The Biodiversity Exploratories

A new approach to the exploration of biodiversity

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1) Context and perspectives

Because we already know so much about our planet Earth and are so familiar with it, we often take its marvels for granted. Such a view fails to do our planet justice, as a glance at the other planets in our solar system shows. While not a single microbe has been detected on any of the other planets and their over 160 moons, an incredible amount of biodiversity has developed on the Earth over billions of years. The total number of species runs into the millions, counting those that have already been documented as well as the many that have yet to be described. Researchers have only recently begun to understand the combination of chance events and biological laws that have led to the proliferation of lifeforms and their organisation in complex ecosystems. Ecological science is also still in its infancy, and there is much to be done when it comes to explaining the interactions between species and with their environment in general theories.

Improving our understanding of such relationships is difficult, given the complexity of the natural relationships. But ecology faces an additional challenge: the diversity of life on Earth is threatened by what may be the largest mass extinction in Earth's history. If current trends continue, it is likely that half of all species around the world will be extinct by the year 2100. Human civilisation is profoundly transforming the world's natural ecosystems, without a proper understanding of the consequences of these changes for ecological communities and the ecosystem processes they perform. However, our own welfare and that of future generations of humans, animals and plants is crucially dependent on many of these processes, such as the water and carbon cycles.

2) The term 'Biodiversity Exploratories'

To boost awareness among the general public of these alarming environmental developments, American evolutionary biologist Edward O.Wilson introduced a new biological term at a conference in 1988. It is a concept that has since come to occupy a central place in science, politics and nature conservation: *biodiversity*. There are two factors that make this shortened form of the words *biological diversity* special. First, it expresses a scientific fact:

biodiversity refers to the variety of species and ecosystems, as well as genetic diversity. Second, it is also a term of appreciation. Since the Rio Convention on Biological Diversity in 1992, biodiversity has been seen as a public good that has not only brought humanity many practical and aesthetic benefits, but is also deserving of care and protection *for its own sake*.

In exploring biodiversity, researchers in the field of ecology initially focused on documenting and describing plant and animal species. Now that computers have made it possible to process large volumes of data, the primary focus of ecology is now on defining relationships of cause and effect. It is possible to uncover these functional relationships in what we call *exploratories*. This term, from the Latin *explorare*, to explore, refers to large areas of land comprising specific study plots. In these, ecological relationships can be identified, both by observation and experiment.

3) The project's key research questions

The spectrum of biodiversity being studied in the exploratories is extremely broad, and ranges from soil bacteria, fungi, plants, mosses and lichens to arthropods, birds and bats. The researchers collect data on the genetic diversity of selected species, and measurements of the diversity of their chemistry, odours, sounds, functions and evolutionary diversity are also made. This data can then be linked to detailed measurements of ecosystem functions, including carbon storage, the water, nitrogen and phosphorus cycles, plant productivity, soil aggregation, the decomposition of organic matter, pollination, and the feeding of herbivores. Ultimately, the Biodiversity Exploratories programme aims to provide answers to the following three questions:

1) What are the interactions between the various components of biodiversity?

2) How are ecosystem processes influenced by biodiversity?
3) What effects do different forms and intensities of land use have on biodiversity and ecosystem processes?

The last two questions in particular are of great importance to both fundamental and applied research.

4) Special features of the Biodiversity Exploratories

As researchers have been studying biodiversity for a long time – albeit under another name – some may wonder what new findings the Biodiversity Exploratories programme can bring to the field. In fact, it is opening up new avenues of ecological research, as it is a unique programme based on completely new methodology.

- The Biodiversity Exploratories bring together a very large number of previously separate research disciplines *under one organisational roof*: zoologists, botanists, microbiologists, geneticists, ecosystem ecologists, soil scientists, specialists in remote sensing and modellers work together on key research questions. Project staff have access to the specific data they need from the internal project database via the internet, enabling smooth exchange of information and pooling of data.

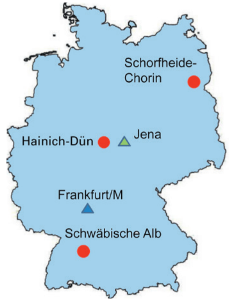
- The Exploratories project was designed based on *standardised methodology* from the start, to ensure that the results of the numerous researchers can be readily collated and compared. In each Exploratory, the researchers work on the same 100 study plots. The researchers are each allocated their own study units within the plots, to prevent any mutual disturbance.
- While most previous research into biodiversity has been on a small scale and over the short term, the Exploratories project is based on a large-scale and long-term framework. The research is conducted in three large-scale conservation areas in different regions of Germany. The study areas cover several thousand hectares and will be studied for at least 12 years. This wide-ranging spatial and temporal framework enables researchers to statistically 'filter out' the effects of local factors and meteorological anomalies, such as an extremely wet summer, allowing them to make the kind of generalisations about natural relationships that are the ultimate goal of all scientific research.

