Identification and Response of the Effect of Environmental Changes and Ecosystem Services on Biodiversity

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ABSTRACT: Environmental change is happening due to natural factors and human activities, which expressively mainly biodiversity. It also has the potential to reduce species that are unable to track the climate to which they are currently adapted, which could result in extinction risk. Therefore, the recent rates of species extinction are estimated to be 100 to 1000 times faster. Consequently, concerns over species extinction are warranted as it provides food for all life forms and primary health care for more than 60–80% of humans globally. Therefore, the objectives of this review is to identify the response to the effect of environmental changes and ecosystem services on biodiversity.

Environmental change can operate at individual, population, species, community, ecosystem, and biome scales, notably showing that species can respond to climate change challenges by shifting their climatic niche along three non-exclusive axes: time (e.g., phenology), space (e.g., range), and self (e.g., physiology). Current estimates are very variable, depending on the method, taxonomic group, biodiversity loss metrics, spatial scales, and time periods considered. Although there is relatively limited evidence of current extinctions caused by climate change, studies suggest that climate change could surpass habitat destruction as the greatest global threat to biodiversity over the next few decades (Leadley *et al.,* 2010; Pereira *et al.,* 2010). Predicting the response of biodiversity to climate change has become an extremely active field of research (e.g., Dillon *et al.,* (2010); Gilman *et al.,* (2010); Pereira *et al.,* (2010); Salamin *et al.,* (2010); Beaumont *et al.,*

(2011); Dawson *et al.,* (2011); McMahon *et al.,* (2011). Predictions play an important role in alerting scientists and decision-makers to potential future risks, provide a means to bolster the attribution of biological changes to climate change, and can support the development of proactive strategies to reduce climate change impacts on biodiversity (Pereira *et al.,* 2010; Parmesan *et al.,* 2011).

Effects and Responses of Climate Change: The multiple components of climate change are anticipated to affect all levels of biodiversity, from organisms to biomes. They primarily concern various strengths and forms of fitness decrease, which are expressed at different levels and have effects on individuals, populations, species, ecological networks, and ecosystems. At the most basic level of biodiversity, climate change is able to decrease the genetic diversity of populations due to directional selection and rapid

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migration, which could in turn affect ecosystem functioning and resilience (Botkin *et al.,* 2007, but see Meyers & Bull 2002). However, most studies are focused on impacts at higher organisational levels, and the genetic effects of climate change have been explored only for a very small number of species. Beyond this, the various effects on populations are likely to modify the web of interactions at the community level (Gilman *et al.,* 2010 & Walther 2010). In essence, the response of some species to climate change may have an indirect impact on the species that depend on them. A study of 9650 interspecific systems, including pollinators and parasites, suggested that around 6300 species could disappear following the extinction of their associated species (Koh *et al.,* 2004). At a higher level of biodiversity, climate can induce changes in vegetation communities that are predicted to be large enough to affect biome integrity. The Millennium Ecosystem Assessment forecasts shifts for 5–20% of Earth's terrestrial ecosystems, in particular cool conifer forests, tundra, scrubland, savannahs, and boreal forests (Sala et al. 2005). Of particular concern are tipping points where ecosystem thresholds can lead to irreversible shifts in biomes (Leadley *et al.,* 2010). A recent analysis of potential future biome distributions in tropical South America suggests that large portions of Amazonian rainforest could be replaced by tropical savannahs (Lapola *et al.,* 2009). Increased temperature and decreased rainfall mean that some lakes, especially in Africa, might dry out (Campbell *et al.,* 2009). Oceans are predicted to warm and become more acidic, resulting in widespread degradation of tropical coral reefs (Hoegh-Guldberg et al. 2007). However, individuals shift their distribution to stay in quasi-equilibrium with the climatic conditions they are adapted to, but they may not be adapted to other abiotic variables such as photoperiod or novel biotic interactions (Visser, 2008). In these cases, micro-evolution may be needed for them to persist (Visser, 2008). To keep up with changing abiotic factors that show cyclic variation over time, such as temperature on a daily or yearly basis, individuals can also respond to climate change through a shift in time (from a daily to seasonal basis). Phenology, i.e., the timing of life cycle events such as flowering, fruiting, and seasonal migrations, is one of the most ubiquitous responses to 20th century climate warming. It has already been documented in many species (Parmesan, 2006; Charmantier *et al.,* 2008). In a meta-analysis of a wide range of species, including plants and animals, the mean response across all species responding to climate change was a shift in key phenological events of 5.1 days earlier per decade over the last 50 years (Root *et al.,* 2003). Flowering has advanced by more than 10 days per decade in some species (Parmesan 2006).

