

Survival through Diversity

In 1992, the **UN CONVENTION ON BIOLOGICAL DIVERSITY** was signed in Rio de Janeiro – the first international agreement to attempt comprehensive regulation of how we deal with nature. The rate at which biological diversity is being lost is supposed to fall significantly by 2010. From May 19 to 30, 2008, representatives of governments throughout the world attended the ninth meeting of the Conference of the Parties (COP9) in Bonn, where they presented the results of the efforts they had undertaken thus far. Scientists at the **MAX PLANCK INSTITUTE FOR BIOGEOCHEMISTRY** want to find out what significance biodiversity has for the ecosystems on our Earth.

On February 26, 2008, a storage facility for four million seeds was opened in the permafrost of Spitzbergen. This Noah's Ark of useful plants, 800 kilometers from the North Pole, is intended to safeguard biodiversity for future generations. More and more of the plant genetic

resources that have been bred over centuries are disappearing – and with them, genetic designs that might one day be vitally important as environmental conditions change. In the last few years, for example, 70,000 types of rice have been lost in Asia alone, either from neglect or because farmers did not have the resources to maintain them.

However, not only useful plants are affected. With changes to agricultural land, over-exploitation of forests and increasing urbanization, humans are changing the Earth's topography and ecosystems – and displacing numerous animal and plant species in the process. The rate at which species naturally become extinct is between one and three per year; as a result of human intervention, the current rate is around one thousand times higher. Scientists estimate that between one and 130 species now become extinct every day! And it should be kept in mind that, up to now, 1.75 million species have been described, but actually 14 million species are estimated to exist on our planet.

Each species is linked in a complex network of interactions with the animate and the inanimate environment. We call this complex structure an ecosystem. The loss of even one single species means structural change. The remaining network reorients and reorganizes itself – but the consequences vary, since the species in an ecosystem are not all of equal importance: certain species can have a crucial influence on the structure and stability of the ecosystem, while others can disappear without perceptible consequences. It is not possible to arbitrarily substitute one species for another.

The result of the diverse interactions between the individuals is that an ecosystem is more than the sum of its parts. Yet the link between biological diversity and the properties and processes of an ecosystem are still barely understood – a frightening shortcoming given the breathtaking speed at which biodiversity is being lost throughout the world. Thus, ecological research has been stepped up in recent decades, generating several key questions: Does it make any difference to the functioning of ecosystems whether many or few species exist? Does the actual number of species per se, that is, irrespective of the identity of the species involved, affect ecosystem processes? Can species that have similar functional characteristics or that fulfill similar functions in the ecosystem replace each other, or does that affect the way in which these systems work?

SPECIES DIVERSITY MEANS GREATER PRODUCTIVITY

The first in-depth results were supplied by the Cedar Creek biodiversity experiment in the US, which was established in 1994 and which is ongoing today, and by the European research project BIODEPTH (Biodiversity and Ecosystem Processes in Terrestrial Herbaceous Ecosystems) carried out from 1996 to 1999. In the BIODEPTH project, meadow plots were laid out in the same pattern at eight European locations that had very different geographical and climate conditions, and various native plant species were sown in them. During the experiment, the researchers varied the number and the species combinations and, during a period of three years, recorded a series of ecosystem characteristics and processes

PHOTO: C. BIRN



In the Jena experiment, more than 480 sections of meadow with different species combinations were created in an area the size of ten soccer fields.



The wild plants that were sown came from a pool of 60 typical species and were assigned to four functional groups.

– particularly its productivity. The data did indeed show a significant positive relationship between the number of plant species and the production of biomass. The researchers still do not know how this effect comes about.

However, one mechanism that plays an important role is “niche differentiation”: as the number of species increases, so does the diversity of morphological and physiological properties. These differences in characteristics between the species mean that available resources, such as light, water and nutrients, are used

more efficiently. We would like to explain this in greater detail with an example: If only one species grows in an ecosystem, then all of the plants have their roots at the same depth and compete for the water available there. Different plant varieties, in contrast, have roots at different depths and thus exploit all of the available water. Niche differentiation therefore increases the performance of the whole community.

