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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).

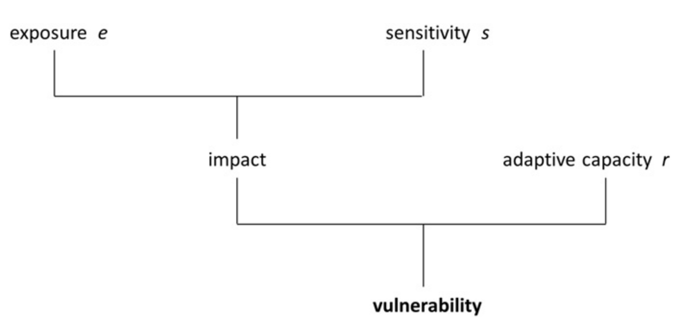

Fig. 1. Relationship between the key factors in the vulnerability framework. *s* and *r* are intrinsic species attributes while *e* corresponds to external abiotic factors such as regional climate change. Impact is where management can act, and the interaction between impact and adaptive capacity is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

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.

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).

Extreme climate events and the impacts of climate extremes are critical determinants of patterns of biological diversity and will affect them differently from impacts resulting from steady climate change (Walther, 2010): in some cases, there may be no change in predicted climate means, but changes in climate minima and maxima. For example, Rebelo et al. (2010) investigated the impact of climate change on European bat distributions, and predicted some population extinctions under higher mean temperature, and some tolerance of increased temperatures in Mediterranean and temperate groups. However, bats are very sensitive to temperature extremes (Sherwin et al., 2012), and in one Australian case temperatures over 42 °C resulted in the death of several thousand individuals in several colonies of flying foxes (Welbergen et al., 2008). Extreme maximum temperature can therefore be a critical factor in the vulnerability of bats to climate change, and failure to consider it in projections of species distributions under climate change could lead to over-estimates of suitable climate space and species' range, and inaccurate assessments of vulnerability.

While it can be difficult to measure the impact of climate extremes on species, in a recent paper Thompson et al. (2013) proposed a method to incorporate climatic variability into assessments of climate change impacts on ecosystems, and there are other examples that do account for extremes. Ameca y Juárez et al. (2013) produced a comprehensive analysis of the impacts of cyclones and droughts on terrestrial mammals, one of the few large-scale studies to consider exposure to extreme events. Their subsequent assessment of terrestrial mammal sensitivity to extreme weather and climate events, identifying biological traits that make large terrestrial mammals more susceptible to climate-induced population declines, moves some way towards addressing the first two challenges identified in this paper. An assessment of the impact of climate change on platypus *Ornithorhynchus anatinus* in Australia established that during the last century, the key climatic determinant of occurrence shifted from rainfall to temperature, as related to thermal tolerance and temperature extremes (Klamt et al., 2011). The models indicated a loss of suitable habitat using annual maximum temperature anomalies, and their results thus incorporated the impact of extreme temperature. Klamt et al. (2011) concluded that because of the impact of extreme temperature, listing the platypus as Least Concern by the IUCN (www.iucnredlist.org), may underestimate its vulnerability.

This shift towards including climate extremes is a positive move, and should be taken up or addressed in comprehensive vulnerability analyses. While incorporating climate extremes and climate variability is complicated, omitting them will almost certainly lead to incomplete understanding of the impacts of climate change on species. The inclusion of historical climate data and relevant ecophysiological information, as in the examples above, along with incorporation of data on climate anomalies, will be very useful.

4. Challenge 3: a primary focus only on the future, disregarding current climate change

Climate change is already happening, with temperature increases of at least 0.75 °C globally, and up to 2 °C in some regions: the change is spatially and temporally variable and largely inhomogeneous (IPCC, 2013). It is widely believed that this has already altered community processes, population dynamics and species' distributions (Parmesan and Yohe, 2003). However, research generally focuses on long-term (>50 years from now), rather than immediate, impacts: almost 80% of published research between 2000 and 2012 considered only long-term future impacts, without accounting for recent and ongoing change (Chapman et al., 2014). While most long term studies may focus on decadal – or longer – climate conditions, many species' life cycles take place within much shorter time scales; scales at which annual, or seasonal, climate factors have a more direct impact on species' vulnerability. Analyses that assume stable rather than dynamic states do not specify a baseline for change, and focus on the far future, which means that vulnerability analyses in relation to long-term impacts may not be relevant for species persistence or guiding appropriate conservation actions now.

