


Department
Biogeochemical Processes

The Department Biogeochemical Processes explores key processes and organisms that regulate exchanges of energy, water and elements between ecosystems and their surroundings. We use observations, experiments and models to improve understanding of how human activities are altering ecosystem function, and the consequences for sustainability and regional and global climate.

Terrestrial ecosystems are undergoing rapid and unprecedented change. Humans have transformed more than half of the global land surface by direct activities such as deforestation and management of land for agriculture or pasture. All land areas experience effects of climate change, elevated carbon dioxide levels and air pollution. At the same time, the land surface is a key component of the global climate system and an important regulator of atmospheric trace gases. Our department seeks basic understanding of the biogeochemical functioning of ecosystems, and the consequences of current changes for climate and the sustainability of vegetation and soils.

Quantifying responses and feedbacks in complex, coupled systems requires a range of tools and approaches. Field studies determine fluxes of energy, water and gases between land and atmosphere in ecosystems ranging from tropical forests and savannahs to managed forests and grasslands in Germany. Laboratory and field experiments manipulate individual factors such as temperature, biodiversity or nutrient availability in order to document how different components of the ecosystem respond to changing environmental conditions. In both field and lab investigations, we develop new analytical tools using isotopes or other tracers that allow us to evaluate the importance of processes across a range of spatial and temporal scales.

We target our research on particular processes and ecosystems where significant uncertainties currently limit the predictive ability of global climate models, and where responses to climate change or direct human management might be expected in the coming century. Because we work at a variety of spatial scales, from organism to ecosystem to region to globe, we collaborate actively with the other departments of the Institute to integrate across these scales using isotopic tracers, models, and spatial analysis tools. Regions of

Portrait of the Director

Susan E. Trumbore has been the Director of the Department Biogeochemical Processes since 2009. Trumbore's research is in the role played by land vegetation and soils in the Earth's carbon cycle. She has received a number of honors and awards, including election to the US National Academy of Sciences and Fellowship in the American Geophysical Union. The department was founded by E.-D. Schulze, who continues his scientific activities as an Emeritus member of the Institute.

contact: susan.trumbore@bgc-jena.mpg.de

special emphasis include investigation of local land management and drought in Germany, documenting disturbance and carbon allocation in tropical forests of the Amazon Basin, and the vulnerability of carbon stored in high latitude soils to warming.

Focus 1. The origin, fate and vulnerability of organic matter stored in soils

Although soil organic matter is fundamental to human well-being and to a number of global biogeochemical cycles, we lack basic understanding of processes that store carbon in soils, and how factors such as climate, organisms, and mineral composition combine to determine how long it remains stabilized. Several groups of our department work on this topic, with goal of synthesizing information on soil carbon stocks, the chemistry and age of the organic matter, and how those are affected by changing vegetation, temperature, moisture, and land management.

Focus 2. Understanding plant allocation, respiration, defense and mortality

Plants use the products of photosynthesis for respiration, growth, defense, storage, and transfer to roots and soil. However, we do not have good theories to predict how allocation strategies among those pathways are determined, or how those allocation patterns will respond to changes in environmental conditions or the community composition. We have developed methods to use carbon isotopes to track allocation pathways and the residence time of carbon in plants. Experiments using drought to manipulate the supply and allocation of carbon in trees provide information on the links between carbon and water cycles and the causes of tree mortality. Measures of the age and use of plant storage and respiration allow improved understanding of how plants respond to stress.

Focus 3. The role of functional traits and biodiversity in biogeochemical cycles

The biota that inhabit ecosystems determine the role of biological systems in global element cycles. A major challenge lies in determining what aspects of the organisms present are required to adequately describe the response of ecosystems to change. Research ranges from experiments that manipulate biodiversity, to investigation of the long-term effects of land management. In tropical forest, we are studying the effects of disturbances, including fire and windthrow associated with downbursts, on species composition and carbon allocation patterns. We will use these field studies as tests of how well plant traits can represent function for analysis at larger spatial scales.

Focus 4. Reconstruction of Past Vegetation and Climate

Plants make compounds that, through their isotopic composition, record environmental variables. These relationships are defined using our ongoing studies and experiments, and can then be applied to reconstruct past variations recorded in tree rings, paleosols, or lake sediments. Ongoing research looks at the effects of past drought in German forests, and changes in monsoons on the Tibetan plateau.

A rain exclusion experiment to determine the causes of tree mortality caused by drought includes sensor monitoring of stressed trees and measurement of carbon fluxes.

Landscape Processes

Scaling biogeochemical measurements from point locations (e.g., soil pits, flux towers, vegetation field-plots) to broader scales is confounded by the high degree of spatio-temporal heterogeneity inherent in ecological systems. We explore the processes that create, maintain and modify landscape heterogeneity, and assess the consequences of heterogeneity for biogeochemical functioning in the context of global change.

Landscapes are mosaics of different patches and gradients, varying in size, shape, composition and spatial configuration at multiple scales. This spatio-temporal heterogeneity has often been ignored in ecology, which traditionally focused on similarities rather than differences in ecological systems. We use remote sensing tools to explicitly quantify heterogeneity within landscapes and explore its underlying causes. We make extensive use of airborne LiDAR (laser altimetry) to map landscape and vegetation structures in three-dimensions (3-D) across a broad range of ecosystems including savannas, tropical forests, and temperate forests (Figure next page, top). We aim to improve understanding and modeling of ecosystem processes across scales and inform biodiversity conservation and land management.

