FUNDED PHD THESIS 2024-2027 - Montpellier

PhD Title
Drought effects on carbon assimilation and allocation in living tree biomass in forests

Host laboratory :
CNRS-CEFE Centre d'Ecologie Fonctionnelle et Evolutive (UMR 5175)
1919 route de Mende, 34293 Montpellier - France

Supervisors :
(1) Jean-Marc LIMOUSIN (CNRS, Montpellier), jean-marc.limousin@cefe.cnrs.fr
(2) Maxime CAILLERET (INRAE, Aix en Provence), maxime.cailleret@inrae.fr

PhD project description

Context
Forests are a major player in the global carbon (C) cycle and at the heart of the climate change mitigation initiatives of the 2015 Paris Agreement. In Europe, forests currently absorb approximately 10% of the region's fossil-fuel emissions, but models strongly disagree on the projection of this C sink under future climate change, and even on whether or not European forests will remain a C sink or become a C source by the end of the 21st century. Main uncertainties arise from the fact that forests C sinks are simultaneously favored by increasing atmospheric CO_2 concentration, nitrogen deposition and longer vegetative periods due to warming, and are more strongly limited by water availability, due to decreasing summer precipitations and increasing evaporation (IPCC, 2021). Three main scientific issues are currently limiting our understanding of climate change effects on forest's carbon sequestration. The first one relates to the allocation of carbon among the different tree organs and the link between carbon photosynthetic assimilation and sequestration in perennial tree biomass. The second one relates to the degradation of organic matter and the sequestration of soil organic carbon under the antagonist effects of warming and soil drying. The third issue relates to the interactive effects of water and nutrient limitations for tree growth and forest functioning. Within a larger scientific project (PEPR FairCarboN Drought ForC – 2023-2028) that aims at studying these three issues, the PhD project will study how the C allocation in tree biomass changes among the different organs (wood, roots, leaves and reproductive organs) in response to increasing water stress and decreasing C assimilation.

Objectives and main tasks:
The main objectives of the PhD thesis are to quantify the consequences of increasing drought on i) forest C assimilation and wood growth, ii) C allocation among perennial and short-lived tree organs, and iii) total belowground C allocation. The research project will use both the results of five long-term rainfall manipulation experiments set in different forest ecosystems (three Mediterranean forests in Southern France, one temperate forest in North-Eastern France, and one eucalypt plantation in Brazil), and of carbon fluxes measured by eddy covariance in different forest sites within the ICOS network, to study the experimental and inter-annual effects of changing water availability.
Three main research topics will be investigated during this PhD project:
(1) **The link between photosynthetic C uptake and wood stem growth**. C allocation to tree growth is commonly represented as a fixed fraction of the amount of C assimilated by

photosynthesis. This view has been recently invalidated by accumulating experimental evidence that tree cambial activity (sink strength) is more sensitive to water stress than carbon assimilation (Körner 2015; Lempereur et al. 2015), and that the decoupling between assimilation and growth increases with aridity (Cabon et al. 2022). To study this phenomenon, the PhD candidate will separately quantify the effects of drought on C assimilation and wood secondary growth, and investigate the temporal relationships between the two by using existing data on C and water fluxes, trunk diameter measurements, and new systematic retrospective measurements of secondary growth via sampling of tree cores. On important challenge with small-scale rainfall manipulation experiments where eddy covariance fluxes are not available will be to estimate the treatment effect on the photosynthetic uptake (Misson et al. 2010). This will be done using a combination of ecophysiological methods, while tree growth and wood biomass increment will be estimated from annual inventories of tree diameter and demography (recruitment and mortality), tree ring width and micro-density measured on wood cores.

(2) **The effects of drought on C allocation among the different aerial tree organs.** Trees adjust to drought by modifying their hydraulic architecture, which implies a larger allocation to the belowground organs and a reduction of the leaf area per unit of sapwood area (Choat et al. 2018). Drought also modifies C allocation to reproductive organs (Bogdziewicz 2021). By modifying the fraction of tree biomass in short- and long-lived organs and in the above- and belowground pools, drought ultimately modifies the C residence time in the ecosystem (Kannenberg et al. 2022) and the forest's C storage potential. Therefore, the drivers of C allocation and their responses to climate change are a major uncertainty and a research priority for projecting forests C sink (Babst et al. 2021). The relative allocation of C to wood, leaves, and reproductive organs, the components of aboveground net primary productivity (ANPP), will be quantified using long-term data of litter quantity collected in litter traps and sorted by organ type (Gavinet et al. 2019). Consequences of drought on tree architecture will also be investigated by retrospective measurements of shoot length, number and type to reconstruct the primary growth (Barthélémy and Caraglio 2007).

