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Biodiversity Research

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Deutsche Forschungsgemeinschaft (DFG)
German Research Foundation
Head Office: Kennedyallee 40, 53175 Bonn
Postal address: 53170 Bonn
Tel. +49 228 885-1
Fax +49 228 885-2777
postmaster@dfg.de
www.dfg.de

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Author: Caroline Möhring
Concept and editing: Jutta Rateike, DFG
Scientific editing: Roswitha Schönwitz, DFG
Translation: SciTech Communications GmbH, Heidelberg
Translation editing: Lisa Hoppe, DFG
Cover design and layout: Angelika Böll, Bonn
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Foreword

Biological diversity is fundamental to our life. Not only does it secure our material needs, it also provides valuable services that humans require from their environment, such as food, clothing, clean drinking water, and medical care. It ensures the stability of our habitats and is an essential basis of our culture and civilisation. Biodiversity also means genetic diversity and is our best safeguard against environmental changes.

No one knows how many species of organisms exist in the world. The total number of described species is estimated at 3.6 to 112 million, with 10 to 20 million currently considered the likeliest range. New species can be recorded very efficiently today, thanks to the quick and automatable method of DNA barcoding. The Deutsche Forschungsgemeinschaft (DFG) supports the development and implementation of this technology with a cooperative project that aims to build a DNA bank network in Germany.

But the biosphere is in a deep crisis today as biological diversity suffers dramatic losses. According to the World Wide Fund For Nature (WWF), 34,000 terrestrial and marine species are currently endangered, and the number of extinctions per day is estimated between 2 and 130. This global mass extinction is the cumulative result of local extinction events, which lead to a decrease in the diversity of local ecosystems long before these species are definitively extinct. That is why the significance and value of biodiversity have been recognised by meanwhile over 180 signatory countries to the Convention on Biological Diversity (CBD), which was concluded at the Earth Summit in Rio de Janeiro in 1992.

Today the biosphere's greatest problems are the human-caused landscape changes that can be observed around the globe, the climate changes, and the accompanying loss of biological diversity. All these changes are summarised under the term "global change" and are interrelated, but little secure knowledge exists about the nature and extent of these relationships. Especially the role of biodiversity in this relationship triangle is largely not understood.

Professor Dr.-Ing. Matthias Kleiner

Basically we can distinguish between three different aspects of biological diversity: first, biodiversity as a product of evolution, which has brought forth and continues to develop a diversity of populations and species; second, biodiversity as a resource for humans; and third, biodiversity as a prerequisite for the functioning of ecosystems. This third, ecosystemic aspect is especially complex because it looks at the functional consequences of changes in biodiversity at various levels of organisation, ranging from the genes of individuals to the species level to the diversity of biotic communities and the interrelationships between organisms. It must also include various spatial and temporal dimensions as well as a variety of parameters, including humans.

The economic component of the use of biodiversity is quite obvious and covered by the CBD, but the Convention falls significantly short when it comes to the issue of habitats. This has to do with the fact that progress in understanding ecosystems tends to be arduous and without immediate economic benefits. But it is particularly the economic dimension that can have a strong impact at the ecosystem level. A case in point is the biofuel business, which replaces huge areas of species-rich tropical forests with sugar cane, oil palm and maize monocultures to produce fuel.

The fact that this is possible in the age of globalisation points to a lack of secure knowledge about the functions of biodiversity and its value at the micro- and macro-scale. One thing, however, is certain: the accelerated extinction of organisms causes a loss not only of genetic resources but also of ecosystem services. This is true for relatively species-poor Germany as much as for the species-rich countries of the tropics and subtropics. By signing the Convention on Biological Diversity, Germany too has pledged action to fight the extinction of species. The key components of this endeavour are environmental protection, educating the public, and research.

A challenge to research

Special challenges, particularly to basic research, are therefore the functional and ecosystemic aspects of biodiversity. For example, it is not exactly clear which of the numerous ecosystem services can be provided by a species-poor ecosystem compared to a species-rich one, or whether a decrease in diversity has a different effect when it occurs in a hotspot of biodiversity as opposed to a system like Antarctica that holds but a handful of species. Another question that begs answering is how changes in climate and landscape affect the origination and extinction of species, and conversely, how changes in biodiversity affect landscapes, climates and people. These are some of the existential questions surrounding the functional significance of diversity.

These functions must not only be described qualitatively, they also have to be defined through measurements and experiments. This calls for a mix of research approaches – those of the life and earth sciences as well as those of the humanities. Research networks are especially well suited for these investigations because they bundle the expertise of multiple disciplines. Biodiversity research always looks at the long term, since it deals with the environment and ecosystem functions can only be examined over longer periods.

The understanding that ecosystem research requires experimental manipulation of the environment as well as long-term investigations has taken a while to catch on in parts of the scientific community. Now these approaches are being pursued worldwide by a dedicated branch of science called Global Change Research. The DFG, through its various funding instruments, supports a number of internationally reputable interdisciplinary cooperative projects that investigate the functions of biodiversity and include experimental approaches. They are designed to run longer than the usual project funding periods. Some of these projects are introduced in this brochure, and they show that the DFG's portfolio of programmes is able to accommodate the peculiarities and demands of biodiversity research. Particularly by establishing biodiversity exploratories, the DFG provides a platform for long-term functional biodiversity research. Germany thus takes on a pioneering role in the international research arena.

Establishing databases

One of the main problems of biodiversity research is the vastness and nature of the data that have been or will need to be recorded. Biodiversity data encompass a multitude of structures, from DNA sequences to data on physiology, morphology, ethology, population and community ecology, and habitats. This diversity of data structures requires a diversity of information technology systems. While there are international approaches to standardise data structure, the development of integrative, networkable databases falls far short of meeting the demands of research. Yet such databases are important to ensure the long-term usability of primary data from research findings, for example in synthesis projects that deal with overriding research issues, but also to increase the long-term relevance of research findings. All of the major projects funded by the DFG now include integral, subject-specific central database projects. Going forward, these databases will need to be networked with each other and with the eight biodiversity data nodes that already exist in Germany. This undertaking is supported not only by the DFG's scientific programmes but also by its Library and Information Systems (LIS) programme.

Better data provisioning was one of the key desirables that a group of biodiversity researchers named when invited by the Alliance of German Science Organisations in early 2008. They also requested that a Forum for German Biodiversity Research be formed to improve information exchange and cooperation among scientists, but also between scientists and research funding organisations as well as government institutions. The Alliance has now established this forum under the leadership of the DFG.

This brochure is published in conjunction with the ninth meeting of the Conference of the Parties (COP 9) to the Convention on Biological Diversity, which in May of 2008 brings together in Bonn about 5,000 delegates from around the world to discuss the conservation and sustainable use of biodiversity. Yet the voice of research has not been sufficiently heard in these discussions so far. With this brochure, the DFG therefore wants not only to demonstrate its interest in funding biodiversity research but also to highlight the crucial importance of science and research for the mission of the Biodiversity Convention. The DFG supports this mission with its commitment to biodiversity research, which contributes to keeping our environment liveable.

Professor Dr.-Ing. Matthias Kleiner
President of the Deutsche Forschungsgemeinschaft

The Fascination and Function of Diversity

An Introduction

Diversity has inspired collectors to collect, painters to paint, world travellers to travel the world, and researchers to do research. The immeasurable variety of life has always fascinated people, arousing awe as well as the urge to describe, but ultimately also the desire to better and better understand this very diversity. Such is the origin of biology. Ever since the times of Swedish naturalist Carl von Linné, scientists have attempted to record and organise the diversity of organisms in a systematic manner – although by the last century it seemed that this endeavour was no longer a priority. Taxonomy and systematics, after all, had come to be seen as old-fashioned and a bit quaint, as life scientists became excited about new methods that promised answers to fascinating questions about the general functional principles of life and its propagation, biochemistry, physiology, and genetics.

Indeed a groundbreaking success for the life sciences was the discovery of the universal genetic code, the key for the transmission of genetic information, shared by all living organisms. This standard genetic alphabet, with four base molecules as letters, also allows countless different words, sentences and chapters to be written in the great book of life. It is one of the very characteristics of animated nature to keep producing new forms – some successful, some less so; some rare, some widespread; some durable, some short-lived. But the ongoing quest for the fundamental laws of nature was intensely focused on that which is uniform and universal, so much so that diversity, variety and change came to be seen almost as static noise, as deviations from the norm. It was only within the last couple of decades that biodiversity, the richness of life, once again became a serious scientific topic. This was not least due to the alarming realisation that diversity is under serious threat and dwindling rapidly in our changing world.

Even a look at the ground below leads us to ask: Is biodiversity simply a whim of nature or does it serve a deeper purpose?

Today biodiversity has become a catchword that keeps popping up in a variety of contexts and yet often remains vague. That is because biodiversity, or biological diversity, has many aspects that shape different definitions of this term. First, biodiversity may refer to various levels: genetic makeup; individuals, species and higher systemic units; or ecosystems, habitats and entire landscapes. Second, biodiversity may be defined for different scopes: within delimited areas, across several areas, or for entire regions. Third, biodiversity may simply measure the number, distribution or variability of the entities under consideration. Last, biodiversity is also used to measure the complexity of interactions in an intricately interwoven network of relationships and interdependencies between living organisms and their environment.

Human beings play a special role here, because the threads they spin within this network are especially thick and often affect the entire web. The fact that biodiversity is now a ubiquitous catchword also means, on the upside, that we have come to be mindful of this role and accept the responsibility. This realisation gave rise to the Convention on Biological Diversity (CBD).

It is the first international set of regulations to extend protection to all elements of the living environment, while also linking it to the sustainable human use of biological resources. The CBD thus goes far beyond the substance of earlier agreements on the protection of the environment and endangered species, such as the Convention on Migratory Species (CMS) or the Washington Convention on International Trade in Endangered Species (CITES). Currently 189 countries and the European Union are parties to the Biodiversity Convention and have thus agreed to incorporate its terms into national law.

As a binding agreement under international law, the CBD aims not only to conserve species diversity, but also to protect biological diversity overall – genetic diversity, the diversity and functioning of ecosystems, and thus the basis of human life. At the same time, the agreement recognises that countries of origin should be fairly compensated for the use of their biological resources by third parties. Finally, the signatory countries have agreed not only to implement the Convention at home but also to help other countries preserve biodiversity.

How and why did the tremendous diversity develop particularly in the tropics? This question continues to challenge scientists.

Open questions and the role of science

Much has since been discussed regarding possible means of implementation, resulting obligations, and economic consequences. Yet one important aspect is at risk of being forgotten: The prerequisites for effective conservation and sustainable use are, first and foremost, the knowledge of biological diversity and the understanding of its functional relationships. This is where science comes in. For there are still too many open questions; only a portion of the inconceivable varieties of life is known, and we have only just begun to grasp the intricate ways in which they are interrelated.

What is ultimately the purpose of biodiversity? What does diversity do, and what is its effect? Are species-rich biotic communities indeed more stable, as is often speculated? Are they able to react with more flexibility and elasticity to changing environmental conditions? In highly diverse ecosystems, is there such a thing as redundancy in the form of multiple species that can take on the same functions within the system and mutually replace each other? Or does each species play a unique role, making it irreplaceable within the system? Are species-rich communities more productive? Do they fix carbon more effectively and thus slow down climate change? Or are modern high-yield varieties superior in this regard? What is the effect of greater plant species richness on water balance and nutrient cycles? Do vegetation forms with greater plant diversity correlate with greater species richness of other organisms – animals, fungi, or microorganisms? Are there feedbacks between species diversity and ecosystem processes? Are the services which ecosystems provide for the environment dependent on their biodiversity? In conflicts, is it more important to preserve species or functions? The list of open questions goes on, and answers are hard to come by.

As a rule, these complex communities defy the natural sciences' favourite tool: the reproducible experiment. Therefore comparative observation of carefully selected areas is often the method of choice for gaining insight. This holds especially true for so-called biodiversity hotspots, where the initial objective is to identify and describe the endangered diversity of species. Since they are located mostly in the Earth's tropical and subtropical zones, an additional aspect comes into play here. Those who use biological resources from foreign countries must follow strict rules. This too is set forth by the Convention on Biological Diversity: Each nation owns the property rights to all the organisms that exist on its territory, as well as to their genetic information. It follows that animals, plants and microorganisms may be collected and examined only with permission, and that appropriate agreements, which may include stipulations for monetary or non-monetary compensation, must be made with the respective country of origin. To avoid hampering basic research, the DFG offers advice to researchers as they design and implement such projects.