Focus 1. Topo-edaphic controls on ecosystem processes

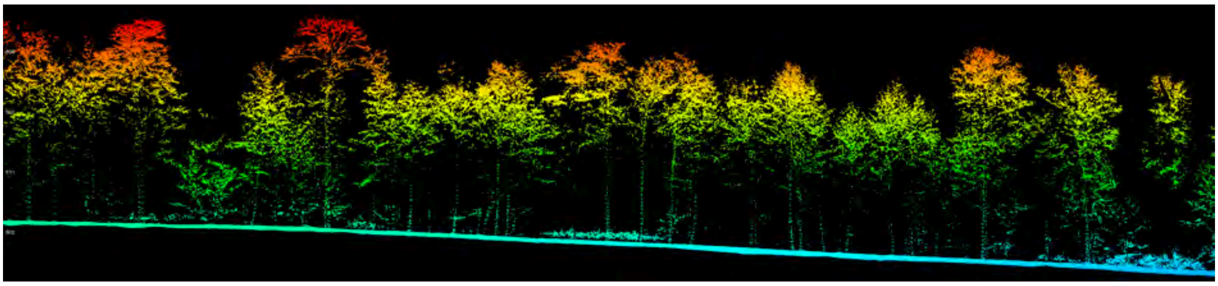
Ecological processes are seldom uniform or random in space, as landscapes contain spatial structures that mediate how energy, materials and organisms move through them. Underlying soil type and hillslope morphology are two primary controls that influence biogeochemical processes, but spatial heterogeneity of these factors is poorly accounted for in regional and global models. We aim to improve understanding of how ecological processes vary across landscapes and to facilitate integration with modeling efforts.

We are studying a range of hillslope catenas (topographically linked sequences of soil, water and vegetation) on different geologies across a rainfall gradient in South African savannas to better understand how climate and substrate influence biogeochemical processes (such as soil carbon storage and flux) at hillslope scales. We are currently expanding this research to sites in Australia and South America to gain a global perspective on hillslope-scale processes in savanna systems.

Portrait of the Group Leader

Shaun Levick studied landscape ecology at the University of the Witwatersrand, South Africa, where he obtained his PhD in 2008. He worked as a postdoc in the Carnegie Institution of Science, Stanford, CA, and as a remote sensing scientist at GNS Science, New Zealand, before joining the Max Planck Institute in 2012. He leads research on the heterogeneity of ecological systems and is particularly interested in savanna and tropical landscapes.

contact: slevick@bgc-jena.mpg.de



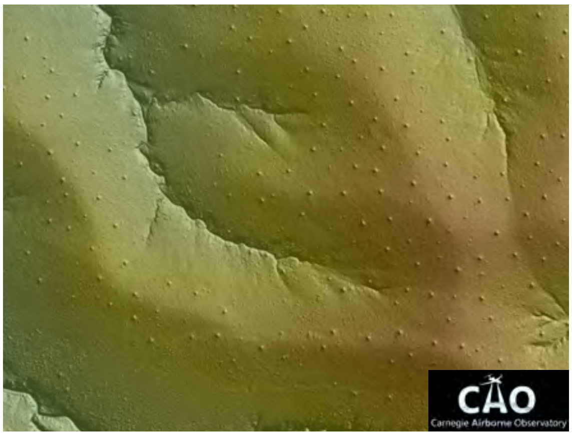
A cross-section through a high-resolution LiDAR point cloud collected over the Hainich National Forest, Thuringia, Germany. LiDAR provides an unprecedented means for mapping forest structure in 3-D over large areas.

Focus 2. Organisms as ecosystem engineers

"Ecosystem engineers" are organisms that directly or indirectly modulate the availability of resources to other species, by causing physical state changes in the abiotic or biotic environment. We are studying the ecosystem impacts of two such engineers in African savannas - termites and elephants.

Termite mounds represent nutrient and biodiversity hotspots within the broader landscape matrix. Termites build their mounds from clays and are a major source of particle and nutrient redistribution in savannas. We are using LiDAR data collected by the Carnegie Airborne Observatory (CAO, http://cao.ciw.edu) to map the spatial location of termite mounds (Figure below) to gain better understanding of the spatial distribution and density of mounds on different soil types and under different rainfall regimes. We are also conducting a range of field studies to assess the scale of termite mound influence as a forage resource for other organisms.

At the larger end of the organism spectrum, elephants modify the physical environment by breaking branches and pushing over trees. Large



An image derived from LiDAR data collected by the Carnegie Airborne Observatory (CAO, http://cao.ciw.edu, © Carnegie Institution for Science). Termite mounds are visible as small, regularly spaced dimples on the hillslope crests.

trees form islands of biogeochemical activity within the landscape matrix, but are disappearing in many savannas through the interaction of increasing elephant densities and fire. We are using satellite imagery and airborne LiDAR (from the CAO) to understand the rate and spatial distribution of elephant impacts on large trees across different substrate, hillslope and rainfall settings. This research is conducted in close collaboration with South African National Parks (SANParks) scientists to understand the biogeochemical consequences of tree loss, and provide crucial information for the setting and evaluation of biodiversity conservation objectives.

Focus 3. Disturbance effects on ecosystem processes

The vegetation present at a given point in a landscape is a function not only of climate and environmental resources, but also of various disturbance agents acting across that landscape. In savannas, vegetation height and biomass is often much lower than what we would expect from climate potential alone, as fire, herbivores, wind and human land-use disturbance reduce standing biomass and are major determinants of vegetation structure and dynamics. We aim to understand how disturbance effects vary spatially across landscapes, and how the relative importance of different disturbances varies with spatial context.

