A SPOTLIGHT ON BIODIVERSITY RESEARCH

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"Biodiversity conservation" is considered to have outstanding societal relevance[1]. The fight against an increasing decline of biodiversity plays an important role in regional to international decision making. Numerous nongovernmental organizations (NGOs) but also international entities such as the United Nations Environment Programme (UNEP) are dealing with the topic and developing elaborate management strategies. In tandem with these efforts, a wide range of scientific methods and activities have been developed. Various Max-Planck-Institutes and their associated research groups are dedicated to biodiversity research. This short essay aims to outline some fundamentals of biodiversity research, its motivations, and societal justifications. We will try to show that even within our "Max-Planck environment" biodiversity research is more diverse than one may expect at first glance.

1.) So, then, what is biodiversity?

The establishment of an unequivocal terminology remains an unresolved issue in ecology[2]. This shortcoming also affects the concept of „biodiversity"[1]. In its most general notation, "biodiversity" comprises the variability among living organisms and associated ecological complexes. Clearly biodiversity is a matter of scale, organization, and interaction of biotic systems ranging from cellular to ecosystem scales. "Biodiversity" is a general terminus comparable to the concept of "variability" in statistics, or "entropy" in information science. It can only be understood in reference to a well-defined target.

The most widely used meaning attributed to "biodiversity" refers to the diversity of animals and plants. While this concept is predominantly a public perception, it bears some scientific limitations - gradual differences between species or different subspecies often imply an unclear species concept. In a refined view this becomes a question of genomic diversity. Here, other questions arise, e.g., how to describe the heterogeneity of other species groups such as prokaryotes? There, effects of horizontal gene transfers would then undermine the "naïve" understanding of biodiversity[3].

Yet, the umbrella term "biodiversity" has obvious merits and embraces many of the most important recent research questions in the environmental sciences. In the following, we will highlight a few select historical and actual aspects of our fundamental interest in biodiversity and biodiversity research. Here, we put special emphasis on the diversity of vascular plants.

2.) Describing biodiversity The nomenclature of our needs

Recognizing and classifying the variety of plants has been, and still remains to be, an essential ingredient of traditional environmental knowledge. Encoding this information into the prevalent system of cultural knowledge follows the human need to exploit natural resources for alimentation, medicinal-, and/or technological purposes. For example, in the beginning of modern times (more precisely after 1536) a medicinal species in Britain was up to 10 times

[1] Chapin III, F. S. et al. (2000) Consequences of changing biodiversity. *Nature*, 405, 234-242.

[2] Starzomski, B.M. et al. (2004). Contemporary Visions of Progress in Ecology and Thoughts for the Future. *Ecology and Society*. 9. 14.

[3] Frenzel, P., personal communication.

more likely to be discovered and scientifically described than non-medicinal plants[4]. This is also because early botanists were medical practitioners and botany was an established field in medical schools.

Later, the introduction of the standardized "Linnaean" taxonomy (first proposed in 1760) promoted the consecutive encoding of species in Europe. This binomial nomenclature has provided the basis for an efficient, ideally non-redundant description of flora and fauna.

While the European classification scheme is still the basis of our current work, it is only one approach to encode "biodiversity". Other cultures developed different methods such as oral traditions for preserving geographical information on patterns on biotic diversity. Indigenous South American cultures are a perfect example of this and have been able to classify most of the Amazon basin into regions according to prevalent useful plants[5].

3.) Biodiversity research

Along these lines, today's biodiversity research follows the needs of humankind. A perceived global "biodiversity crisis" has increased scientific and public awareness. The primary focus of the matter is the interplay between strong economic and ecological arguments[6]: Ecosystem goods and services have become the predominant justification for biodiversity research. In addition to already mentioned resources, "services" such as soil fertility, climate regulation, or pest control are essential factors to support human life. Nowadays such arguments receive additional weight in the light of a rapidly increasing human population under changing climate conditions.

Let's have a closer look: three overarching research topics shape the research at the MPI for Biogeochemistry in Jena, but also play a predominant role in other MPIs:

A: Observing current biodiversity and monitoring long-term development.

B: Effects of the (altered) environment on biodiversity.

C: The role of biodiversity in the earth system.

A: Observing Biodiversity

Observing biodiversity is more than stamp collecting. The great hope in the middle of the last century was to describe the worlds species inventory based on a coherent (Linnaean) taxonomy. This led to the construction of a wide range of national scale faunistic and floristic databases. Today these data collections could provide a basis for understanding the relationship between the physical environment and the diversity of living organisms.

