

Ideas for a Diversity Inventory

Biodiversity is relevant to nutrition, natural products, medicine and ecological stability, but also to cultural and aesthetic experience. For centuries, human activity has been reducing biological diversity at an ever-increasing pace. The United Nations declared 2010 the “International Year of Biodiversity.” However, many questions in the field of biodiversity research remain unanswered – also due to a lack of focus and integration of new research approaches.

TEXT **RUDOLF AMANN, ANTJE BOETIUS AND DIETHARD TAUTZ**

Following arduous expeditions and decades of work, Charles Darwin and some of his contemporaries succeeded in developing a theory on the evolution of life by observing variation, selection and spatial distribution. Today, 150 years later, many biodiversity researchers are still explorers and describers. They are hoping to derive, from the spatial and temporal patterns of the

losses by 2010, including sociopolitical, economic and cultural measures such as promoting biodiversity research.

A simple but nonetheless still unanswered question in biodiversity research is that of “how many”: estimates on the number of species that currently populate our planet vary between ten million and ten billion. How many different species of animals, plants, fungi, single-celled protozoa and bacteria are there on Earth? These questions come up in the public discussion especially in connection with the finding that we are currently in an age of mass extinction of species.

But such fundamental questions about the diversity of life also derive from the natural curiosity of humans about the makeup of their environment – just like the children’s song “Do you know how many stars there are?” In astronomy, systematic cataloging of stars is indeed a key component of the research approach. Tracking diversity has been a core issue in biology for centuries, too, but now that we are seeking to understand biodiversity, it is rather taking a back seat.

Biology currently takes a very functional approach. Collecting and describing is shrugged off as free of hypotheses. With this stance, however, biology runs the risk of robbing itself of one of its basic principles. >

We live in an age of mass extinction

immense diversity of life on Earth, rules that explain the processes of adaptation and evolution of species and communities.

To date, this has been a complex and often inefficient process. But progress in genome sequencing and bioinformatics is now creating major opportunities for a much better understanding of biodiversity. The study of the immeasurable diversity of life is making great strides – and just in time: like many other nations, Germany had ratified the Convention on Biological Diversity (CBD) and is obliged to develop a strategy for counteracting species and habi-



The diversity of species on our planet is vital, and research into it needs new impetus.

Systematic tracking of biodiversity must once again become an accepted goal of basic research in biology. In this context, though, new concepts must also be developed to meet the challenge of the sheer numbers of species. Currently, some 20,000 species are scientifically described each year, with animals account-

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ing for the lion's share. Even for the most conservative estimate of ten million species, at the current rate, it would take another 400 years to complete a full inventory of just the animals and plants on Earth. We need to accelerate the process of scientifically identifying species, describing them and even naming them by at least one order of magnitude. Only in this way can we obtain an encyclopedia of life within a reasonable time.

A "census" is a systematic method of biodiversity research. Its main goal is to quantitatively track biodiversity at all taxonomic and organizational levels, thus creating solid foundations both for research into habitats and for developing strategies to preserve them. In basic research, the transition to a quantitative description always represents a great gain in knowledge. This will be no different in the case of biodiversity. By systematically researching biodiversity, we will recognize the patterns that point to the adaptation of organisms and their communities to the changing environment, as well as to the consequences for material flows and food networks.

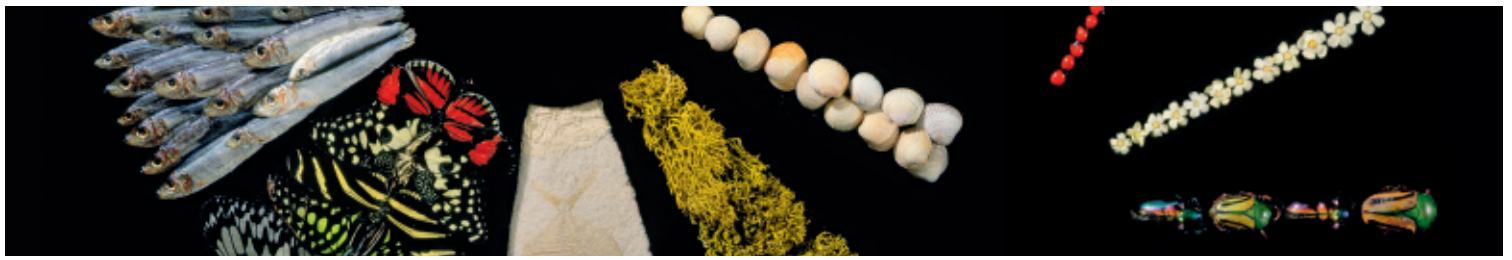
Besides the question of "how many," there are the questions of "where" and "when" – of the spatial and temporal dynamics in the number and relative frequency of organisms in their habitat, and their rela-

tionship to one another and to the inanimate environment. In this context, the focus is increasingly shifting from individual organisms to symbioses, from understanding biological niches to the dimensions of habitats and movement corridors. Modern biodiversity researchers are thus expected not only to compare molecular data sets with each other, but also to link them with data from Earth observations to derive trends and rules.

