39th New Phytologist Symposium

Trait covariation: Structural and functional relationships in plant ecology

27–29 June 2017
Exeter, UK

New Phytologist

Programme, abstracts and participants

39th New Phytologist Symposium

Trait covariation: Structural and functional relationships in plant ecology

Xfi Building, University of Exeter, Exeter, UK
27–29 June 2017

Scientific Organizing Committee

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Colleen Iversen *(Oak Ridge National Laboratory, USA)*
Jens Kattge *(Max Planck Institute for Biogeochemistry; German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Germany)*
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New Phytologist Trust

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Programme, abstracts and participant list compiled by Jill Brooke
'Trait covariation: Structural and functional relationships in plant ecology' logo by A.P.P.S., Lancaster, UK

Contact email: *np-symposia@lancaster.ac.uk*

Table of Contents

Information for Delegates

Symposium location

The 39th New Phytologist Symposium will be held in the Xfi Building, University of Exeter, UK. All presentations will be given in the Henderson lecture theatre and posters will be displayed in the Atrium of the Xfi building. https://www.exeter.ac.uk/eventexeter/venues/xfi-building/

A map showing the location of the venue is on page 82. An interactive version can be found online at: http://www.exeter.ac.uk/visit/directions/streathammap/
Xfi building: number 30
Holland Hall: number 62

Catering

For delegates staying in Holland Hall breakfast will be served between 07:30 and 09:00 in Holland Hall dining room.

All coffee breaks will be served in the Atrium, Xfi Building. Lunches on Tuesday, Thursday and Friday will also be in the Atrium; on Wednesday all delegates will be provided with a packed lunch to take on the trip to Dartmoor National Park.

Dinner will be provide for all delegates (those staying in Holland Hall and those staying elsewhere in Exeter) in Holland Hall dining room on Tuesday and Wednesday evening.

Restaurants

If you are staying in Holland Hall on Monday or Thursday evening there are a number of restaurants and pubs close to the University. Unfortunately no restaurants on campus will be open in the evening. Pret-a-manger in the Forum (on campus) is open 08:00 – 18:00 out of term time.

The below sites show shopping areas in Exeter with restaurants and bars. Queen St is a 10-minute walk from campus, Princesshay 15 min walk; buses run regularly from campus to the city centre.
https://www.queenst-exeter.com/
http://www.princesshay.co.uk/

There is also:
The Imperial – 3-minute walk
The City Gate – 10-minute walk
The Ghandi Indian – 5-minute walk

Field trip to Dartmoor National Park

On Wednesday afternoon there will be a trip to Dartmooor National Park. Buses will leave the Xfi building at 11:45. Valuables (laptops, tablets etc.) can be left in seminar room C in the Xfi building and this will be locked when the group leaves.

We will arrive in Haytor at 12:30 and will be taken in smaller groups on a guided walk (2–3 miles approx. 2 hours). All delegates will be provided with a packed lunch. Please bring a waterproof coat, sun hat and sturdy trainers/walking shoes. After the walk we will be taken to Widecombe for afternoon tea and arrive back at the Xfi building around 17:00.
There is no charge for this trip, it is open to all delegates attending the 39th NPS.

Posters
Posters should be prepared so that they are no larger than A0 size, portrait orientation (118 cm high x 84 cm wide). Posters should be put up during registration (07:30–09:30 on Tuesday 27 June) and will be displayed for the duration of the meeting. Delegates are welcome to view posters during coffee and lunch breaks; there will also be dedicated poster sessions from 17:00 to 19:00 on Tuesday 27 June and from 18:30 to 19:30 on Wednesday 28 June. Please stand by your poster for part of these sessions (we appreciate as poster presenters you will also want to view and discuss the other posters). Please note there will be prizes for the best posters.

Internet access
For delegates staying in Holland Hall free WiFi passwords will be provided via a leaflet in each bedroom. The Eduroam wireless service is also available across campus and will allow delegates from participating organisations to access the wireless using their home institution's credentials. There is also a UofE_Guest network which can be connected to and then registered for by entering your name and email address. This provides 24 hours of WIFI access daily but you do need to re-register each day.