Where species distribution modelling is used to inform species' vulnerability, the model links the occurrence of the species with current climate variables, with the 'current' climate baseline as, for example, as used by the IPCC, 1961–1990 (Bindoff et al., 2013). In fact, shifts in climate prior to that period may have been important drivers of the species' current distribution. This could be particularly problematic for animals as vulnerability may be underestimated if a species has already shifted its range in response to climate pressure, as with small mammal communities over the last century in Yosemite National Park, USA (Moritz et al., 2008). Vulnerability may also be underestimated in cases where a species has not shifted its range (e.g., long-lived plant species): counts of adults may mask the fact that recruitment failure is already occurring.

Recent shifts in climate have driven, and are driving, species' distributions, so that current distributions are not fixed points from which to navigate future vulnerability. For example, VanDerWal et al. (2012) showed that climate in Australia had shifted rapidly in the previous 60 years, and had led to equally rapid shifts in climatic niche space for more than 450 Australian bird species. They concluded that previous analyses had underestimated both the scale of climate change impact on species, and the speed of tracking that would be required by species to remain within their climatic niche (VanDerWal et al., 2012). In another study, Buisson et al. (2008) investigated future distributions, turnover and species assemblages for French river fish. Projected mean climate for 2051–2080 was used and they found that headwater species would be most negatively impacted while downstream species would expand their ranges by this time (Buisson et al., 2008). However, the proportion of warm-water species has already increased significantly in the last 25 years. In addition to loss of species and changes in diversity, shifts in fish community assemblages may affect community functioning, and conservation actions are required now: such actions will be most effective if they are informed by what is happening now rather than changes projected half a century from now.

Some species or populations may already be in decline due to loss of suitable habitat (they may be sink populations occupying marginal habitat at the edge of their range, or remnant populations), and in these

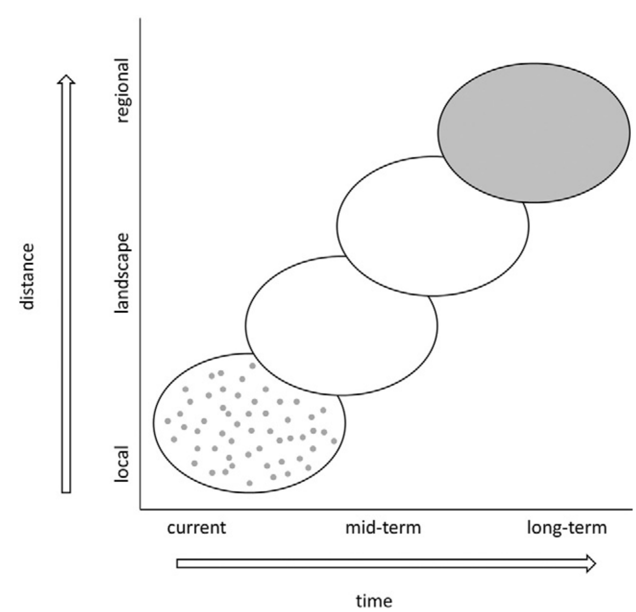

Fig. 2. Shifts in habitat suitability through space and time. Currently, a relict or sink population occupies marginal habitat, which will become unsuitable under climate change. As it is a sink population, it has no capacity to disperse over time to suitable habitat further away. Protection of the future suitable habitat now will therefore be pointless; assisted translocation could be indicated to enable the species to persist.

cases, protection of habitat that will be suitable in future will not be sufficient on its own, as there is very low possibility of the species or population dispersing there through space and time (Fig. 2). More drastic intervention could be required, such as assisted translocation (Seddon et al., 2014). Taking account of the timing and spatial variation across the landscape of the climate change impact is critical in such cases (McDonald-Madden et al., 2011).