Sharing benefits

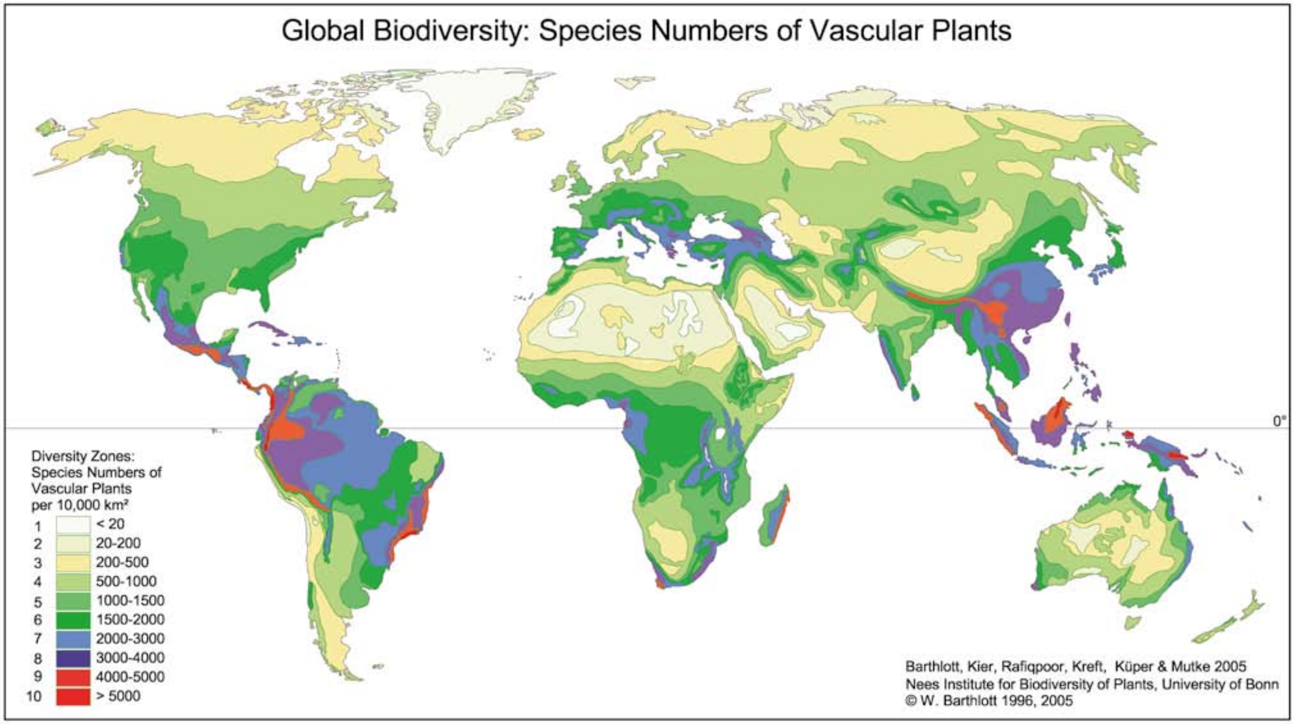
For many years the DFG has funded two endeavours of this kind – one in the rainforests of Ecuador (pp. 13-18), and one at the margins of Indonesian rainforests (pp. 19-24). In both cases, German scientists from various disciplines work closely with researchers from the respective host country. In Indonesia, for example, German scientists cooperate both with the country's largest university, the Institut Pertanian Bogor, on Java, and the local Universitas Tadulako on the island of Sulawesi, where the investigations take place. Once the linguistic groundwork had been laid, an intensive scientific exchange ensued. Today German and Indonesian researchers share research facilities and jointly publish findings in internationally recognised peer-reviewed journals. Several hundred students and young scientists from the host country have taken advantage of a training that complements textbook knowledge with hands-on research. Many of them have also seized the opportunity to obtain an internationally recognised degree and a doctorate abroad. But then they are happy to return back home, where attractive tasks await them.

A similarly intensive form of collaboration has been launched in Ecuador. Here too, as is customary across South America, universities are institutions that exclusively pass on knowledge. Traditionally they do not conduct research. But the cooperation with German scientists has changed that. A case in point: the Universidad Técnica Particular de Loja, where German researchers – braving suspicious customs officials – have not only established laboratories for biochemistry and for soil science, but also introduced faculty and students to the practice of research. Meanwhile the Technical University in Loja has decided that it will no longer just transmit knowledge but generate it as well, by expanding into a teaching and research university that will also be able to award doctoral degrees. Currently young scientists have to go abroad to get their doctorates because the country's teaching-only universities are unable to grant them. The Ecuadorian researchers, however, who as a part of this project received their doctorates in Germany, are now enthusiastically helping to expand their own university.

Observation and experiment

Both research projects, in Ecuador as well as on Sulawesi, rely on experimental, in addition to comparative, observation. In Ecuador, for instance, an elaborate fertilisation experiment was set up, and in Sulawesi researchers even built a roof over part of the forest to simulate the effects of droughts, which are expected to become more frequent as our climate changes. The project bridged not only the line between observational and experimental investigation, but also the often blurry line between basic and applied research. After all, sustainable use is only possible if the limits of a system's capacity are known.

In species-poor Germany, on which naturally much more research exists, comparative observation likewise remains a valuable approach, for example in examining long-lived and complex ecosystems such as forests. The better-known the conditions on the research plots and the longer the recorded periods, the greater the knowledge gain. This type of research can provide helpful clues about the significance of natural conditions and of the type and intensity of land use for biodiversity and ecosystem processes. But the full picture does not emerge until comparative observation is complemented by experimental investigations on adjacent plots. Based on this simple and persuasive consideration, a globally unique system of research platforms called exploratories was established with DFG support (pp. 25-28). On numerous experimental plots in forests, grasslands and pasturelands, they combine observation and experiment. In three exemplary German regions with diverse and varied land use, a unique infrastructure for functional biodiversity research was thus created, which will be available on a long-term basis for a variety of investigations. The synthesis of the intended comprehensive findings on all aspects of biodiversity and ecosystem processes should make this work, in its richness and depth, extraordinarily valuable and build an excellent foundation for further research.



In one of these regions, with support by the DFG, a Research Training Group was established as well, in which young scientists work on a wide range of issues surrounding the biodiversity of forests (pp. 29-32). These hard-to-explore biotic communities still attract significant scientific attention, which is not surprising considering the many welfare functions or services they are believed to provide for the environment and thus for humans. The fact that researchers investigate these functions by examining and measuring the same objects from widely different vantage points makes the particular scientific appeal of such a Training Group.

But scientists also try to approach the fundamental questions of biodiversity from the opposite side, as it were – by conducting an actual experiment on a scale that is still manageable. For the Jena Experiment (pp. 33-38) researchers created artificial grassland ecosystems that allow them to vary and manipulate a range of factors. With 60 different plant species alone on 480 experimental plots, the Jena Experiment is so far the largest of its kind in the world.

Even bigger and more ambitious, however, is an experiment currently underway in China: On devastated grounds in a subtropical biodiversity hotspot, more than 350,000 trees and shrubs will be planted according to a sophisticated system that allows researchers to gain fundamental insights into the interactions between diversity and function (pp. 39-42). The experiment, conducted in equal partnership by European and Chinese scientists, is hoped to produce its initial findings as soon as the next decade. But even fifty or a hundred years from now, science and forestry are still likely to benefit from this gigantic undertaking.

And then there is the exemplary special case of a micro-scale ecosystem for which scientists are trying to find a macro-scale equivalent. Scouting the world's oceans, researchers from Kiel are trying to discover, among other things, the principles that also determine how the human intestinal flora functions (pp. 43-46). The diversity of interrelations created by the selective pressure of the sea has inspired medical researchers to seek new methods for effectively fighting lifestyle diseases at the surfaces of the human body. After all, the human skin, lungs and bowel also harbour highly diverse microbial life communities with many different functions and interactions, which scientists have only begun to identify and understand.

Finally, in order to support the different approaches to recording and organising the diversity of life with modern techniques, the DFG also funds a new type of research collection: DNA banks, which can store genetic material for long periods, thus allowing researchers to reproduce the findings of analyses and experiments (pp. 47-52). These facilities, designed according to the criteria of modern data processing and communication, provide the basis for intensive scientific exchange and the meaningful synthesis of research findings on the enormous diversity of life.

This diversity of projects also reflects the diversity of funding instruments offered by the DFG: Research Unit and Collaborative Research Centre, Cluster of Excellence and Research Training Group, Research Grant and Infrastructure Priority Programme – each one of them plays an important part in promoting biodiversity research. What all of these projects have in common is a longer-than-usual funding period. Only research conducted over extended periods of time stands a chance to actually gain new insights into the diversity of the life surrounding us, along with its functional relationships. This brochure presents eight exemplary approaches to this challenge.

How Can We Use a Biodiversity Hotspot Responsibly?

Biodiversity and Sustainable Management of a Megadiverse Mountain Ecosystem in South Ecuador

This region could hold records. The Reserva Biológica San Francisco appears to be a particularly hot biodiversity hotspot. Some 98 different species of vascular epiphytes have been found on a single tree here. In a grove of six neighbouring trees some 225 species of flowering plants and ferns were found, all of which have adopted the same life strategy: to grow on the stems and branches of other plants, in the crowns of trees that are suffused with light, without investing their biomass in growing a trunk of their own. And, because this strategy is so widespread in this biotope, they compete for light not only with their hosts up in the crowns of the tropical rainforest, but also with each other.

Both the flora and fauna exhibit a variety that is particularly impressive to Central Europeans and appears remarkably unique, even on a global scale. With a total of 2,396 species, the moths in this region hold the world record – to date. Birds and bats also abound, with an exceptional number of species. So, where better than here to study how biological diversity develops, persists, and what impact it has on the ecosystem as a whole?

Hard to see: Many groups of insects have developed amazing forms of camouflage and a fascinating species richness.

Of course it is more than just scientific curiosity that makes the researchers interested in studying this region, supported by grants from the DFG. The Ecuadorian Andes are considered not only one of the hottest biodiversity hotspots, but also one of the most endangered areas in the world. Nowhere else in South America is such a high proportion of the forest destroyed each year as in Ecuador, and worldwide it is also in the "Top Ten" when it comes to destruction of tropical rainforest. The reason for this is the persisting poverty of the rural population and their striving for a better standard of living. This triggers a vicious circle: The methods of land use to date have seriously disrupted the ecological balance and led to a downwards spiral into an inescapable poverty trap, as the degraded environment becomes increasingly unable to provide the resources on which the local people built their existence. Yet even if policy decision-makers strive to strike a balance between the needs of present and future generations, they often lack the necessary information on ecological interdependencies. This applies, in particular, to such unique areas of the tropical Andes as the region in which the Reserva Biológica San Francisco lies.

The key question

The researchers participating in the "Biodiversity and Sustainable Management of a Megadiverse Mountain Ecosystem in South Ecuador" project build on the results of a number of preceding studies conducted over the past ten years. Bearing in mind the fact that the exceptional biodiversity is one of the major formative ecological factors of that region, their current key question is: Can we achieve science-directed sustainable land-use systems, that at the same time preserve biodiversity and its underlying ecosystem processes, rehabilitate attenuated diversity and lost usability, and guarantee a better livelihood for the local population?

As in the previous projects, biologists, geoscientists and social scientists with different areas of specialisation are working together to find answers to these overriding questions. One of the special features of this multidisciplinary approach is the fact that all of the projects are working in the same core area, the eleven square kilometre heart of the Reserva Biológica San Francisco.

The formation of biodiversity hotspots

In spite of the complexity that characterises an ecosystem with such exceptional biodiversity, the researchers strive to identify factors and processes that have contributed to the high biodiversity of the area and to its sustenance. The Reserva Biológica San Francisco lies in the Amotape-Huancabamba depression, which stretches from the south of Ecuador to northern Peru. Here the Andes are barely 4,000 metres high, but are broken up into many mountain chains. The varied types of landscapes in combination with pronounced horizontal and vertical climatic gradients lead to the formation and coexistence of a great variety of habitats, which in turn promote the development of great species diversity.

Another reason for the great biodiversity, according to the scientists, is the history of the region since the uplifting of the Andes in the Tertiary period. Glaciation during the ice ages and drought situations in warm periods, accompanied by major changes in vegetation, obviously prevented species from migrating and resulted in an enhanced evolution of species. Four regions with a particularly large number of endemic plant species have been identified in Ecuador – the core area of this project is part of one of them.

