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Integrative research efforts at the boundary of biodiversity and global change research

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Abstract: Global environmental change and biodiversity loss are closely linked through different feedback mechanisms. The University of Zurich Research Priority Programme on 'Global Change and Biodiversity' approach is to work with interdisciplinarity and transdisciplinarity to integrate mechanisms of interactions, feedback and scale and improve our understanding of the feedbacks between global change and biodiversity effects. Such work across research disciplines is not without its challenges. Here we share some of the questions that arose from our research approach over the last five years and how we addressed these challenges. First, our transdisciplinary approach allows combining different disciplines into a more holistic perspective towards integrative research, but demands collaborative work to establish common terminology, concepts, and metrics. Second, the research theme's common perspective (biodiversity is desirable, global change is not) may also induce a confirmation bias from preconceived ideas. Third, new challenges emerge from scaling mechanisms and feedbacks at different spatial and temporal scales. Fourth, we investigate how to relate biodiversity, global change, ecosystem services and functions using interdisciplinary approaches. Fifth, we identify gaps between existing experiments and data requirements, and propose the definition of new experimental setups by linking processes and performing experiments at typical experimental scales as well as at larger scales. We conclude by emphasising the necessity to integrate theory, experiments, modelling and simulation, high performance computing and big data to understand feedbacks between biodiversity loss and processes of global change.

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Integrative research efforts at the boundary of biodiversity and global change research

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Abstract

Global environmental change and biodiversity loss are closely linked through different feedback mechanisms. The University of Zurich Research Priority Programme on "Global Change and Biodiversity" approach is to work with interdisciplinarity and transdisciplinarity to integrate mechanisms of interactions, feedback and scale and improve our understanding of the feedbacks between global change and biodiversity effects. Such work across research disciplines is not without its challenges. Here we share some of the questions that arose from our research approach over the last five years and how we addressed these challenges. First, our transdisciplinary approach allows combining different disciplines into a more holistic perspective towards integrative research, but demands collaborative work to establish common terminology, concepts, and metrics. Second, the research theme's common perspective (biodiversity is desirable, global change is not) may also induce a confirmation bias from preconceived ideas. Third, new challenges emerge from scaling mechanisms and feedbacks at different spatial and temporal scales. Fourth, we investigate how to relate biodiversity, global change, ecosystem services and functions using interdisciplinary approaches. Fifth, we identify gaps between existing experiments and data requirements, and propose the definition of new experimental setups by linking processes and performing experiments at typical experimental scales as well as at larger scales. We conclude by emphasising the necessity to integrate theory, experiments, modelling and simulation, high performance computing and big data to understand feedbacks between biodiversity loss and processes of global change.

Introduction

Biodiversity loss is one of the important processes affected by global change drivers, summarised in the Millennium Ecosystem Assessment as the 'big five': land use change, climate change, invasions, exploitation, and pollution [1]. Biodiversity loss and global change are strongly bound together through feedback mechanisms taking place at spatial and temporal scales that are usually smaller than those currently incorporated in global earth system models [2]. Each of the 'big five' has been shown to negatively impact on biodiversity [3]. However, studying these drivers independently is unlikely to provide a coherent understanding which can be used to predict how global change affects biodiversity and *vice versa*. These considerations are at the very core of the University of Zurich Research Priority Programme on "Global Change and Biodiversity" (URPP GCB). Within this programme, a multi-disciplinary group, which includes ecologists, geneticists, remote sensing, physical and human geographers, mathematicians and philosophers, collaborates to integrate mechanisms of interactions, feedback and scale to improve the understanding of the feedbacks between global change and biodiversity effects.

Because of this diversity of research interests, methodology and conceptual approaches, specific questions on how to address the impact of global change drivers and the feedbacks with biodiversity were discussed in our group. This led to intense transdisciplinary questioning of research directions. Here, we consider transdisciplinarity as our common effort to address scientific problems by differentiating and integrating knowledge from different scientific and societal sources [4]. Whereas including more scientific disciplines may provide a more holistic vision, it creates new hurdles to overcome. Here, we share some of the challenges that arose from our common work over the last five years, and how we are currently working towards resolving such challenges.