(3) **The belowground C allocation and its response to drought**. Belowground C allocation may represent from 22% to 63% of the total gross primary production of forests and it increases with water limitations, but it is understudied and poorly represented in models due to methodological difficulties (Litton et al. 2007). Total belowground carbon allocation (TBCA) is considered as the sum of C allocated to coarse and fine roots, transferred to mycorrhizae, or lost through root autotrophic respiration and exudation of C compounds to the soil. TBCA is often calculated as the difference of gross primary production (GPP) and ANPP plus the above ground autotrophic respiration (Rambal et al. 2014), which can be deducted knowing soil respiration. The PhD will contribute to go further in our understanding of TBCA by measuring directly the allocation to roots and mycorrhizae within the different rainfall manipulation experiments of the project. The coarse root biomass will be estimated in soil pits and soil cores (Addo-Danso et al. 2016). Fine root production will be estimated several times throughout the project using in-growth cores. The C flux to mycorrhizae will be estimated with buried hyphal bags that will be regularly collected and measured for ergosterol contents (Wallander et al. 2013).

References:

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Rambal S, Lempereur M, Limousin JM, Martin-StPaul NK, Ourcival JM, Rodriguez-Calcerrada J. (2014) How drought severity constrains gross primary production (GPP) and its partitioning among carbon pools in a Quercus ilex coppice? Biogeosciences, 11: 6855-6869, doi: 10.5194/bg-11-6855-2014
Wallander et al. (2013) Evaluation of methods to estimate production, biomass and turnover of ectomycorrhizal mycelium in forests soils - A review. Soil Biol. & Biochem. doi:10.1016/j.soilbio.2012.08.027

Work environment

The PhD candidate will be hosted at the Centre for Evolutionary and Functional Ecology (CEFE) of the CNRS Montpellier, one of the largest and most dynamic research units in ecology in France. Within the CEFE she/he will work within the FORECAST research group in the Functional Ecology department, a group that focuses mainly on the functioning and dynamics of forested ecosystems under climate change. The FORECAST group manages the long-term ecological experimental site of Puechabon, since 1984, a Mediterranean *Quercus ilex* forest equipped with an ICOS-labelled eddy covariance flux tower and one of the longest rainfall manipulation experiment in the world.

The PhD project will be supervised jointly by Jean-Marc Limousin at the CEFE in Montpellier and Maxime Cailleret at the INRAE RECOVER in Aix-en-Provence. Jean-Marc Limousin is a tree ecophysiologist working on the consequences of drought on the functioning, vulnerability and functional responses of trees and Mediterranean forests. He is specialized in experimental research based on rainfall manipulation experiments, and the Principal Investigator of the AnaEE long-term rainfall manipulation experiment in Puéchabon since 2015, and of the co-localized ICOS Class 2 station since 2019. He has published 65 papers in scientific journals (h-index: 32) and supervised 3 PhD students and 2 Postdocs. Maxime Cailleret is a forest ecologist studying the impacts of climate change on vegetation dynamics, with a main focus on tree growth and mortality. He is a Principal Investigator of the AnaEE rainfall manipulation experiment in Font-Blanche, a *Pinus halepensis* and *Quercus ilex* forest studied by INRAE since 2007. He has published 52 papers in scientific journals (h-index: 28) and supervised 4 PhD students.

The PhD project will take place within the PEPR FairCarboN 'Drought ForC' project, a large research project and consortium involving 25 researchers from 9 different research units in France. The PhD candidate will have the opportunity to contribute to the ecological and physiological measures in the field at Puéchabon and Font-Blanche, to travel to the different experimental forest sites throughout France involved in the project, to collaborate with experts

from different fields and backgrounds, and to widen the scope of her/his research by participating in meetings with researchers studying soil functioning, tree mineral nutrition, and forest modelling. The national FairCarboN PEPR program, on carbon cycling in terrestrial ecosystems will also offer a stimulating research context for a young researcher and many opportunities for networking with all the experts in the topic.

The PhD project is fully funded by the PEPR program, salary plus travel expenses and cost associated with the research work. The net monthly salary will be around 2150 €/month for three years starting in autumn 2024.

Desired qualifications and skills

Master student in ecology, forestry, biogeochemistry, ecophysiology or a related field, or an engineering degree in agronomy.

The PhD candidate should have a strong interest in forest biogeochemical cycles and ecophysiology, be willing to conduct experimental research in the field and work outside in forests, and have skills in statistical analysis and the handling of large and complex datasets. Good communication skills in French and in English orally and in writing is also requested.

Applications: CV and application letters sent by e-mail to Jean-Marc Limousin (jean-marc.limousin@cefe.cnrs.fr) and Maxime Cailleret (maxime.cailleret@inrae.fr) from now and until the position is filled.

Preferred start date of the contract: October or November 2024