatic conditions, is wholly insufficient to capture the impact of decadal or annual trends, let alone the sub-annual climate events to which the life histories of species are often intimately linked, or entirely dependent upon.

The predominance of work exploring long-term impacts is unsurprising given that climatologists have greater confidence in forecasts of longer-term patterns based on 20 or 30 year averages, than in predicting short-term annual and sub-annual changes (IPCC, 2007). Furthermore, extreme events (e.g. drought, flood, cyclones) are, by definition, rare, and thus both prediction of their future frequency and the detection and attribution of changes in past frequency are difficult (Seneviratne *et al.*, 2012). This lack of confidence in predicting short-term climatic means and climatic extremes has meant that the datasets available for use in species distribution modelling and other common techniques used by conservation scientists have been limited to projection of long-term mean climatic conditions. Despite the uncertainties in predicting exactly where or when an extreme event will occur there are examples of efforts to integrate the impact of such events into conservation vulnerability assessments. Ameca y Juárez *et al.* (2013), for example, used information on the historic distribution of cyclones and droughts and range maps for 5760 mammals to identify areas were mammals are most likely to be exposed to two extreme events. They found that 31.9% of terrestrial mammals are significantly exposed to either cyclones or droughts, and suggest that the IUCN Red List of Threatened Species may vastly underestimate the number of species impacted by extreme events (Ameca y Juárez *et al.*, 2013).

Finally, it is important to note that the focus on the longer term persists in studies that consider both direct and indirect impacts of climate change (Table 1). This may be particularly problematic given that human adaptation responses are ongoing, hence indirect impacts on biodiversity will manifest over short as well as longer time-scales (Bradley *et al.*, 2012; Wheeler & von Braun, 2013). Furthermore, many human adaptations arise in response to the increased risk of extreme events (Berrang-Ford *et al.*, 2011), for example construction of sea walls to protect against high tides or water storage systems to protect against droughts, both of which are likely to occur in the short as well as longer term (Grantham *et al.*, 2011).

CONSEQUENCES FOR ADAPTATION PLANNING AND ACTION

This study has highlighted a dominant focus in the conservation literature that needs to be addressed. While the growth of climate-oriented research is encouraging, the majority of vulnerability research has focused on assessment of long-term, direct impacts. Although there is still more important work to be done on understanding these impacts and refining existing models (Huntley *et al.*, 2010), it should not come at the expense of a holistic understanding of climate change that includes the impact of short-term, acute events and indirect impacts caused by human adaptation responses. This is in part because the life-cycles of species and the time-scales of many ecological processes are typically shorter than the long-term time-frames considered by most of the conservation literature reviewed here. However, it is also important in relation to policy decisions as political cycles in most democracies are typically three to 5 years which means that many decision-making processes are happening over time-scales better matched to the short-term, indirect impacts of climate change (Day, 2013). Politicians who wish to be (re) elected are likely to gain from distributing funds to projects of immediate concern to their electorate (e.g. Krueger, 1974). It may therefore be more challenging to have policy enacted based on impacts solely projected to happen in the distant future. Behavioural economics tells us that people tend to place a higher value upon rewards received immediately than those received in the future (e.g. Thaler, 1981; Frederick *et al.*, 2002; Wittmann & Paulus, 2008). Thus, if the goal of vulnerability assessments is to facilitate adaptive action, then it logically follows that research questions should be tailored to inform and motivate policy and practice.

This research has shown that in the conservation literature, if not the conservation community, we have become too accustomed to looking at the long-term implications of climate change and by forecasts of what the planet may look like in five decades or at the end of century. While these long-term impacts are important, almost all lines of evidence show that species and ecosystems are becoming increasingly threatened by climate change and non-climate stressors that are occurring now (IPCC, 2013). These short-term, indirect impacts are the figurative 'bumps in the road' that we must be able to navigate to ensure their survival. Incorporating the indirect impacts and short-term climate changes into research, vulnerability and monitoring assessments and subsequent decision-making will require significant changes in the methods conservation scientists currently use, including greater focus on social, economic and political issues. The benefits to biodiversity will also be significant, in the form of conservation responses that truly address the full range of climate change impacts.

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REFERENCES

Ameca y Juárez, E.I., Mace, G.M., Cowlishaw, G., Cornforth, W.A. & Pettorelli, N. (2013) Assessing exposure to extreme climatic events for terrestrial mammals: extreme climate and exposure for mammals. *Conservation Letters*, **6**, 145–153.

