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.

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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.

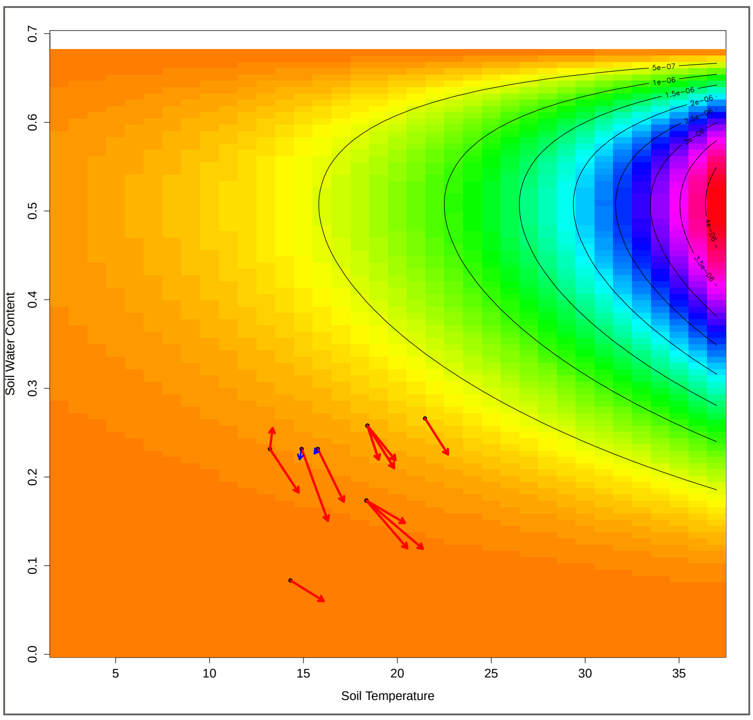
Currently we are studying the role of belowground resources (nutrients and water) on the allocation of the products of NPP. We are using as a model system an Amazon forest landscape that includes a series of forests growing under soils at different levels of development, but under similar climatic characteristics.

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.