5) The three exploratories

All three exploratories have plots in large-scale conservation areas. This is essential, as it is only in conservation areas that forest and grasslands managed at *low intensity* can be found. By studying such areas alongside sites with higher land use intensities, the influence of different land use intensities on biodiversity can be systematically investigated. Protected areas in different regions of Germany have been selected to ensure the research findings are applicable throughout the country.

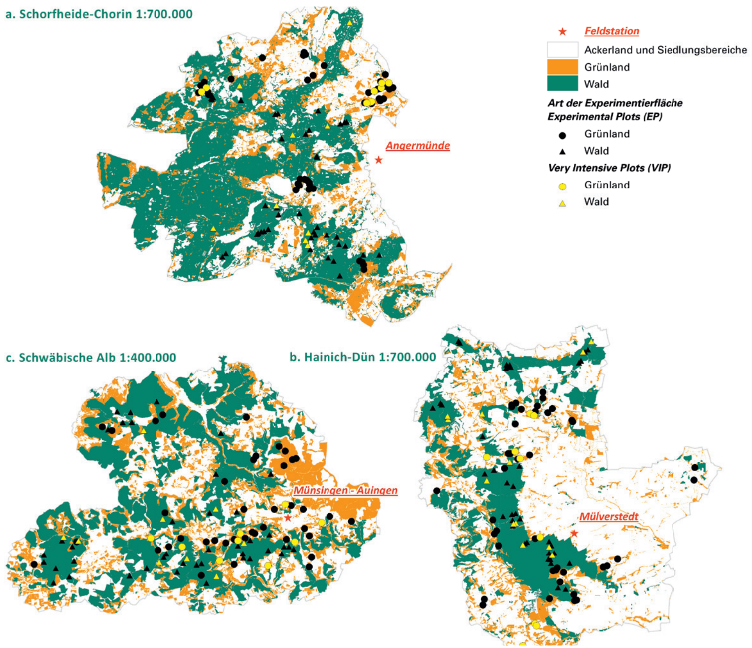
- The *Schorfheide-Chorin* Biosphere Reserve is located in Brandenburg and is approximately 1,300 km² in size.

- The *Hainich* National Park in Thuringia, together with the surrounding area, forms an exploratory with an area of 1,300 km².
- The *Schwäbische Alb* Biosphere Reserve is located in Baden-Württemberg and covers an area of 420 km².



As well as the three exploratories, two other locations are marked on the map of Germany above: the organisational headquarters of the project at the *Senckenberg Gesellschaft für Naturforschung* in Frankfurt, and the central data management facility at the *University of Jena*.

As research at the Biodiversity Exploratories is carried out exclusively in forests and grasslands, these two types of landscape are highlighted on the maps of the three exploratories on the left: forests are shown in dark green, and grassland in orange. The remaining white areas are composed of farmland, lakes and residential areas. The black dots represent the 100 Experimental Plots (EPs) in each exploratory. 50 are in forest and 50 in grassland. Nine or 12 of each type of these *Experimental Plots* are investi-

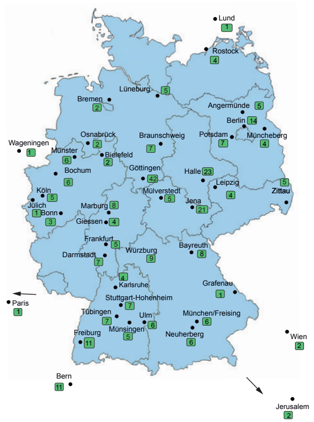


gated in great detail. These are known as *Very Intensive Plots (VIPs)* and are marked in yellow here. In these areas, investigations are undertaken that are either too time consuming or too expensive to be carried out on all 100 plots in an exploratory.