Fire effects on carbon storage in savannas represent significant uncertainty in global carbon budgets, driving disparities between potential and realized biomass. We are using a network of long-term fire experiments in the savannas of southern Africa, northern Australia, and South America to improve understanding of how fire influences vegetation structure and carbon storage. This research is closely connected with land managers in these systems, who are interested in the biodiversity and carbon management implications of different fire policies.




Soils and Ecosystem Processes

Soils play an important role in the global greenhouse gas balance. They are relevant for many ecosystem processes, e.g. plant production and decomposition of organic material, comprising the largest terrestrial carbon reservoir. We analyze the dynamics of soil carbon storage and the natural or anthropogenic mechanisms determining its stability. We therefore monitor soil carbon stocks and study the complex interactions between vegetation, climate, soil organisms and properties.

Soil is an important site factor and its fertility determines plant and food production. It is also the habitat for a huge and diverse community of soil organisms which are responsible for the decomposition of dead organic material. Soil organic carbon content is a good indicator for site fertility, and soils are the biggest terrestrial reservoir for organic carbon on Earth. This reservoir is fed from carbon fluxes entering the soil (mainly as dead plant material), and reduced by carbon being mineralized (especially by microbes). As mineralization leads to the release of CO_2 into the atmosphere, soils can be a significant source of this greenhouse gas. Therefore it is important to understand soil carbon dynamics and the response of soil processes to global environmental changes and land use.

Soil processes determining carbon turnover are still largely unresolved due to their high complexity. Soil processes depend on interactions between vegetation composition and productivity, soil organism abundance and activity, abiotic soil properties, and climate. They are additionally modified by land use and management, e.g. by vegetation changes, fertilization, or soil disturbance by plowing. The huge spatial variability of soils, their invisibility from the surface, and destructive sampling procedures so far hampered better characterization of soil carbon turnover and upscaling of point measurements to larger areas.

Focus 1. Soil carbon monitoring

Today it is assumed that European forests and grasslands are soil carbon sinks while croplands are minor sources. Evidence comes from gas exchange measurements and model results. Because of the large numbers of samples and long time periods required, direct observations of changes in soil carbon stocks are very difficult. Still they are necessary to verify the trends described above. In 2004, our group started a long term plot-based soil carbon monitoring at 12 European FLUXNET sites,

Portrait of the Group Leader

Marion Schrumpf studied geoecology at the University of Bayreuth where she also received her PhD. During that time her main research focus was on soils and nutrient fluxes in mountain rainforest ecosystems of Africa and South America. She came as a postdoc to MPI-BGC Jena in 2004, to study the soils part of the EU project "CarboEurope". Her current focus now lies in the determination of the temporal and spatial variability of carbon stocks in European soils, the processes underlying this variability, and sensitivities to environmental changes.

contact: marion.schrumpf@bgc-jena.mpg.de

including forests, grasslands, and croplands (CarboEurope-IP). The first forest site, an old growth forest in central Germany, was resampled in 2009. The results indicate that the soil was a small net carbon sink during the last five years which is in line with gas exchange measurements. The resampling of other sites is ongoing.

Focus 2. Mechanisms determining soil carbon storage

Dead plants are the main source for new carbon entering the soil, but only a fraction of this carbon will form new soil organic matter. We follow the flow of carbon from plants into the soil using stable isotope labeling of living plants in greenhouses. This allows us to determine how much of the plant carbon is respired, integrated in the soil microbial biomass, or stored as soil organic matter under different environmental conditions (QUASOM-Project).

All organic material in soils is potentially degradable by microorganisms, provided the environmental conditions favor microbial growth. However a number of mechanisms reduce the bioavailability of organic material in soils. One of those mechanisms is the association of organic carbon with minerals. We want to characterize the factors driving the mobilization and immobilization of organic carbon adsorbed to the mineral phase, and the relevance of this protection mechanism for different soil types.

Distribution of our soil monitoring sites in Europe (circles), including grasslands (green), croplands (red), deciduous forests (black) and coniferous forests (blue).

Focus 3. Land use, biodiversity, and environmental changes

Ecosystem processes are affected by different kinds of disturbances, such as land use change, climate change, or nitrogen deposition. Within the Biodiversity Exploratories (http://www.biodiversity-exploratories.de/) we are studying the effect of land use and management, and related changes in plant and microbial diversity, on soil carbon storage and turnover at the plot and landscape scale. As we found out, changes in plant species composition affect the amount and quality of organic matter entering the soil. Roots are frequently overlooked in ecosystem studies and we are especially interested in their role for soil carbon storage at different depths. We also address soil moisture and temperature effects on soil processes in laboratory and field experiments.

In greenhouses we study the fate of new plant-derived carbon in the soil, by continuous labeling of peppermint plants. We further determine how new plant carbon sources affect the decomposition of old soil organic matter (QUASOM field experiment).



Seeing the forest for the trees – changes in tree physiology in a drier world

Forests are the most important terrestrial ecosystems but their survival is threatened by increasingly frequent occurrences of global-change-type drought spells. Mechanisms of drought-induced tree mortality are not well understood; however, a thorough knowledge of the underlying processes is key to understanding feedback loops between global change and vegetation dynamics. Our project investigates physiological processes in trees dying from drought.