Combining information on species' distribution ranges and historical/recent climate events or changes (see Ameca y Juárez et al., 2013) provides scope to react to changes that are already taking place. As climate change is variable spatially as well as temporally, regional climate models and data may also usefully inform this process. Of course this kind of analysis is challenging as in many cases robust long-term data for previous distributions are lacking. Consideration of vulnerability needs to account for the current situation and not only focus on future forecasts.

5. Challenge 4: too much focus on the direct impacts of climate change on species, without accounting for indirect effects

Climate change is reshaping the ways in which people use the landscapes and seascapes they inhabit (Oppenheimer, 2013), and a significant shortfall in the climate change vulnerability literature is that most assessments ignore the single most significant indirect impact: how humans are responding, or likely to respond and adapt. Although there are some examples that do this (Bradley et al., 2012; Lawler et al., 2013; Turner et al., 2010), many impact and planning assessments published to date do not recognise that many species' ability to respond to climate change is already impaired by a myriad of interacting threatening processes driven by human activities (e.g., habitat destruction, fragmentation, altered fire regimes, changing agricultural practices; Chapman et al., 2014), and as humans continue to respond to a changing climate, these threatening processes are likely to change in both space and time.

Examples of human adaptation responses that 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, changing grazing systems to cropping systems (and vice versa), and the planting of non-native forestry tree species that are better suited to changed climatic conditions (Mendelsohn, 2000). Changing precipitation and temperature patterns are reducing the productivity of some arable lands and creating new opportunities for cultivation in intact areas (Oppenheimer, 2013). The park system landscape matrix may look very different in future, as a result of these human responses, and may lead to changes in the requirements for protected areas, such as increased connectivity, as existing reserves decrease in size and habitat quality. Finally, greening cities to make them more resilient to heat waves (e.g. Declet-Barret et al., 2013), or restoring mangrove and wetland communities to protect against storm surges (e.g. Jones et al., 2012), presents opportunities for conservation to capitalize on human responses to climate extremes.

We need to understand and predict how humans will respond to climate change in conjunction with future climate change scenarios (which do include human behaviour in the emissions projections). In particular, information on changing human values and risk tolerances in response to future conditions will be critical. Human responses to climate change should not automatically outweigh biodiversity conservation requirements; in places where there will be conflict between conservation and human priorities, complex cost–benefit analyses may be required. Predicting human behaviour is difficult, requiring collaboration with social and agricultural scientists and economists, but by putting humans into the picture, and by using the best available knowledge and predictions, we have a better chance of efficiently achieving conservation goals. This is increasingly happening, especially in marine environments (Weeks and Jupiter, 2013), coastal ecosystems (Reece et al., 2013), and agricultural areas (Estes et al., 2014), and new methods for combining information on predicted climate change and ecological evaluation with social adaptive capacity are being developed (Maina et al., 2015).

6. Using species' vulnerability to inform planning

A focus only on which species are most vulnerable is clearly useful for generating comparative lists, such as the IUCN Red List (www.iucnredlist.org), but without the right framing, may not be useful for conservation actions on the ground. Several indices, for example, have been developed with the aim of producing an 'answer' or single value (for each species) which can then inform management practice (e.g. Foden et al., 2013). While this method enables comparison between the species being considered, and for the production of rankings, it does not provide any useful information around what management actions should be taken and how they should be prioritised (Game et al., 2013; Lee et al., 2015).

Some work has focused on planning and prioritisation incorporating species' vulnerability, including investigating how this information is being used (Young et al., 2014), and developing decision pathways for reducing the impacts of climate change. For example, Shoo et al. (2013) provide a very comprehensive decision framework for climate change-specific management actions. The Adaptation for Conservation Targets (ACT) framework developed by Cross et al. (2012) presents a two-phase process, of which the first step is to identify the conservation feature and define the management objective. By doing this, the ACT framework aims to translate general recommendations into actions specifically linked to species, habitat or site (Cross et al., 2012). This focus on establishing the management objective(s) at the outset of the process, as also underlined by Stein et al. (2013), enables conservation managers to apply the framework to their specific target, and allows for other important components for adaptation (such as conserving 'the stage'; Beier et al., 2015) to be considered. However, where such vulnerability frameworks are not objective-based, they may merely increase the list of actions rather than help us choose between them. We need to be clear about the intention of the vulnerability assessment and what we need to do in response: by designing the assessment around an objective, this can be achieved (Game et al., 2013).