6) The researchers

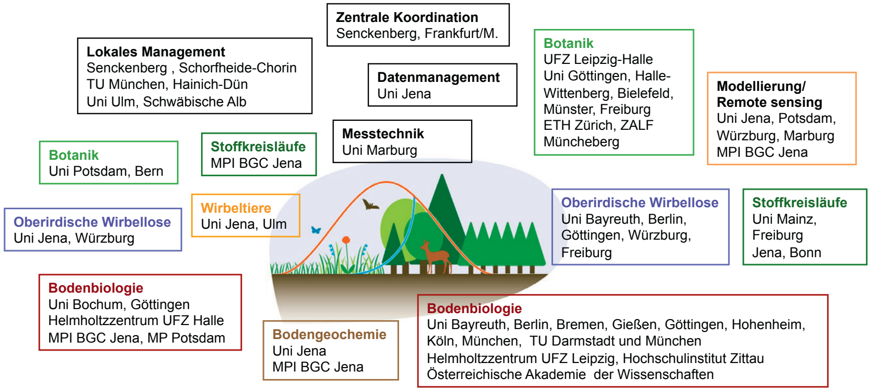
A special feature of the Biodiversity Exploratories project is that it is not limited to just a small circle of select institutes, but is open to all biodiversity researchers in Germany and the surrounding area. The map on the previous page illustrates the origins of the staff members working in the project team, who come from an impressive 42 different cities. The conditions for participation are as follows:

- The central scientific objectives are shared
- The jointly agreed methodological standards are upheld
- The necessary capacities and structural requirements are met
- The research proposals have been evaluated by the Deutsche Forschungsgemeinschaft (German Research Foundation, DFG) and international experts, and found to be of a sufficiently high level to enrich the overall project.



The research being carried out in the Biodiversity Exploratories programme began with

six key projects in 2006. These continue to form the core of the research studies. Since then, another 34 institutions, with researchers from various disciplines, have joined the programme (see diagram on the right), which currently includes around 250 scientists and 40 individual projects.
This large number could understandably lead to concerns that the study plots may be frequented by so many researchers that they would be significantly disturbed. There are three reasons why this is not the case: First, only a few of the 250 scientists are engaged in data collection and thus work on-site; second, these few field researchers are spread over 300 study plots. Finally, all investigations are effectively coordinated to ensure that they are comprehensive and complementary.



On the other hand, it is undeniable that the Exploratories project brings an increased number of visitors interested in nature to the regions. Guest houses, restaurants and shops benefit *directly* from this increase by providing accommodation and meals to researchers, as well as *indirectly* from their subsequent positive reports to friends and family about the study regions.

7) Selection of study plots

Looking at the map of the three exploratories on page 7, it is clear that the study plots are not evenly distributed. How were *these* particular locations chosen? When the project began in 2006, a 100 x 100 metre grid was laid over each of the three areas (see image on the right). An initial selection of 1,000 *Grid Plots (GPs)* was made from the grid points that happened to lie on forests and grassland. These formed the basis for the final selection, from which the 100 Experimental Plots were chosen. As mentioned above, 50 of these are in forest and 50 in grassland.

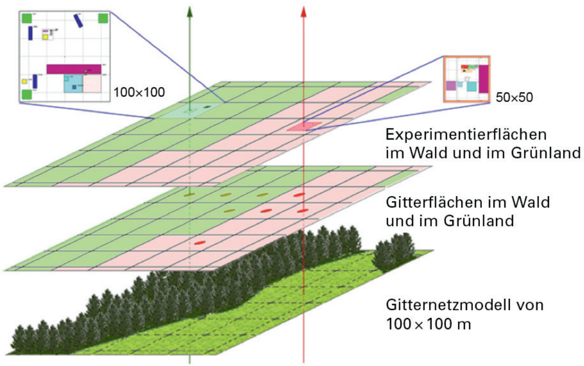
In order for a Grid Plot to become an Experimental Plot, it had to meet three criteria:

- For both forests and grasslands certain site characteristics had to be present. These were ascertained by means of soil samples and vegetation surveys, in order to ensure *comparability* of the various plots.
- It had to be *eligible for approval*. Grid Plots could only be considered if the relevant owners, land users or nature conservation authorities had first given their consent. Plots in protected zones around the nests of large birds, for example, were thus eliminated from the outset.
- The intensity of land use had to be defined according to a particular *land use gradient*. After all, one of the three key challenges of the project was to identify the relationship between biodiversity and intensity of use.

To be able to answer this question quantitatively, the researchers needed to define criteria for the type of land use. These criteria were required in order to position the Experimental Plots along a *linear scale* between the two poles of 'very intensive use' and 'little to no use'.

Three parameters were chosen for this purpose for *grassland*: (1) grazing intensity, (2) frequency of mowing and (3) fertilisation. These criteria are combined using a mathematical formula to obtain a standardised parameter called the *Land use Intensity Index (LUI)*.