Social media
We encourage all attendees to join in discussions on social media sites. Follow @NewPhyt on Twitter and fb.com/NewPhytologist on Facebook for updates before, during and after the meeting. Please use the hashtag #39NPS in all of your tweets.

Taxis
Apple Central Taxis, 3-4 Isambard Parade, Exeter EX4 4BX, 01392 66 66 66. If arriving by train to Exeter St David's, Apple's booking office can be found in the parade of shops to the right of the main exit.

Banks
There are two cashpoints and banks on campus.
Natwest Bank is located on the ground floor of the Forum. Opening hours: 09.00–16.30 weekdays.
Santander is located on the first floor of Devonshire House. Opening hours: 10.00–18.00 weekdays.

Contact
For further information, and in case of any emergencies, please contact Helen Pinfield-Wells. Email: h.pinfield-wells@lancaster.ac.uk, np-symposia@lancaster.ac.uk; tel: +44 7966 450 389.

Meeting Programme

Tuesday 27 June	
07:30–09:30	Registration (Xfi Building) and Breakfast served in Holland Hall dining room
09:30–09:45	Welcome from the Meeting Organisers and *New Phytologist*

Session 1: Trait relationships to plant and ecosystem function
Chair: Stan Wullschleger
09:45–13:00

09:45–10:15	**S1.1 Peter Reich** Setting the stage: What can plant traits tell us about the function of individuals, communities, and ecosystems?
10:15–10:45	**S1.2 Belinda Medlyn** Traits, from leaf to ecosystem: a perspective from an ecophysiological modeller
10:45–11:00	**Selected talk Haydn Thomas: P57** Global plant trait relationships persist at environmental extremes
11:00–11:30	**Coffee/Tea break**
11:30–12:00	**S1.3 Luke McCormack** Linking root traits to ecosystem processes: updating definitions and conceptual frameworks
12:00–12:30	**S1.4 Jens Kattge** 10 years TRY: on-going developments, challenges & perspectives
12:30–13:00	**S1.5 Kirsten Thonicke** Plant trait diversity and ecological resilience in tropical forests
13:00–14:00	**Lunch**
14:00–15:30	**Breakout sessions – *see participants list (page 77) for your group (1–5) allocation. More information (questions and rooming) is on page 9.***
15:30–16:00	**Coffee/Tea break**
16:00–16:30	**Feedback from breakout sessions: Henderson lecture theatre**
16:30–17:00	**Poster flash talks: Henderson lecture theatre**
17:00–19:00	**Poster reception: Atrium, Xfi Building**

19:30	**Symposium Welcome dinner: Holland Hall dining room**

Wednesday 28 June

07:30–09:00	Breakfast: Holland Hall dining room

Session 2: Fundamental limits on trait space
Chair: Owen Atkin
09:00–18:30

09:00–09:15	**Opening remarks: Owen Atkin**
09:15–09:45	**S2.1 Sandra Diaz** The global spectrum of plant form and function – charting essential plant functional diversity
09:45–10:15	**S2.2 Nikolaos Fyllas** Incorporating functional trait variation in dynamic vegetation models
10:15–10:45	**Coffee/Tea break**
10:45–11:00	**Selected talk Julia Joswig: P22** Environmental signals in plant traits: A dichotomy of soil and climate driven traits
11:00–11:30	**S2.3 Colin Prentice** Leaf traits and environment: towards a comprehensive theory derived from biophysical and eco-evolutionary constraints and supported by field measurements
11:45	**Buses depart for trip to Dartmoor National Park (return 16:00 arriving back at the Xfi Building 17:00)**
17:30–18:00	**S2.4 Michael Dietze** There and back again: a model-data assimilation tale
18:00–18:30	**S2.5 Isla Myers-Smith** Biome-scale patterns in tundra plant traits and warming-induced change over time
18:30–19:30	**Poster reception**
19:30	**Dinner: Holland Hall dining room**