Bawa, K.S. & Dayanandan, S. (1997) Socioeconomic factors and tropical deforestation. *Nature*, **386**, 562–563.

Bellard, C., Bertelsmeier, C., Leadley, P., Thuiller, W. & Courchamp, F. (2012) Impacts of climate change on the future of biodiversity. *Ecology Letters*, **15**, 365–377.

Berrang-Ford, L., Ford, J.D. & Paterson, J. (2011) Are we adapting to climate change? *Global Environmental Change*, **21**, 25–33.

Bradley, B.A., Estes, L.D., Hole, D.G., Holness, S., Oppenheimer, M., Turner, W.R., Beukes, H., Schulze, R.E., Tadross, M.A. & Wilcove, D.S. (2012) Predicting how adaptation to climate change could affect ecological conservation: secondary impacts of shifting agricultural suitability. *Diversity and Distributions*, **18**, 425–437.

Brook, B., Sodhi, N. & Bradshaw, C. (2008) Synergies among extinction drivers under global change. *Trends in Ecology & Evolution*, **23**, 453–460.

Corlett, R.T. (2011) Impacts of warming on tropical lowland rainforests. *Trends in Ecology & Evolution*, **26**, 606–613.

Dawson, T.P., Jackson, S.T., House, J.I., Prentice, I.C. & Mace, G.M. (2011) Beyond predictions: biodiversity conservation in a changing climate. *Science*, **332**, 53–57.

Day, N. (2013) The politics of posterity: expertise and long-range decision making. *Future directions for scientific advice in Whitehall* (ed. by R. Doubleday and J. Wilsdon), pp. 106–114. University of Cambridge, Cambridge UK.

De Chazal, J. & Rounsevell, M.D.A. (2009) Land-use and climate change within assessments of biodiversity change: a review. *Global Environmental Change*, **19**, 306–315.

Foley, C., Pettorelli, N. & Foley, L. (2008) Severe drought and calf survival in elephants. *Biology Letters*, **4**, 541–544.

Frederick, S., Loewenstein, G. & O'donoghue, T. (2002) Time discounting and time preference: a critical review. *Journal of Economic Literature*, **40**, 351–401.

Grantham, H.S., McLeod, E., Brooks, A., Jupiter, S.D., Hardcastle, J., Richardson, A.J., Poloczanska, E.S., Hils, T., Mieszkowska, N., Klein, C.J. & Watson, J.E.M. (2011) Ecosystem-based adaptation in marine ecosystems of tropical Oceania in response to climate change. *Pacific Conservation Biology*, **17**, 241.

Hein, L., Metzger, M.J. & Leemans, R. (2009) The local impacts of climate change in the Ferlo, Western Sahel. *Climatic Change*, **93**, 465–483.

Heinen, J.T. & Kandel, R. (2006) Threats to a small population: a census and conservation recommendations for wild buffalo *Bubalus arnee* in Nepal. *Oryx*, **40**, 324.

Heller, N.E. & Zavaleta, E.S. (2009) Biodiversity management in the face of climate change: a review of 22 years of recommendations. *Biological Conservation*, **142**, 14–32.

Hof, C., Levinsky, I., Araújo, M.B. & Rahbek, C. (2011) Rethinking species' ability to cope with rapid climate change. *Global Change Biology*, **17**, 2987–2990.

Hoffmann, M., Hilton-Taylor, C., Angulo, A. *et al.* (2010) The impact of conservation on the status of the world's vertebrates. *Science*, **330**, 1503–1509.

Hughes, T.P., Baird, A.H., Bellwood, D.R., Card, M., Connolly, S.R., Folke, C., Grosberg, R., Hoegh-Guldberg, O., Jackson, J.B.C., Kleypas, J., Lough, J.M., Marshall, P., Nystrom, M., Palumbi, S.R., Pandolfi, J.M., Rosen, B. & Roughgarden, J. (2003) Climate change, human impacts, and the resilience of coral reefs. *Science*, **301**, 929–933.

Huntley, B., Barnard, P., Altwegg, R., Chambers, L., Coetzee, B.W.T., Gibson, L., Hockey, P.A.R., Hole, D.G., Midgley, G.F., Underhill, L.G. & Willis, S.G. (2010) Beyond bioclimatic envelopes: dynamic species' range and abundance modelling in the context of climatic change. *Ecography*, **33**, 621–626.