However, these data rely exclusively on expert knowledge. One consequence is that such spatial data collections often suffer from slight taxonomic confusions but also from systematic sampling artifacts: For example, we could show that the German Floristic inventory "FLORKART" is clearly influenced by the federal boundaries. These coincide in many cases with the spatial organizational units of the floristic survey. This illustrates that even under highly standardized classification conventions, the geographically bounded expert knowledge will introduce some degree of bias[7].

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[4] Bebber, D.P. et al. (2006) Ethnobotany and the first printed records of British flowering plants. *Global Ecology and Biogeography*. 16, 103 – 108.

[5] Mann, C.M. (2005) 1491: New revelations of the Americas before Columbus. *Alfred A. Knopf.* New York.

[6] Novacek, M.J. (2008) Engaging the public in biodiversity issues. *PNAS*. 105, 11571-11578.

[7] Mahecha, M.D. & Schmidtlein, S. (2008) Revealing Biogeographical Patterns by Nonlinear Ordinations and Derived Anisotropic Spatial

On global scales, conventional classifications fail. This is because in many highly diverse systems, especially in the tropics, accurate species identification is almost impossible[8]. Classification schemes developed for central European plant species are not suitable. Thus, alternative methods are currently being explored. One promising way to obtain large-scale inventories could be the rapidly evolving DNA-barcoding technique. It was recently reported that the first extensive species inventories now comprise full "hotspots of biodiversity"[9]. These tools are also not fully error-free but suggest an encouraging research direction.

At the Max Planck Institute for Biogeochemistry, different strategies are being explored. In light of our need to understand ecosystem functioning in relation to environmental factors, "functional" monitoring perspectives are undergoing development. The overall task is to create new refined global databases of "plant functional types" or "plant traits"[10]. These databases are essentially collections of plant properties. They allow the investigation of biodiversity on a *meta* level and open the way to integrate different datasets - remote sensing products, soil datasets, and climate datasets help to make the essential features of global biodiversity more explicable. This philosophy has been identified as the most promising and technically realistic way "Towards a Global Monitoring Scheme"[11]. Global-scale dynamic modeling approaches appear to be most effective when the research focus is directed at species functional behavior rather than explicitly on species type – less is more sometimes.

B: Environmental controls on and by biodiversity

One fundamental observation is that many more species occur in the tropics compared to higher latitudes. This raised the question among early plant geographers about the environmental determinism of plant diversity. In 1878, Wallace, one of the most influential early biogeographers had already discovered[12]: "in the equable equatorial zone there is no ...struggle against climate. Every form of vegetation has become alike adapted to its genial heat and ample moisture, which has probably changed little even throughout geological periods". Disentangling the different underlying mechanisms contributing to geographic patterns in species richness could shed light on the origin of diversity. This would also have direct implications for conservation planning. However, the discussion about environmental controls *versus* historical effects remains essentially controversial.

Today scientists are equipped with powerful simulation tools that can help to develop mechanistic approaches to these questions. For example, it is possible to model the global geographic variation in the diversity of plant growth based on a few principles[13]. The key is our increasing understanding of how the physical environment constrains plant ecophysiology. Even if only the effects of climate are considered as driving forces, simulation results on a global scale are in good agreement with observed patterns of

Filters. *Global Ecology and Biogeography*, 17, 284–296.

8 Mahecha, M.D. et al. (accepted) Identification of Characteristic Plant Co-Occurrences in Neotropical Secondary Mountain Forests. *Journal of Plant Ecology.*

9 Lahaye et al., (2008) DNA barcoding the floras of biodiversity hotspots. *PNAS*. 105, 2923–2928.

10 www.try-db.org

11 Scholes, R.J. et al. (2008) Toward a Global Biodiversity Observing System. *Science*. 321, 1044 – 1045.

12 Wallace, A.R. (1878) Tropical Nature and Other Essays. *MacMillan*, London.

13 Kleidon A. & Mooney H. A. (2000) Global distribution of biodiversity inferred from climatic constraints: results from a process based modeling study. *Global Change Biology*. 6, 507 – 523.

species richness (fig. 1). Extending this perspective is expected to give a potential avenue to understand the connections of biodiversity and climate in the Earth system.

However, we need to account for more than just climatic constraints. In particular, it was hypothesized that biodiversity affects internal ecosystem processes and ecosystem stability. “The Jena Experiment”[14] is a large experimental area of grasslands species. This long-term experiment aims to clarify the role of species diversity for nutrient cycling and trophic interactions in an exemplary grassland community. This will help to determine whether the role of certain plants in an ecosystem can be partially redundant.