Terminology between disciplines

Joint research across disciplines requires a shared vocabulary, and shared understanding of the terminology used in different disciplines. We observed when discussing terminology that consolidating the equivocity of the vocabulary in a given discipline is often a research question in itself [5], and unifying the terminology across large overarching fields seems a major challenge. For example, the biodiversity concept can be based on species richness, however genetic composition or species traits may be included to characterize biodiversity in other interpretations within the same discipline. Others might refer to the varying perceptions and values different people have of biodiversity, for instance, as 'nature's contributions to people' [6,7]. This makes comparisons of results from studies using different terminologies very difficult, sometimes even impossible. There are efforts underway to address this challenge, such as the ongoing selection and definition of essential biodiversity variables, which will assist in harmonizing monitoring biodiversity at global scale [8]. Another approach is to develop ontologies (e.g.[9]). In our research programme we address this challenge with a series of "terminology briefs", where researchers from different disciplines work together towards a common definition of pivotal terms, such as integration, global change or phenology.

We further address such transdisciplinarity and multidisciplinarity questions directly within our research programme by combining concepts such as essential biodiversity variables, earth system processes, ecosystem services and resource frontiers within one integrative framework (fig. 1). Each of the individual projects within the URPP GCB is located within and across the concepts encouraging transdisciplinary approaches on a daily basis [10,11].

The positive connotation of biodiversity, the pejorative meaning of global change

Biodiversity is mostly perceived positively and as something to be preserved and promoted. In contrast, global change is perceived negatively, a threat, which requires mitigation or adaptation to strengthen resilience, although this framing is contested in the literature [12]. This juxtaposition is well backed up in the literature and it is not our aim to question these positive or negative connotations per se. It is interesting, however, to observe that both the concepts of biodiversity and of global change may suffer from confirmation bias [13,14], i.e. the tendency to favour information in a way that confirms pre-existing predispositions towards a particular framing of these terms. Defining a more careful framing of these two ideas presents a major challenge.

Such confirmation biases have an outcome on how experiments are designed, read and analysed; the data collected, and how publications are written. Experimental designs evaluating the effect of global change tend to overestimate the amplitude of the changing drivers [15], whereas biodiversity research tends to focus on the positive effects of a larger, more diverse, number of species [14].

A major challenge is therefore to question existing connotations, to be open to all results that fulfil the standards of scientific research although they may not fit into the normative framework, and to be aware of conflicts of interest. This means taking into account the connotations of the concepts of biodiversity and global change [16]. In our research program, researchers address such a challenge by, for example publishing non positive [17] or contradicting results [18], or having an in-depth ethical reflection on our research topic [19]. To challenge existing paradigms further, we need to understand our motivation for and interests in the research, such as by thinking about how we choose our research areas, subjects of study and how we formulate our research questions.

Links to stakeholders

True transdisciplinarity spans not only different research disciplines but integrates concerned stakeholders into research designs, data collection and policy transfer [20]. This gives rise to the question of "governance" [10], firstly governance of the research process, and secondly governance of the process of translating research insights into policy. A global question here is "who is asking and who is addressing the question". Stakeholders are rarely consulted at the initial stage of research when scientific questions are formulated despite the major influence of such questions on the experimental design and observations [21–24]. At the same time, powerful stakeholders partially dictate which studies and infrastructures are selected and promoted for funded projects [21], giving rise to conflicts of interest as a result of political agendas. For example, the attention given to certain organisms may not reflect their importance in the ecosystems. Animal, and to a lesser extent plant, biodiversity loss is highlighted, however microbiomes are much less studied despite their major role in ecosystem functioning.

One clear challenge for future research is to evaluate what role stakeholders, policies and politics should play in the design and outcome of research and how to take this into account. Including practitioners or lay people viewpoints while developing research questions may result in very different knowledge forms (more qualitative and multidimensional but less standardized) than the results of a purely scientific approach, as shown by the involvement of beekeepers in studies about pollination [25]. Integrating the new type of data collected in citizen science [26] is a way to achieve this local and holistic overview. But caution is needed: the global picture of global change, as well as of biodiversity research, may look quite different when applied at a local scale and specific location. Transdisciplinarity research may provide more insights on how research may affect policy and practices. The link between research and conservation programs still needs to be assessed in a more holistic way [27]. Caution is required in the assessment of "efficiency of conservation", as conservation policies often fail because they are designed without taking the livelihoods of local populations into consideration and because different stakeholders have different or conflicting interests in conservation programs [10,28].

In our program, we work directly with institutions that link our research with stakeholders. We host the project office of the Future Earth global research project bioDISCOVERY [29], which manages a framework to support biodiversity and ecosystem services for policy and decision making. We lead a project to develop remotely-sensed Essential Biodiversity Variables (rs-enabled EBVs) observing and monitoring key characteristics of global biodiversity (http://www.globdiversity.net/) [30]. We lead an outreach project, "Biodiversity means life" (http://biodiversitymeanslife.ch/), with the aim of creating an active dialogue between scientists and the general public on the topic of biodiversity.

Scaling and feedbacks: from where to where?

