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EDITORIAL

Ecological effects of environmental change

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Abstract

This Special Issue of *Ecology Letters* presents contributions from an international meeting organised by Centre National de la Recherche Scientifique (CNRS) and *Ecology Letters* on the broad theme of ecological effects of global environmental change. The objectives of these articles are to synthesise, hypothesise and illustrate the ecological effects of environmental change drivers and their interactions, including habitat loss and fragmentation, pollution, invasive species and climate change. A range of disciplines is represented, including stoichiometry, cell biology, genetics, evolution and biodiversity conservation. The authors emphasise the need to account for several key ecological factors and different spatial and temporal scales in global change research. They also stress the importance of ecosystem complexity through approaches such as functional group and network analyses, and of mechanisms and predictive models with respect to environmental responses to global change across an ecological continuum: population, communities and ecosystems. Lastly, these articles provide important insights and recommendations for environmental conservation and management, as well as highlighting future research priorities.

Keywords

global change, environmental change, biodiversity, climate change, habitat destruction, invasive species, ecological scaling, scale effects.

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INTRODUCTION

One of the prominent and most challenging features of the modern world is its fast-pace of change. Change is a pervasive characteristic of human civilisations, but appropriation of resources and habitats has increasingly become a global concern. As human populations increase and expand, ecosystems are more often, more generally and more deeply affected. In particular, the ever-increasing pressure of rapid anthropisation exerts a heavy toll on the planet's resources, profoundly modifying landscapes, altering habitats and affecting ecological networks, biodiversity and ecosystem functioning.

Environmental changes are global in spatial scale and deep-reaching in extent. They range from modifications of the atmosphere and the climate to the degradation or destruction of habitats through vast exploitation of lands and seas, and the massive introduction of non-native invasive species and chemical contaminants around the world. Consequently, global changes are important sources of biodiversity loss and represent major threats for ecosystem functioning, ecosystem services and human societies.

Change is a key challenge for both fundamental and applied environmental research. Consequently, one of the major developments in ecology over the past 20 years is the increase in usage of the concept of global environmental change. The fields of ecology and evolution have generated an exponentially growing number of publications on global environmental changes since the early 1990s. Like the world it studies, the science itself is changing. It is therefore timely to synthesise accumulated knowledge over the past two decades, and to discuss fruitful approaches, with the goals of stimulating future research and aiding environmental management.

With these objectives in mind, the *Centre National de la Recherche Scientifique* (CNRS) and the journal *Ecology Letters* co-organised an international meeting in Paris, France on the 22nd of June 2012. Internationally recognised experts from various disciplines in ecology and conservation presented their views on the key insights required to increase our understanding of the multiple facets of environmental change at local and global scales. The collection provided by the presentations and the articles selected for this Special Issue also celebrates the first 15 years of *Ecology Letters* and the journal's success.

OVERVIEW OF THE PROBLEM

The theme of the meeting and Special Issue is based on a consensus that ecosystems worldwide are currently subject to changes in the biology and ecology of a very large number of aquatic and terrestrial groups of living organisms and of their communities (Vitousek *et al.* 1997). Most of these changes are rapid, especially compared to the generation times of many species. To escape extinction, species can tolerate, resist, evolve adaptations or move. In some cases, geographical distributions have already changed and species extinctions are anticipated (Bellard *et al.* 2012). Conversely, other species may benefit from environmental changes; some will become invasive or agricultural pests, while others may be of less concern with respect to biodiversity and economic impacts (Thrall *et al.* 2011; Simberloff *et al.* 2012).

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Evidence for the effects of environmental change comes from a variety of biological and ecological levels, from the physiology of individuals, the ecology of target species, the functioning of local communities and regional patterns. For example, climate change has been shown to have significant effects on both life-history traits and behavioural responses of ungulate populations, leading to spatial shifts and the colonisation of hitherto suboptimal habitats (Gaillard *et al.* 2013).

THE NEED TO CONSIDER INTERACTING EFFECTS

The many drivers of global change do not act independently of one another, and some authors have focused on multiple influences, particularly on the importance of their combined impacts. Studying the effects of global changes on some species or even regions may actually require the inclusion of all major contributors, such as climate change, land use and biological invasions. Regional variation in the relationship between protecting living carbon stocks while preserving biodiversity creates a need to evaluate complementarity between the two in each region (Thomas *et al.* 2013). In this regard, because of the complexity of biological systems and the intricacy of underlying drivers, overall impacts cannot be predicted by simply studying the individual effects of separate factors (Parmesan *et al.* 2013). Importantly too, authors of this Special Issue emphasise that it is essential to identify and quantify interactions, and in particular the major roles played by synergies and feedbacks. Disentangling the effects of interactions is complicated by the different levels at which the drivers act, with some stemming directly from human activity and some more indirectly so. The combination of proximate and ultimate anthropogenic sources of environmental change is probably best exemplified by degradation and simplification of plant and animal communities caused by agriculture and its effects on the spread of pathogens and pests (Bissett *et al.* 2013). However, a shortcoming of many climate-change studies is the focus on the attribution of such complex effects, which risks detracting from the immediate need to act to minimise climate change (and other forms of global change) and mitigate against its effects (Parmesan *et al.* 2013).