7. Discussion

Conservation choices made to address climate change will be different according to which factors are taken into account, and some of the challenges we describe may be more important than others. In the case of climate extremes, completely different management decisions may be made when only shifts in climate averages are considered compared with when climate extremes and extreme events are taken into account. Climate change is operating on a long time scale, and some facets will not have large impacts in the near- or mid-term, but it is clearly crucial to take into account the fact that climate change is already having an impact in some places. It is of course difficult to draw meaningful conclusions over the short-term given the large uncertainty associated with short-term climate projections, which decreases with longer-term forecasts. In terms of human responses and synergistic and feedback interactions, the distinction between local (human-driven change) and global (climate change) drivers, and the choices taken to manage them, is critical to ensure that actions operate at the appropriate scale (Brown et al., 2014).

Gaining new information on species' intrinsic traits that can inform understanding of their sensitivity and adaptive capacity is expensive, and in some cases might reduce resources for direct conservation actions (e.g. restoring habitat, which is a key conservation strategy in some regions). Furthermore, there will be cases when reducing uncertainty about a species' ecophysiology will not change their perceived vulnerability to climate change. Value-of-information analysis is one approach to making decisions about information gain and can quantify the benefits of reducing ecological uncertainty before making a management decision (Maxwell et al., 2015). There is now considerable scope for novel application of value-of-information analysis to evaluate the benefits of refining knowledge of species ecophysiology or life history traits before implementing management actions. Adaptive management is another way conservation managers can approach uncertainty (Conroy et al., 2011): conservation actions can be implemented within a system of reiteration, so that monitoring informs evaluation and leads to adjustment of the conservation action (Hansen et al., 2010).

The challenges we describe here are of course not the only ones relevant to all biodiversity conservation outcomes. Local population declines, reductions in range size, and the erosion of genetic diversity can all impact upon functional diversity and the provision of ecosystem services (O'Neil et al., 2014), and all lead to loss of genetic variation which impacts 'evolutionary resilience' (Sgrò et al., 2011). We note that these aspects of biodiversity need to be planned for and fostered in conservation actions, especially considering that evolutionary adaptation, where it is rapid, can enhance species' capacity to cope under changing conditions (Hoffmann and Sgrò, 2011; Skelly et al., 2007).

The scale and grain size of exposure projections used to assess species' vulnerability can significantly bias analyses of climate change impacts, both in terms of climate parameters, such as temperature range variation across and within different sized cells (Ackerly et al., 2010), and suitable climate space for plant species (Randin et al., 2009), where larger-scale analyses disagree with fine scale results. As exposure assessments at coarse grain sizes can be inaccurate or unreliable, within-cell variation and microclimate heterogeneity across the landscape should also be considered.

8. Conclusion

We are now at a cross roads – assessing species' risk from climate change as a discipline is well over a decade old – and there are hundreds of papers being published each year on the subject of species' vulnerability (Chapman et al., 2014). Factors contributing to the lack of development around overcoming the challenges we describe probably relate to research favouring datasets that are easy to access and use (e.g. WorldClim), rather than those that are difficult to acquire and involve high levels of uncertainty, and the difficulty of predicting both climate extremes and changes in human behaviour. Issues of scale are also important. Global or even continental analyses may not be useful for informing actual planning and management at regional and smaller scales. In many cases, managers and planners need to predict and respond to conservation issues without having access to detailed information and diagnostic tools: there is a clear need for the conservation science community to increase sharing of skills and information with those implementing conservation actions on the ground.

It is important to recognize that in some situations, it may not be possible for all of the challenges we describe to be effectively addressed, and even if they were, they may not lead to a large difference in conservation outcomes. Overcoming the challenges that climate change presents to conservation practitioners requires not only adequate data to help overcome these challenges but also the adequate institutional frameworks to act upon this information (Cross et al., 2012). So efforts, beyond more science, need to be undertaken to ensure institutional frameworks are set up that are flexible and adaptive and capable of dealing with uncertainty, to ensure effective management may be implemented even in the face of data limitations.

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