IPCC (2007) *Climate change 2007: Impacts, Adaptation and Vulnerability: contribution of Working Group II to the fourth assessment report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, U.K, New York.

IPCC (2012) *Managing the risks of extreme events and disasters to advance climate change adaptation: a Special Report of Working Groups I and II of the Intergovernmental Panel on Climate Change*. Cambridge University Press, New York, NY.

IPCC (2013) Summary for Policymakers. *Climate Change 2013: The Physical Science Basis. Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press, Cambridge, UK and New York, NY.

Jackson, J.B.C. (2008) Ecological extinction and evolution in the brave new ocean. *Proceedings of the National Academy of Sciences USA*, **105**, 11458–11465.

Jetz, W., Wilcove, D.S. & Dobson, A.P. (2007) Projected impacts of climate and land-use change on the global diversity of birds. *PLoS Biology*, **5**, e157.

Kearney, M. & Porter, W. (2009) Mechanistic niche modelling: combining physiological and spatial data to predict species' ranges. *Ecology letters*, **12**, 334–350.

Keith, D.A., Akçakaya, H.R., Thuiller, W., Midgley, G.F., Pearson, R.G., Phillips, S.J., Regan, H.M., Araújo, M.B. & Rebelo, T.G. (2008) Predicting extinction risks under climate change: coupling stochastic population models with dynamic bioclimatic habitat models. *Biology Letters*, **4**, 560–563.

Knight, A.T., Cowling, R.M., Rouget, M., Balmford, A., Lombard, A.T. & Campbell, B.M. (2008) Knowing but not doing: selecting priority conservation areas and the research-implementation gap. *Conservation Biology*, **22**, 610–617.

Krueger, A.O. (1974) The political economy of the rent-seeking society. *American Economic Review*, **64**, 291–303.

Lane, J.E., Kruuk, L.E.B., Charmantier, A., Murie, J.O. & Dobson, F.S. (2012) Delayed phenology and reduced fitness associated with climate change in a wild hibernator. *Nature*, **489**, 554–557.

Maclean, I.M.D. & Wilson, R.J. (2011) Recent ecological responses to climate change support predictions of high extinction risk. *Proceedings of the National Academy of Sciences USA*, **108**, 12337–12342.

Mantyka-Pringle, C.S., Martin, T.G. & Rhodes, J.R. (2012) Interactions between climate and habitat loss effects on biodiversity: a systematic review and meta-analysis. *Global Change Biology*, **18**, 1239–1252.

McClanahan, T.R. & Cinner, J.E. (2011) *Adapting to a changing environment: confronting the consequences of climate change*. Oxford University Press, New York.

McMahon, S.M., Harrison, S.P., Armbruster, W.S., Bartlein, P.J., Beale, C.M., Edwards, M.E., Kattge, J., Midgley, G., Morin, X. & Prentice, I.C. (2011) Improving assessment and modelling of climate change impacts on global terrestrial biodiversity. *Trends in Ecology & Evolution*, **26**, 249–259.

Mendelsohn, R. (2000) Efficient adaptation to climate change. *Climatic Change*, **45**, 583–600.

Metzger, M.J., Schröter, D., Leemans, R. & Cramer, W. (2008) A spatially explicit and quantitative vulnerability assessment of ecosystem service change in Europe. *Regional Environmental Change*, **8**, 91–107.

Mokany, K. & Ferrier, S. (2011) Predicting impacts of climate change on biodiversity: a role for semi-mechanistic community-level modelling. *Diversity and Distributions*, **17**, 374–380.

Nobis, M.P., Jaeger, J.A.G. & Zimmermann, N.E. (2009) Neophyte species richness at the landscape scale under urban sprawl and climate warming. *Diversity and Distributions*, **15**, 928–939.

Parmesan, C. & Yohe, G. (2003) A globally coherent fingerprint of climate change impacts across natural systems. *Nature*, **421**, 37–42.

Parry, M., Rosenzweig, C. & Livermore, M. (2005) Climate change, global food supply and risk of hunger. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **360**, 2125–2138.

Paterson, J.S., AraúJo, M.B., Berry, P.M., Piper, J.M. & Rounsevell, M.D.A. (2008) Mitigation, adaptation, and the threat to biodiversity. *Conservation Biology*, **22**, 1352–1355.

Sarma, P.K., Mipun, B.S., Talukdar, B.K., Singha, H., Basumatary, A.K., Das, A.K., Sarkar, A. & Hazarika, B.C. (2012) *Assessment of habitat utilization pattern of rhinos (Rhinoceros unicornis) in Orang National Park, Assam*. Pachyderm, India, pp. 51.

