CENTA Project Proposal Form – 2024 entry

Project Title	The macroevolution of leaf venation
University (where student will register)	The Open University
Which institution will the student be based at?	As above
Theme (Max. 2 selections)	Climate & Environmental Sustainability ☐ Organisms & Ecosystems ☒ Dynamic Earth ☐
Key words	Palaeobotany, networks, phylogenetics, complexity
Supervisory team (including institution & email address	**PI: Luke Mander, The Open University, Luke.Mander@open.ac.uk** **Co-I: Tom Stubbs, The Open University, Thomas.Stubbs@open.ac.uk** **Sidonie Bellot, Royal Botanical Gardens, Kew, s.bellot@kew.org**
Is the PhD suitable for part time study?	Yes ☒ This is a requirement of NERC

Project Highlights:

- Development of skills in phylogenetic comparative methods and network science
- Potential for fieldwork to collect living and fossil leaves
- Exciting blend of specimen-based, theoretical, and computational work

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 (Brodbribb 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). Therefore, leaf venation is a key trait underlying the incredible biodiversity of vascular plants.

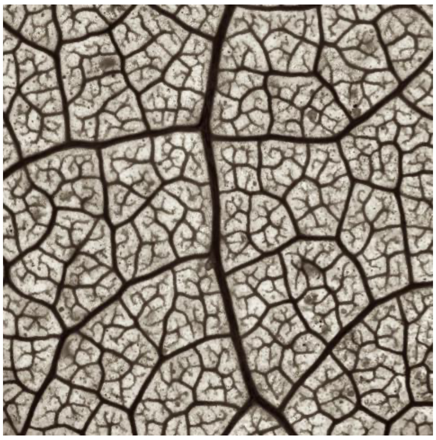

Figure 1: Segment of a Populus *leaf with its characteristically complex venation network* (from ClearedLeavesDB.org).

Alt-text: Image shows a portion of a Populus *leaf with its 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, potentially linked to external drivers such as climate change or herbivore diversity (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 and quantify the macroevolutionary history of venation architecture, by mapping morphological traits related to leaf venation onto a phylogeny of vascular plants. The project has three specific objectives: (1) to reconstruct the pattern of leaf venation evolution in vascular plants, integrating data from fossils and living plants; (2) to determine the rate at which key venation traits such as reticulation evolve, and to assess whether this is consistent through geological time, and across major groups such as ferns and flowering plants; (3) to test whether complex reticulate network topologies may be an outcome of selection for resistance to damage by examining network robustness and the degree to which venation architecture evolved in concert with herbivorous insects as part of the Angiosperm Terrestrial Revolution (Benton et al. 2022).

Methodology:

Leaves will be examined and scored for venation traits, using herbarium collections for living plants and museum collections for fossil plants. Where these collections are deficient, new material will be gathered from botanical gardens (e.g. Royal Botanical Gardens, Kew) and rock outcrops. Where necessary, 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.

Venation traits will be scored by examining leaves microscopically, and traits related to the robustness of venation will be quantified using Python code that has been developed by the PI. Vascular plant phylogeny will be reconstructed using data in GenBank and existing phylogenetic character matrices of extinct plants. Leaf venation traits will then be analysed in a Bayesian phylogenetic comparative framework to quantify evolutionary rate variation and the evolutionary landscape of venation complexity. These results will be placed in a temporal context and compared with potential external drivers, such as climate change records or herbivore diversity.

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 the project offers an opportunity to develop skills in phylogenetic comparative methods, as well as programming and data wrangling skills that are 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, as well as evolutionary theory and methods.

The School of Environment, Earth and Ecosystem Sciences at the OU has a thriving community of researchers who have a strong track record of publications in the Earth and Biological sciences. Full training and development in all aspects of the project will be provided by the supervisory team as required.

Partners and collaboration (including CASE):

Name of L1/L2 Partner (where applicable)	Royal Botanical Gardens, Kew

This project involves collaboration with Dr Sidonie Bellot (Royal Botanical Gardens, Kew), and the successful student will visit the botanical garden and herbarium for the purpose of sampling, and Dr Bellot for the purpose of discussing plant traits and their evolution.

Possible timeline:

Year 1: Examine living and fossil leaves in herbaria (e.g. Kew Gardens) and museum collections, collect more material where necessary. Process and image leaves in OU laboratories where necessary. Score living and fossil venation networks for key morphological traits.

Year 2: Construct phylogeny of vascular plants, including both fossil and living representatives. Analyse images of leaf venation in living and fossil plants to assess their robustness to damage, and generate a narrative of herbivorous insect evolution to compare with venation evolution.

Year 3: Map venation traits onto the phylogeny of vascular plants in order to reconstruct their evolutionary history and determine the rate at which they evolve. Compare the record of venation trait evolution with the record of herbivorous insect evolution to test for co-evolutionary relationships. Presentation of results at an international conference. Write up thesis.

Further reading:

Benton, M.J., Wilf, P. and Sauquet, H. 2022. The angiosperm terrestrial revolution and the origins of modern biodiversity. *New Phytologist*, 233, 2017–2035.

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:

Students should have a strong background in Earth science or biology and enthusiasm for plants. Experience of undertaking independent fieldwork and research work in a laboratory is desirable. A driving license would be beneficial for fieldwork. The student will join a well-established team researching ecology and evolution at The Open University.

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