In spring 2002, researchers at the Max Planck Institute for Biogeochemistry in Saaletal near Jena launched a project on a scale that

far exceeded that of any previous biodiversity experiments: More than 480 meadow plots with different species combinations were established in an area the size of ten soccer fields. The plants sown there came from a pool of 60 typical species. Each species was assigned to one of four different functional groups, each of which comprised species with similar properties that possibly have more influence on the processes in the ecosystem than species diversity per se.

The Jena experiment, which was carried out in cooperation with, among others, the Institute of Ecology at Friedrich Schiller University, not only quantified carbon storage and, for the first time, the whole of the nitrogen and phosphorus cycles, but also the interactions between the individual plant species and the different trophic levels (food chain levels), that is, plants, invertebrates and microorganisms. Working groups from the fields of hydrology, biogeochemistry, soil science, botany, zoology and agrarian ecology are collaborating closely on this project.

BIOTREE – RESEARCH WITH A LONG-TERM PERSPECTIVE

The first results show that species-rich meadows are not only more productive, but also that more carbon is stored in the soil of species-rich meadows. Both of these – the production of more biomass with photosynthesis and the increased carbon stores in the soil – remove the greenhouse gas carbon dioxide from the atmosphere and thus contribute to stabilizing the climate.

All the experiments carried out thus far have in common that they are being conducted on fast-growing and small model ecosystems. It is not surprising that there are as yet no similar analyses of forests, although forests fulfill a number of important functions, such as storing carbon,

conserving ground water and producing timber. Biodiversity experiments with forests inevitably entail a very long period of investigation – trees take many years to form a complete stand.

The interesting question is whether forests will prove to function in a similar way to meadows. Does a species-rich forest grow better than a species-poor one, and does it absorb correspondingly more carbon? BIOTREE (BIODiversity and ecosystem processes in experimental TREE stands) is a worldwide unique experiment that we at the Max Planck Institute in Jena started in 2003 to investigate the effect of biodiversity on the ecosystem processes in forests. Some 200,000 seedlings were planted on a total of 70 fallow hectares at three locations with different geological and climatic conditions.

However, the extremely dry summer of 2003 caused us considerable problems when we planted the small trees, which were 20 - 60 centimeters in height. We lost all of the very small pine trees at one of the three locations, and two-thirds of the newly planted European beeches and sessile oaks also died. However, it was easier to establish the wych elms, the small-leaved limes, the ashes and the rowans and the three different species of maple – losses here totaled less than 20 percent. We thus had to reach for our spades again the fol-

lowing year to plant more trees and to ensure that around 85 percent of them would grow successfully in each of the experimental areas.

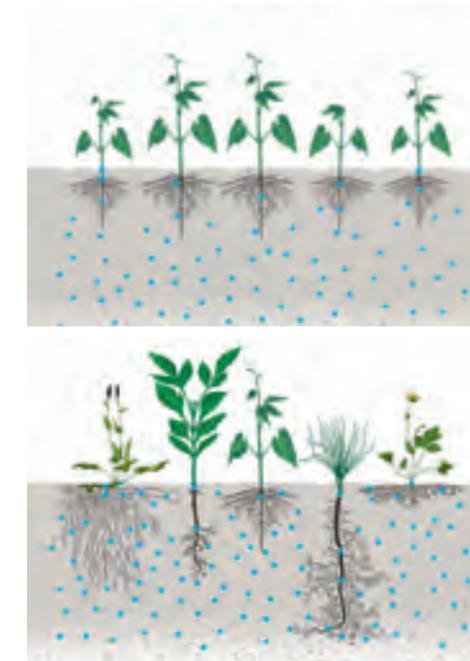
At two of the three locations, the number of tree species varied. In the areas with chalky soil, there are one, two, four or six, while the areas with sandstone have one, two, three or four species. All the theoretically possible combinations of species from the species pool were created. Unlike the experiments in the grassland, it is possible, when planting trees, to vary the positioning of the species within the section. In principle, individual trees can be distributed randomly, or arranged in a regular pattern or in smaller groups. In our experiment, we planted each species grouped on eight-meter squares in order to prevent weaker, less competitive species from being displaced prematurely. This was to ensure that the planned levels of diversity would become successfully established.