Thursday 29 June

07:30–09:00	Breakfast: Holland Hall dining room

Session 3: Trait tradeoffs and covariation **Chair: Jens Kattge** **09:00–12:30**	
09:00–09:15	**Opening remarks: Jens Kattge**
09:15–09:45	**S3.1 Ian Wright** Trait trade-offs and covariation – a brief overview
09:45–10:15	**S3.2 Isabelle Aubin** Collaborative science to investigate above- and belowground intraspecific trait variability at continental scale
10:15–10:30	**Selected talk Leander Anderegg: P2** Traits on trial: Within-species trait variation challenges our understanding of the causes and consequences of trait variation and covariation
10:30–11:00	**Coffee/Tea break**
11:00–11:30	**S3.3 Etienne Laliberté** Tough leaves, weak roots? Trait trade-offs and covariation with declining soil fertility
11:30–12:00	**S3.4 Monique Weemstra** Towards a multidimensional root trait framework: From trait correlation to integration
12:00–12:30	**S3.5 Rosie Fisher** Harder, better, faster, stronger? Trait representation in the Community Land Model Version 5.0
12:30–13:30	**Lunch**
Session 4: Predicting plant traits in response to changing environmental conditions **Chair: Stephen Sitch** **13:30–16:30**	
13:30–13:45	**Opening remarks: Stephen Sitch**
13:45–14:15	**S4.1 Peter van Bodegom** Plant trait concepts for a next generation of global models
14:15–14:45	**S4.2 Anna Harper** Impact of using trait-informed plant functional types in a dynamic global vegetation model
14:45–15:00	**Selected talk Nadja Rüger: P48** Scaling from functional traits to demographic strategies
15:00–15:30	**Coffee/Tea break**

15:30–16:00	**S4.3 Simon Scheiter** Projecting traits, communities and functional diversity: novel approaches to ecosystem modeling
16:00–16:30	**S4.4 Peter Thornton** Prediction of plant traits and future climates in an Earth system model
16:30–17:00	**Final comments and close of the symposium**

Breakout session

Tuesday 14:00–15:30

Five questions will be discussed in groups of 20–25 people. Each delegate has been assigned to a group (please see the participant list on page 77–81) to ensure we have similar numbers of people and can accommodate the group in the room allocated.

There will be an opportunity for each group (approx. 5 mins per group) to feedback to everyone attending the symposium at 16:00–16:30 in the Henderson lecture theatre.

Group 1 **How are traits represented in models?**
Henderson lecture theatre

Discussion Leader: Peter Thornton
Scribe: Etienne Laliberté

Group 2 **How do environment and climate gradients influence traits and trait-trait values?**
Conference room 1

Discussion Leader: Julie Messier
Scribe: Anne Bjorkman

Group 3 **How does trait-trait covariation reveal itself in whole plants?**
Conference room 2

Discussion Leader: Hendrik Poorter
Scribe: Leander Anderegg

Group 4 **What fundamental questions remain unanswered in our understanding of plant traits and how they change across space and time?**
Seminar room A

Discussion Leader: Jens Kattge
Scribe: Franziska Schrodt

Group 5 **How can we link plant traits and ecosystem function, with an emphasis on both above- and below-ground processes?**
Seminar room B

Discussion Leader: Luke McCormack
Scribe: Lina Mercado

Speaker Abstracts

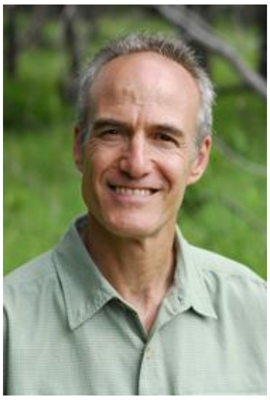
S=speaker abstract; P=poster abstract; Bold indicates presenting author