Two different indices have been developed to describe the intensity of use in *forest*: the *Silvicultural Management Intensity Index (SMI)* and the *Forest Management Intensity Index (ForMI)*. For the SMI, the following two parameters are used as indicators of current and past interventions:



(1) tree-species-dependent survival of forest stands and (2) wood biomass in an area compared to the maximum possible wood biomass. In comparison, the ForMI comprises three components: (1) the proportion of harvested tree volume, as an assessment of the harvest intensity, (2) the proportion of tree species that are not part of the natural vegetation, and (3) the proportion of dead wood showing signs of saw cuts. Although both indices are based on completely different approaches, they lead to a very similar quantitative assessment of the management intensity of individual forest stands.

8) Structure of the study plots

If you approach a grassland Experimental Plot, often the only thing you can see is the small weather station surrounded by a 3 × 3 metre wood-and-wire fence, which protects the measuring instruments from wildlife and grazing animals. In the forest plots, the fencing is slightly larger at 12 × 12 metres, because it also accommodates what are known as exclusion experiments, which are research projects that specifically exclude browsing by game animals.
Weather stations are mandatory for all 300 Experimental Plots, as weather and climate are key factors affecting biodiversity and its variations. Automated measurement of temperature, humidity and soil moisture levels are taken on all plots, and air pressure, radiation, precipitation and wind are also being measured on 21 study plots. In total, over 60,000 individual measurements are recorded in each exploratory *each day*. This data is periodically transmitted to the data centre at the University of Jena, as is the meteorological data from four measurement towers in beech forests.

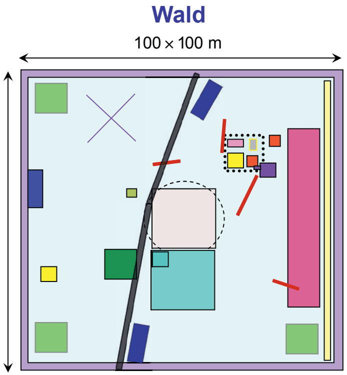
The weather measuring instruments only cover a small part of the total area of each Experimental Plot. This can be seen on the two diagrams showing the layout of a standard plot in forest (100 × 100 metres) and in grassland (50 × 50 metres) (see diagrams on the right). The area for the measuring instruments is shown in *grey with a yellow border*. All other areas are specifically allocated to individual research groups, so that the various groups focusing on different research questions do not get in each other's way. For example, in the middle of each plot there is always a core area that is reserved for recording vegetation (*pink*); the *light blue* area below is for soil research; the *dark blue box and red* lines indicate experimentally positioned deadwood or dead wood found naturally in the plot; and the *magenta* area on the right side was previously used to record small mammals.

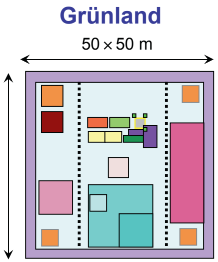
A key methodological aspect of all studies in the exploratories is that most of the area of each Experimental Plot continues to be managed as normal. If part of an Experimental Plot is fenced off and is not managed, management of the area is simulated in line with surrounding land use. For example, in grassland, the project staff will mow the area regularly using a grass trimmer to simulate the normal land use.

9) Data management and organisation

Thirty years ago, the kind of coordination required to achieve the objectives of a major project like the Biodiversity Exploratories would have been unthinkable because of the required harmonisation and synchronisation of activities between regions and because of the data management required.

Each of the three exploratories has a five-member local management support team to ensure that activities on the study plots can run as smoothly as possible and exactly as in the other regions. The team coordinates all of the researchers' field activities, both within the project and with the relevant farmers and foresters, and regularly records data on current land use. It maintains the 100 weather stations and items of equipment on the plot and looks after the project house where the researchers live during their

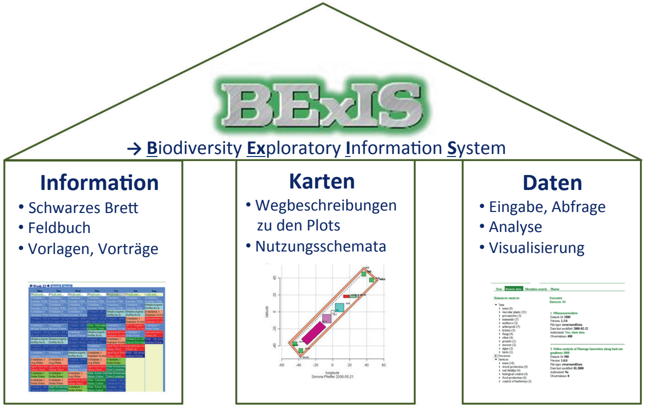




stay at the exploratory. It is also in close contact with the nature conservation authorities and the reserve managers.