TREE GROWTH WITH A MEMORY EFFECT

The size of the squares was determined by the average crown diameters of mature trees. In a roughly 100-year-old forest stand, each square should eventually be occupied by one individual.

Just setting up this experiment required thinking and planning in time scales that are rather unusual in research. At the third location in the experiment, the number of species remained constant. Four tree species belonging to different functional groups were mixed together.

BIOTREE offers a unique opportunity to trace the development of diversity-function relationships in forests over a very long period. We



Plants of the same species all root at the same depth (above). Different plant species, in contrast, root at different depths and make better use of the available water. Researchers call this niche differentiation.

will be recording various parameters at intervals of several years. These include growth of the tree species, carbon storage in the wood biomass, stand structure and population dynamics, development and productivity of ground vegetation, nutritional content in plants and soil, hydrologic balance, and litter decomposition. Using artificial shade covers, we want to find out how trees compete for light and how they internally redistribute their resources, for example energy storage products such as starch.

Everyone knows from their own observations that every tree always exhibits the most important characteristics of its species, but develops its individuality in response to its environment. A free-standing spruce therefore looks quite different from one that has grown up in the cramped surroundings of a thick forest stand. As woody plants invest the majority of their biomass in long-lived and irreversible structures, they are not able to react flexibly to the changes in their current environment, but their shape is marked by their whole life history.

A paradigm of biodiversity research is that species-rich stands are more



Researchers measure the hay yield: Areas with less plant diversity yield less biomass.

PHOTOS AND FIGURES: MPI FOR BIOGEOCHEMISTRY (2)

PHOTOS: MPI FOR BIOGEOCHEMISTRY (3)



More than 200,000 seedlings were planted as part of the BIOTREE project. Their quality and the way they were handled when they were planted were crucial to their success.



The researchers want to use artificial shade covers to find out how trees compete for light, and how they redistribute their resources internally.



Hainich National Park is one of the three sites for the exploratories. There, arthropods develop as Larvae in the ground; zoologists install traps to catch them.

stable than species-poor stands. Accordingly, even in young afforestation projects, such injurious factors as gnawing by water voles or rabbits should cause less damage to species-rich stands than in monocultures. We therefore monitored how successfully 19 different tree species in the BIOTREE experiment had grown in the first two years after planting. We were able to attribute up to 20 percent of losses in one tree species to water vole damage. These small rodents usually dig extensive passages directly under the plants, and are particularly fond of eating the roots of young trees. The tree species we investigated were affected to differing extents: we found the most damage by water voles on oaks in all the locations, whereas the lime trees remained practically unaffected.

ELIMINATING THE RODENT NUISANCE

Because the tree species were planted in groups, species that are highly susceptible to gnawing and water voles are positioned next to less susceptible trees in the BIOTREE experiment. It is interesting that the damage from both water voles and hares was not randomly distributed over the experimental areas, but clearly depended on the number of tree species in the section in question. The areas with a mixture of six tree species suffered less damage per species than the areas with fewer species. This finding is all the more surprising when one considers the many influential factors that determine the growing success of trees. It confirms other results that also indicate that ecosystems function better and respond more flexibly to disturbance when more species exist.