Scaling processes and biodiversity in space and time may be one of the most obvious challenge for biodiversity and global change research. One technical and scientific challenge is to scale up processes and feedbacks based on ecosystem functions to the level of ecosystems [31]. Research on modifications of biophysical processes induced by biodiversity change at smaller or larger scales are needed, particularly for the prediction of the dynamics in the long-term [32,33].

In our program, we propose a number of strategies to study such issues of scaling. The genetic diversity, the genetic evolution and the dynamics of model organisms, which are widespread globally, could potentially be monitored, for example *Arabidopsis* sp. or oak (*Quercus* sp.) for the plant kingdom [34,35]. Local to regional scale biodiversity scoping studies support assessment of scaling processes [36]. Investigating one model species would help our understanding of the cascade of constraints that a plant experiences in different ecosystems with their associated drivers. This would help us to disentangle the major drivers of change at different scales of study.

Another approach would be to scale up from manipulative experimental plots to landscape scales. Biodiversity-ecosystem functioning relationships have been established primarily through experimental research at the plot scale. Similar patterns found in plot experiments may be observed at landscape scale [37], although it may be less obvious to detect, because of confounding factors.

Time scales are a challenge as they add new dimensions to the above questions. It is actively studied whether the supply of genetic and epigenetic variation might not be in line with the ecological demand for adaptation as set by the rapid rate of global change [35,38]. In addition to the existing need to predict evolution over decades, changes in plant phenology triggered by global change highlights the need to scale evolutionary processes to seasons [39]. Furthermore, socio-spatial processes of resource extraction often alter landscapes within very short time scales to dramatic effects, in particular in so-called resource frontiers [40].The interlocking of different time scales highlights the need for current predictive assumptions to be redefined: non-linearity and non-steady states should be increasingly considered when modelling across scales.

Integrating new types of data in transdisciplinary studies

Following the exploration of several scales by disciplines like remote sensing, transdisciplinary projects need to integrate new types of data, providing unprecedented coverage of biodiversity indicators [41]. Such data may partly solve the spatial representativeness and abundance issues of traditional field-based assessments [42]. However, remote sensing data does have limitations that need to be considered when interpreting results. For example, biodiversity and processes occurring below-ground cannot be measured directly, and the assessment of biodiversity in aquatic systems using remote sensing or other novel approaches such as eDNA [35,43], are only beginning to be fully exploited. The challenge is to reconcile biodiversity considerations at the level of an ecosystem, such as a forest, grassland or freshwater body [44], to mechanisms taking place at a much smaller scale, such as microbial processes. The unequal access to structured data by all scientists and the heterogeneous spatial distribution of such data, make it a biased source of information to be used with caution [45]. In our program, we try to tackle this point by physically working on a given set of predefined research sites, giving us the chance to connect our data and information consistently, even by using own research practises as part of our scientific approach [46]

Relating species traits to ecosystem function and ecosystem services

One overarching challenge is the link between ecosystem services, i.e. the services provided by the ecosystem to human society, and ecosystem functions, i.e. the physical, chemical and biological processes taking place in the ecosystems [47]. The temptation to associate specific functions with measured values of a given service is great, leading to a potential quantification of ecosystem services and thus to their exchangeability or even tradability that is highly problematic [48]. This may provide a means to justify conservation policies, but may also give a partial number-based evaluation of complex services like cultural ecosystem services [49]. It is also important to remember that not all concerns about biodiversity have a functional motivation or rationale, biodiversity is often also associated with intrinsic values or relational values (preferences, principles, or virtues that people associate with relationships) [50]. One way forward may be to then translate traits into functions and predict functions based on traits [51,52].

In our project, remote sensing is one of the key discipline we use to link functions and services at large scales by deriving functions from traits [36]. Increasingly, remote sensing is used to link *in-situ* observations to mechanisms and functions to ecosystem services [41]. The association between remote sensing and genomics may lead to comprehensive phenotyping and the definition of genetically based phenomes as high-throughput sequencing of RNA (RNA-seq) provides monitoring information for diverse physiological traits such as drought stress, nutrient level and phenology [53]. Combining the spectral analysis of plant canopy reflectance and biogeochemical measurements, such as organic compounds or isotope patterns, may also contribute to linking global services and specific functions of a given ecosystem [54]. In aquatic systems, remote sensing could be used in combination with other monitoring tools such as environmental DNA to identify long-term shifts in community structure due to global change [55].