Trees are exceptional organisms and form the most important terrestrial ecosystem – forests. These cover nearly 30% of the land surface and foster the majority of our planet's terrestrial biodiversity. Forests also play a central role in the cycling of live-sustaining elements like carbon and nitrogen and control the global redistribution of water and solar energy. Their distribution is limited to regions where heat sums are sufficient for growth and reproduction and where precipitation is abundant.

Changes in precipitation pattern over the last decades have increased the frequency and severity of drought events with catastrophic consequences for forest ecosystems. Tree mortality rates have increased in many regions and wide-spread vegetation die-off events from heat and drought have been observed all over the globe – and this tendency is expected to increase during the upcoming decades.

Surprisingly enough there are still large knowledge gaps on how drought kills trees. Current working hypotheses – carbon starvation, impeded carbon translocation from sources to sinks within the tree and hydraulic failure of cellular metabolism – are still not entirely supported by experimental evidence (Figure next page, bottom right).

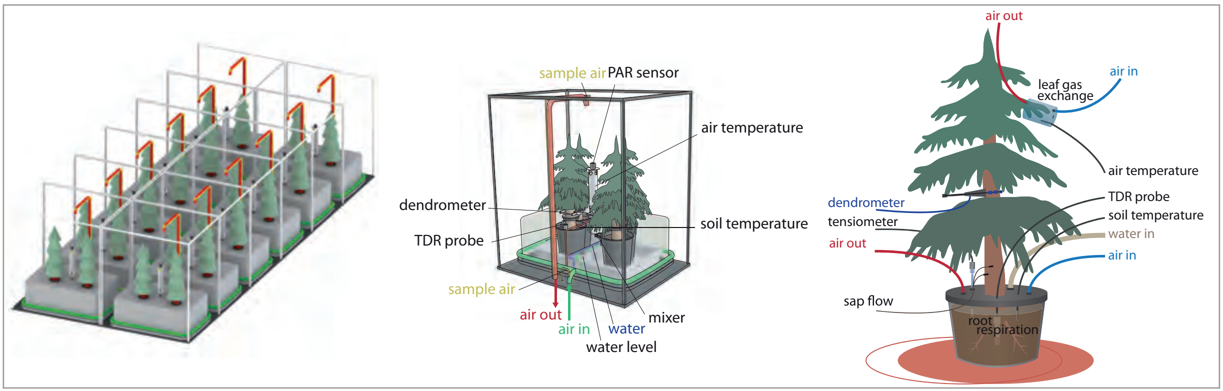
A thorough understanding of the mechanisms underlying drought-induced mortality is key to understanding the impact of future drought events on vegetation dynamics and on the cycling of life-supporting elements through forest ecosystems. The Jena Drought Stress Experiment comprises a series of experiments specifically designed to investigate the underlying processes of drought-induced tree mortality. The experimental setup allows a detailed assessment of morphological, functional and physiological processes in trees under induced lethal drought and carbon starvation.

The simultaneous impact of drought on carbon assimilation (through stomatal closure) and carbon

Portrait of the Group Leader

Henrik Hartmann has been living in Canada for almost 20 years and was trained as a forestry technician and forest engineer. In 2009 he received his Ph.D. at the University of Quebec in Montreal with investigations on sugar maple mortality after stand disturbances. He returned to Germany as a postdoc and has continued his research on tree mortality at the MPI. He now investigates stress-induced changes in tree physiology with a particular focus on the carbon balance of trees.

contact: hhart@bgc-jena.mpg.de



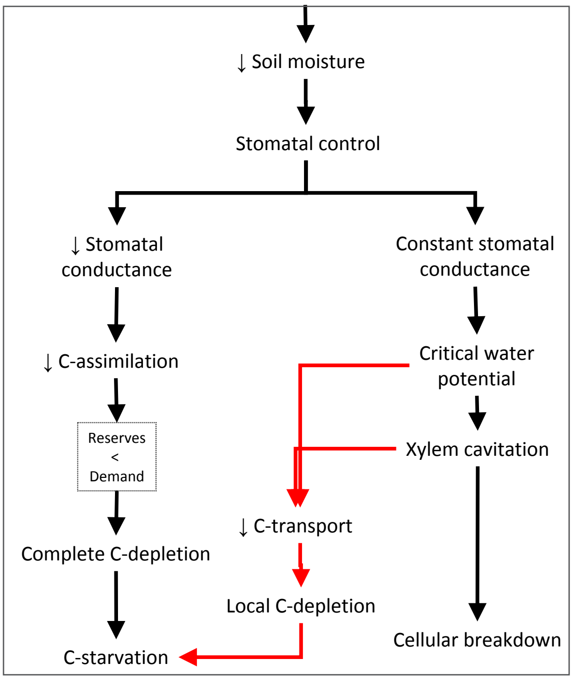
Trees are monitored continuously and extensively during the experiment – similar to patients in an intensive care unit (left). In order to partition drought effects on carbon assimilation from drought effects on carbon translocation, we simulated drought-induced reduction in carbon assimilation by withholding CO_2 from the atmosphere (middle and right).

translocation (through reduced hydration of vascular tissue) hampers a clear identification of their individual contribution to tree death. This is why we are simulating drought effects on carbon assimilation by withholding CO_2 from the atmosphere while simultaneously maintaining vascular tissue hydration at functional levels. This allows us to partition drought effects on carbon assimilation from (simulated) effects on carbon translocation. To do so we have designed and implemented a unique and complex facility at the MPI for Biogeochemistry in Jena (Figure at top of page).