Tropical forests are normally in a state of dynamic equilibrium, in which all stages of forest development coexist. The experts refer to this as a mosaic climax – and it is this dynamism that they see as one more reason for the broad biodiversity. Another characteristic feature of the research area is a

Easterly winds carry plenty of moisture from the Atlantic Ocean over the Amazon basin up as far as the Andes. When the air masses rise there, clouds form, almost permanently covering the eastern ranges. Eleven months of the year precipitation by far exceeds evaporation.

high frequency of landslides presumably caused by the sheer weight of the forest and the instability of the water-saturated soil on the steep slopes. Where a landslide has occurred, the deeper soil layers or even the bedrock become exposed. Since these are very poor in nutrients, plant regrowth, starting with mosses and lichens and a few orchids, is usually very slow and pioneer stages can last for exceptionally long periods. In contrast, in gaps caused by the falling of individual trees, the forest recovers in just a few years. The hypothesis that these kinds of instabilities in the vegetation cover stabilise the high level of biodiversity is thus only apparently paradoxical. Another hypothesis stresses the lack of nutrients, which prevents the dominance of individual tree species that could make better use of an ample nutrient supply, displacing others by growing faster. The absence of such key species also contributes to a high biological diversity. Measurements have shown that the nutrient content of the plants here is significantly lower, and that the litter decomposition rate is much slower than in tropical lowland forests.

Interrelationships and interaction

In order to understand an ecosystem, it is first necessary to know the components it consists of, and the ways in which these interact: a commonplace that is nevertheless incredibly hard to achieve in a biodiversity hotspot. In the Reserva Biológica San Francisco there are many groups of organisms that are now fairly well understood, but there are also others about which almost nothing is known. The researchers have teamed up with specialists from the European Distributed Institute of Taxonomy to fill this information gap. At the same time, the subproject "Biodiversity: Mechanisms and Processes" will study functional relationships: plants, as primary producers of biomass, as well as herbivores and decomposers. A unique feature of the project is the focus on the interrelationship between the plants and soil life, in particular mycorrhizal fungi and soil fauna as decomposers. In contrast to the outstanding plant diversity, the soil life is not exceptionally rich in species. This discrepancy is one of the riddles the researchers hope to solve by conducting ecological experiments. Behind this lies the question as to whether a hotspot of biological diversity extends to all groups of organisms to the same extent.

On the American continent Colibri *and bats often assume the task of pollinating flowers, which elsewhere is carried out by insects.*

Observations, and even quantifying measurements, can at best suggest cause and effect relationships. Proof, however, requires experimentation. Some experiments are already underway in the area around the research station. For instance, one experiment examines the effect of light on the diversity of the epiphytes by comparing the growth of different types of epiphytes on isolated trees with that on trees in shaded stands. Another experiment investigates the reactions of soil fauna and microorganisms on artificially reduced quantities of rainfall. The most complex experiment is a large-scale fertilisation experiment, which the researchers hope will shed light on how plant nutrient deficiency affects forest growth and biodiversity. Aiming at a more applied aspect, a forest management experiment is going on to uncover the effects of thinning regimes on the growth of commercially valuable indigenous trees and on the diversity of plants and insects.

Environmental gradients in ecosystem research

Experiments are the classical route to understanding ecosystem processes. However, their inevitably reductionistic approach faces serious limitations in such complex ecosystems as a tropical mountain rainforest. Against this backdrop, the analysis of a wide variety of ecosystem parameters along environmental gradients provides an effective, and for special questions probably the only feasible approach.

Over the past ten years of ecosystem research, the researchers have used two types of environmental gradients: the altitudinal gradient from about 1,800 to 3,200 metres, and the gradient of human impact. The valley of the Rio San Francisco is ideally suited to studies of this kind. Two variants of the same ecosystem border each other at the valley bottom: on the one side a widely untouched mountain rainforest, which covers the southeastern slopes up to an altitude of 2,800 metres, and on the other grazing land, where the forest has been, and still is, cleared by slash and burn. Major parts of these pastures have already been abandoned again, as the farmers are unable to control the aggressive weed growth in the long term.

The findings of ten years' worth of research have been compiled in a volume of the Ecological Studies series. The new research programme has shifted the focus from the natural forest system to man-made "replacement" systems and human activity. On the basis of the knowledge that has been amassed over the past ten years, the researchers hope it will be possible to demonstrate services of the natural and the anthropogenic ecosystems. They are conducting long-term observations and setting up experiments to help achieve this goal. So far, studies on the pastures have focussed primarily on the impact of recurrent burning on the vegetation. But knowledge of the effects of frequent fires on soil properties and soil life, on the microclimate, on fungal and animal life is still missing. With the outcome of these studies, the researchers hope to quantify at least some of the ecosystem services and assess their sustainability. The different effects of both ecosystems on the region's water balance are already evident: The local hydroelectric power plant runs solely on water collected from the forested slopes.

Long-term observations also make it possible to address the question of regeneration of the original vegetation. The prospects for natural reforestation of the abandoned pastures are considered to be very low. The weed cover is too thick, and the natural

Farmers use fire in an attempt to keep pastures clear from weeds and to stimulate grass regrowth. Time and time again, the fire gets out of control.

forest is too far away. The hope that seedlings from the intact rainforest may become re-established on the abandoned land seems almost futile. Therefore, reforestation projects using indigenous and exotic trees have been underway for several years now. Yet even with foresters' assistance, the native pioneers establish much more slowly than the foreign Eucalyptus and pine trees. One reason for this, the researchers suspect, is that the mycorrhizal fungi in the soil, which these trees rely on, have been destroyed by the repeated burning of the pastures.

This example also shows how basic research merges with applied research. Only profound knowledge of the functional interdependencies within the ecosystems makes it possible to assess the opportunities for their sustainable exploitation, or to estimate

The Estación Científica San Francisco offers ideal conditions for research. Here, German scientists cooperate closely with local scientists.

the potential for the regeneration of a particular region's vegetation for the benefit of its local population. However, even if the endeavour to gradually re-establish the forests is successful, the new forest will have a much simpler structure than the natural mountain forest. The original species diversity is probably lost for good.

The Estación Científica San Francisco, in the middle of the area under investigation, which is managed by the "Naturaleza y Cultura Internacional" foundation, offers ideal conditions for research. Here, German scientists cooperate closely with local scientists.

Profile

Project name: Biodiversity and Sustainable Management of a Megadiverse Mountain Ecosystem in South Ecuador

Form of research funding: Research Unit, 27 subprojects

Prospective funding period: 2007–2013. Research going on since 1997

Study site: South Ecuador, tropical mountain rainforest and its anthropogenic replacement systems

Habitat: Forest, grassland and bushland

Participating disciplines: Geosciences: soil science, climatology, remote sensing, hydrology; biology: plant taxonomy, ecophysiology and population ecology, ethnobotany, entomology, mycology; soil biology, palaeontology: climate-, vegetation- and landscape history; forestry: forest management and reforestation; social economics: land-use systems

International collaboration: Four Ecuadorian universities, Municipality of Loja, Foundation "Naturaleza y Cultura Internacional" (San Diego and Loja)

Project features: Thorough knowledge and first description of the biological diversity of several groups of organisms. Unique project in tropical ecosystem analysis, with all subprojects working on the same core area. Two manifestations of the ecosystem – natural forest, pasture area – within a small distance. These preconditions will allow the assessment on the role of biodiversity for the stability of the ecosystem and the examination of biodiversity-related ecosystem services. Worldwide unequaled instrumentation and infrastructure in a tropical high mountain ecosystem, encompassing a well-equipped research station in the centre of the core area.

Website: www.tropicalmountainforest.org

The Dark Side of Chocolate

Stability of Rainforest Margins in Indonesia

STORMA

Sulawesi is but one example. In spite of all warnings and better knowledge, tropical rainforests continue to dwindle at an alarming rate and especially rapidly in Southeast Asia. Indonesia, for instance, has lost about 40 percent, or 64 million hectares, of its forests over the last 50 years. The resulting losses are inestimable – nature is becoming less diverse, the performance of ecosystems deteriorates, and as a consequence, people suffer economically. The causes for the progressive destruction of tropical forests are essentially well known: the poverty of rural populations, ineffective use of resources, and the ongoing conversion of forests into farm or grazing land, often only to be abandoned after a short time. But how can this fatal development be broken?

Critical for the protection of tropical forests are their margins and the stability of these margins, in an ecological as well as in a social and economic sense. Currently they are nowhere near stable. The only viable key to stabilising these zones is robust knowledge of the ecological and socioeconomic factors that influence land use and the way it changes. Once these factors, their synergies and interactions are known, a compromise between ecology and economy may be within reach. It may even become possible to develop an economy that will ultimately benefit both causes: protecting the environment and fighting poverty in the rural regions of the tropics.

With these goals in mind, scientists from many disciplines have come together at the margins of Lore Lindu National Park on the Indonesian island of

A wide roof in the middle of the forest allows researchers to explore the reactions of plants and the entire ecosystem to unusual drought periods, as they have been predicted for Southeast Asia due to climate change.

Sulawesi to form the DFG Collaborative Research Centre "Stability of Rainforest Margins in Indonesia" (STORMA). Agronomists and biologists, climatologists and computer scientists, economists and forestry specialists, geoscientists and hydrologists, legal experts, palaeontologists and soil scientists from the universities of Göttingen and Kassel have been collaborating here since the beginning of the millennium with partners from two Indonesian universities, to analyse the causes and consequences of deforestation and to explore avenues of sustainable economic development. During the third phase of this project, from 2006 to 2009, they focus mainly on two phenomena of global change that particularly affect the margins of tropical forests: the growing intensification of agriculture and the increasing frequency of dry spells caused by El Niño.

Modern research strategies

Intensive collaboration is one of the hallmarks of this Collaborative Research Centre. This concerns not only the interplay between disciplines but also the cooperation with local partners, which has produced a mutually beneficial Indonesian-German research network.

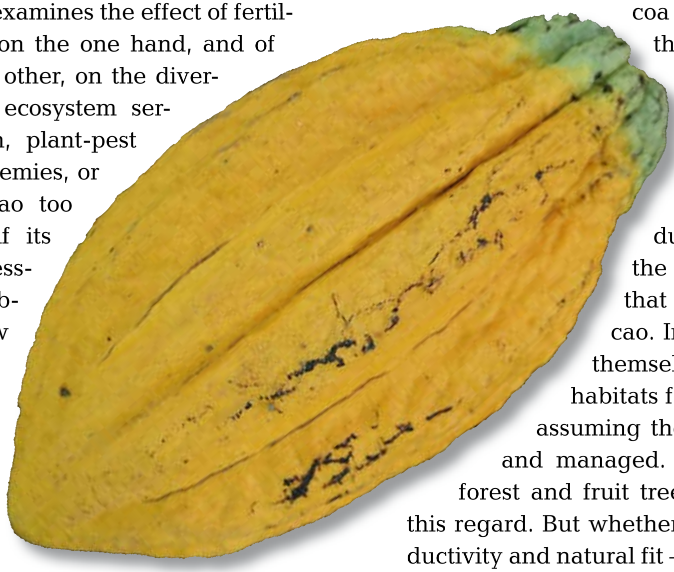
Another key feature of this Centre is its innovative approach to its topics. The researchers want to measure, model, and understand the processes that can help stabilise the margins of tropical forests. In the third phase of STORMA they explore three focus areas, each of which includes ecological as well as socioeconomic aspects. The first area is the development of integrated land-use models that allow realistic predictions of the effects of changes in climate and in land use, for individual households as well as entire landscapes. The second area is dedicated to the ecological and socioeconomic evaluation of agroforestry systems, which are often the last remaining forest type in tropical regions. The third area looks at the dangers that climate change brings for rainforests and agroforestry. For this investigation, the researchers have designed a desiccation experiment that allows them to anticipate the expected increase of droughts caused by El Niño and explore the consequences for various types of vegetation and land use.

How do the fine roots of rainforest trees, accustomed as they are to plentiful moisture, react to dryness? The answer is difficult to find, and yet crucial.

Understanding the role of species richness

Biodiversity issues feature prominently in all three focus areas. Incidence and interplay of species ultimately determine the functioning of ecosystems and of all the services they provide for the environment – from delivering food to mitigating floods and droughts, from purifying water and air to maintaining soil fertility and securing harvests that require blossoms to be pollinated and vermin to be eaten. Little is known about the significance of species richness for all these services. In some cases, so-called key species have been identified, which play an important role within a biotic community and cannot be replaced by others. In most ecosystems, however, several species take on similar functions. This redundancy has been interpreted as a failsafe for biotic communities against disturbances. A case in point: STORMA has been able to demonstrate that big coffee yields depend on a great richness in bee species, which can only be found wherever coffee is grown near a forest margin. The interplay of biodiversity and function is one of the major challenges facing biological research, also in terms of how ecosystems react to natural and human disturbances.

