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Challenges in assessing the vulnerability of species to climate change to inform conservation actions

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ABSTRACT

Understanding climate change impacts on species is vital for correctly estimating their extinction risk and choosing appropriate conservation actions. We perceive four common challenges that hamper conservation planning for species affected by climate change: (i) only considering climate exposure in assessments of vulnerability to climate change, ignoring the two other components of vulnerability (sensitivity and adaptive capacity); (ii) treating climate change as a long-term, gradual threat without recognising that it will change the frequency and magnitude of climate extremes; (iii) treating climate change as a future threat, disregarding current impacts of existing change; and, (iv) focusing on direct impacts of climate change, ignoring its interactions with other threats. We describe the implications of these challenges and urge that establishing management objectives in relation to species' vulnerability is crucial for choosing effective and efficient conservation action.

1. Introduction

Climate change is already having major direct impacts on biodiversity (Parmesan and Yohe, 2003; Dawson et al., 2011), altering human behavior (Oppenheimer, 2013), and interacting with other current threatening processes in a myriad of ways (Mantyka-Pringle et al., 2011). As greenhouse gas concentrations continue to rise in the Earth's atmosphere, this will increasingly be the case. As a result, the costs, benefits, and chances of success, of conservation actions are, or will soon be, profoundly affected by climate change (Heller and Zavaleta, 2009): rapid climate change is redirecting and redefining the ways in which we undertake environmental management.

Spatial conservation planning generally aims to determine the most effective and efficient actions to avert threatening processes in space and time (Moilanen et al., 2009). Recognition of the increasing impact of climate change on biodiversity has led to the rapid development of a range of different approaches to assessing vulnerability, which variously aim to inform us about which species and ecosystems will be most affected, and how those species and ecosystems will be affected (Pearson et al., 2013). Indeed, a recent review showed that hundreds of papers have been published on the impacts of climate change on species in the conservation literature over the last decade (Chapman et al., 2014).

To comprehensively assess species or ecosystem vulnerability to climate change, all – and not just some – of the contributing factors that cause vulnerability need to be taken into account. A number of techniques have dominated this field of research, e.g., correlative models, such as species distribution models (SDMs), and it has been rapidly evolving due to computational and methodological advances (Pacifici et al., 2015). However, in spite of these advances, we perceive four common challenges in using assessments of impacts on species to inform conservation planning processes: 1) too great an emphasis on climate exposure, to the exclusion of sensitivity and adaptive capacity; 2) ignoring the impact of climate extremes; 3) a primary focus on the future, disregarding the impacts of current climate change, and; 4) a major focus only on the direct impacts of climate change. These are seriously affecting how vulnerability is being evaluated, understood and acted upon by scientists, policy makers and ultimately, conservation managers.

Practitioners may be unable to use information on species' vulnerability to develop conservation action plans that accommodate climate change, for reasons ranging from data limitations to lack of analytical robustness (McGahey et al., 2013), and a poor understanding of the

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mechanisms behind why species are vulnerable is affecting how we plan (Young et al., 2014). To close this implementation gap, future research must address these challenges. Here, we synthesise and expand on the challenges in more detail and explain why—if they are not addressed—they are likely to be having a detrimental impact on how we use information on climate change impacts for choosing effective conservation actions. We then discuss how this relates to objective-based climate adaptation planning for conservation: it is critical that vulnerability is analysed in a way that can inform conservation action.

2. Challenge 1: a predominant focus on exposure

Researchers commonly measure only the *exposure* to climate change, such as increasing temperature, to establish the level of threat to a species posed by climate change (e.g. Beevor et al., 2015; Chapman et al., 2014). However, this can result in an underestimation or overestimation of vulnerability, which is also driven by two other factors: the *sensitivity* to a given magnitude of climate change, and the *capacity to adapt* to climate change (e.g. Williams et al., 2008; Dawson et al., 2011; Fig. 1). By focusing only on exposure, the implicit assumption is being made that all species have equal *sensitivity* and *adaptive capacity*. This is manifestly not the case. Consider four species that inhabit the same part of eastern Australia and hence have the same exposure to climate change where their ranges overlap. The peregrine falcon *Falco peregrinus* has a low sensitivity to climate change as it is a habitat generalist with a large spatial distribution (Lawler, 2009), while the southern corroboree frog *Pseudophryne corroboree* has a high sensitivity as it is restricted to peat bog habitats, a habitat itself highly sensitive to climate change, and as such has a narrow spatial distribution (Hunter et al., 2009). The common crow butterfly *Euploea core* has a high adaptive capacity as it can use a range of different food plants and a short generation time (Scheermeyer et al., 1989) but the koala *Phascolarctos cinereus* has low adaptive capacity due to its specialist diet and longer generation time (Adams-Hosking et al., 2012). Although these species have different range sizes and climate niches, they may all be found in the same region (e.g. Kosciusko National Park, in eastern Australia), and thus subject to the same (climate change) exposure at this location, but their vulnerability will clearly vary according to their species-specific sensitivity and adaptive capacity, as determined by species traits. A consideration of exposure only is likely to be seriously hampering efforts to understand how to manage and set priorities for species effectively in a changing climate.