Defining the next generation of experiments

Most of the challenges described above require the acquisition of new data, structured in a different way to that which already exists: global coverage or at least global representativeness, but capturing processes at local scale, more related to traits and functions, more related to models. We need therefore to define the next generation of experiments, which can be used to extrapolate across temporal and spatial scales with increasing complexity and diversity (Fig. 2). Improved measurements may allow the collection of higher dimensional data across organisational levels, expression states, environmental conditions, and developmental timing [56].

In many parts of the different disciplines we are involved with, "proof of concept", i.e. the case study highlighting a concept, has often been preferred to research on the effect size, i.e. a more complete overview, including data contradicting the proposed theory. It appears also that most existing experimental setups are subject to bias, such as the island effect in global change impact studies [57] or artificial ecosystem mimicking [14]. Defining new experimental setups, linking processes and large scale, biogeochemical and –physical function and remote sensing information and ground measurement, which can be directly extrapolated by models, is a new frontier in our research field. To integrate part of these aspects, Schmid et al. [58] have recently proposed guidelines for biodiversity experiments.

Along with these new sets of data we need to collect, our transdisciplinary group of researchers requires more comprehensive modelling at every level of the questions linking biodiversity and global change, from processes to ecosystem services predictions [59,60]. The transition from a modelling sand-box to nature could help to define the right type of data one needs, particularly with the aim to coordinate global change drivers and feedbacks and biodiversity evolution. Genetic evolution, phenology or trait distribution prediction in particular may help provide a new outlook on the links between global change feedbacks and biodiversity.

Concluding remarks

Here we present seven challenges related to global change and biodiversity that we experienced as a group of researchers coming from as diverse disciplines as ecology, philosophy, geography and mathematics. We are trying to overcome hurdles like terminology, confirmation bias, link to stakeholders, scaling, ecosystem services cascade or new experimental setup with a series of measures, directly implemented in our research program. Opportunity costs of working in a transdisciplinary fashion are not evident momentarily, but will pay off in the near future. Still, the key to successful transdisciplinary work involves willingness and the ability to work across disciplinary boundaries, and the capability to understand the limitations of current approaches, expanding them beyond current capabilities.

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Featured articles

* Harrison, P.A., Berry, P.M., Simpson, G., Haslett, J.R., Blicharska, M., Bucur, M., Dunford, R., Egoh, B., Garcia-Llorente, M., Geamon, N., Geertsema, W., Lommelen, E., Meiresonne, L., Turkelboom, F., 2014. Linkages between biodiversity attributes and ecosystem services: A systematic review. Ecosystem Services 9, 191–203. doi:10.1016/j.ecoser.2014.05.006

This literature review links biodiversity characteristics and traits to a selection of ecosystem services. It shows several positive relationships, but also the complexity of the interactions between the biodiversity and the service provision.

* Chan, K.M.A., Balvanera, P., Benessaiah, K., Chapman, M. & Díaz, S., 2016. Why protect nature? Rethinking values and the environment. *PNAS*, 113(6), pp.1462–1465.

This opinion paper is linking environmental policy, nature protection and values associated to nature. It is reframing the discussion about instrumental and relational values.

* Chandler, M., See, L., Copas, K., Schmidt, A., Claramunt, B., Danielsen, F., Legrind, J., Masinde, S., Miller Rushing, A.; Newman, G., et al., 2016. Contribution of citizen science towards international biodiversity monitoring. Biological

Conservation. doi:10.1016/j.biocon.2016.09.004

This article shows the use of citizen science to assess the essential biodiversity variables. It explores what can be learnt from successful experiences.

** Pereira, H.M., Ferrier, S., Walters, M., Geller, G.N., Jongman, R.H.G., Scholes, R.J., Bruford, M.W., Brummitt, N., Butchart, S.H.M., Cardoso, A.C., Coops, N.C., Dulloo, E., Faith, D.P., Freyhof, J., Gregory, R.D., Heip, C., Höft, R., Hurtt, G., Jetz, W., Karp, D.S., McGeoch, M.A., Obura, D., Onoda, Y., Pettorelli, N., Reyers, B., Sayre, R., Scharlemann, J.P.W., Stuart, S.N., Turak, E., Walpole, M., Wegmann, M., 2013. Essential Biodiversity Variables. Science 339, 277–278. doi:10.1126/science.1229931

This article describes the basis of a harmonized monitoring of biodiversity at global scale. It defines the theoretical background of such effort, but put it also into practice.

** Wardle, D.A., 2016. Do experiments exploring plant diversity-ecosystem functioning relationships inform how biodiversity loss impacts natural ecosystems? Journal of Vegetation Science 27, 646–653. doi:10.1111/jvs.12399

This article questions point by point the validity of the biodiversity experiments as developed until now. It addresses specifically the question about the analogy between these experiments and the “real” ecosystems.