Atkin, Owen	P3, P4, P67
Aubin, Isabelle	**S3.2**
Van Bodegom, Peter	**S4.1**, S4.2, P59
Diaz, Sandra	**S2.1**, S1.4, P17
Dietze, Michael	**S2.4**, P52
Fisher, Rosie	**S3.5**
Fyllas, Nikolaos	**S2.2**
Harper, Anna	**S4.2**
Kattge, Jens	**S1.4**, S2.1
Laliberté, Etienne	**S3.3**
McCormack, M. Luke	**S1.3**
Medlyn, Belinda	**S1.2**, P11, P28
Meyers-Smith, Isla	**S2.5**, P57
Prentice, I. Colin	**S2.3**, S1.4, S2.1, P55
Reich, Peter	**S1.1**, S4.4, P3
Scheiter, Simon	**S4.3**
Sitch, Stephen	S4.2
Thonicke, Kirsten	**S1.5**
Thornton, Peter	**S4.4**
Weemstra, Monique	**S3.4**
Wright, Ian	**S3.1**, S2.1, S2.3

Speaker Abstracts

Session 1: Trait relationships to plant and ecosystem function

Chair: Stan Wullschleger



Setting the stage: What can plant traits tell us about the function of individuals, communities, and ecosystems?

S1.1

PETER REICH

09:45–10:15

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[1]Department of Forest Resources, University of Minnesota, St. Paul, MN 55108, USA; [2]Hawkesbury Institute for the Environment, Western Sydney University, Penrith, New South Wales 2751, Australia

Plant traits result from evolutionary and physiological processes, and reflect variation in ecological strategies. They provide a lens through which those ecological strategies, and their consequences, can be compared among taxa that co-occur locally, as well as across climate zones and vegetation types worldwide. Traits are not random: not all trait combinations exist in nature, because they are selected against, are biophysically impossible, or both. What does exist are several multiple-trait axes that show how most taxa have traits that reside somewhere along a continuum from a 'slow' to a 'fast' return on investment design strategy, as well as along other axes such as size. The plant economic spectrum is one name given to the pattern and distribution of plant traits (morphological, biochemical, metabolic, longevity) in multi-dimensional trait space and represents an interpretation of its underlying mechanics. The causes of the diversity of successful strategies reside at least in part in the trade-offs that equalize fitness at multiple positions along the economic axes. The position of a taxa on those axes influences whole-plant function, biotic interactions, and plant-environment interactions, and hence, the assembly, dynamics, structure, and function of communities and ecosystems. To date, we know much more about causes and consequences of leaf traits than of other traits, or of relationships among different kinds of traits (roots, stems, leaves). Advances in these realms will accelerate the way in which trait economic spectra help provide an integrated approach to quantifying and modeling plant-plant competition, organ to plant to ecosystem-scale gas fluxes, coupled C, N, P and water physiology, decomposition and soil mineral element cycling, and feedbacks between ecosystems and the coupled carbon cycle - climate system. Given the potential of trait-base approaches, many groups are at present actively exploring how to better use traits to explain nature and to make simulation models more realistic, accurate, and dynamic. However, we should remember both that traits are not some kind of panacea to all ecological ignorance and that failure to explain everything with trait spectra is not the same as failure to explain some very important things.

Traits, from leaf to ecosystem: A perspective from an ecophysiological modeller

S1.2

BELINDA MEDLYN

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Hawkesbury Institute for the Environment, Western Sydney University, Richmond NSW, Australia

10:15–10:45

I will first consider the definition of a plant trait, and discuss how plant traits relate to model parameters and variables. The definition of 'plant trait' in common usage is quite broad: it incorporates almost anything one can measure on an individual plant. I will focus on traits involved in plant carbon, water and nutrient cycling. From a process-model perspective, some traits may be assumed to be constant for a given species, and thus are typically input parameters. Examples might include leaf mass per area (LMA) or maximum Rubisco activity at 25°C ($V_{cmax,25}$). Other traits vary through time and thus correspond to model variables: for example, leaf photosynthetic rate or leaf biomass. I argue that it is useful to distinguish between parameter and variable traits.
I will then discuss the ecophysiological basis for the linkages between commonly-measured plant traits and ecosystem function. The ecosystem functions I will consider include plant productivity and water use, and their responses to increasing CO_2 concentration and drought. I'll discuss the mechanisms embedded in process models to predict these ecosystem functions, and examine how model predictions are influenced by the parameter traits.