By ignoring adaptive capacity, it is possible to overlook the fact that the species' capacity to adapt to climate change has been greatly reduced by several human-mediated factors (e.g. land clearing, facilitation of spread of invasive species, changes in fire regimes and reduced population size; Watson et al., 2013). Moreover, including adaptive capacity in conservation planning based on vulnerability could lead to different management actions (Beevor et al., 2015). For example, Segan et al. (2015) showed that 10% of Important Bird and Biodiversity Areas (IBA) identified in southern Africa that were previously considered 'low risk' based on their exposure to climate change, were actually 'high risk' when other climate-related factors were considered (the adaptive capacity of human populations, in this example, and their related potential impact on these important conservation areas. Also see *Challenge 4*). Conversely, over-estimations of vulnerability were made for the mountain gorilla, *Gorilla beringii beringei*, in two areas in Central Africa, as their ability to shift their reliance on different types of vegetation was not taken into account (Thorne et al., 2013). Similarly, the pinyon mouse *Peromyscus truei* found in the Sierra Nevada Mountains has extended its range into previously unsuitable habitat types in response to climate change, and shifted from being a habitat specialist to a habitat generalist, and is therefore less vulnerable to climate change than was previously considered (Yang et al., 2011).

There have been several calls for the inclusion of other aspects of vulnerability, including Dawson et al. (2011), who highlighted the importance of accounting for all three aspects of vulnerability, Williams et al. (2008), who included species' traits, and Van Allen et al. (2012) and Fordham et al. (2012), who included vital rates and demographic processes in assessments. Crossman et al. (2012) developed a transferable framework that included measures of sensitivity and adaptive capacity for plants to identify priority areas for vulnerability reduction at the landscape scale. Foden et al. (2013) carried out a global analysis for birds, amphibians and coral species, using all three components of vulnerability, and found that areas of high vulnerability related to high sensitivity and low adaptive capacity differed from areas identified as highly vulnerable on the grounds of exposure alone. The NatureServe Climate Change Vulnerability Index (CCVI) integrates several indicators that modify exposure, for example, traits that drive species interactions, plasticity and evolutionary capacity (Young et al., 2014). Lee et al. (2015) identified and mapped individual components of sensitivity and adaptive capacity, such as species' reliance on particular moisture regimes or levels of genetic variation, to demonstrate climate adaptation management needs to target the reasons why species are vulnerable, not just the extent to which they are vulnerable.

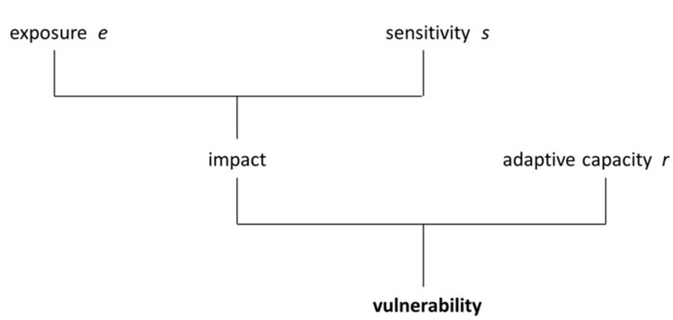

Fig. 1. Relationship between the key factors in the vulnerability framework. *s* and *r* are intrinsic species attributes while *e* corresponds to external abiotic factors such as regional climate change. Impact is where management can act, and the interaction between impact and adaptive capacity is essentially what determines vulnerability. Adaptive capacity encompasses evolutionary response, behavioural response and population growth.

3. Challenge 2: changing frequency and magnitude of climate extremes and variability may be ignored

Where climate change is treated as a gradual, predictable and continuous change in environmental conditions over time, other important climate change components are not accounted for (Chapman et al., 2014). While seasonality is at least partially captured by standard bioclimatic variables, inter-annual variation and extreme events are rarely considered. Over recent decades, extreme weather and climate events have increased in frequency and intensity in many regions of the planet (Kerr, 2011). This pattern is likely to accelerate during this century (Jentsch et al., 2007; Cai et al., 2014), leading to increases in extreme events such as drought duration and intensity in the Mediterranean, Central America, Northeast Brazil, Southern Africa, and flood frequency in East Africa, Central Europe, Canada and Northern Asia (IPCC, 2013). A shifting climate can embody an increasing occurrence of climatic extremes, including discrete events ranging from heat waves to hurricanes; climate variability is the mean fluctuation in regular weather patterns, such as seasonal rainfall.

Intensification of extreme events is one of the most significant aspects of climate change, and research in this space is increasing, accounting for 20% of experimental climate research publications in 2004 (Jentsch et al., 2007). However, across the ecology and conservation literature, the focus has mainly been on population extinctions or declines, and there has previously been a failure to discuss catastrophic events (Good et al., 2008; Reed et al., 2003).