Carbon and Water Cycling in a Changing Amazon

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Background

Tropical forests process more carbon, water and energy, and are more diverse than any other terrestrial ecosystem. The Amazon Basin contains the largest continuous tropical forest in the world and plays an important role in global climate and atmospheric chemistry. Amazon tropical forests and soils contain ~100 billion metric tonnes of carbon in plants and soils that is potentially vulnerable to release by fires associated with land clearing or increased tree mortality associated with climate change. Amazon forests also play an important role by removing about 0.4 billion metric tons of carbon from the atmosphere every year, in many years completely offsetting deforestation releases. However, we know little about the fundamental processes that underly this carbon uptake and whether it can be sustained given expected changes in forest diversity and structure in response to global warming and expected increases in climate extremes like drought.

Concern for the future of Amazon forests results from the synergies between climate change and deforestation. The removal of forests increases local surface temperatures because crops and grasses decrease the evaporative cooling offered by deeper-rooted trees. This in turn reduces the water available for precipitation and further lengthens

the dry season. Several studies have suggested that the Amazon is reaching a tipping point, where the existing forests can no
longer be sustained but will increasingly be replaced by savanna-like ecosystems. Such changes would result in large losses of carbon and biodiversity, but also have consequences for the viability of crops that will also experience regional high temperatures and longer droughts. The southern Amazon is a perfect location to study whether and how compounding disturbances may drive severe and persistent transformation of forests into highly degraded savanna-like vegetation. The Tanguro Ranch is located in the 'Arc of deforestation', where it is expected to become hotter and drier in the near future (something that is already underway), and in the zone where forest borders savannas further to the south. The region is also home to one of the most dynamic agricultural frontiers in the planet, with large tracts of forests and pasturelands being replaced by large-scale mechanized agriculture, which exports most of its soy, cotton, and corn to Europe and China.

The Research Project

Prof. Trumbore's Balzan research project aims to initiate new research at the Tanguro Ranch and in the region to improve fundamental understanding of how individual trees and forest communities respond to extreme drought. This research will be integrated with ongoing remote sensing and flux data to study how forests can either recover or be degraded to the point where they will transition to a new state, and how that in turn may feed back to climate. The proposed research integrates radiocarbon measurements with a study of the role of carbon reserves and water fluxes in trees that will discover which tree species will be most likely to be killed by extreme drought and which will survive and recover. It will conduct measurements on trees in an existing gradient of disturbance to study how that response depends on conditions. An additional manipulative experiment (girdling) to simulate carbon starvation associated with drought will also be conducted. The proposed two-part research project will take advantage of the long-running data collected by collaborators at the Tanguro ranch, including the knowledge of tree species distributions in intact and degraded forests. The main collaborator is Dr. Paulo Brando, who is affiliated with IPAM and an Assistant Professor at the University of California Irvine. Together with Prof. Trumbore, he will supervise the postdocs and PhD student. As Dr. Brando is not affiliated with MPI-BGC, Dr. Henrik Hartmann in Trumbore's department will take over financial and scientific responsibilities if needed, collaborate scientifically, and help supervise the PhD students.

The first question the project seeks to answer is: How are the carbon storage and water cycling traits of different tropical tree species (growth rate, rooting depth, wood density) related to their ability to survive under drought and heat stress? The high diversity of trees in Amazonia includes a mix of species that have developed different evolutionary strategies for carbon allocation and water availability. The causes of tree death during a drought, especially in tropical forests, are still not well understood. One hypothesis is "carbon starvation", reflecting the fact that leaf photosynthesis shuts down in dry, hot conditions, meaning the trees must rely on stored reserves to survive. A second hypothesis is hydraulic failure, which has to do with the ability of trees to bring water up through their roots and stems to their leaves. Trees that maximize short-term growth tend to die young, store less carbon in reserve, and use more water for the amount of carbon they fix, while other trees live longer, grow slower, and store more carbon reserves. The aim of this part of the research project is to link carbon storage patterns in tree stems and roots to the traits of that species, and to measure the age of the storage reserves using radiocarbon. The group will also use radiocarbon to calibrate growth rings and thereby study growth rates over the last 60 years for the studied tree species. This work will be led by a postdoctoral researcher employed at MPI-BGC (Max Planck Institute for Biogeochemistry). A PhD student just finishing his studies at the institute, David Hererra, has developed a novel histological staining method to quantify spatial distributions of stored sugar, starch and lipids, and relate these to the anatomy and life traits of different trees. He was starting to install additional field measurements at the research site in Tanguro Ranch, Brazil, to assess how these traits related to mortality, sap flux and growth rates, but the covid pandemic interrupted these activities. With Balzan funds, his employment at MPI-BGC as a postdoctoral researcher will continue and allow him to follow up on this promising line of research. A new PhD student would support the research by measuring radiocarbon in respired carbon and nonstructural carbohydrates in stems and roots, and by including linking wood anatomy to root traits. Both the postdoctoral researcher and PhD student would travel to Brazil for field research (presumably starting in 2022). In the first year, rather than travel, a similar amount of funds would be required to procure high quality computers for data processing and communication to allow virtual presence. Moreover, consumables for analyzing sugars, starches, lipids, and isotopes in collected samples will also be necessary.

The second aim of the project is to upscale our understanding of how trees with different traits will respond to stresses like drought in order to answer these questions: How will tree communities evolve in response to multiple stresses? Will they cross a tipping point and how does this affect climate services such as evaporative cooling and carbon storage? This work will fund a Brazilian postdoctoral researcher who will work primarily at the Tanguro ranch (employed through an ongoing agreement with IPAM). Leonardo Maracahipes is finishing his PhD at the Federal University of Mato Grosso in Brazil. He has been working with plant trait data and long-term growth data as well as managing the data collection and maintenance of the eddy towers. He will add new sapflux measurements of the selected trees and link these to the eddy covariance and leaf phenology data from the sites and analyze the existing long-term data to link the traits observed for species to track patterns of tree mortality at the stand level.

To support this research, Trumbore has requested that the entire sum of the Balzan Prize funds be used for research purposes, and that it be administered through the Max Planck Institute for Biogeochemistry.

Outreach Activities

In addition to the proposed support for the postdocs and PhD students, Balzan funds will also be used to support two workshops. These will include a field school for students to learn field methods in 2022, and a workshop in Europe on radiocarbon tools being developed to be used for studying tropical carbon cycling and global carbon cycling.