In cooperation with other branches of the Earth and life sciences, it should also be possible to answer the most difficult question, that of "why." What does it mean, ecologically speaking, when a taxonomic group exhibits immense diversity? How important is biodiversity for the function and productivity of ecosystems? Are rare species also important to communities? How valuable is species diversity to us? And what happens to an ecosystem if just a single member disappears? Can this cause the system to become unstable, like in the butterfly effect in chaos theory? There is already agreement in society and politics that biodiversity and the underlying genetic resources are essential to human life. Biodiversity is relevant to nutrition, natural products, medicine and ecological stability, but also to cultural and aesthetic experience. For centuries, however, human activity has been reducing biological diversity at an ever-increasing pace. This causes the inherent value of biological organisms to be irretrievably lost.

New land areas are constantly being put to agricultural use for the world's rapidly growing population, and energy crops are accounting for more and more of this land use. Solutions are being sought for the negative effects of climate change. However, converting natural vegetation to plantations for carbon fixation in an effort to protect the climate will not only sanction the next wave of species extinction, but virtually subsidize it.

The current discussion about climate change shows that the environment can change regionally much faster than previously thought. Some events, such as the melting of glaciers and sea ice, the in-



creasing flooding of river delta regions or the spread of new diseases, take place on time scales like those used in lab experiments to study natural adaptations. Nevertheless, there is surprisingly little research on the biological consequences of global change to address these phenomena. Against this background, the – thus far sparse – long-term ecological observations on land and at sea are becoming increasingly valuable to science.

The theoretical, conceptual and infrastructural basis of this discipline is not in good shape, either. The reasons for this are rooted in history and scientific culture and owe, for example, to the separation of taxonomic research from other life and environmental sciences, or to the lack of integration of molecular and classical methods of biology in university departments and museums.

We believe that the multidisciplinary branch of science known as biodiversity research, as a part of environmental research and Earth observation, is undergoing a shift – just as medical research has taken completely new approaches to studying humans and their various symbionts, parasites and pathogens since the age of high-throughput genome sequenc-

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ing. The new technical possibilities for tracking biodiversity go well beyond the pure continuation of traditional taxonomy – it's about reinventing an old discipline without losing sight of its roots.

One of the most urgent problems, and one that has ever affected all areas of biodiversity research, is the characterization and counting of species. There are currently many species concepts, specialized for

each group of organisms. The biological species concept of Ernst Mayr, which defines species as “groups of actually or potentially interbreeding natural populations, which are reproductively isolated from oth-

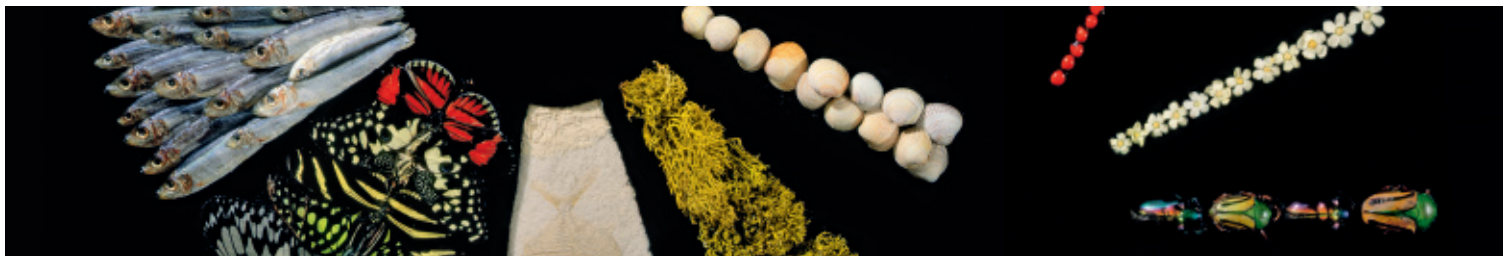
Comparative sequence analysis will permit more accurate analyses of species formation

er such groups,” can reasonably be applied only to the higher animals and flowering plants, not to fungi, protozoa and the two kingdoms of prokaryotes, the bacteria and archaea.