Five STORMA subprojects are currently investigating these issues. One of them looks at the distribution, diversity and composition of plant communities in dependence on environmental factors such as elevation and topography, soil and climate, as well as human land use. Another examines the effect of fertilisation and weed control on the one hand, and of increasing dryness on the other, on the diversity of insects and their ecosystem services, such as pollination, plant-pest control through natural enemies, or litter decomposition. Cacao too can only produce fruit if its blossoms have been successfully pollinated. A third subproject investigates how the fine roots of trees in undisturbed forests and agroforestry systems react to increasing dryness. Yet another subproject explores the significance of endophytic fungi living symptom-free in the leaves of cacao trees. Is the assumption correct that the number and diversity of endophytic fungi decrease as cultivation becomes more intense, and are therefore lower in monocultures than under the roof of pristine forests? And is it true that greater diversity in endophytic fungi makes cacao trees less vulnerable to diseases and pests, as well as droughts?



For example: cocoa

Today cocoa is the most important source of income in the region at the margins of Lore Lindu National Park. For almost twenty years, the area for cultivating cacao trees, which are native to the undergrowth of Middle and South American rainforests, has been rapidly expanding on the island. In fact, Indonesia is now the world's third-largest producer of cocoa, and four-fifths of this cocoa is harvested on Sulawesi. It is grown in areas that were previously used otherwise or in newly cleared forests, even within the limits of the national park.

But farmers typically do not operate in a very professional manner. They often have little knowledge or willingness to invest time and energy in cocoa production. A big portion of the potential crop is destroyed by pests and diseases, and yields are significantly lower than they could be with optimised cultivation. The hope is that higher productivity could put an end to the ongoing clearance of forests that keeps making way for cacao. In addition, cacao plantations themselves could provide suitable habitats for native plants and animals, assuming they were properly developed and managed. It appears that shading by forest and fruit trees is especially important in this regard. But whether both goals – increased productivity and natural fit – can be combined is an open question.

Researchers are approaching the answer from many sides. To thoroughly explore the numerous interactions between people and nature, social economists and natural scientists jointly examine the cocoa economy at the margins of the national park. They document the agricultural practices employed on 144 cacao plots in 12 villages. Using these data they want first to get a better understanding of farming households and their decision making. In a comprehensive experiment, scientists further want to investigate the effect of different forms of land-use management on species richness and ecosystem functions.

To do so, they compare, for instance, different types of fertilisation, shading, and weed control. This kind of research is unquestionably laborious. Every other week, blossoms and fruits, yields and infestations of selected sample trees are documented. Trees and herbs, fungi and insects, rats and lizards are recorded. Soil properties, treetop architectures, and incoming sunlight are scrutinised. Smaller experiments look at the relationships between different organisms. One of the findings: A common ant species is responsible both for keeping vermin away from cacao trees and for spreading the spores of cacao-pod rot.

Surprises and new questions

There are also other recent discoveries that show some of the structures and connections within ecosystems to be even more complex than previously thought. And there have been some surprises too. For example, Sulawesi was long considered an island with significantly lower biodiversity than other regions of Indonesia. New findings from the third phase of STORMA now indicate that this assumption may have been based on the fact that species had been recorded less diligently here than elsewhere. But now scientists have found a surprising variety of trees and even discovered some previously unknown species.

The correlation between biodiversity and land-use intensity also turned out to be less than clear-cut. Diversity analysis of four plant groups and eight animal groups, along a gradient ranging from pristine rainforest to three cacao plantations of varying intensity, resulted in a differentiated picture without a consistent trend. Included in the investigation were trees, lianas, ground herbs, and epiphytic liverworts, as well as birds and butterflies, ants and beetles of the lower crown level, dung beetles, bees and wasps, along with their parasites. Only in four of the twelve groups – trees, lianas, liverworts, and dung beetles – was higher land-use intensity correlated with fewer species. Conversely, herbs and beetles became more diverse, ants showed no reaction at all, and the other groups were richest in species when land-use intensity was medium.

Growing cacao has become a major source of income at the margins of the national park. Developing sustainable forms of land-use management is one of the scientists' goals.

The drought experiment has also produced its initial findings. Trees apparently react to dry soil with varying degrees of sensitivity, depending on the density of the wood. Assuming this tendency holds, scientists conclude that the changing climate, with its expected increase of El Niño droughts, is likely to alter significantly the composition of species even in pristine rainforests and may lead to the extinction of some species.

Trees and lianas are vulnerable to human interference, while other groups of organisms may actually become more diverse.

Ultimately, these studies should allow economic costs and benefits as well as ecological pros and cons of the various methods of agriculture and food production used at the edge of the rain forest to be compared with one another in order to derive recommendations for a better future – for the benefit of humanity and of nature.

Profile

Project name: Stability of Rainforest Margins in Indonesia (STORMA)

Form of research funding: Collaborative Research Centre, 17 subprojects

Prospective funding period: 2000–2009

Study site: Sulawesi, Indonesia

Habitat: Forest, agroforest (Lore Lindu National Park)

Participating disciplines: Agricultural sciences, biology, forest sciences and forest ecology, geoscience and geography, computer science, law, economics

International collaboration: Institut Pertanian Bogor (Bogor, Java) and Universitas Tadulako (Palu, Sulawesi)

Project features: Aims at capacity building both at regional (Sulawesi) and national levels (Indonesia) in the fields of scientific environmental assessment and conflict analysis, based on ecological and socioeconomic research. STORMA has established standards with respect to scientific cooperation between northern and tropical countries in this field based on mutual benefit sharing. STORMA is also unique in tropical environmental research because socioeconomic and ecological groups and approaches are tightly linked, thereby overcoming the usual separation of different research efforts. Further, STORMA addresses three innovative and topical foci, the threats to rainforest and agroforestry by climate change, the socioeconomic and ecological trade-offs and synergies of agroforestry management, and scenario testing with integrated land-use models.

Website: www.uni-goettingen.de/de/sh/40515.html

Diversity in the Cultural Landscape

Exploratories for Functional Biodiversity Research

Three areas stand for the whole of Germany. Three representative regions, one in the northeast, one in central Germany and one in the southwest, all linked by a long-term study of biodiversity and the ecosystem involving observation and experimentation that is the first of its kind. This is why they have been called exploratories. The intention is to use these exploratories to overcome the limits of existing research strategies. On the one hand, they aim to design clearly focussed experiments on the basis of the observation of natural systems, and on the other hand, they hope to use the findings of experiments involving the manipulation of individual factors in artificial systems to draw reliable conclusions about entire landscapes.

What effect does biodiversity have on ecosystems? And how does it change under the influence of mankind and land use? These are the two fundamental questions behind this research work – and they also form the link from basic research to application, and even to social and political topics. After all, humanity, with all its doings, remains part of the ecosystems that it influences and uses.

Collecting pollen helps researchers understand the relationship between plants and pollinating insects.

There is hardly anywhere left in Central Europe that mankind has not had an impact on over the past centuries by cultivating or working the land. This initially led to increased diversity in the landscape. Forests covering large expanses had to give way to the now characteristic alternating pattern of fields, meadows and woods that typify the charm of agricultural landscapes. The great complexity and rich variety at the macroscopic level of the landscape is also reflected at the microscopic level. Diverse habitats came into being and were colonised by a wide variety of communities of fauna, flora, fungi and microorganisms.

So far so good, in theory. It should also be added that any beneficial effect which mankind once had, has since been reversed and undone. With new methods of mechanised cultivation designed for maximum efficiency, modern forms of land use leave little room for many organisms. The species richness is falling rapidly. It should also be added that, although this appears plausible, it is very hard to actually verify in reality. Although the relationship between land use and biodiversity has been studied in great detail for some groups of organisms, it remains unknown for many others. Over and above this, the functional significance of biodiversity for natural systems remains unclear, as various management strategies mask the effects. By both monitoring and measuring the functional diversity in carefully controlled experiments, this study aims to help clarify the interactions between changes in land use, genetic diversity, species diversity, the diversity of biological interactions and the services of ecosystems within natural landscapes.

The regions selected

Three different landscapes with a variety of woodland and grassland use were selected for the study. The furthest north is the biosphere reserve Schorfheide-Chorin in Brandenburg. Sandy soil as well as ground and end moraine define the landscape in this part of Germany that was formed by the ice age, providing the basis for a great diversity of vegetation with the variety of soils they offer. Large birds such as cranes, the white-tailed eagle and black storks are among the most impressive creatures which inhabit the Schorfheide. The areas to be studied in the exploratory focus on the eastern part of the biosphere reserve.

In Thuringia, almost exactly in the middle of Germany, lies Hainich, one of the largest coherent deciduous forests in Germany, covering some 16,000 hectares. Part of this forest was declared a National Park in 1997. It has a remarkable variety of tree species as well as large stands of beech and mixed forest, ranging from virgin forest to forest types with non-regular felling, and areas that are used for intensive forestry. The surrounding fields, which are included in the exploratory, are also cultivated to varying degrees.

Finally, there is the designated biosphere area Schwäbische Alb, in the state of Baden-Württemberg, which covers more than 80,000 hectares in southwestern Germany. Large expanses of grassland, which have been used as pasture for grazing sheep for centuries, cover the chalky soil over large ranges of hills, interspersed by small woods, large forests and more intensively farmed fields and meadows. The majority of the area covered by the exploratory is also in this mosaic of forest and grassland.

The design of the study plots

All three exploratories share a broad spectrum of forms of land use, both of the forests and the grassland. This makes it possible to study both types of vegetation at every level, from near-natural to intensively used areas, and thus to study gradients of land-use intensity. In order to have a reliable basis to work with, the number of study plots selected for the study was generous, with 1,000 in each exploratory,

Catching invertebrates can take some preparation and effort.

500 each of forest and of grassland. For these areas, the type and intensity of land use, the number of species and the total vegetation cover as well as various soil parameters are being recorded by the study. The diversity of vertebrates will also be recorded.

Of these study plots, 100 so-called experimental plots in each exploratory – 50 in the forest and 50 on grassland – will be selected to represent a gradient of land-use intensity. Equipped with instruments for measuring soil and air temperature as well as soil humidity, these plots will be used for long-term observation and experiments. Six weather stations in each exploratory will be used to measure wind and precipitation.

In the near future there are plans to study the soil in greater depth in order to assess the variability of carbon levels in the soil and to provide material for soil ecology studies. The forest subproject will study the structure and diversity of the forests, the biomass reserves and the development of the forests in relation to land-use intensity. Seed sowing and fencing experiments are also planned by this subproject. The botanists will not only study the species diversity, but also the functional and genetic diversity of the plants. Seed sowing and invasive experiments will shed light on how well the different species can assert themselves and also how well communities are able to regenerate.

The studies of vertebrates concentrate on their habitat requirements along the land-use gradients and on interactions between the different species. For example, there are plans to exclude birds and bats from the treetops using nets to assess their effect on insects and other arthropods in the crowns of trees and on their seeds. Since invertebrates play a significant role in many interactions – for example for the pollination or as predators or prey in the food chain – there will also be a great deal of diversity in the experiments conducted.

Long-term perspectives

One of the characteristics of the study is that all of the data will be saved in a single central database, so that it is available to scientists, public authorities and any institutions that are interested long term. By linking the data within the project and integrating information from existing databases, complex and interdisciplinary analysis of the data will be possible. In addition to this, the land owners and users will be interviewed about the current forms of management employed and the historical forms of land use will be investigated, too.

The exploratories will thus create a unique infrastructure for long-term interdisciplinary study of functional biodiversity and ecosystem research of grassland and forests. Scientists from various disciplines will collect data in the same areas, allowing the complex relationships and feedback mechanisms between biodiversity, land use and ecosystem processes to be analysed. The combination of observations and experiments will, for the first time, enable functional biodiversity research to be performed at a variety of spatial levels in real landscapes. Over the coming years more projects will be added, to study species and ecosystem functions that have not previously been investigated. The exploratories will thus serve as a platform to stimulate German biodiversity research as a whole – indeed, it is hoped that they will even be emulated in other European countries, allowing a broad network of fertile hotbeds of research to be established. ◂

Profile

Project name: Exploratories for Functional Biodiversity Research

Form of research funding: Infrastructure Priority Programme, 1 core project and currently 29 individual projects

Prospective funding period: 2006–2011

Study site: Three exploratories in Germany: Biosphere Reserve Schorfheide-Chorin; Hainich National Park and the surrounding area; and the designated Biosphere Reserve Schwäbische Alb

Habitat: Forest and grassland

Participating disciplines: Botany, zoology, ecology, microbiology, soil science, meteorology, modeling, remote sensing, computer science

Project features: Open project, in which the exploratories will become established as research platforms for biodiversity and ecosystem research in Germany. The frequent addition of new projects will lead to a continuous integration of new avenues of research and new approaches. The project studies landscapes in Germany, conducting research while the land is in use, involving close cooperation with the land owners and land users (no land will be rented/leased for the study). Data is collected in a central database for long-term data storage and intense exchange of information.