The *Biodiversity Exploratory Information System* (*BExIS*) is what makes the required exchange of information and management of data possible. This internal project database at the University of Jena comprises three areas to which all project staff members have varying degrees of access via the internet (see diagram on the next page).

- The *Data* area (right column) represents the database in the narrowest sense. This uses predefined data formats for entering and searching, allowing for harmonisation of the data across the wide variety of disciplines involved in the project. It also enables analysis and graphic representation of the data.
- In addition to the data section, there is also a *Maps* area. This contains directions to the plots, photos with coordinates for orientation in the field and diagrams showing usage of the plots by the various research teams.
- The third area is for *Information Exchange* among the researchers themselves and with the management teams within each region. A 'notice board' provides information on current special features in the three exploratories; an online field book enables the researchers to coordinate when they will be visiting each area, and is also used to help reserve accommodation and certain items of equipment such as drying cabinets and metal detectors. Finally, researchers can also view and provide presentations and publications via the web, so that everyone can keep up to date with the latest research developments.



10) Example subprojects and initial results

Now that we have presented the objectives, organisational structure and methodology of the exploratories, in the last part of this brochure we would like to describe some of the specific studies the researchers are undertaking on the Experimental Plots in forest and grassland. If we recall that there are around 40 working groups carrying out research in the exploratories, a large volume of research is produced and the following four brief profiles represent just a small fraction of the overall project. Each profile introduces a different aspect of the work in the exploratories.

The first is in grassland (a), the second is in forest (b), the third illustrates the coordinated methodology (c) and the fourth highlights the cross-disciplinary approach (d).

a) How does the land use intensity in grassland influence the interactions between flowering plants and their pollinators? To investigate this question, researchers from the Technische Universität Darmstadt studied the composition of insect fauna and flowering plants in all three exploratories. A surprising result of their study was that, with increasing intensity of management, the diversity of flowering plants decreased by about half to two-thirds, but the diversity of pollinators did not decrease – it only changed. Increased land use intensity created winners, such as flies, and losers, such as butterflies. This change in species composition can be explained by a decreased diversity of feeding relationships; highly specialised pollinators, like many butterflies, are usually at a disadvantage in the intensively cultivated areas because of the low variety of flowering plants there. To preserve these highly specialised pollinators, it is therefore advisable to reduce the intensity of cultivation.

b) What is the ecological importance of dead wood in forests? Scientists at the University of Freiburg were able to provide some interesting answers to this question. They documented the long road from photosynthesis of the tree, to death, decomposition by wood-degrading fungi, and back to atmospheric carbon dioxide. They found that the rate of decomposition of the dead wood was predominantly dependent on the identity of the tree species and the activities of the decomposer communities. If a lot of dead wood is left in the forest, the diversity of fungi species is higher, resulting in faster decomposition. In a Central European beech forest, this takes around 50 years on average. The study therefore highlights the importance of dead wood for the preservation of the decomposer biodiversity and the functional role this performs.

c) What microorganisms live in soil and what influence do they have on nutrient cycles, water storage, soil structure and plant growth? A large number of researchers working on more than ten projects at various universities and scientific institutions are addressing these questions. In 2014, they worked together to take carefully coordinated soil samples on all 300 Experimental Plots for a third time. To do this, they took a total of 4,200 core samples, each 5 cm in diameter, along specially measured paths called transects, over a period of 14 days. The material was then divided into thousands of individual samples, cooled to -80^0 C and then sent to the various project laboratories throughout Germany. New microorganism species are regularly discovered as part of this kind of analysis. In fact, only 1% of the approximately 50,000 species found in a teaspoon of soil are known to science!

d) How does increasing land use intensity affect the biodiversity of a grassland ecosystem as a whole? 58 scientists from 16 institutes have pooled their data to provide quantitative answers to this broad question. The *multi-diversity index* that they have created is based on 49 groups of organisms ranging from bacteria, algae, fungi and plants to insects and birds, and forms a new way of measuring the entire biodiversity of an ecosystem. A key finding of this interdisciplinary approach was that multi-diversity decreased when the land was used more intensively. It was also found that both total diversity and the diversity of regionally rare species increases when the land use intensity is low, and varies across time. In summary, it can be deduced that both the reduction of land use intensity and its variation over the years are of great importance in the preservation of biodiversity in grassland. This variation can be achieved by changing the number of grazing animals each year, or by varying the frequency of mowing.

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