Single-celled organisms and most of the highly diverse small invertebrates that exist in soils, sediments and aquatic habitats, or as parasites or symbionts on plants and animals, harbor many cryptic species that cannot be phenotypically distinguished, but often have completely different functions in the environment. For this reason, the “general lineage” concept that defines species as independent evolutionary lineages has been gaining ground in recent years. Identifying such lineages requires integrating different sets of characters rather than applying solely classical morphological methods.

DNA-based techniques promise a way out of this dilemma, having developed rapidly in recent years. High-throughput technologies (such as next-generation sequencing, NGS) now make it possible to track biodiversity quantitatively beyond the narrow limits of specialized biological groups with their specific species concepts.

Furthermore, comparative sequence analysis will permit more accurate analyses of species formation and, in conjunction with population genetics models, can contribute to a desperately needed comparability of species concepts. >



For microorganisms such as bacteria and archaea, which occur in several thousand taxonomic units per liter of water or sediment – of which we still know only a few percent – only the high-throughput methods of molecular biology permit study on various spatial and temporal scales. In connection with high-resolution measurements of contextual environmental parameters, it also allows comparative sequence analysis to study rules of organisms' association with each other and with special niches or habitats, and to quantify changes in diversity that are influenced by environmental factors.

Metagenomics provides many new findings on microorganisms

Rethinking the traditional categorization that Carl von Linné once used to bring order to animate nature may be an important result of such studies.

Initial attempts to sequence all genomes occurring in a habitat – the so-called metagenome – have already brought many new findings on the dominant microorganisms. In many habitats, a few species of bacteria or archaea appear to dominate a significant portion of the biomass of the community. What makes these species so successful? Or might it, in fact, be a heterogeneous collection of many differently adapted ecological types?

Genetic and epigenetic adaptation to a changing environment may be of particular importance as a response of species to rapid climate change. However, we currently understand far too little of the mechanisms that permit a species to adapt to new conditions and habitats. A combination of methods from quantitative genetics and genome analysis of microorganisms are currently producing new approaches for decoding the functional principles.

Given the high number and variety of microorganisms even in the most extreme habitats, knowledge of biodiversity is an important foundation and possibly even an important functional parameter of eco-

Biodiversity is an important functional parameter of ecosystems

systems. The first data sets on the phylogenetic diversity of microorganisms in the environment show that the observed patterns are neither random, nor can they be explained simply by the selection of populations – for example due to energy availability or other environmental conditions. Rather, they indicate that biological interactions, as well as spatially restricted movement corridors, genetic evolution and other historical conditions, play a strong role. It is still entirely unclear whether the theories of diversity of plants and animals apply equally to microorganisms.

The importance of species-specific microbiomes and their role in the biology of organisms is becoming increasingly clear. For humans, the “human microbiome” is currently being studied in order to identify all microorganisms that are linked to humans, and to draw conclusions about diseases and human well-being. However, it is important to discover specific associations with microorganisms for all other organisms, as well. This includes the intestinal microbiome of animals, the interaction of plants with organisms of the rhizosphere and phyllosphere (roots and leaves) and the fascinating world of fungi.

How various species develop together and adapt to one another such that specific changes occur in the genotype and phenotype – right down to a common life cycle – remains one of the most interesting questions in biology. This may include the key to understanding the evolution of the immune system.

Likewise, we are hoping for answers to questions regarding the origins of life and its ability to adapt to the environment.

The role and repercussions of biodiversity on general geochemical and climatological conditions are high on the list of global change issues, as are food webs and the flow of energy and matter through ecosystems. We still know very little about how the network of interacting organisms reacts to and buffers changes in environmental parameters, such as temperature and CO₂ concentration. Using solid knowledge of these most important components of biodiversity in certain habitats as a basis, it will be possible to approach these questions with models and experiments.

The comparative study of ecosystem functions and connections with biodiversity and the environment can extend from the early history of the Earth to biological models, and focuses on linking and synthesizing field data and experimental findings with ecosystem models.

In this regard, biodiversity research can help provide more precise answers to the elemental questions of “where from” (evolution) and “where to” (the fu-

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ture of life on Earth) and thus put the spotlight on the ecological relationship of humans to their environment. Here, biology needs structures like those we currently know from major international experiments in physics and astronomy. Research into the evolution, function and ecology of biodiversity on Earth is so fundamental for humankind that we should not shy away from this new dimension. ◀

THE AUTHORS



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