Website: www.biodiversity-exploratories.de

Experimental Design by Nature

The Role of Biodiversity for Biogeochemical Cycles and Biotic Interactions in Temperate Deciduous Forests

The Hainich region is a stroke of luck for science. Here in western Thuringia lies one of the largest coherent deciduous forests in the country, covering some 16,000 hectares. This forest grows on rich soil composed of limestone covered by loess. It is a forest with a rich structural variety, due in part to the various ways in which it has been cultivated over the centuries. There is "Plenterwald" (selection forestry), and even-aged forest, former "Bauernwald" (which is used by farmers) and even patches of natural forest that are completely unmanaged, which were declared a National Park in 1997. European beech, which dominates so many parts of Germany, is often just one tree species among many, which primarily include small-leaved lime, large-leaved lime and European ash. Sycamore maple, Norway maple, hornbeam and common oak are also found frequently. Field maple, sessile oak, wych elm, wild cherry, field elm, aspen, service tree and silver birch contribute as well to tree species diversity in these forests. It is thus the ideal place for anyone wishing to study the relationship between biodiversity and the function of forest ecosystems.

The researchers use a cross window trap to study the species diversity of insects and spiders.

In general the number of tree species in any Central European forest is fairly low. They are not only species-poor in comparison to the tropics, but even in comparison to other forests in similar climate regions around the globe. The reason for this lies in the past and, for once, is not due to mankind's intervention. It was in fact the ice ages that displaced many of the species that were previously native to Central Europe, as has been revealed by pollen analyses. Cultivation by mankind, which created a varied cultural landscape, initially brought about a considerable increase in species diversity. This trend was reversed some time ago, however, and the biodiversity of every habitat in Central Europe has fallen significantly, and continues to fall.

Forests are considered to be particularly important ecosystems in terms of the role they play in the environment, yet at the same time they are difficult to study. This is especially due to the long time they take to develop, which makes it quite impossible to conduct manipulative experiments. This is why, in contrast to grassland ecosystems, there has been very little research so far into the interrelationships between species diversity on the one hand and plant growth and water and nutrient metabolism on the other. However, forests are precisely where such knowledge is urgently needed, since forestry in Central Europe is currently seeing a switch from large pure stands to mixed stands, thus creating a "fait accompli" for the coming centuries. One reason behind this is to protect the species diversity of indigenous forests for the future, and support the role they play in water and nutrient cycles. If, and to what extent, species-rich or species-poor forests actually differ in

Using 3D scans such as this one, the researchers can create three-dimensional maps of the forests, showing structural information that provides the basis for combined quantitative analysis of data in ecosystem models.

terms of the mesh of interactions between fauna and flora as well as water and nutrient cycles is not sufficiently understood at present.

Young researchers participating in a DFG Research Training Group in the Hainich forest are addressing seven fundamental questions to find out more about the relevance of tree species diversity for ecosystem function in mixed deciduous forests: Is higher tree species diversity accompanied by higher diversity of other organisms? Does higher tree species diversity result in increased production of plant biomass? Is it simply the number of tree species, or the specific properties of individual species, that dictate carbon fixation, water consumption and groundwater recharge? Can a forest with a large number of species exploit soil nutrients better than a forest with less species, and thus reduce the leaching of nutrients by seepage? Are the metabolism of energy, water and nutrients and the production of biomass more heterogenous in stands with higher tree species diversity? Is nutrient turnover in species-rich stands less sensitive to disturbance and abiotic stress such as extreme weather conditions? Are forests with a higher tree species diversity less susceptible to harmful insects?

It is impossible to study the characteristics of "real forests", of old stands that have grown over the course of centuries, in an artificially created system within a short period of time. After all, the conditions that govern the forest's present day functions have arisen gradually over a prolonged period, by means of growth, changes in species composition, accumulation of substances, and other processes that cannot be simulated in a few years. In the Hainich region, however, much to the delight of the scientists, there are forests that naturally present many of the conditions that would need to be created artificially in order to conduct experiments. The selected forest area for the study has not been managed for the past 40 years and features an unusually high level of diversity for Central Europe, with as many as 14 tree species per hectare. Nevertheless, the stands' tree species diversity ranges – in a homogeneous environment – from pure stands to high diversity stands on a smaller spatial scale. This provides the researchers with the opportunity to find forest stands that are analogous to an experimentally created system, that vary primarily in terms of their diversity of tree species, while keeping all other factors that depend on the location constant. This allows them to study the effect of diversity by comparing various ecosystem functions in twelve different plots, which are classified according to three levels of diversity. As many of the variables will vary significantly from year to year, the most important variables will be measured for a period of nine years. In addition to this, a project on environmental economics will attempt to measure the economic value of ecosystem services by forests with high tree species diversity.

So far, the first general trends are already becoming apparent. For instance, it has been found that the biomass of the herb layer and the diversity of insects, crustaceans and spiders increase with increasing diversity of tree species. As well as this, beech litter decomposition, which is usually very slow, is accelerated and nitrogen is mineralised faster, meaning it is available to plants sooner. The production of the fine roots increases, as does the base saturation of the topsoil. In species-rich forests, being as dense as pure stands of beech, both throughfall and transpiration are higher than in beech forest. The damage to young beech trees due to foraging is lower, as is the lignin content of beech wood and the level of activity of spiders.

The factors that gave rise to these results and the consequences for performance of the forests will be the topic of further study by the researchers, who will combine these new measurements with existing knowledge. Quantitative analyses using ecosystem models will be used as well as georeferenced collection of the measurements in a database. It will also serve another main objective of the Research Training Group, which is to train postgraduates in modern ecological techniques. To avoid endangering the near-natural stands, methods will be used that are as non-invasive as possible, for example by means of forest crown research, which is done at a height of 30 metres using elevating platform trucks, as well as isotope marking, gene sequencing of fungi, sap flow measurement of trees, or automated 3D measurement of stand structure. However, traditional methods of biodiversity research are also taught by the Research Training Group, for instance, techniques for determining animal and plant species and their biomass. And this programme will also promote international cooperation, in particular with the Finnish Graduate School in Forest Sciences. These young researchers will join forces across borders to uncover the basic principles that will enable us to create the best possible forests of the future.

Profile

Project name: The Role of Biodiversity for Biogeochemical Cycles and Biotic Interactions in Temperate Deciduous Forests

Form of research funding: International Research Training Group (training doctoral researchers in Germany and Finland), 14 subprojects

Prospective funding period: 2005–2014

Study site: Hainich National Park

Habitat: Forest

Participating disciplines: Plant ecology, forest hydrology, entomology, forest biometry, soil science, mycorrhizal research, animal ecology, biogeochemistry, environmental economics, ecological modeling

International collaboration: Finnish Graduate School in Forest Sciences

Project features: The Research Training Group is a training establishment involved in international cooperation. It studies biodiversity effects in old, near-natural forests that differ only in terms of their tree species diversity. The benefits of interdisciplinarity are ensured by conducting spatially coordinated sampling in the same plots.

Website: www.forest-diversity.uni-goettingen.de

The Jena Experiment

The Role of Biodiversity for Element Cycling and Trophic Interactions: An Experimental Approach in a Grassland Community

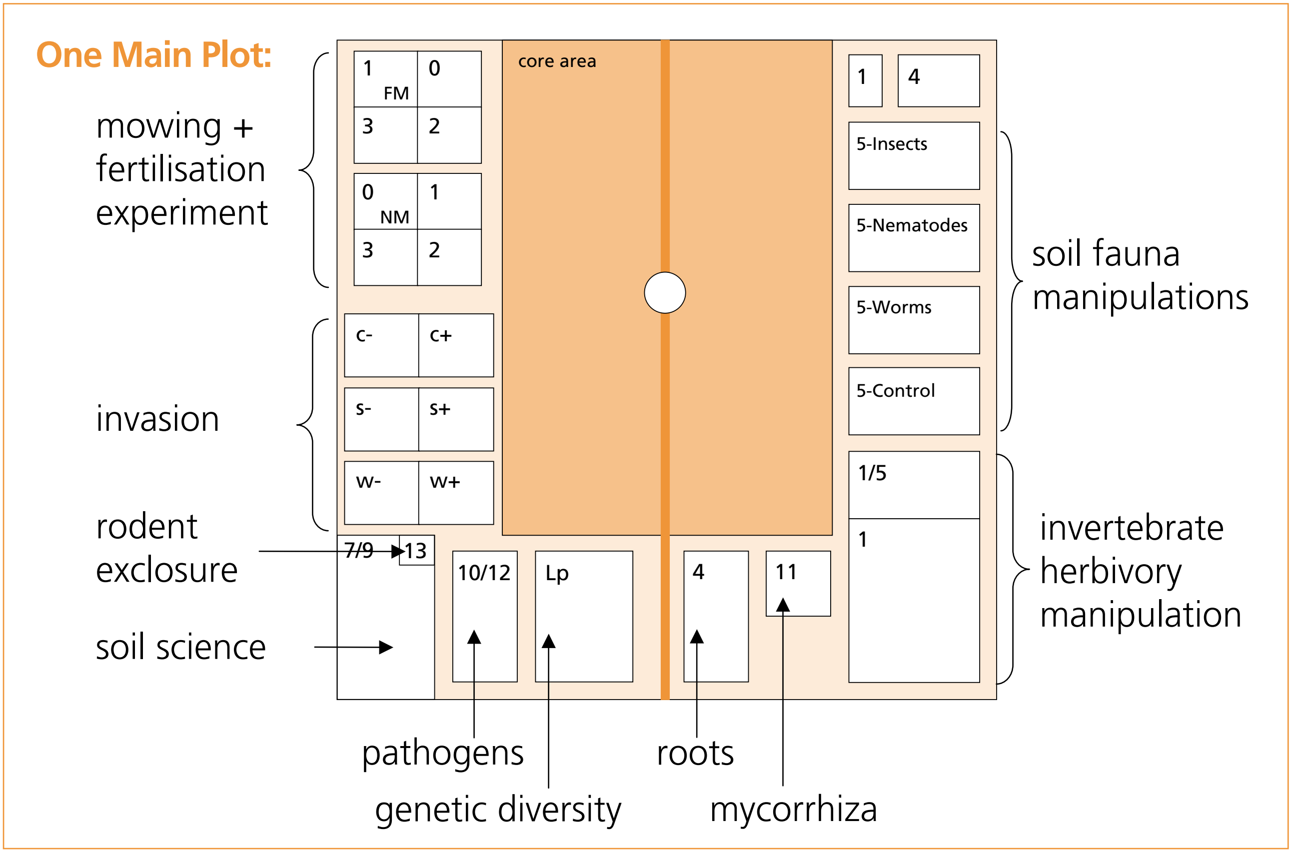
They chose a meadow – a very common type of vegetation in Central Europe, with moderate human intervention through biannual mowing, clear seasonal changes but a stable flora, a manageable number of species yet enough complexity to study the intricate nature of interactions in natural ecosystems. Here, in the Saaleaue near the city of Jena, Thuringia, the world's largest research experiment in grassland biodiversity has been underway since 2002. It is a project of superlatives: not only the largest, but also one of the two longest running experiments of its kind, as well as the most comprehensive and thorough one. A total of 480 experimental plots have been set up to measure over 300 parameters. The undertaking involves twelve scientific institutions and several generations of doctoral researchers. Together they investigate how plant diversity influences all kinds of ecosystem processes – from productivity to insect occurrence, from carbon storage to groundwater quality.

Biodiversity from above – even from a distance it is apparent that very different grassland plots have developed during the experiment in the valley of the Saale River. They are maintained through biannual weeding and mowing.

From a bird's-eye view, the site looks like a motley chessboard. Each of the 90 large experimental plots measures 20 by 20 metres – an unusually large area for this type of experiment. In addition there are 390 smaller plots of 3.5 by 3.5 metres with monocultures of the various species, additional experiments, and control areas to verify all findings. The scientists have seeded 60 common plant species here in various mixtures, allowing them to investigate the intensely debated question whether ecosystem functions are based on individual species, functional types, or diversity per se. To this end, the plants have been categorised into four functional groups: grasses, small herbs, tall herbs, and legumes.

The number of species and the number of functional groups were varied as independently from each other as possible, thus setting this long-term experiment apart from previous undertakings of its kind. Over 20 sub-experiments are conducted on each plot – a unique approach that is only viable due to the generous size of these areas. The Jena Experiment is also distinct for examining, on the basis of plant diversity, element cycles within ecosystems as well as interactions between species, both at the plant level and between plants and other parts of the food chain, such as herbivores, carnivores, and decomposers.