Results obtained so far indicate that drought stress disrupts the physiological integrity of trees by separating individual tree compartments (leaves, branches, stem, roots) from each other. Above-ground tissues seemingly died from hydraulic failure (figure below) while roots were able to maintain functional levels of tissue hydration for longer and hence were capable of remobilizing stored carbon better than above-ground tissues. This didn't prevent our trees from dying; roots died last and from carbon starvation.

Experimental trees (spruce) during the field trial. Droughted trees died after ~13 weeks (right) while control trees survived the experiment (left).

The results of our experiments significantly contribute to the general understanding of drought-induced tree mortality. In doing so, they will also be useful for developing mitigation strategies against climate-change-type tree and forest mortality in a warmer and drier future world. However, we acknowledge the limitations of greenhouse and garden experiments with respect to their implication for natural forests. This is why we are currently planning to extend our research to similar manipulations in natural ecosystems. This will increase the general outreach and the applicability of the expected results.



During drought trees have to reduce water consumption (stomatal closure) but also prevent carbon assimilation. This may cause carbon starvation on the long run but only if plant hydration is sufficient for cellular survival and allows the mobilization of stored carbon.



Theoretical Ecosystem Ecology and Modeling

We study transfers of energy and matter within terrestrial ecosystems with a strong focus on mathematical models to represent relevant processes. The allocation of carbon to different vegetation components and the transformations of organic matter within the soil system are two main topics of our group. We are particularly interested in studying the responses of forest carbon stores to changes in climate and interactions among multiple biogeochemical cycles.

Ecosystem ecology integrates processes occurring in both vegetation and soils, and focuses on understanding the mechanisms controlling stocks, fluxes, transfers, and transformations of carbon and other biogeochemically-relevant elements. Compared to the theory of population and community ecology, theoretical ecosystem ecology is still in a development phase, which offers opportunities to contribute to this branch of ecology.

An important aspect of ecosystem ecology is carbon cycle research and global change. Natural and anthropogenic ecosystems store large amounts of carbon and play a significant role in regulating the rates of cycling of other biologically-relevant elements. Advances in theoretical ecosystem ecology can lead to improved numerical models to predict the interactions between the carbon cycle and climate as well as the effects of human activities on ecosystem's carbon and nutrient cycles.

Overarching research questions that guide our work include: What is the sensitivity of terrestrial ecosystems to simultaneous changes in climatic variables as well as in nutrient additions or removals? What controls and how can we characterize the residence and transit time of biogeochemically-relevant elements in ecosystems? Are there general mathematical models to represent biogeochemical cycling in terrestrial ecosystems? How can temporal variability, system heterogeneity, and perturbations be included in these general models?

Focus 1. Soil organic matter dynamics

Currently, one of the major challenges in Earth system science is to reduce the uncertainty related to a possible positive feedback between soil carbon stocks and global atmospheric temperatures. Soils store large quantities of carbon, and as temperature increases more carbon can be transferred from soils to the atmosphere by microbial respiration. In the atmosphere this extra carbon can cause more warming which in turn can promote more carbon

Portrait of the Group Leader

Carlos A. Sierra obtained a Bachelors degree in forestry at the National University of Colombia, and received his Master of Science and PhD in forest science from Oregon State University. He joined the Max Planck Institute for Biogeochemistry in 2010 as a postdoc and since then started building up the Theoretical Ecosystem Ecology and Modeling group within the Department of Biogeochemical Processes.

contact: csierra@bgc-jena.mpg.de

release from soils.

This problem however, has been difficult to study due to limitations in observational data and the lack of a coherent theoretical framework. We are working on advancing the mathematical theory of soil organic matter decomposition; specifically, on how organic matter is stabilized and destabilized in soils, and how this processes responds to changes in multiple environmental variables such as climate.

To integrate our theoretical work, we are currently developing the SoilR modeling framework. This is an add-on software for the R programming language. SoilR integrates theoretical concepts we have developed and allows for the implementation of a large number of different soil organic matter decomposition models, with multiple choices for the temperature and moisture responses of decomposition. It is open source software freely available on the internet.

Focus 2. Ecosystem-level carbon allocation

When carbon enters a plant through photosynthesis it can be allocated to foliage, branches, stems, or roots, or it can also be respired during cell metabolism. There are a large number of observations, experiments, and models addressing this research problem, but there is a paucity of work on synthesis and development of mathematical theory.

Our work in this area focuses on ecosystem level carbon allocation rather than at the single-plant level. At the ecosystem level we study how the products of Gross Primary Production (GPP) and Net Primary Production (NPP) are assigned to different ecosystem compartments such as foliage, stems and roots as well as how much it is respired.