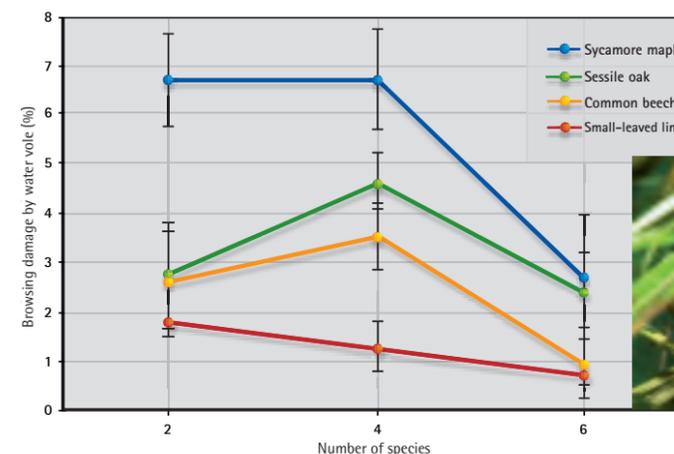
In the experiments described here, we have created model ecosystems that have uniform local conditions and a uniform history of land use. In this way, we can exclude these two

factors as influencing variables and reveal the links between ecosystem processes and the different levels of biological diversity that we have established. However, these model ecosystems can be compared with natural systems only to a limited extent. In the “Biodiversity Exploratories,” which were established in 2006, the goal is to investigate species diversity in existing natural landscapes.

The Exploratories were set up in three 100-square-kilometer sample areas in the Schorfheide-Chorin biosphere reserve (Brandenburg), and in and around Hainich National Park (Thuringia) and the Swabian Alp biosphere area (Baden-Württemberg). In a long-term study, we will work together with more than 30 different research institutions to find out how changes in land use and their intensity affect biodiversity. To do this, we need to record the complex interactions between local and climate factors, animals, plants, microorganisms and land use.

Species extinction and the processes responsible for it, climate change and the destruction of natural habitats are global phenomena. We are thus interested in the question of whether findings from experimental research are significant on a large scale – that is, for the entire Earth system. The first Earth system models to predict climate change differentiated only between sea and land surfaces. The crucial significance of plants on the continents and in the oceans was not recognized until later.

Today, we are taking the first steps toward mapping plant diversity in global climate models. To do this, we must first record the functional abundance of plants. Thus, as part of the international TRY project, scientists are gathering the characteristics of as many plant species as possible. The database now contains entries for more than 30,000 species – equivalent to approximately 10 percent of our Earth’s flora.



Many tree species are susceptible to damage by water voles. Areas with a mixture of six different species exhibited the least damage.

The first analyses show that individual functional species groups and their particular characteristics can have a major impact on the element cycles in the Earth system. For example, there are more fires in the boreal forests of Siberia than those of Canada because the dominant tree species in each area have different ways of adapting to fire. Tropical rainforest species on young soils exhibit rates of photosynthesis that are considerably higher than those of trees on old exhausted soils. That has significant consequences for the water and carbon cycles of the entire Amazon basin. The rate at which carbon can be stored in the dead wood of the forests depends crucially on the tree species and the properties of their wood.

PLANT DIVERSITY IN THE CLIMATE MODEL

Obviously, we will never be able to take the dynamics and the influence of 350,000 plant species into account

in a climate model. We can, however, at least identify the most important players and understand, on the one hand, how they affect ecosystem processes and, on the other, how they respond to global change. When we have understood this interplay between plant diversity and climate, we will have a chance to make better and more precise predictions about the climate.

We assume today that the impoverishment of ecosystems to monocultures is taking its toll on stability. These systems can yield only a fraction of what an ecosystem with species-rich systems delivers. The creation of permanently stable ecosystems would thus be an important economic goal. Yet, even though a wide diversity of species might not be the critical factor given constant and favorable environmental conditions, under changing environmental conditions, species diversity could be of crucial importance.



DR. AXEL DON wrote his doctoral thesis as part of the BIOTREE project. He is now

investigating how it is possible to manage land use systems and their biogeochemical cycles in order to reduce greenhouse gas emissions.



DR. CHRISTIAN WIRTH is head of the Independent Junior Research Group “Organismic Biogeochemis-

try.” He is using models and plant databases to understand the impact of functional plant diversity on different ecosystem processes.



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PHOTOS: MPI FOR BIOGEOCHEMISTRY (3)

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