SCALING AND THE MULTISCALE NATURE OF GLOBAL CHANGE

Several contributors focus on the need to understand large-scale patterns of biodiversity change using coarse approaches, such as species–area relationships, or at a more detailed level, examining for instance how spatial structure interacts with genetic structure. Species–area relationships have attracted a good deal of attention in ecology and contributors presented two important examples of their utility for considering how fragmentation and habitat loss alter species diversity. Chase & Knight (2013) show convincingly that environmental changes such as habitat degradation often have scale-dependent effects, with proportionately larger effects on rarer species. This alters the shape of the species-abundance distribution and decreases the slope of the species–area relationship, with profound implications for inferences at the global scale, based on regional or local studies. Rybicki & Hanski (2013) take a different approach and look at the predictive ability of species–area and endemics–area relationships when habitat is lost and fragmented. They demonstrate that species–area relationships are more accurate as long as more than 20% of habitat remains; below this, neither approach works well. Their approach is used to draw conclusions for habitat and biodiversity management. Considering biodiversity at the level of genetic variation, Albert *et al.* (2013) use network analyses in a dynamic landscape to show how studies of network modularity can be used to inform the effects of habitat loss and fragmentation. Finally, building on the seminal work of Levin (1992), Chave (2013) explores the relationships between scaling in ecology and ecosystem complexity, and shows how genes can link to ecosystems. Chave's provocative review suggests that ecosystem functioning depends not only on the flux of energy and materials but also on cellular metabolism, evolution and species assemblages. He also emphasises the many ways in which scaling is of paramount importance for ecology.

PREDICTIONS ABOUT FUTURE ECOLOGICAL CONDITIONS

The intrinsic complexity of ecosystems makes ecological responses especially challenging to understand and predict. This arises because of the multiplicity of interacting global drivers, the inadequate level of current knowledge of biodiversity (i.e. 90% of species remain undescribed) and because of the multidimensional space through which biodiversity interacts with ecosystem functions and services, and species interact with each other.

There is widespread agreement that improving our capacity to make predictions is crucial to the success of global change ecology, and that this necessarily means combining disciplines and integrating approaches. Indeed, the importance of integrating eco-evolutionary perspectives in global change modelling was emphasised independently by several contributors. Notably, it is shown how integrating palaeobiology, macroevolution and ecology can generate innovative phylogenetic models to help us understand how environmental change has affected biodiversity in the past, and predict how it could affect it in the future (Condamine *et al.* 2013). At a more contemporary timescale and small spatial scale, resource stoichiometry and enzyme kinetics were shown to be crucial to understanding mycorrhizal dynamics, an underestimated player in our changing world (Johnson *et al.* 2013).

Prediction need not necessarily be preceded by mechanistic understanding, as shown by the success of species distribution projections obtained from bioclimatic models (Pereira *et al.* 2010; Aráujo & Peterson 2012). Yet, the current limitations of such statistical approaches and the call for an integration of more realistic ecological dimensions demonstrate the need for more mechanistic approaches with process-based information. In this respect, Turnbull *et al.* (2013) argue for hybrid modelling, which combines phenomenological and process-based models. Such an approach might be effective at making rapid progress, in a similar way to Platt's (1964) call for testing multiple hypotheses to make rapid strong inference.

The effects of global change on the links between biodiversity and stability of ecosystem functioning are well illustrated by studies combining theoretical and empirical approaches (Turnbull *et al.* 2013). More generally, global change is a fertile ground for the emergence of new theoretical developments. These include mechanistic approaches that encompass stochasticity for the study of ecosystem stability (Loreau & de Mazancourt 2013) and new eco-evolutionary models focusing on functional groups (Thuiller *et al.* 2013).

Yet, theory alone is clearly limited in addressing how global change impacts ecology. Similar to the importance of combining disciplines, emphasis was also put on the benefits of multiple approaches. This viewpoint is epitomised by how the plethora of large-scale, long-term experimental work at Cedar Creek, served as a means of testing new theoretical models. For example, by including stochastic community dynamics in ecosystem models, Loreau & de Mazancourt (2013) predict that asynchrony in species responses to environmental changes is a key mechanism responsible for the ecosystem stability (biological insurance) provided by biodiversity.

CONCLUSIONS

This Special Issue synthesises a set of directions, ideas and observations to contribute to our understanding of global environmental change. Notably, species adaptability and plasticity still remained underrepresented in studies of global change, and ecophysiologists ought to play a more central role in studies on this theme. Similarly, the notion of ecosystem resilience should be better integrated into future frameworks as a way of conceptualising system dynamics. Lastly, ecologists need to focus more on how humans are part of ecological effects of global environmental change, including urbanisation, pollution and resource overexploitation. Ascribing influence and causation to the many factors involved in global change is and will continue to be a daunting challenge. The contributions to this Special Issue provide ways forward to increasing understanding and predictability.

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