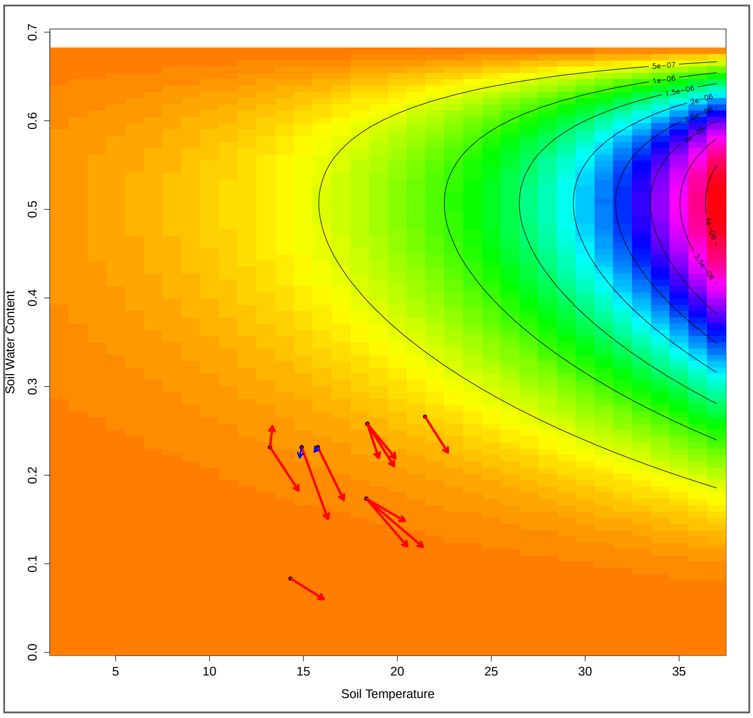
Currently we are studying the role of belowground resources (nutrients and water) on the allocation of the products of NPP. We are using as a model system an Amazon forest landscape that includes a series of forests growing under soils at different levels of development, but under similar climatic characteristics.

Additionally, we are developing a mathematical theory to integrate the theories of allometry and allocation under a common framework. We expect this work to help us to better understand global patterns of allometry and allocation, and to integrate these theories in new numerical models.

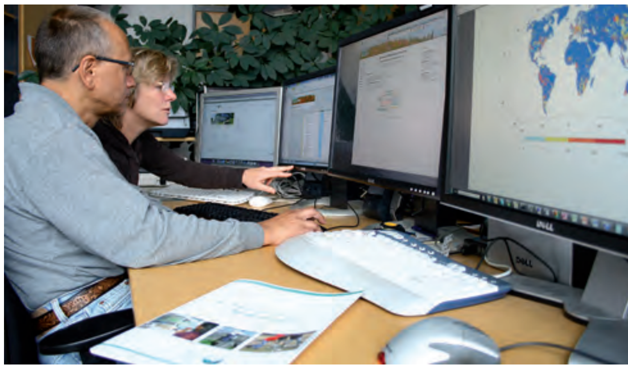
Focus 3. Forest carbon balance

Carbon cycling at the ecosystem level integrates above and belowground processes related to transfers of carbon among different pools and transformations to different compounds. We explore the temporal dynamics of forest carbon stores and investigate how they respond to natural and anthropogenic disturbances.

In this area we have developed models of ecosystem carbon accumulation in regrowing forests for the main carbon pools, and have studied the consequences for carbon accounting in continental-scale carbon budgets. We also have explored the effects of forest management on ecosystem carbon stores and their potential for carbon sequestration projects.



Sensitivity of soil organic matter decomposition to simultaneous changes in temperature and moisture. Points represent the combination of soil temperature and soil water content of the control treatment of experiments, and arrows represent the direction of change imposed by the treatments. Red arrows represent soil warming while blue arrows cooling. Contours and colors in the background represent model predictions of the sensitivity of reaction velocities for enzymes.



The Functional Diversity of Plants

The functional diversity of plants determines the response of the terrestrial biosphere to environmental changes - ranging from acclimation and adaptation to migration or extinction of single species or whole ecosystems. In the group Functional Biodiversity we therefore aim at consolidating empirical data bases to characterize plant functional diversity at global scale, understand links to ecosystem functioning, and improve its representation in Earth system models.

During the last centuries humans have increasingly modified the environment worldwide, with large consequences for biodiversity. Every day up to 130 biological species go extinct on our planet and human activity promotes the spread of alien species across the globe. How are ecosystems influenced by the loss or addition of species? How will the ecosystems interact with climate-driven shifts in disturbance regimes? How will these interactions modify species distribution - and vice versa? To address these questions we have to bridge the gap from species occurrence and richness to biodiversity in terms of variability of biogeochemical processes linked to ecosystem functioning. Here plant traits – the morphological and physiological properties of plants – determine how the primary producers respond to environmental factors. Traits provide a quantitative link from species occurrence to ecosystem functioning. However, so far data on plant traits have been dispersed over numerous databases, most of them not available to the scientific community. The functional biodiversity group has therefore initiated an international initiative, called TRY, to consolidate the data basis of plant traits at global scale and make these data available.

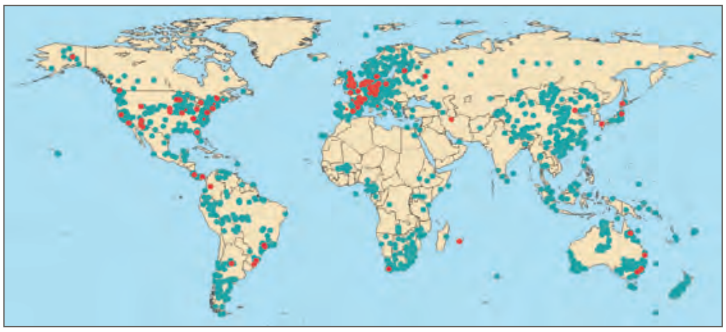
The TRY initiative (www.try-db.org) is an international network of vegetation scientists from more than 100 institutions, jointly headed with DIVERSITAS (International Programme of Biodiversity Science), IGBP (International Geosphere-Biosphere Programme), University of Leipzig, Multidisciplinary Institute of Plant Biology (IMBIV-CONICET, Córdoba, Argentina), Macquarie University (Sydney, Australia), CNRS and University of Paris-Sud (France). So far TRY has brought together 93 separate plant trait databases to produce a global database containing 3 million trait records for about 69,000 of the world's ~300,000 plant species. This database covers more than 1,000 different plant traits, ranging from leaf area, to fire tolerance, and nitrogen fixation