Under this view, the question of species diversity turns into a question of functional diversity. Still, an all-embracing characterization of functional diversity is lacking and hence pure modeling or experimental approaches remain elusive. To address the question of the role of functional biodiversity in the global environment, neither monitoring species richness nor simplified experiments under controlled conditions are sufficient. In their synthesis though, a basic understanding does evolve.

C: The role of biodiversity in the earth system

In view of a changing climate, biodiversity research gains fundamental importance. Plants mediate fluxes of energy and matter via various traits they possess. As mentioned above, these traits are constrained by the (bio)physical environment. More importantly, they sum up to the important features of ecosystem functioning of the “biosphere-atmosphere” feedback system.

Terrestrial ecosystems with their particular biodiversity structure affect the global climate system through the modification of

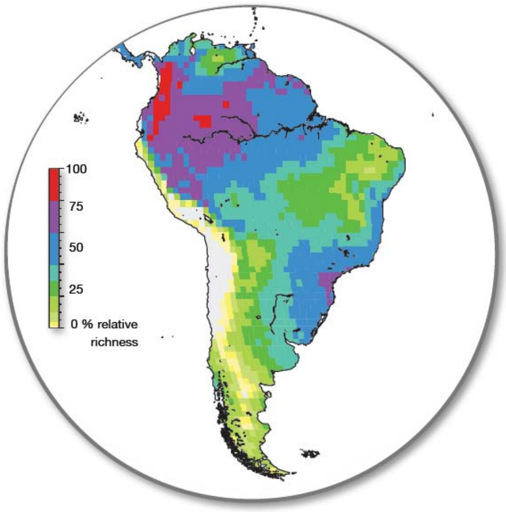

Figure 1 Theoretical pattern of species richness in dependence of climatic conditions only (model structure after [12])

CO_2 and H_2O fluxes. Modified atmospheric greenhouse gas concentrations and climate conditions in turn, shape biodiversity structure and thus the development of ecosystems. It remains a highly speculative question as to how this feedback system has evolved during Earth’s history and how it will develop in the near future.

Through its diversity, the global vegetation possesses many degrees of freedom. Reductionist principles account for all involved causes and effects but their results are discouraging. Nonetheless, a great deal of effort is made in order to extrapolate potential biospheric adaptations to a changing climate. For such simulations, modelers use current knowledge and observations to constrain numerical simulation models. An alternative means to evaluate a model is its application to back projections. This, in turn can be compared to what is known from historical (paleoecological) records. Thus, it is a great challenge for modelers to reproduce phenomena, which do not occur in the present but have occurred in the past, thus being the key to understanding the present and eventually explore the future. However, processes encompassed in models are at

[14] http://www2.uni-jena.de/biologie/ecology/biodiv/index.html

best based on the current state of art or on subjective considerations.

The major expectation of the models is to come up with a range of possible behaviors of the earth system in the near future. The most important point is to understand the breadth and severity of possible risks. Modeling under these conditions is less about predictions that about uncertainty and probability estimation.

4.) Concluding remarks

There are two main motivations that drive the overarching research topics on biodiversity and justify its preservation. First, most aspects of biodiversity are tied to our current needs and future progress as a globalized yet sustainable society. Secondly, it remains an unresolved secret what an increasing loss of biodiversity may cause for the climate system of our planet or for other aspects not yet conceived. Not considering these aspects is an irresponsibility we cannot afford.

In light of the uncertain future and our limited prediction capacities, "biodiversity conservation" as well as "biodiversity research" is an obligation, serving as an incalculable investment in the future to prevent irreversible losses of biodiversity currently conducting unquantified ecosystem services.

One final remark must consider that not all mutualisms between humankind and biodiversity can be reduced to a biophysical problem. In addition to aesthetic, moral, or religious arguments, other cultural values have been identified. For example the great geographical overlap of biodiversity hotspots and areas of cultural and linguistic diversity is astonishing - as is the fact that both currently face a similar threat of extinction[15].

This essay is too short to provide an in-depth introduction to biodiversity research. However, we did highlight a wide range of research activities implying biodiversity questions that shape our work at the MPI for Biogeochemistry, Jena. For further information we refer the interested reader to the www[16].

Acknowledgments:

We thank Sebastian Schmidtlein and Lee Miller for useful comments.

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[15] Sutherland, W.J. (2003) Parallel extinction risk and global distribution of languages and species. *Nature*. 423, 276-279

[16] Biogeochemical Model-Data Integration Group: www.bgc.mpg.de/bgc-mdi
Biospheric Theory and Modelling: www.bgc.mpg.de/bgc-theory
Organismic Biogeochemistry: www.bgc.mpg.de/bgc-organisms