There is little existing research into these relationships. Plant diversity is only one component of ecosystem diversity, albeit one that happens to be prominent and relatively easy to examine. But studies of other, equally diverse groups of organisms, let alone of interactions within and between them, are scarce – even though the interplay between plants and their pollinators, herbivores and their natural enemies, microorganisms and decomposers is crucial for the functioning of the plant community and of any ecosystem as a whole. Against this backdrop, the DFG Research Unit conducting the Jena Experiment looks at fundamental questions of biodiversity research, such as: Does the number of species



The large plots of the Jena Experiment cover an area of 400 m², in squares of 20 m x 20 m. Along the sides of the plots there are 5 m strips with various secondary experiments that surround the untouchable core, which is 10 m x 15 m in size.

itself influence the processes within an ecosystem? What is the role of the number and composition of the functional groups for the performance of an ecosystem, regardless of the number of species involved? Are there particular key species with a disproportionately large impact? Does the relationship between plant diversity and ecosystem functioning also depend on the diversity of other groups of organisms?

Building on existing knowledge as well as experiences with previous biodiversity studies, the Jena Experiment was designed to mix in various ways the diversity of the plants and of their functional groups in its model ecosystem, grassland. Through pure observation in the core areas of the large plots, as well as through a variety of, sometimes manipulative, interventions at the margins designated for this purpose, scientists from different disciplines work together to investigate the influence of plant diversity on various ecosystem processes. This may involve applying fertilisers or insecticides, foregoing the pulling of weeds, or purposely excluding or even increasing herbivores or soil fauna, in the outer areas of the plots. Researchers examine the impact of diversity on the carbon and nitrogen cycle, and look for the key components in these processes. They also try to identify the factors that determine the stability of plant communities and overall ecosystems. These functional aspects of biodiversity are also and especially relevant for humans, closely connected as they are to ecosystem functions such as productivity, carbon storage, water purification, and erosion prevention.

Findings and trends

Many of the findings obtained so far allow new insights into functional relationships of the ecosystem. In other areas, scientists confirmed what they had previously hypothesised but were unable to prove. A case in point is system stability, defined as resistance to outside invaders. The greater the number of species in a model meadow, the harder it is for invaders to get a foothold there. The findings so far suggest that a potential invader's functional group is irrelevant. However, the composition of the resident plant community (assuming the same number of species) does matter: Grasses significantly increase resistance to invaders, while legumes lower it. It appears that newcomers too benefit from the ability of legumes to fix nitrogen. This example shows that a feature such as a plant community's stability or invasion resistance depends not only on the variety in species but also on functional group composition.

Other measures, such as the productivity of the grassland plots, likewise present a differentiated picture. Here too it holds true that greater species richness translates into greater aboveground productivity, both on fertilised and unfertilised soil. Belowground productivity likewise depends on biodiversity. Here scientists look especially at root properties that influence humus content or nutrient leaching from the soil, such as the rooting depth, biomass, or mortality rate of roots. For this purpose they collect soil samples, rinse out the roots they contain, and measure them with a scanner. Alternatively, researchers also observe root growth alongside transparent plastic tubes inserted into the soil, using an endoscope. It turns out that grasses in particular increase root growth, whereas nitrogen fixation in legumes appears to require fewer roots for nutrient absorption, thus enabling the plants to invest more in aboveground biomass.

As the scientists expected, the basic principle holds true for fauna as well: More plant diversity also means more animal diversity, for example when it comes to insects, the most species-rich group of terrestrial animals. In the grassland, as

Pollinating insects play an important role within the ecosystem. The greater the number of plant species, the more diverse they are as well.

elsewhere, insect species by far outnumber higher plant species – yet little is known about their influence on productivity, on plant community composition, or on element cycles. That is why Jena scientists investigate how insects and other invertebrates, such as spiders and snails, influence the processes on the grassland plots, and how the number and variety of insects depend on plant diversity. It has become clear that the insect community establishes itself relatively quickly. Two years after the plots were planted, a large number of species could already be found there – and even on the smaller plots, the variety and number of insects depend directly on plant diversity.

The picture that emerges for other groups of organisms is more complicated. For example, when more species of plants are present, earthworms become more frequent and numerous, yet the number of earthworm species does not increase. Ants show no reaction to greater plant diversity, nor do the numbers of springtails, mites, and roundworms in the soil. Conversely, plant lice actually have a harder time because the number of their natural enemies increases. The experiments also show that the influence of plant-eating insects on the harvest of hay is less significant than previously assumed. While individual plants may lose up to one-tenth of their biomass, their plant communities compensate for it.

Different functional groups also have an effect on the fauna. Legumes, for instance, increase the incidence of earthworms, ants, centipedes, millipedes, and roundworms. In addition, the activity of plant-eating insects rises. Conversely, under the influence of grasses, earthworms and millipedes become less frequent, whereas the lifespan of grasshoppers increases.

In addition to food chains, scientists also look at the fluxes of carbon, nitrogen, phosphorus, and water within the ecosystems. However, because soil as a storage medium is very slow to react, these effects can only be measured with some delay. But six years into the experiment it becomes clear that greater bio-

Even under optimum conditions, field research is not always comfortable. Analysing biodiversity requires diligence and a trained eye.

diversity is related to increased carbon and nitrogen storage in the soil. This connection, which for the first time has been demonstrated beyond doubt by the Jena Experiment, is quite relevant in terms of climate protection and the political debate surrounding the Kyoto Protocol, because grassland covers a substantial portion of the Earth's landmass. If it were possible to transform it into a carbon sink, this could have a significant impact on the global carbon balance.

Greater grassland biodiversity brings yet another benefit. It significantly increases the filter capacity of the soil, thus allowing less nitrate – which is toxic to humans – to enter the soil water, as well as retaining more phosphate and organic nitrogen. The explanation is plausible: Diverse grassland uses more of the available nutrients. Creating a comprehensive model for all of these fluxes is one of the research group's ambitious goals.

In keeping with the scientists' expectations, the findings demonstrate the powerful impact that the

Grassland productivity depends significantly on the diversity of both species and functional groups.

functional group of legumes has on the nitrogen level of the soil. By absorbing atmospheric nitrogen, soils underneath species mixtures that include legumes contain significantly more nitrogen than those in plots without legumes. An increased number of species causes lower nitrate concentration in the soil particularly in the second vegetation period. One important practical conclusion can already be drawn: Biodiversity is especially important for grasslands with legumes, which exhibit high productivity and are thus economically lucrative.

Even answers to the fundamental questions of biodiversity research are slowly beginning to emerge. It appears that, at least for grassland productivity, the number of species and the number and type of functional groups are significant. Especially important – and proven for the first time by the Jena Experiment – is the fact that even within each functional group the number of species is significant. Species richness, at least under this aspect, is therefore not redundant. Whether this holds true for other functional relationships as well remains to be seen as further findings emerge in the coming years.

Profile

Project name: The Role of Biodiversity for Element Cycling and Trophic Interactions: An Experimental Approach in a Grassland Community (The Jena Experiment)

Form of research funding: Research Unit, 9 subprojects

Prospective funding period: 2002–2010

Study site: Saaleaue Jena, Thuringia, Germany

Habitat: Grassland

Participating disciplines: Soil science, botany, geology, genetics, hydrology, mathematics, ecology, zoology

International collaboration: ETH Zurich, Switzerland; University of Zurich, Switzerland; INRA Clermont-Ferrand, France

Project features: Allocation of species to functional groups combined with an orthogonal design enables the separation of the influence of functional diversity from the influence of the number of species. Simultaneous measurements concerning single plants, plant community, soil, soil water, and interactions with and within other trophic levels (microorganisms, invertebrates, and small mammals) enable the assemblage of species interaction networks and quantification of the effects of manipulated diversity on ecosystem pools and fluxes, i.e. water, carbon, and nitrogen.

Website: www.the-jena-experiment.de

Forests for Science

The Role of Tree and Shrub Diversity for Production, Erosion Control, Element Cycling, and Species Conservation in Chinese Subtropical Forest Ecosystems

They stand in line, neatly arranged and awaiting their future destination. Seedlings of 100 different species of woody plants, 50 species each of trees and shrubs, 50 species each of evergreens and deciduous plants. Thousands upon thousands of them will soon be planted on a 100-hectare plot, according to a carefully devised plan, as part of a vast experiment. Because of the scale and numbers involved, China seems like the perfect place for it. There is another, scientific reason, though. Southern China, on the boundary between the subtropical and the temperate climate zones, is one of the most important biodiversity hotspots in the northern hemisphere. Plant families, in which evolution has produced trees or shrubs, have been particularly successful at developing a unique species diversity here, greater than anywhere else in the Holarctic realm. This is why it is here that European and Chinese researchers want to study a question that is of increasing importance in the light of global climate change: How does biodiversity in forests contribute to the stability and the services of ecosystems – and how can it be promoted and used?

This experiment is novel, and in some ways unique. Although forests probably play the most important role in our environment, for instance with respect to the carbon, nutrient and water cycle, they are less convenient for experimental study due to the long time needed to reach maturity and their complexity. This is why, to date, experimental studies investigating the relationship between biodiversity and ecosystem functioning have generally been restricted to vegetation composed of herbs and grasses. Only recently a number of experiments have been established with forests, notably in Finland, Germany, Panama and Borneo, and thus in the boreal, temperate and tropical zones. The experiment in China will be the first in the species-rich subtropics. It builds on experiences gained in various other projects – but will go considerably further than these previous studies.

And this not only refers to the unusual diversity of species involved. For the first time, this experiment will simultaneously vary the number of species in two different functional groups: trees and shrubs. Within these two groups, the experiment will also include functional subgroups such as the evergreens and deciduous plants. Already, at this early stage, the plots are being designed in such a way as to allow future manipulation of further groups of organisms, for instance herb species, fungi, herbivores, predators and decomposers, as the experiment proceeds. Additionally, the study will include a comparison of natural forests, monocultures and plantations of commercially relevant species. Finally, the study will, for the first time, look at how forest biodiversity affects the prevention of soil erosion, as one of the key ecosystem services in this region.

It is precisely this, the loss of valuable soil by erosion, that is becoming an increasingly urgent problem

The immensely species-rich near-natural forests in the subtropics will serve as a basis for comparison.

in the subtropics, where intense rain events are frequent. This is especially the case in China, where the rapid pace of economic development in recent years has not only led to a rapid drop in the number of species, but has also entailed numerous other problems such as serious atmospheric pollution, severe damage due to erosion, and substantial loss of fertile soil. The extreme amounts of sediment carried by the rivers bear witness to this issue. The measures intended to put a stop to this calamitous development include large-scale afforestation projects, which have also created the opportunity to conduct an experiment such as this one. Eighteen European researchers from Germany and Switzerland are participating in the project, including ecologists, forest scientists, and soil scientists, who will contribute a wealth of expertise in a wide variety of fields, ranging from taxonomy to statistics, and from botany to geographical information systems. They will be cooperating with a group of Chinese scientists with complementary areas of expertise, from the Institute of Botany at the Chinese Academy of Sciences and the College of Environmental Sciences at Peking University.

Step by step, the researchers will attempt to untangle the relationships between biodiversity and forest functioning, and thus measure variables such as productivity, carbon sequestration, nitrogen cycling, and protection against soil erosion, soil formation and community stability. They have split the entire species pool for the experiment into three sections, each consisting of 16 tree species and 16 shrub species. From each of these three sets of species, they will then create six different levels of species diversity in the tree layer – with zero, one, two, four, eight or sixteen different tree species – each level repeated several times and combined with four different levels of species diversity in the shrub layer. In addition to this, there will also be areas planted with three tree species that are frequently used in monocultures for commercial purpose, as well as monocultures of each of the individual species in the project, and finally areas that are left to natural succession. All in all, more than 300 plots will

To the European observer these forests are unusually diverse – cauliflory is one example of the wealth of phenomena in tropical and subtropical forests.

be established in the entire experiment. Natural forests and existing secondary forests of varying age will be used as a control.

From this complex experimental approach, the researchers hope to gain fundamental insights into the relationship between biodiversity and ecosystem processes in a climate zone that has, so far, not been studied in depth and yet constitutes a significant part of the biosphere. One of their hypotheses is that the biodiversity in the tree layer of subtropical forests is governed by other groups of organisms such as herbivores and pathogens, while the ecological niches of the tree species often show an extensive overlap. The design of this experiment, which will also be applied to soil properties and physical variables, as well as to the interactions between organisms above and below ground, will also allow to test such fundamental hypotheses.

At the same time, this work also has a multitude of practical aspects related to the appraised value these ecosystems have for humans. For example, there is the question of whether species-rich forests provide

What impact does a species-rich tree layer have on the diversity of other organisms? Just one of the questions which this experiment will seek to answer.

better protection against erosion than less diverse forests or monocultures. Then there is also the question of whether forests with a higher level of biodiversity are more stable, because they are able to react to changes in environmental conditions more flexibly and are more resistant to physical stress – for instance prolonged periods of drought – or biological stress – such as outbreaks of pests. The project also studies whether increased productivity due to greater species diversity actually leads to increased carbon sequestration, and thus mitigates global warming. And lastly, there is the question of the contribution of species diversity at the level of the primary producers to maintaining biodiversity at other trophic levels.

