Climate change and biodiversity conservation: impacts, adaptation strategies and future research directions

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Abstract

The impacts of climate change pose fundamental challenges for current approaches to biodiversity conservation. Changing temperature and precipitation regimes will interact with existing drivers such as habitat loss to influence species distributions despite their protection within reserve boundaries. In this report we summarize a suite of current adaptation proposals for conservation, and highlight some key issues to be resolved.

Introduction and context

Changing temperature and precipitation regimes [1] are expected to interact with other drivers to impact a range of biological processes and influence species distributions [2,3] (Figure 1). In the past 5 years a growing body of empirical evidence has documented climate-change-attributed changes in processes, including phenology [4–6], net primary production [7], and species interactions [8]. Changes in species distributions have also been observed in both above-ground [3,9–11] and below-ground communities [12].

This situation poses fundamental challenges to existing approaches for biodiversity conservation because targets (for example, species) are currently managed within spatially and temporally static reserves [13–18]. As a result of changing species distributions, some populations and species will no longer be viable in reserves created for their protection. Additionally, altered disturbance regimes may enhance the ability of invasive species to colonize reserves more easily [19].

Thus, a central unresolved question in conservation biology is: how can we manage for biodiversity objectives in an era of accelerated climate change? In this report we provide a brief overview of a current suite

of proposed adaptation approaches, and identify some future challenges and key issues to be resolved. Both mitigation and adaptation strategies are crucial to respond to climate change. Although reserves can play a role in carbon storage and sequestration - for example, through initiatives such as reducing emissions from deforestation and degradation (one aspect of climate change mitigation) - here we focus solely on adaptation strategies.

Major recent advances

Below we highlight four commonly proposed adaptation strategies for biodiversity conservation given climate change. In this overview report we focus on a selection of commonly proposed *in situ* adaptation strategies in response to the impacts of climate change. For a journalistic overview of *ex situ* strategies, such as captive breeding, seed and gene banking, in the context of responding to climate change, the reader is referred to [20].

The first three approaches seek to reduce extinction risk primarily by addressing the effects of climate change on species distributions (the pattern), and in part by passively influencing mediating drivers (for example,

Figure 1. Diagrammatic representation of some of the global change drivers, mediating drivers and biodiversity (pattern) responses in terrestrial ecosystems

Within and between each of these levels, the global change drivers, mediating drivers and responses can interact and feed back to each other.

providing corridors for movement). The last considers a more controversial interventionist option (Table 1).

Managing the matrix as a buffer should both protect core populations (but often not in the matrix, rather by insulating reserves) and also facilitate shifts across a landscape; new and dynamic reserves function primarily by protecting core populations and also by accommodating (rather than facilitating) target movement.

New reserves and corridors

The most common proposed approach for conservation adaptation is to expand linked networks of protected areas including migration corridors [15,17,18,21–23]. These researchers argue that the existing network does not provide enough area to allow for organisms to respond autonomously to changing climatic conditions.

The principal purpose of new protected areas is to mitigate the risk of extinction by providing the potential for species distributions to shift; a secondary contribution is that they may also enhance micro-evolutionary potential through enhanced population size and diversity. Therefore, corridors may reduce extinction risk by enabling the passive shifting of some species to new geographic ranges, and by reinforcing species distributions (in a metapopulation context).

A crucial challenge for this approach is determining where to site corridors and new reserve areas. The current state-of-the-science is to use species distribution models

or bioclimate envelope models to generate projections of future species' responses to various climate scenarios [24–27]. Many view this information as providing essential insight into the strategic siting of new protected areas [28]. At the same time, myriad uncertainties impact the validity of these projections [29–34]. Efforts to address these uncertainties are ongoing [27,35], but many uncertainties may remain (or even increase) within decision-making time frames nonetheless.

Schemes for siting new areas may be more robust to uncertainties by incorporating coarse scale environmental gradients, such as edaphic and elevational ranges (for example, [21]).

Matrix as buffers

As a complement to protected areas expansion, many researchers highlight the importance of matrix areas [36,37] or the wider landscape, as being particularly crucial for biological adaptation in an era of change [15,21]. For example, some land uses, such as forestry or agro-forestry (or lower impact marine activities), may provide a spatial buffer for populations as they respond to climate change and move outside core reserves. In order for this proposal to be effective, matrix areas must be of sufficient size, and landowners must be willing to adjust their activities as monitoring indicates [21]. Incentives may increase the viability of this proposal. The logic of this approach is similar to new protected areas and corridors: more benign matrix areas may passively facilitate species shifts by promoting movement across land- and seascapes; they may also reinforce species distributions at fine scales (around reserves).

Dynamic reserves

The management of matrix areas for biodiversity objectives further supports a third proposal. Dynamic reserves implemented on managed landscapes (or seascapes) are areas whose locations and levels of protection change through time and space [18,22,38,39]. This approach may be particularly important in areas where there is little spatial opportunity available for new core protected areas. At the same time, the issue of ownership and property rights requires further examination in different contexts in order to more fully understand the implementation challenges of this potential approach in particular localities. This approach involves the future passive facilitation of shifting species distributions in response to future conditions, rather than prediction of conditions.