Seneviratne, S.I., Nicholls, N., Easterling, D., Goodess, C.M., Kanae, S., Kossin, J., Luo, Y., Marengo, J., McInnes, K., Rahimi, M., Reichstein, M., Sorteberg, A., Vera, C. & Zhang, X. (2012) Changes in climate extremes and their impacts on the natural physical environment. *Managing the risks of extreme events and disasters to advance climate change adaptation*. (ed. by C.B. Field, V. Barros, T.F. Stocker, D. Qin, D.J. Dokken, K.L. Ebi, M.D. Mastrandrea, K.J. Mach, G.-K. Plattner, S.K. Allen, M. Tignor and P.M. Midgley), pp. 109–130. Cambridge University Press, Cambridge, UK, and New York, NY.

Sieck, M., Ibisch, P.L., Moloney, K.A. & Jeltsch, F. (2011) Current models broadly neglect specific needs of biodiversity conservation in protected areas under climate change. *BMC Ecology*, **11**, 12.

Thaler, R. (1981) Some empirical evidence on dynamic inconsistency. *Economics Letters*, **8**, 201–207.

Thomas, C.D. (2010) Climate, climate change and range boundaries. *Diversity and Distributions*, **16**, 488–495.

Turner, M.G. (2010) Disturbance and landscape dynamics in a changing world. *Ecology*, **91**, 2833–2849.

Turner, W.R., Bradley, B.A., Estes, L.D., Hole, D.G., Oppenheimer, M. & Wilcove, D.S. (2010) Climate change: helping nature survive the human response. *Conservation Letters*, **3**, 304–312.

Vervuren, P.J.A., Blom, C.W.P.M. & de Kroon, H. (2003) Extreme flooding events on the Rhine and the survival and distribution of riparian plant species. *Journal of Ecology*, **91**, 135–146.

Visconti, P., Pressey, R.L., Giorgini, D., Maiorano, L., Bakkenes, M., Boitani, L., Alkemade, R., Falcucci, A., Chiozza, F. & Rondinini, C. (2011) Future hotspots of terrestrial mammal loss. *Philosophical Transactions of the Royal Society B: Biological Sciences*, **366**, 2693–2702.

Watson, J.E.M. (2014) Human responses to climate change will seriously impact biodiversity conservation: it's time we start planning for them. *Conservation Letters*, **7**, 1–2.

Watson, J.E.M. & Segan, D.B. (2013) Accommodating the human response for realistic adaptation planning: response to Gillson et al. *Trends in Ecology & Evolution*, **28**, 573–574.

Watson, J.E.M., Cross, M., Rowland, E., Joseph, L.N., Rao, M. & Seimon, A. (2011) Planning for species conservation in a time of climate change. *Climate change (volume 3) research and technology for climate change adaptation and mitigation*, pp. 379–402. InTech Publishers, Rijeka, Croatia.

Watson, J.E.M., Iwamura, T. & Butt, N. (2013) Mapping vulnerability and conservation adaptation strategies under climate change. *Nature Climate Change*, **3**, 989–994.

Wetzel, F.T., Kissling, W.D., Beissmann, H. & Penn, D.J. (2012) Future climate change driven sea-level rise: secondary consequences from human displacement for island biodiversity. *Global Change Biology*, **18**, 2707–2719.

Wheeler, T. & von Braun, J. (2013) Climate change impacts on global food security. *Science*, **341**, 508–513.

Whittaker, R.J., Araújo, M.B., Jepson, P., Ladle, R.J., Watson, J.E.M. & Willis, K.J. (2005) Conservation biogeography: assessment and prospect. *Diversity and Distributions*, **11**, 3–23.

Wittmann, M. & Paulus, M.P. (2008) Decision making, impulsivity and time perception. *Trends in Cognitive Sciences*, **12**, 7–12.

Yates, C.J., Elith, J., Latimer, A.M., Le Maitre, D., Midgley, G.F., Schurr, F.M. & West, A.G. (2010) Projecting climate change impacts on species distributions in megadiverse South African Cape and Southwest Australian Floristic Regions: opportunities and challenges. *Austral Ecology*, **35**, 374–391.

Young, T.P. (1994) Natural die-offs of large mammals: implications for conservation. *Conservation Biology*, **8**, 410–418.

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