Of course, the researchers hope to find answers to these questions within the foreseeable future, but some will be impossible to answer in only a few years. The large-scale China experiment is a far-sighted project that is set to last well into the future. On the one hand, it offers outstanding opportunities for training the next generation of researchers and for cooperation across the continents, and on the other hand, some of the results may only become evident to our grandchildren or great grandchildren – in just the same way as German forestry continues to benefit from the experiments in forestry conducted in the 19th century, when the so-called long-term monitoring plots were planted.

Profile

Project name: The Role of Tree and Shrub Diversity for Production, Erosion Control, Element Cycling, and Species Conservation in Chinese Subtropical Forest Ecosystems

Form of research funding: Research Unit, 10 subprojects

Prospective funding period: 2008–2014

Study site: Subtropical China

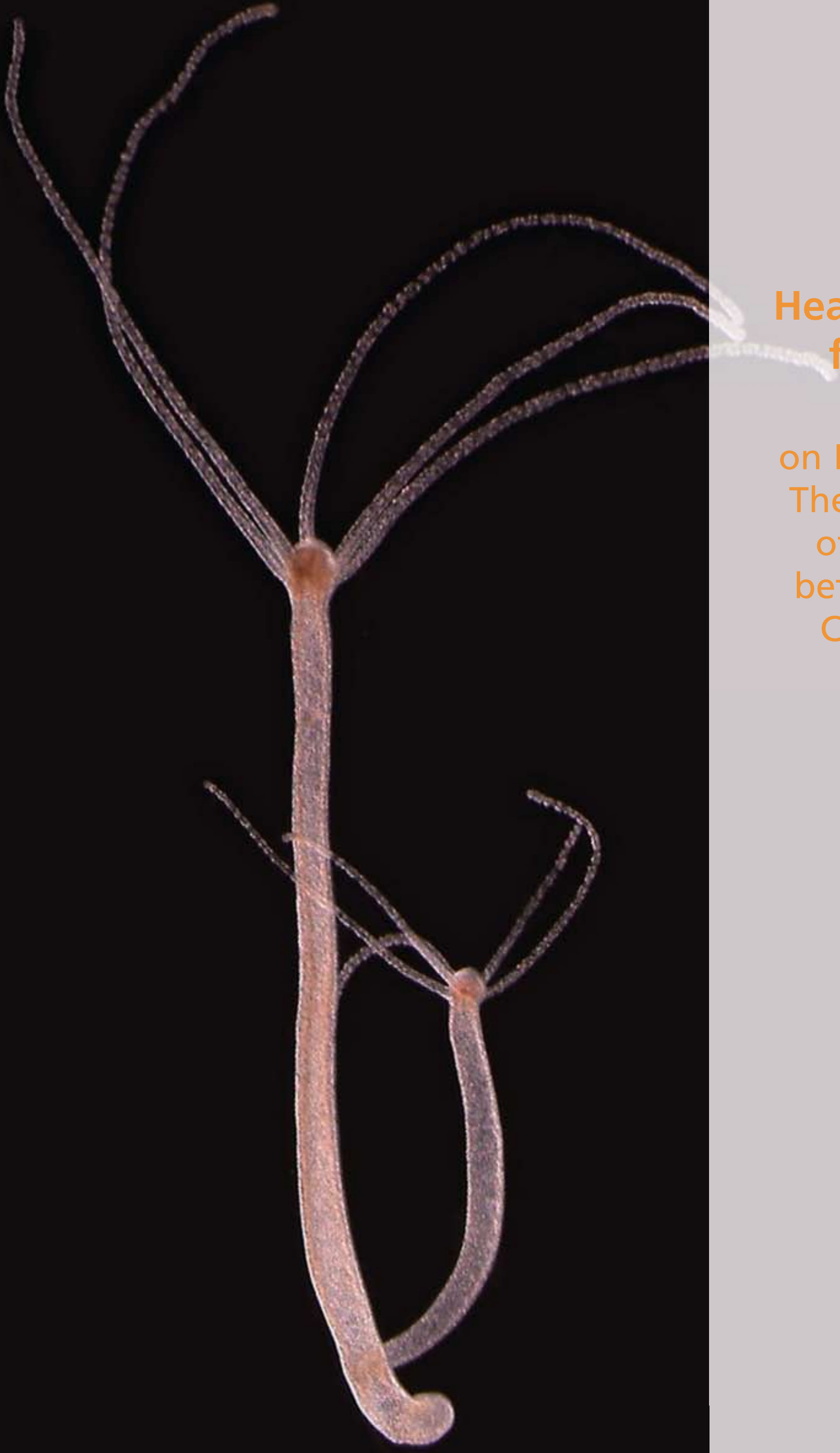
Habitat: Forest

Participating disciplines: Ecology, botany, environmental sciences, population genetics, forestry, mycology, soil science, statistics

International collaboration: Trilateral German-Swiss-Chinese cooperation project with complementary, Sino-European matches of subprojects

Project features: An experimental compilation of different levels of diversity in the tree and shrub layer of the forest, using a large pool of woody plant species. Biodiversity is looked at as a predictor for ecosystem functions, such as ecosystem stability, and as a predictor for ecosystem services, such as protection against erosion, productivity, carbon sequestration, and resistance to invasion. The project provides a comparison with natural systems. It is the first study of a biodiversity hotspot in the subtropics, conducted by an international consortium collaborating in a research network.

Website: www.botanik.uni-halle.de/bef-china



Healing Knowledge from the Sea?

Biodiversity on Epithelial Surfaces: The Pathophysiology of the Interaction between a Host and Commensal Flora

Why would medical researchers want to study the biodiversity of the ocean? What does a little polyp with the rather grand name *Hydra* have in common with a human being? More than first meets the eye is the simple but surprising answer – a finding that even astonished the scientific community. Until recently, scientists assumed that the simpler a creature's body structure is, the fewer genes its DNA would contain. After all, the two most popular model organisms amongst the invertebrates, the fruit fly *Drosophila melanogaster* and the nematode *Caenorhabditis elegans*, are missing a lot of genes that are crucial in determining the body structure of vertebrates. However, Cnidaria, which have populated the world's oceans

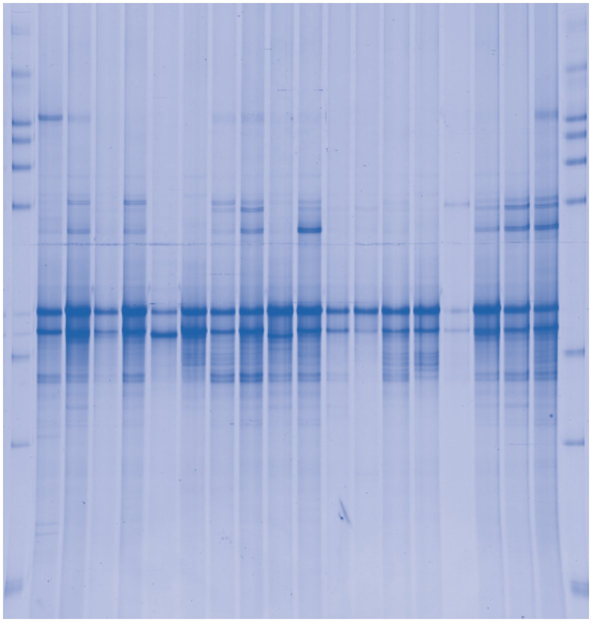
They have neither a heart nor a brain, but are very capable of defending themselves – medusae or jellyfish are the mobile generation of Cnidaria.

for around 600 million years and seem particularly primitive, possessing neither blood nor a heart nor a brain, have DNA that is actually – as we now know today – incredibly similar to vertebrate DNA, both in terms of the number and type of genes.

The Cnidarian genome, which was recently decoded, is thus no reflection of the very simple body these organisms have. In fact, their bodies are essentially a sack of tissue – although many of them occur in two different forms, depending on the stage of life they are at, either as sedentary polyps, which cling to the surface using a foot and have an opening surrounded by tentacles at one end of their tube-like bodies, or as medusae, or jellyfish, which are umbrella-shaped, mobile, and have an opening that serves as a mouth and tentacles on the underside of their bodies. These simple organisms, with their wealth of genetic material, are now gaining popularity as a model organism, as they lend themselves especially well to the study of basic cellular and molecular biological phenomena. This is not only of interest to developmental biologists. Medical researchers have also found Cnidarians to be a valuable experimental subject, for instance when studying immune responses.

Although these primeval polyps and jellyfish do not actually possess an immune system, with antibodies or immune cells with memory function, they are very good at coping with the innumerable bacteria, viruses and fungi to be found in their environment. They appear to do this using a protective mechanism that we, as humans, also have, the so-called innate immune system. In humans and polyps alike, this mechanism can be found – logically – at the boundary between the organism and the environment, in the epithelial cells of the skin and mucous membranes, for example.

It is these barriers, their function and their failure, that are of increasing interest to medicine. Diseases of the barrier organs (the skin, the lungs, or the bowel), such as asthma, neurodermatitis and psoriasis, or inflammatory diseases such as Crohn



A gel image reveals the great diversity of bacteria that exist in the bowels of different subjects. Each column represents an individual test person, each black line at least one type of bacterial strain.

disease or ulcerative colitis, have witnessed a dramatic increase in recent decades. The causes of these illnesses are thus being sought in the changed environment of the industrialised world in which we live, and the effects these changes have on the naturally occurring microorganisms, for example those found on our skin or in the bowel. What is the effect of a chronic inflammatory disease on the composition of the stool flora? Can these diseases be prevented from spreading by modifying this flora? What role does the natural protective layer of bacteria on the skin play in infectious diseases or neurodermatitis? Questions such as these will be studied by researchers from a wide variety of disciplines in the cluster of excellence "Inflammation at Interfaces" being funded by the DFG at Kiel University. It is now known, for example, that bacteria found in the bowel can also be found in the plaque of coronary blood vessels, and that alterations in bowel flora also play a role in obesity. This is why the researchers are convinced that one of the keys to combating many such diseases lies in understanding the alteration in the biodiversity of the natural microbial flora at the body's boundaries.

One area they will focus on will be interactions between hosts and microflora. This will also allow them to benefit from another cluster of excellence that is also based in Kiel, "The Future Ocean". This project will take a detailed look at the world's oceans, their development, hazards they are subjected to, and their potential, including the potential for developing new medicines and active ingredients that may be found underwater. The species diversity of marine organisms, the chemical language and make-up of which are now becoming accessible thanks to novel biotechnological methods, is seen as a seemingly inexhaustible reservoir. Marine microorganisms can be used, for example, to obtain new enzymes for industrial use, and it is hoped that the immense library of marine substances will also serve as the basis for novel cancer drugs. This has also led to the development of new model systems that are being used in the search for therapeutic and preventative strategies for barrier diseases in humans. Cnidaria are, after all, a kind of "miniature bowel" with a wealth of genetic material, and are thus an ideal model for studying the interaction between the barrier of the bowel wall and bacteria, for example to investigate how the receptors in the innate immune system are able to differentiate between harmful and harmless bacteria.

It has now been discovered that simple polyps such as *Hydra* possess a flora that is very specific to their own species, and which they actively maintain – and that they even use the same mechanisms of defence and protection against bacteria as the gut epithelia humans possess. If a thorough understanding of these mechanisms can be attained, it will then be possible, the researchers hope, to discover why genetic variations in the barrier genes have led to

Sea creatures such as the sea urchin have developed immense genetic variety in response to the great selective pressure of marine biodiversity.

diseases in humans, and to find new ways of treating these diseases. Other marine organisms are also under the researchers' spotlight. For instance, they are using sea urchins and shellfish to study the evolution of the signals that the epithelial cells transmit to professional immune cells such as the phagocytes. The receptors of the epithelial cells play a decisive role in this, since they are able to identify the bacteria both outside and inside cells. Many of these marine organisms have developed receptors with immense genetic diversity in response to the great selective pressure of marine biodiversity. One of the things the researchers from Kiel are now doing is comparing the variants of certain receptors that occur in sea creatures, such as the common jellyfish or sea urchins, in different habitats – for instance those that live out on the open sea and those that live in coastal regions. They hope to discover, amongst other things, which variants have prevailed in which habitats, and possibly even identify substances or bacteria that may be able to be used to strengthen the human immune system. Healing knowledge from the sea? The researchers from Kiel hope so.