Assisted colonization

More controversial is the interventionist proposal for 'assisted migration' [40,41] or 'assisted colonization'

Table 1. Selection of central current proposed adaptation approaches for conservation: mechanisms and types of intervention for minimizing extinction risk given climate change

Approach	Main role		Timing		Type of intervention	
	Protect cores	Facilitate movement	Now and over time	Specific points through time	Passive	Active
New reserves	✓		✓		✓	
Matrix as buffers	✓	✓	✓		✓	
Dynamic reserves	✓			✓	✓	
Assisted colonization		✓		✓		✓

[42]. Both describe a management option in which species are deliberately introduced into an area where it has not existed in recent history for the purpose of achieving a conservation objective. This proposal has emerged in response to the mounting evidence that some species may not be able to track changing climatic conditions quickly enough [3,43], or because there are natural or human barriers in the way. This approach would involve actively shifting species distributions.

The assisted colonization proposal is at odds with current reserve management in which substantial efforts are directed at keeping non-native species out. It also carries with it substantial risks because introduced species may become invasive and displace other valued ecosystem elements. Nevertheless, assisted colonization may be seen as a necessary last resort in some cases. In anticipation of this, Hoegh-Guldberg *et al.* [42] have proposed a framework for decision making within which the costs, benefits and risks of the translocation event would be evaluated. Other researchers have inferred the risk of potential invasion of assisted colonization from comparisons of intra-continental and inter-continental past invasions [44].

Future directions

In this last section we identify a collection of key challenges and issues to be resolved for reserve management suited for an era of change. We divide these challenges into five categories: focus on processes, projections and uncertainties, monitoring, implementation, and norms and expectations.

Focus on processes

In the main, conservation activities have focussed on maintaining biodiversity patterns and indirectly enabling natural processes: for example, by protecting space for species to exist (represented by the first three categories referred to above). As climate change influences mediating drivers, the attributes that make certain places conducive to species flourishing (critical habitat) will change, and in some cases disappear. For species

whose critical habitat changes dramatically or disappears, it will be increasingly necessary to consider approaches that involve the active management of mediating drivers.

Restoration activities have long involved management of disturbance regimes, ecosystem function, and species interactions. Adapting to the impacts of climate change may require more such active management, including assisted colonization, and other interventions, such as enhancement of evolutionary adaptation [45], and active maintenance of pre-climate change processes and conditions.

Projections and uncertainties

A key area of future research is to improve our capacity for forecasting species responses to changing climate - for example, by incorporating biotic interactions in bio-climate models [46], and refining species-specific process-based models [47]. Other areas include the long-standing scientific challenge of understanding when a given species will become invasive in a given context [44]. Efforts to reduce the ecological uncertainties just mentioned will represent a key contribution to the literature on adaptive reserve management.

In addition to ecological uncertainties, there are various parametric and model uncertainties relating to species distribution models. This includes uncertainties relating to so-called 'unknown unknowns'; where key processes are not yet recognized, understood or incorporated into model structure, or as parameters. Yet such processes may play critical roles in ecosystem dynamics nonetheless. Moreover, there are uncertainties relating to the climate scenario models that influence the outputs of envelope models [48]. Lastly, there are critical socio-political uncertainties (in values, impacts, responses and feedbacks).

Thus, a second key area of future research is the development of conservation approaches that are robust to uncertainty, recognizing that many of the above

uncertainties are irreducible. As ecological and social systems co-adapt, non-linear dynamics will lead to perpetually surprising outcomes [49]. Therefore, even with the best scientific research and most comprehensive models, species responses may surprise us. Indeed, uncertainties may also increase with new research and insights [50]. Thus, the implementation of safe-to-fail adaptive management policies may be as or more important than efforts to reduce uncertainties.

Monitoring

In many ways, conservation adaptation requires recognition of what is changing and where (for example, assisted migration, dynamic reserves). Thus, there is an urgent need for monitoring of impacts. While existing monitoring programs could be adapted and used for this purpose, programs specifically targeted to assessing the impacts of climate change would support the most effective adaptation responses possible under highly uncertain circumstances.

Implementation

So far, the adaptation proposals outlined above have focussed primarily on biological dimensions. This effort has provided a critical foundation, but land-use decisions, including reserves, are social decisions made in the context specific places. Therefore, a key area of future research is to identify through applied case studies the factors that determine the relative receptivity or resistance of communities to new and additional conservation measures. This effort will provide crucial insights by which conservationists can foster socially sustainable conservation action.

Changing norms and expectations for reserve management

To date, core protected areas have been managed with a preferred minimum intervention (with exceptions for active management including controlled burns, programs to limit grazers, and efforts to minimize the impacts and distributions of invasive species, for example). Proposals for more widespread intervention, including assisted colonization, raise many unanswered questions. When do we intervene and to what extent? To what extent and under what circumstances are we willing to sacrifice the persistence of one species to save another? Who decides? And by what decision process? Addressing these questions, including latent and even more controversial proposals for conservation triage [51], will be a key challenge moving forward.

Ultimately, one of the biggest challenges to fostering biological adaptation may be a willingness across stakeholders, scientists and managers to re-calibrate

existing expectations of nature and reserves in responding to an era of global change.

Competing interests

The authors declare that they have no competing interests.

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