Portrait of the Group Leader

Jens Kattge studied biology and chemistry with major subjects plant ecology and soil sciences at the University of Gießen, where he also received his PhD. In 2002 he joined the Max Planck Institute for Biogeochemistry working as a postdoc on terrestrial biosphere modeling and data assimilation. He has been head of the group 'Functional Diversity of Plants' since 2010.

contact: jens.kattge@bgc-jena.mpg.de

capacity. The database was developed and is hosted at the Max Planck Institute for Biogeochemistry in Jena. Several groups worldwide use plant trait data via TRY. Within the Department of Biogeochemical Processes, the TRY database is used to study the impact of disturbances on species composition and ecosystem functioning in the Amazonian rain forest, and provides empirical large-scale context for specific process studies, *e.g.* plant respiration, litter quality, or decomposition rates.



Location of partner institutes (red) and sample sites (cyan) of the TRY network (status 03/2011).

In addition, research of our functional biodiversity group focuses on the following areas:

Focus 1. Quantifying and scaling plant trait variation at the global scale

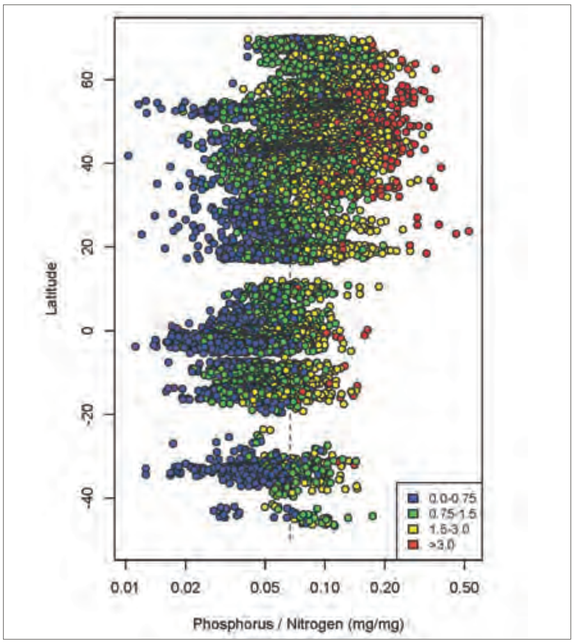
We aim to use the rich compilation of data in the TRY database to quantify and understand patterns of plant trait variation at the global scale. For example, through projects such as 'Plant Functional DIVersity of GRASSlands' (DIVGRASS) and a funded collaboration with the our Department of Biogeochemical Integration and the University of Minnesota, we are characterizing plant trait variation in terms of statistical distributions and focusing on describing how plant traits vary spatially and in relationship to climate and soil characteristics. Other measures of variation allow us to identify phylogenetic constraints, explore the covariation of different traits, and disentangle variation within and between species and plant functional types, including those commonly used in global vegetation models.

Focus 2. Plant functional diversity and ecosystem functioning

The exchanges of carbon dioxide, water vapor, and energy are emergent properties of the ecosystem - the interplay of soil and vegetation. Plant trait data are required to link ecosystem functions and properties to plant function and diversity: Is there an effect of plant functional diversity on ecosystem functions and properties (a) between sites and (b) within? Here, eddy covariance measurements provide the opportunity of moving beyond "static" measures of ecosystem function like peak biomass towards using dynamic measurements, like evaluation of gross primary production (GPP), or drought sensitivity to determine the importance of functional diversity in controlling ecosystem function. In cooperation with our modellers this focus brings together plant traits and eddy covariance measurements.

Focus 3. Improving the representation of the terrestrial biosphere in Earth system models

Many Earth system models employ plant traits as parameters, but these models are still far from fully exploiting the wealth of available information. In cooperation with the Max Planck Institute for Meteorology and the IGBP initiative on Biome Boundary Shifts, we connect the respective scientific communities with the goal to channel plant ecological information into Earth system models. Getting from plant traits to model parameters and dealing with numerous covariates requires new statistical tools. We apply and develop inversion techniques and Hierarchical Bayesian models. Typical results that have also been applied in global models show that e.g. the nitrogen/phosphorus stoichiometry of plant leaves is dominated by phosphorous limitation on old soils in the tropics and southern hemisphere, with consequences for carbon sequestration.



Latitudinal gradient of the phosphorus/nitrogen ratio in plant leaves. The colors indicate P content per dry mass (blue: low, red: high; mg/g; TRY database, 12651 observations).

W2 Research Group
Molecular Biogeochemistry

The research group explores key processes in the global biogeochemical cycles at the molecular level. Biomarkers and their isotopic content hold information on the regulation of the individual processes. The group is developing new tools and is applying existing techniques to investigate single key processes.

Biomarkers are molecules that contain information on the presence of individual organisms in the environment. They span a variety of molecules with different chemical characteristics and are read using the "omic" approaches. DNA and RNA, for example, contain the genetic information of organisms that can be read to identify individual organisms. Both molecules, however, are very easily decomposed in the environment and consequently provide only snapshots of actual organisms and communities. In contrast, lipids are compounds used to make cell membranes and cuticular waxes that can persist for a long time in the environment, and can even be isolated from Archaean rocks. Lipidomics is used to develop lipid profiles that allow identifying individuals or groups of organisms as well as profiles characteristic for environmental conditions including salinity, anoxia, and desiccation.