Global plant trait relationships persist at environmental extreme

Selected talk
Session 1
10:45–11:00
Poster 57

HAYDN J. D. THOMAS[1], ANNE D. BJORKMAN[1,2], ISLA H. MYERS-SMITH[1], TUNDRA TRAIT TEAM[3]

[1]School of Geosciences, University of Edinburgh, Crew Building, Kings Buildings, Edinburgh, EH9 3FF, UK; [2]Department of Bioscience, Aarhus University, Ny Munkegade 116 DK-8000 Aarhus C, Denmark; [3]Group Authorship based on data contribution comprising approximately 143 authors

Trait based ecology offers the promise of predicting community assembly, ecosystem function, and responses to environmental change across biomes. However, development of generalizable trait theory relies on reducing the variation of life to a few simplified dimensions. There is evidence that the majority of variation in plant traits can be explained by just two axes, corresponding with growth strategy and plant morphology. However, these findings focus on global scales so may not represent all biomes equally, and ignore variation within species. Here, we use the largest tundra plant trait database ever compiled to test whether global plant trait relationships are observed in the tundra biome. We found that tundra plants exhibited a two-axis spectrum of plant form and function, consistent with global findings, but that only traits associated with plant morphology, and not resource acquisition, were constrained relative to other biomes. Trait variation was primarily explained by differences between species, rather than between functional groups or within species; however, within-species differences strongly influenced trait variation at community scales. Our findings indicate that global plant trait relationships are maintained at the edges of trait-space in the temperature-limited tundra biome, providing the basis for prediction of plant trait change with climate warming.

Linking root traits to ecosystem processes: Updating definitions and conceptual frameworks

S1.3

<u>M. LUKE MCCORMACK</u>[1], COLLEEN M. IVERSEN[2]

11:30–12:00

mltmcc@gmail.com

[1]Department of Plant and Microbial Biology, University of Minnesota, USA; [2]Climate Change Science Institute and Environmental Sciences Division, Oak Ridge National Laboratory, USA

Fine roots have evolved a complex array of strategies to effectively capture plant resources belowground. These diverse strategies are often represented by traits expressed at the individual root level and the resulting patterns of variation across fine-root systems. For example, aspects of root morphology are often linked with resource acquisition strategies while patterns of fine-root lifespan help define the total cost of a root system. Patterns of root trait variation may then provide a tractable means to understand whole-plant growth strategies and plant impacts on ecosystems processes. While the potential and promise for understanding fine-root trait variation is real, progress has been slow despite growing amounts of interest and data. It is likely that efforts to synthesize patterns of fine-root trait variation have been hindered by both methodological and conceptual treatment of these essential belowground organs. Here we raise two fundamental questions to steer our understanding of fine-root contributions to plant function: What are fine roots? And, how do fine roots do what they do?

In answer, we first redefine fine roots, traditionally defined as all roots less than 2 mm in diameter, now explicitly considered as a heterogeneous pool of roots that diverge in their capacity for resource absorption and resource transport. Using this framework, we show how a two-pool model of fine roots substantially improves our ability to capture fine-root processes and their roles in ecosystems. Second, we present analyses from a heuristic model and probe the Fine-Root Ecology Database to revisit long-held assumptions of what it means to be an acquisitive root. Both model and data-based approaches highlight the fact that fine-root and whole-plant strategies belowground cannot be meaningfully defined without capturing tradeoffs and complementarity among individual roots, their expressed traits, and interactions with mycorrhizal fungi.

10 years TRY: On-going developments, challenges & perspectives

S1.4

JENS KATTGE[1,2], SANDRA DÍAZ[3], SANDRA LAVOREL[4], GERHARD BÖNISCH[1], I. COLIN PRENTICE[5, 6], PAUL LEADLEY[7], CHRISTIAN WIRTH[1,2,8]