Profile

Project name: Biodiversity on Epithelial Surfaces: The Pathophysiology of the Interaction between a Host and Commensal Flora

Form of research funding: Clusters of excellence "The Future Ocean" and "Inflammation at Interfaces"

Prospective funding period: 2007–2012

Study site: Kiel, Germany, and the world's oceans

Habitat: Epithelial surfaces, diverse habitats ranging from the open seas to the human bowel

Participating disciplines: Microbiology, gastroenterology, marine biology, dermatology, economics

International collaboration: University of Toronto, Canada; University of Michigan, USA; Université de Lille, France; King's College London School of Medicine, United Kingdom

Project features: Two clusters of excellence located at Kiel University study various aspects of biodiversity, cooperating closely on the interface project "Biodiversity on Epithelial Surfaces". Using Cnidarians, shellfish and sea urchins as model systems, this project will investigate problems such as the way diseases occur at the body's barriers, and study the interaction between host organisms and their commensal bacterial flora. It is hoped that the findings may lead to new ways of treating or preventing (chronic) skin, lung and bowel diseases, the occurence of which has increased dramatically in recent years.

Websites: www.ozean-der-zukunft.de/index-e.shtml, www.inflammation-at-interfaces.de/en_startseite.phtml

Systematic Diversity

Establishing a DNA Bank Network as a Service for Scientific Research

Collecting is an integral part of science, especially if it is concerned with the world around us. Indeed, collections have always formed a key basis for biological research in natural history. The samples and preparations contained in these collections, which are accessible worldwide by being made available on loan, are a key resource for taxonomists, horticulturalists and geneticists, allowing a means of direct comparison between different organisms that would otherwise require great effort, or may not be possible at all. Such comparison is traditionally done at a wide variety of levels, for instance morphologically-anatomically for herbarium specimens and collections preserved in alcohol, or micromorphologically for the analysis of surface structures, or biogeographically by means of evaluation of the details on the origin of a sample, or biochemically by analysis of the substances a specimen contains. The progress made in genetic analysis in recent years has added the new level of storing genetic material. This also necessitates a new form of natural history collection.

Indeed, the processes used in DNA analysis have had a dramatic impact on biological research. Some assumptions concerning the relationships between different organisms or the evolution of certain characteristics have been proven wrong by the new insights granted by molecular biology, or been replaced by new hypotheses. This also applies, in particular, to the complex issues of research into biodiversity, which can now be studied by means of molecular analysis. On the one hand, the researchers focus on elucidating the genetic diversity of species and their spatial dynamics and on the other on locating genetic hotspots within populations or species and finally on identifying ecologically relevant genes.

The results of studies in molecular biology are statistically evaluated, analysed and condensed to their key conclusions in scientific publications. If the findings have been arrived at by comparison of defined sequences of nucleotides, these are stored in publicly accessible nucleotide sequence databases, so that the original data remains available. In theory, at least. For a long time, one important fact was ignored: The molecular data has itself been extracted from the complexity of an organism, with the primary data encoded in that organism's DNA. By extracting some of the information, one obtains secondary data, including the taxonomic name, which is defined according to characteristic features, as

Conventional herbarium samples have their very own charm, which lasts for centuries.

well as tissue and DNA analyses. However, for any detailed analysis of an individual specimen, it is essential to refer back to the primary data; otherwise the secondary data obtained is worthless. Because this fact was generally neglected in the past, it is now impossible to verify a lot of studies. This strikes a blow to the heart of science, as its very nature is to produce reproducible and verifiable results. Such checks seem absolutely essential in some cases. Recent random samples have shown that as many as 20 percent of all DNA sequences in major databases are either incorrectly annotated or have been assigned the wrong scientific name. This significantly reduces the value of such databases.

Setting a good example

This is why scientists have now begun storing the original biological material that belongs to the genetic data in collections in the traditional way, just as they have done since von Linné's times, so that it is available for subsequent evaluation or for further study. It is still a very time consuming business to find, request and review such material contained in traditional collections, as a large proportion of what is available in research collections is yet to be catalogued, digitised and made available online, which means that its influence on the correction of research findings is minimal. This situation can and will be solved by a new type of central collection facility, designed from the outset to use modern communications technology to allow the data to be accessed via a digital documentation system that makes it permanently available online, and allows you to find what you are looking for in next to no time.

These so-called DNA banks are technically sophisticated service facilities for the long-term storage of well-documented genetic material intended to ensure the long-term usefulness of this DNA for the scientific community. Basically, they consist of two key features: A DNA collection, which also includes tissue samples, and a database which is used to document all of the relevant data such as the site where the sample was found, the date it was found, the current storage location, the person who collected it, fixing of the specimens, a digital voucher, the extraction method, the quality and concentration of the DNA, sequence data and information on publications. Such central facilities are also in a better position to guarantee optimum storage conditions for the sensitive genetic material than each individual institution or working group that works with the original material. They can also provide simple access to the samples and develop standards for automated processes such as molecular biological processing of the DNA or database query procedures. For medical purposes and forensic science such DNA banks have existed for some time now, but central databases for the DNA of organisms in the wild are only now coming into existence. The best known institutions that collect plant DNA are currently the Royal Botanic Gardens Kew DNA Bank in the UK, the Korean Plant DNA Bank in South Korea, the DNA Bank Brazilian Flora Species in Brazil and the DNA Bank at Kirstenbosch in South Africa.

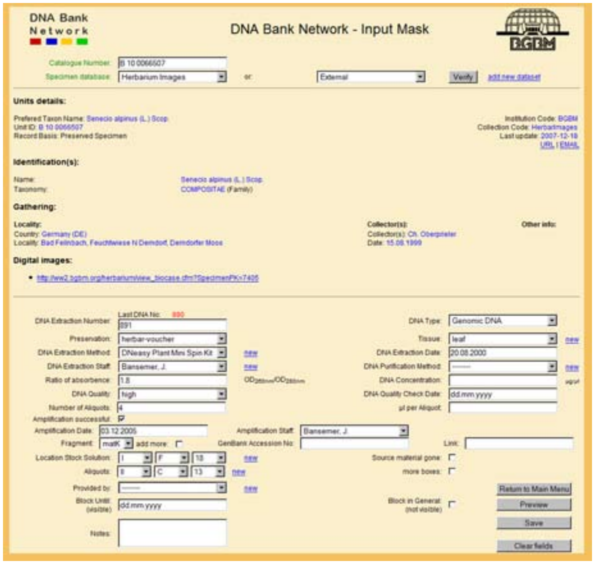
A network for Germany

In Germany, four major research institutions specialising in natural history with collections that focus on different areas have now joined forces, with DFG support, to form the DNA Bank Network. This reflects – in much the same way as the distribution of the natural history museums – the principle of federalism that applies in Germany, and is thus a compromise between the aspiration to have a central facility that is most cost-effective and distributed collections of research specimens and expertise. To guarantee the long-term future of this project, the institutions selected to participate in this network were those that are already dedicated to the long-term storage of such collections, with each of them continuing to concentrate on their existing core focus. The Botanic Garden and Botanical Museum in Berlin-Dahlem is, on the one hand, responsible for coordinating the network and for developing and integrating the various modules that make up the database, the system of data retrieval used to query the various databases in the network and for the web portal, and on the other hand is also the location of the DNA bank node for plants, algae and protists. The DNA bank for specimens of certain groups of invertebrates as well as of lower deuterostomes and fungi is located at the Bavarian State Collection of Zoology in Munich, and the central DNA storage bank for other groups of invertebrates and of vertebrates is located at the Forschungsmuseum Alexander Koenig in Bonn. The fourth and final DNA bank is located at the German Collection of Microorganisms and Cell Cultures in Braunschweig.

In order to document genetic diversity reliably, one needs standardised procedures and great precision.

At present, the members of the network are upgrading their laboratories, storage facilities and databases for the new collection. For example, DNA storage experiments are underway, which aim to ensure the long-term preservation of the genetic material without any loss of quality. To date, there have been very few scientific studies on this topic. Fundamentally, however, it is known that the DNA from those parts of the organism that serve to spread the genes or sustain the line, such as seeds or spores, which are designed to survive in inhospitable environments, are the most resilient. It is also known that the quantity and quality of DNA that can be extracted is higher if fresh tissue is processed straight away. At -20 °C it can take several months for there to be any significant loss of quality, and at -80 °C several years. When dried, the degradation of the genetic material is also much slower. For this reason, the network recommends that the tissue should be desiccated as soon as possible, while still in the field, using silica gel. For precisely the same reasons even samples from herbariums and natural history collections which are already quite old can still contain fairly high quality DNA, as long as they were dried quickly and thoroughly enough, and were not treated with toxic preservatives.

According to current knowledge, storage at -80 °C or in liquid nitrogen is the safest and most durable way of storing DNA. However, not only is the equipment required for storage in liquid nitrogen expensive to purchase, the ongoing costs are high too – a significant argument in favour of storage at -80 °C and for having centralised collections. Since the quality of the genetic material is presumably affected the most while being frozen and while thawing, the DNA banks belonging to the network also separate the DNA that is extracted so that they have one master sample and several aliquots that can be provided immediately when required, which are



Using state-of-the-art technology it is also possible to allocate and relocate genetic diversity.

stored in different freezers, so as to protect the master samples from temperature fluctuations.

Apart from the quality of the DNA, the other decisive factor for the scientific value of a sample is the documentation. For each new sample added to the German network, a so-called DNA barcode is recorded. Such a barcode sequence can be used to prove that the taxonomic-systematic identity of the sample matches the documentation and that there has been no cross-contamination with other organisms. In an age of global connectivity, regardless of the classification system used within any single collection, international standards have to be developed to facilitate global data exchange. As yet, there are no universal standards for biological DNA banks, so the German DNA Bank Network is participating in SYNTHESYS (Synthesis of Systematic Resources), a project working to establish standards for the management of collections and databases held by natural history collections in Europe.

Now, it is no longer necessary to store all of the information in a single database, especially as databases that are too large become unwieldy and hard to manage. Instead, it is now possible to use a "globally unique identifier" (GUID) to link each object in a database to the other databases in order to obtain all of the relevant information quickly and simply. This can be done using a wrapper, which acts as a kind of translator for the different system of tables and columns used by each database. In this translated form, all of the databases have exactly the same structure, which makes querying them faster and also makes it possible to query several databases simultaneously. This makes it possible to find out where the specimens for a certain species are located by searching the databases for several hundred collections in parallel.

Integration of research

At the moment, the four centres in Germany are busy entering all of their own research projects and the associated data into the DNA banks. Priority is also being given to storage of the genetic material of protected and endangered species as well as of German fauna and flora. For instance, the Botanical Garden in Berlin is cooperating with the Botanical Association of Berlin-Brandenburg to collect in the field and document approximately 80 percent of the flora of the region by the end of 2008. That would account for as much as 60 percent of all German vascular plants. Scientists from all disciplines and institutions are invited to contribute genetic material to the network's DNA banks from their own research projects, together with the associated information. They are also encouraged to collect DNA material, in accordance with the specified standards, while on field trips.

Primarily, the members of the network are working to integrate the existing biological collections – such as the samples of specimens, in vivo collections, seed banks, tissue banks and DNA banks – into

Botanical gardens are traditionally places where biodiversity is exhibited and conserved.

international collection databases, in order to allow scientific users to access both the specimens and the data quickly and easily. This is the only way that optimum usability of all of the resources contained in the collections can be achieved. A number of projects such as the Global Biodiversity Information Facility (GBIF), the Biological Collection Access Service for Europe (BioCASE), the Information System on the Biodiversity of Terrestrial Algae, AlgaTerra, and the Consortium for the Barcode of Life (CBOL) are addressing precisely this problem. In this context, DNA banks are able to provide the ideal link between traditional collections of biological specimens, the DNA as a biological information carrier and the DNA sequences stored in the databases.

Profile

Project name: Establishing a DNA Bank Network as a Service for Scientific Research

Form of research funding: Research grant as part of the LIS funding programme: "Subject-specific Information Networks", 4 subprojects

Prospective funding period: 2007–2009

Study site: DNA sampling from specimens held in natural history collections, from collections of special interest, and from locations in the field worldwide

Habitat: All habitats of wild organisms, worldwide

Participating disciplines: Botany, microbiology, zoology, molecular biology, taxonomy

International collaboration: Participation in the SYNTHESYS project (Synthesis of Systematic Resources) funded by the EU and on international projects working to develop guiding standards for DNA banks

Project features: Aims to establish a network of DNA banks as an institution that will provide a service for biological research, especially research into biodiversity. These will be technically advanced facilities for long-term storage of well-documented DNA, which will provide access to genetic resources and protect the DNA of extinct or endangered species. It is a unique concept, worldwide, to network DNA banks with differing, but mutually complementary collections. Simplified access to samples and documentary data by means of a common, central online network portal. The mission: the isolation of DNA, high-quality purification, determination of DNA quality and concentration, storage of the samples, and provision of samples on request. Specialised research into the optimisation of long-term storage of DNA and full documentation, which will then be made available online.

Website: www.botanischer-garten-berlin.de

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