These phenological changes can help species keep up with cyclical abiotic factors. Yet, they can also be disruptive by increasing asynchrony in predator-prey and insect-plant systems (Parmesan, 2006), which may lead to species extinction. Last, species can cope with changing climatic conditions by adapting themselves to the new conditions in their local range rather than tracking their current optimal conditions in space or time. For lack of a better term, we refer to these in situ changes that are not related to spatial or temporal changes as changes in self-axis caused by physiological alterations that allow tolerance to warmer or drier conditions or by behavioural Space-Time (e.g. phenology) (e.g. range).Species can cope with climate change by shifting along one or several of these three axes. Although they are often less obvious than changes in time or space, some physiological responses have already been reported (Johansen & Jones 2011) during the 20th century climate change, especially from many ectotherms, as their locomotion, growth, reproduction, and sex determination are temperature sensitive (*Tewksbury et al.,* 2008). However, for many traits, plastic phenotypic responses should reach a physiological limit and saturate in extreme environments.

Assessment of future global biodiversity: Our understanding of the effects of global climate change on biodiversity and its different levels of response is still insufficiently well developed. Yet, it is enough to raise serious concern for the future of biodiversity. The most pressing issue is to quantitatively assess the prospects for biological diversity in the face of global climate change. Although several methods exist to draw inferences, starting with existing palaeontological or recent data, experiments, observations, and meta-analyses (e.g., Lepetz *et al.,* 2009), ecological modelling is the most commonly used tool for predictive studies. Progress in this field is characterised by both an extremely high pace and a plurality of approaches. In particular, there are three main approaches to projecting species loss, concentrating either on future changes in species range or species extinction or changes in species abundance. However, all three modelling approaches have so far largely focused on one axis of response (change in space), largely overlooking the importance of the other aspects. In addition, they seldom account for the mechanisms underlying these responses (plasticity and evolution). Plant species are represented as groups with similar physiological and structural properties, termed Plant Functional Types (PFTs), which are designed to represent all major types of plants (Sitch *et al.,* 2008). PFT distributions can then be used to estimate changes in biomes or habitat ranges. Currently, DVMs are of limited use for directly

projecting responses in biodiversity (i.e., the absence of animals and the limitation to c. 10 PFTs exclude direct utilisation). However, coupled with extinction models, they allow extinction risk for species to be estimated at the regional or global scale (e.g., van Vuuren *et al.,* 2006). Species loss models components. The simplest method for calculating extinction risk is to assume that species go extinct when they no longer have any suitable habitat (Jetz *et al.,* 2007).

Improvements and needs: Climate change ecology is still in its infancy, and tremendous improvements are being made rapidly in virtually all aspects of this emerging field. Critical requirements to be able to predict future trends include the need to study a much larger part of biodiversity, to overcome several major model limitations, to account for co-extinctions and other major drivers of biodiversity loss, and to validate models by comparing projections with observations.

Climate scenarios: Climate scenarios depend on a wide range of socio-economic storylines for greenhouse gas emissions in the future, including the Special Report on Emissions Scenarios for the Millennium Assessment and Global Biodiversity Outlook scenarios (Pereira *et al.,* 2010), and on a broad suite of General Circulation Models used to calculate climate change for given trajectories of greenhouse gas emissions. This means that the projections of species loss can yield highly contrasting results depending on the choice of combinations of emission scenarios and climate models, independent of the model of biodiversity response that is used (Beaumont *et al.,* 2008). In addition, internal climate model variability could result in greater differences in projected species distributions than variability between climate models (Beaumont *et al.,* 2007). In addition, 4–39% of the world's landmass will experience combinations of climate variables that do not currently have equivalent values anywhere on the globe (Williams *et al.,* 2007). One key challenge is to provide robust and credible uncertainty intervals for all model outcomes and, if possible, to reduce them.