The key questions in molecular biogeochemistry are: Who is there, what are they doing, and why? Proteomic and metabolomic approaches bridge from the presence of organisms to their function in the environment. However, in order to explore the function of individual processes and in particular how the microbial fluxes link to the overall functioning of ecosystems, additional information is drawn from the isotopic information of biomarkers. Compound-specific isotopes (^{13}C, ^{14}C, ^{15}N ^{18}O and ^{2}H) of biomarkers trace the flow of matter through the element cycles. Our group combines approaches using the natural abundance of stable isotopes, isotope labeling, and stable isotope probing (SIP) to quantify key processes in the environment.

Focus 1. Understanding the origin, fate and stability of organic matter in soils

Soil organic matter (SOM) remains the largest single unknown in the terrestrial carbon cycle. We investigate in various projects how abiotic factors, like organic matter input, parent material, humid-

Portrait of the Principle Investigator

Gerd Gleixner is senior group leader in the Department Biogeochemical Processes and holds a professorship for organic geochemistry at the Friedrich Schiller University in Jena. He studied agricultural sciences and biotechnology at the Technical University of Munich. His research interests are terrestrial organic matter cycling, metabolic isotope fractionation, and palaeoclimate reconstruction.

contact: gerd.gleixner@bgc-jena.mpg.de

ity and temperature (see also QUASOM project) as well as biotic factors such as stand age, plant, and microbial diversity, influence SOM storage. The isotopic information of ^{13}C, ^{14}C, and ^{15}N of biomarkers from individual compounds and fractions determine the molecular turnover of SOM and suggest high vulnerability of SOM stored in soils.

Installation of a litter exchange experiment in the Hainich National Park

To understand the role of dissolved organic carbon (DOC) in the environment we determine its molecular and isotopic composition. The molecular fingerprint of DOC established by pyrolysis-GC/MS and LC/MS helps to identify sources of DOC. The isotopic content of DOC in soil depth profiles suggests that DOC from the surface is reactively transported in the soil and that DOC in deeper soil horizons is not related to the DOC in upper soil horizons.

Focus 2. Understanding carbon flow in plant metabolism

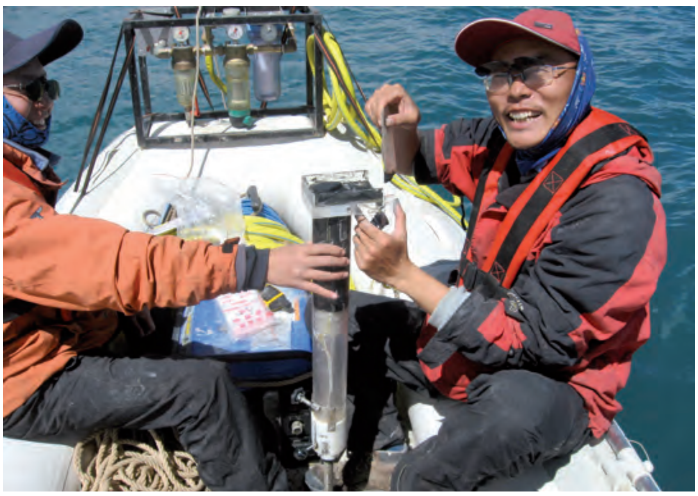
Carbohydrates are the central molecules in plant metabolism. In the daytime they transport energy and carbon fixed by photosynthesis to support respiration, storage, growth and defense. At night, they provide energy for the cellular metabolism using mitochondrial respiration. However, the regulation of carbohydrate metabolism and the role of different processes in plant metabolism are still not completely understood. Our group develops and applies molecular techniques to use the isotopic information of plant metabolites to trace the flow of carbon in plants and to understand its regulation.

Focus 3. Understanding the role of biodiversity in biogeochemical cycles

Plants react not only to abiotic factors like climate, but also to the presence of other plants and microorganisms in the soil. The interaction can be positive if, for example, resources are used complementarily but also negative if pathogens are infecting plants. At the community level, these interactions are difficult to investigate. Molecular tools can help to differentiate between the responses of individual species and communities. We focus on the effect of tree and grassland diversity on (1) the link between above- and below- ground diversity; and (2) the link between plant diversity, soil organic matter (SOM) dynamics and export of dissolved organic matter. In short term experiments we use isotopic labeling to trace the effect of diversity on how carbon is allocated from plants to soil microorganisms and SOM. In the long term we investigate if higher plant diversity assures a long term success of the community, even if some individual species of the community may fail in events like drought, late frost, and flooding (insurance hypothesis of biodiversity).

Focus 4. Understanding and reconstructing past climate and vegetation dynamics

Understanding the links between ecosystems, past, and present climate will improve our prediction for future climates and how they may affect biodiversity and ecosystem function. Reconstructions of the Holocene climate are strongly linked to information from polar ice cores, while climate reconstructions for larger areas that permit separation of the effects of local climate effects from large-scale circulation patterns are still very sparse. We explore the use of hydrogen isotopes in biomarkers as a proxy for palaeoclimate reconstructions. A major focus has been the construction of quantitative transfer functions linking hydrogen isotopes to the hydrologic cycle across humid, tropical, boreal, and mountain ecosystems. These methods are now being applied to the large-scale climate reconstructions of monsoon variation in the past 10,000 years on the Tibetan plateau.



Development of global transfer functions for hydrogen isotopes from biomarkers (Garcin et al., 2011)