12:00–12:30

jkattge@bgc-jena.mpg.de

[1]Max Planck Institute for Biogeochemistry, Jena, Germany; [2]German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Germany; [3]Instituto Multidisciplinario de Biolog.a Vegetal (IMBIV), CONICET and FCEFyN, Universidad Nacional de Cordoba, Argentina; [4]Laboratoire d'Ecologie Alpine, UMR 5553, CNRS – Universite Grenoble Alpes, France; [5]Department of Biological Sciences, Macquarie University, Sydney, Australia; [6]AXA Chair in Biosphere and Climate Impacts, Grand Challenges in Ecosystems and the Environment and Grantham Institute – Climate Change and the Environment, Department of Life Sciences, Imperial College London, UK; [7] Laboratoire d'Ecologie, Systematique et Evolution (ESE), Universite Paris-Sud, 91495 Paris, France; [8]Department of Systematic Botany and Functional Biodiversity, University of Leipzig, Germany

The TRY initiative (www.try-db.org) has started in February 2007 as outcome of the IGBP Fast Track Initiative on Refining Plant Functional Classifications with the expectation to 'help generate reliable predictions of how vegetation boundaries and ecosystem properties shift with climate and land-use changes' (Nature, July 2011). Thanks to continuous support by the ecological community and funding by the Max Planck Institute for Biogeochemistry, we are now able to review 10 years of history, point out on-going developments and discuss future challenges and perspectives of the TRY initiative. I would therefore like to take this opportunity and ask for feedback on which aspects of TRY should be improved to better serve the community in quantifying and understanding trait relationships to plant and ecosystem function.

Plant trait diversity and ecological resilience in tropical forests

S1.5

<u>KIRSTEN THONICKE</u>[1], BORIS SAKSCHEWSKI[1], ALICE BOIT[1], WERNER VON BLOH[1]

12:30–13:00

kirsten.thonicke@pik-potsdam.de

[1]Earth System Analysis, Potsdam Institute for Climate Impact Research (PIK), Potsdam, Germany

Plant trait diversity describes the difference in plant trait values and their distributions. Different values and ranges of plant functional traits describe the functionally diverse influence on ecosystem function and structure. Plant traits are also functionally related and form plant functional groups which influence ecosystem functions and ecological resilience. Dynamic Global Vegetation Models (DGVM) simulate the influence of plant functional traits on carbon and water-related ecosystem functions but used single and static parameters for plant functional types that described average conditions at the biome level. Diversifying plant traits by implementing ranges of trait values is only a first step that further requires to incorporate trade-offs between related plant traits. One opportunity is the implementation of the leaf and stem economics spectrum into a DGVM framework to couple plant trait diversity and ecosystem function. We present the LPJmL-Flexible-Individual-Trait (LPJmL-FIT) approach which links plant trait diversity, trait trade-offs and gap dynamics with carbon-related ecosystem functions. Applying the LPJmL-FIT approach allows investigating the importance of ecological sorting and tests the role of the insurance hypothesis for ecological resilience of tropical forests. We further discuss how the LPJmL-FIT approach like other variable trait concepts can be developed further to incorporate adaptive responses of plant individuals.

Poster flash talks – Tuesday 27 June
Session 1: Trait relationships to plant and ecosystem function
16:30–17:00

		Poster No.
16:30–16:35	**Julie Messier** Understanding similarities and differences in intrapopulation trait integration of coexisting tree species: Consistent hydraulic relationships amidst widely different integration patterns	**P37**
16:35–16:40	**Teresa Rosas** Hydraulics constrain the scaling of the leaf economics spectrum	**P46**
16:40–16:45	**Catherine Roumet** Fine root traits co-variations: Structural and functional relationships at the global scale	**P47**
16:45–16:50	**Roberto Salguero-Gómez** The StrateGo network: A global network for predictive functional population ecology	**P49**
16:50–16:55	**Alexey N. Shiklomanov** Leaf optical properties shed light on foliar trait variability at individual to global scales	**P52**
16:55–17:00	**Anne G. Uilhoorn** Global fitness maximizing approaches to evaluate the trade-offs involved in the evergreen and deciduous conundrum	**P59**

Session 2: Fundamental limits on trait space

Chair: Owen Atkin

The global spectrum of plant form and function – charting essential plant functional diversity