Scale choice: The choice of the spatial resolution scale is probably one of the most important factors generating variability. For example, a coarse, European-scale model (with 10×10 grid cells) predicted a loss of all suitable habitats during the 21st century, whereas a model using local-scale data (25×25 m grid cells) predicted the persistence of suitable habitats in up to 100% of plant species (Randin *et al.,* 2009). These differences are probably explained by the failure of coarser spatial scale models to capture both local topographic diversity and habitat heterogeneity (Luoto & Heikkinen 2008; Randin *et al.,*

2009). On one hand, global models can be used for a large number of species but focus on one type of species response and therefore lack biological realism. On the other hand, population or species models provide insight into a very limited range of species, typically at regional scales (i.e., adaptation phenology, dynamic population), but cannot provide global scale trends. This is a classical trade-off between precise small-scale models and coarse large-scale models that lack biological realism (Thuiller 2003).

Positive effects: Climate changes could also have positive effects on biodiversity. For instance, more clement temperatures and increased CO_2 are likely to be beneficial to many plants, resulting in an acceleration of biomass production. Milder winters might increase the survival of many currently threatened species in temperate regions. Increased precipitation may also benefit some plant communities and species, depending on them. Moreover, several studies have reported detrimental effects of climate change on biological invasions (e.g., Peterson *et al.,* 2008). Although few studies report beneficial effects of global changes on biodiversity, they certainly exist and add to the difficulty of getting a clear overview of the effects of climate change on the biodiversity of our planet.

Biodiversity measure: Even in the most ambitious studies, the range of species studied always represents a small percentage of known biodiversity. All studies are taxonomically biassed, as they generally concentrate on a few conspicuous taxonomic groups such as plants, mammals, and birds (Thuiller *et al.,* 2011), with a particularly strong bias towards terrestrial vs. marine biodiversity. However, it is generally recognized that the vast majority of biodiversity in terms of species richness, evolutionary divergence, biomass, and even ecosystem functioning is represented by ryptic biodiversity, especially micro-organisms and insects (Esteban & Finlay 2010). Similarly, there are important biases in data collection both across regions and ecosystems (McMahon *et al.,* 2011). Furthermore, most studies focus on species richness because it is thought to influence the resilience and resistance of ecosystems to environmental change. However, a few studies have explored the impact of climate change on functional (Thuiller *et al.,* 2006) and phylogenetic diversity (Thuiller *et al.,* 2011), and the effects on genetic diversity are only beginning to be explored. Moreover, it is likely that different levels of biodiversity are affected differently by climate change, so these should be evaluated in parallel to provide a broad picture of biodiversity responses to climate change (Devictor *et al.,* 2010). In addition, there are different indicators of

biodiversity change, such as the number of species committed to extinction (Thomas *et al.,* 2004; Pereira *et al.,* 2010), extinction risk (Thuiller *et al.,* 2005), or change in abundances (Alkemade *et al.,* 2009; Leadley *et al.,* 2010). The number of species committed to extinction is probably not the most appropriate metric to forecast the future of biodiversity because the extinction debt could vary from decades to centuries (Kuussaari *et al.,* 2009).

Species responses: Current global extinction models make very coarse assumptions about species responses. For example, dispersal capability is a major issue for projections of future biodiversity. Until recently, models often addressed dispersal issues by using the two extreme assumptions of either unlimited or no species dispersal (Thomas *et al.,* 2004). This is clearly convenient for practical purposes, but most species are between these extremes. In addition, exceptional occurrences of long-distance dispersal are thought to have helped past species surmount prehistoric climate changes (Dawson *et al.,* 2011 and references therein). Although rare, these events are of crucial significance in the current context, as they could in many cases make the difference between species survival and extinction, especially as human-mediated long-distance dispersion is now common for many organisms. Despite growing evidence for rapid adaptive evolution in response to climate change, the consequences of such evolution on species persistence remain to be explored (Lavergne *et al.,* 2010). Moreover, populations can be locally adapted to specific climatic conditions, so models treating a species as a single homogeneous unit might be flawed. Consequently, studying under what circumstances losses in genetic and species diversity at local to regional scales occurred in the past could improve model outputs (Dawson *et al.,* 2011 & McMahon *et al.,* 2011).

