CENTA

UKRI Natural Environment Research Council

Project Proposal Form – 2022 entry

Project Title	**OU7 - Leaf venation and the macroevolution of flow phenotypes**
University (where student will register)	Choose an item.
Which institution will the student be based at?	Choose an item.
If other	
Theme (Max. 2 selections)	Climate & Environmental Sustainability ☐ Organisms & Ecosystems ▯☐ Dynamic Earth ☐
Key words	
Supervisory team (including institution & email address	**PI: Luke Mander, The Open University, Luke.Mander@open.ac.uk** **Co-I: Kadmiel Maseyk, The Open University, Kadmiel.Maseyk@open.ac.uk** **Hywel Williams, University of Exeter, H.T.P.Williams@exeter.ac.uk**
Is the project co-designed by a student?	Yes ☐ No ▯☐
Is the PhD suitable for part time study?	Yes ▯ ☐ This is a requirement of NERC

Project Highlights:

- Exciting blend of specimen-based and theoretical work
- Potential for fieldwork to collect living and fossil leaves
- Acquisition and development of network science skills

Overview:

Leaf venation is a biological distribution network that is strikingly beautiful and highly diverse. Some networks are characterised by a simple tree-like topology in which linear veins bifurcate without reconnecting, while others are characterised by a complex hierarchical reticulate topology in which veins of different sizes branch unequally and reconnect to form loops (Brodribb et al. 2016). It is thought that different network topologies reflect different design solutions for optimizing transport efficiency, cost of construction, and resistance to damage from processes such as herbivory and embolism (Ronnellenfitsch and Katifori 2019).

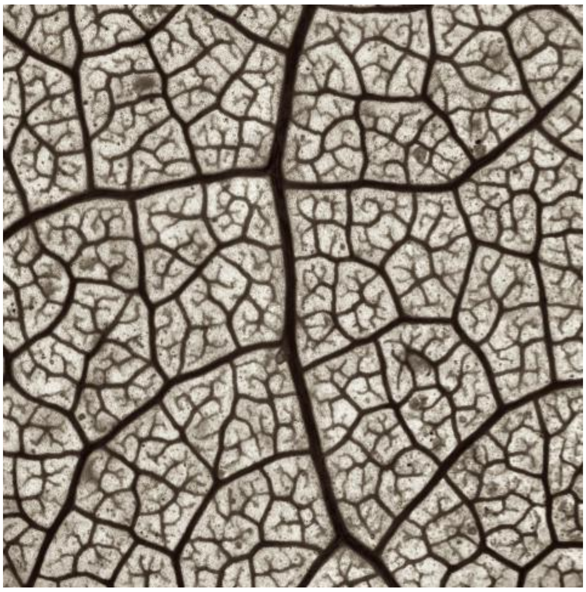

Figure 1: Segment of a Populus *leaf with its characteristically complex venation network* (from CleearedLeavesDB.org).

Alt-text: Image shows a portion of a Populus *leaf that has been chemically treated so that the venation network is visible.*

Relatively simple topologies appeared early in the history of plant evolution and are found in plants such as *Ginkgo*, while more complex topologies are found in the leaves of flowering plants (angiosperms) such *Populus* shown in Figure 1. However, there is a lack of basic data on the macroevolutionary history that underlies these two end-members. Consequently, it is unclear whether the macroevolution of venation architecture is characterised by a smooth expansion in complexity through time, or whether there were periods where complexity rose or fell markedly in response to changing functional demands (see Leslie et al. 2021 for a recent analysis of the history of morphological complexity in land plants).

The overall goal of this project is to uncover the macroevolutionary history of venation architecture by building computational models of leaf venation networks and studying how the properties of these networks vary among different taxa. This will involve generating a phenotypic space for the venation networks of a broad phylogenetic sample of living and fossil plants encompassing ferns, gnetophytes, as well as primitive and derived angiosperms. Key questions that will be explored include —1— how do different network topologies differ in terms of their robustness to damage? —2— did complex hierarchical reticulate topologies evolve and diversify in concert with other biotic events such as insect evolution, or did they appear gradually through time? —3— how does venation network topology map onto vein density, is topological complexity a mechanism by which plants generate high vein density?

Methodology:

Leaves of living plants will be harvested from botanical gardens, and the leaves of fossil plants will be gathered from rock outcrops in the UK. Living and fossil leaves will be chemically treated in the laboratories of The Open University in order to reveal their venation. Images of the venation of living and fossil plants will be captured in the laboratories of The Open University.

Fieldwork is not essential to this project. Depending on the goals of the successful candidate in terms of the acquisition and development of transferrable skills (see below), this project could be based around images contained in open-source repositories such as ClearedLeavesDB.org.

Models of leaf venation will be constructed and analysed using open-source imaging software and Python code that has been developed in-house.

Training and skills:

Students will be awarded CENTA2 Training Credits (CTCs) for participation in CENTA2-provided and 'free choice' external training. One CTC equates to 1⁄2 day session and students must accrue 100 CTCs across the three years of their PhD.

This interdisciplinary project has been designed to provide transferrable scientific skills at the interface between Earth science, evolutionary biology and network science. For an Earth science or biology graduate who has experience of computational and/or statistical work, this project offers an opportunity to develop programming and data wrangling skills that are becoming increasingly important in both academia and industry. For a computer science or mathematics graduate with a strong interest in organismal and evolutionary biology, this project offers an opportunity to develop practical skills in fieldwork and laboratory work including specimen preparation and imaging.

The School of Environment, Earth and Ecosystem Sciences has a thriving community of researchers who have a strong track record of publications combining theory with data in the Earth and Biological sciences. Full training and development will be provided in Python programming and network science, as well as laboratory work and imaging as required.

Partners and collaboration (including CASE):

This project will involve collaboration with Prof. Hywel Williams, University of Exeter, UK.

COVID-19 Resilience of the Project:

If necessary this project can be undertaken entirely from home using digital resources in online repositories.

Possible timeline:

Year 1: Build an image library of the leaves of living plants. Familiarization with network theory and code developed in-house.

Year 2: Analyse images of living plants. Build an image library of fossil leaves. Presentation of results at an international conference.

Year 3: Analyse images of fossil leaves. Presentation of results at an international conference. Write up thesis.

Further reading:

Brodribb, T. J., Bienaime, D., and Marmottant, P. (2016) 'Revealing catastrophic failure of leaf networks under stress', *Proceeding of the National Academy of Sciences, USA,* 113, 4865–4869.

Leslie, A. B., Simpson, C., and Mander L. (2021) 'Reproductive innovations and pulsed rise in plant complexity', *Science,* 373, 1368–1372.

Ronellenfitsch, H. and Katifori, E. (2019) 'Phenotypes of vascular flow networks', *Physical Review Letters*, 123, 248101.

Further details:

Please contact Luke Mander, (Luke.Mander@open.ac.uk) for further information and informal discussion about this project.

Applications should include:

- an academic CV containing contact details of three academic references
- a CENTA application form, downloadable from: CENTA application
- and an Open University application form, downloadable from: Home OU application form (if you are resident in the UK) or an Overseas OU application form (if you are an international applicant).

Applications must be sent to **STEM-EEES-PHD@open.ac.uk by Friday 7th January 2022 (12 pm, noon)**