Co-Extinctions: Whether centred on a single species or taking into account large taxonomic groups, most studies and all models have disregarded interspecific relationships such as competition, facilitation, or mutualism. Beyond single-species extinctions, both direct and indirect processes can lead to cascading and catastrophic co-extinctions, also called chains of extinction (Brook *et al.,* 2008). Despite the importance of interspecific interactions, these relationships are exceptionally difficult to model; this is especially true in the context of a lack of data on population dynamics and trophic webs (McMahon *et al.,* 2011). As each species comes with its own cortege of specific parasites and symbionts, as well as many trophic relationships, the consequences of global change on biodiversity might be substantially underestimated when focusing on species-specific extinction rates (Koh *et al.,* 2004; Yang & Rudolf, 2010). There is an urgent need not only to go beyond the single-species approach but also to get past the species richness approach and consider interspecific interactions, trophic webs, and ecological networks (Bascompte, 2009).

Management of biodiversity: The large variation of responses among different species necessitates the use and integration of multiple approaches to further our understanding of the impacts climate change can have on biodiversity (Dawson *et al.,* 2011). Similarly, our responses in terms of biodiversity management ought to transcend disciplines. Beyond this, global climate change prompts several methodological issues and has implications for the conservation and management of biodiversity and ecosystem services.

Ecosystems and conservation of species: The large projected impacts of climate change on biodiversity at all levels mean that ecologists must quickly rise to the challenge of providing scientific guidance for the development of conservation strategies (Pressey *et al.,* 2007; Araujo *et al.,* 2011; Dawson *et al.,* 2011). A major role of conservation planning is to design reserve networks that protect biodiversity in situ. Currently, few studies have attempted to use modelling for conservation purposes (Araujo *et al.,* 2011). It is increasingly important to protect the heterogeneity of habitats as well as the genetic diversity within a species to sustain that species capacity to adapt. Also, the characteristics of protected areas, where planning has to be done decades in advance (Hansen *et al.,* 2010), need to be reviewed under climate change.

Services of the ecosystem: Other aspects of biodiversity management will be affected by global change and will need adapting, including wildlife exploitation [e.g., forestry (Dale *et al.,* 2010) or fisheries (Stram& Evans 2009)], agronomy (Howden et al. 2007), pest and invasive species control (Ziska *et al.,* 2011), and human and wildlife disease management (Harvell *et al.,* 2002). For example, major challenges in agronomy include the need to shift to species or varieties better adapted to particular components of climate change or to rethink strategies to control invasive and pest outbreaks; finding solutions to the increasing competition for water between the natural and agricultural ecosystems; improving infrastructure; and adapting cropping systems to meet the future demands of a growing population living on poorer biodiversity resources (Howden *et al.,* 2007).

Conclusion: The species and ecosystems can be impacted by climate change. The timing of species life cycle events is expected to be further altered; species distributions will change radically; trophic networks will be affected; and ecosystem functioning may be severely impaired, leading in the worst cases to countless species extinctions. Over the past decades, some of this understanding has been effectively translated into mathematical models that can be used to forecast climate change impacts on species distributions, abundance, and extinctions. These models are characterised by their high diversity of underlying structures and assumptions, with predictions differing greatly depending on the models used and species studied. Most of these models indicate alarming consequences for biodiversity, with worst-case scenarios leading to extinction rates that would qualify as the sixth mass extinction in the history of the earth (Barnosky *et al.* 2011). An evaluation of known mechanisms of climate impacts on biodiversity suggests that the lack of several key mechanisms in models may lead to either very large underestimations or overestimations of risks for biodiversity. Improvements in existing models and, in particular, a new generation of models must address the shortcomings of current models to reduce uncertainties. It is also crucial to improve our understanding of the vulnerability of biodiversity to climate change, to develop other predictive approaches, and to go beyond predictions. Crucially, the diversity of approaches, methods, scales, and underlying hypotheses used has led to an ensemble of global quantitative predictions that can rarely be compared. Consequently, we are left with a mosaic of information that cannot provide a quantitative, coherent picture of future biodiversity loss. The standardisation of future studies (of taxonomic groups, methods, time horizons, scales, etc.), which might help decrease uncertainty, would do so at the expense of the breadth of knowledge and of much-needed innovation in this field. In this regard, a solution may come from a collective effort in conducting large meta-studies that would encompass many components of variability (biodiversity, time and space scales) to both infer similarities and assess sources of inconsistency. A major near-term target to substantially improve our understanding, predictive capacity, and reactive potential will be to contribute to this new IPCC-like assessment of biodiversity and ecosystem services.

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