S2.1

09:15–09:45

SANDRA DÍAZ[1], JENS KATTGE[2,3], J. HANS C. CORNELISSEN[4], IAN J. WRIGHT[5], SANDRA LAVOREL[6], STEPHAN DRAY[7], BJOERN REU[8], MICHAEL KLEYER[9], CHRISTIAN WIRTH[3], I. COLIN PRENTICE[10], ERIC GARNIER[11], GERHARD BOENISCH[2], MARK WESTOBY[5], JULIA S. OSWIG[2]

sandra.diaz@unc.edu.ar

[1]Instituto Multidisciplinario de Biología Vegetal (IMBIV), CONICET and FCEFyN, Universidad Nacional de Córdoba, Córdoba, Argentina; [2]Max Planck Institute for Biogeochemistry, Jena, Germany; [3]German Centre for Integrative Biodiversity Research (iDiv) Halle-Jena-Leipzig, Leipzig. Germany; [4]Systems Ecology, Institute of Ecological Science, VU University, Amsterdam, Netherlands; [5]Department of Biological Sciences, Macquarie University, Sydney, Australia; [6] Centre National de Recherche Scientifique, Grenoble, France; [7]Universite C. Bernard, Lyon, France; [8]Universidad Industrial de Santander, Colombia; [9] Institute of Biology and Environmental Sciences, University of Oldenburg, Oldenburg, Germany; [10]Imperial College, London, UK; [11]Centre d'Ecologie Fonctionnelle et Evolutive, CNRS, Montpellier, France

The idea that the remarkable diversity of plant life on Earth is underpinned by general, simple, recurrent patterns of specialization has a long tradition in ecology. However, until recently it was not possible to test for them at the global scale. Here we present the first quantitative picture of essential functional diversity of vascular plants, based on functional trait theory and enabled by the worldwide communal database of plant traits, TRY. The analysis is based on information on six traits: plant height, stem specific density, leaf mass per area, leaf nutrient content, leaf size and propagule size. These traits capture essential aspects of the Darwinian struggle for existence, and at the same time are available for thousands of vascular plants worldwide.

As compared to different null models, the six-dimensional trait space occupied by vascular plants is strongly constrained, and can be captured by a two-dimensional global spectrum of plant form and function. One major dimension within this plane reflects the size of whole plants and their parts; the other represents the leaf economics spectrum. We found both consistent differences between herbaceous and woody plants (beyond the obvious ones known since antiquity), and also commonalities across them in trait coordination and trade-offs. In addition, the trait space shows a marked heterogeneity in density of occupation by species, with densely populated 'functional hotspots' and sparsely populated 'functional cold spots'. The global spectrum of plant form and function provides the widest context so far for empirically examining theories of plant ecological strategies. It also provides a backdrop for charting plant and vegetation responses to past and future environmental changes.

Incorporating functional trait variation in dynamic vegetation models

S2.2

<u>NIKOLAOS M. FYLLAS</u>[1,2], YADVINDER MALHI[1]

09:45–10:15

nfyllas@gmail.com

[1]Environmental Change Institute, School of Geography and the Environment, University of Oxford, Oxford, UK; [2]Forest Research Institute, Hellenic Agricultural Organisation – "Demeter", Vasilika, Thessaloniki, Greece

Plant functional traits have been extensively used in dynamic vegetation models (DVMs). The current trend in local and global scale simulations of vegetation dynamics is to replace the 'static' representation of functional diversity, i.e. the use of constant trait values for different species and/or plant functional types, with trait continua. Although this approach is more realistic and consistent with the epitome of natural selection, there are two important issues that need to be addressed, especially in cases that trait-spectra DVMs are applied across environmental gradients and/or under global change conditions. The first issue relates to the way geographic variation in functional traits is included in dynamic vegetation models. The second one relates to the way temporal variation, within the trait distribution of a local community, is simulated. In this talk we will try to describe why the above two issues are important for the next generation of dynamic vegetation models, what are the difficulties of addressing them and how emerging trait datasets could be used to better constrain DVMs. Examples will be given using the trait-spectra and individual-based forest simulator (TFS), applied along Tropical and Mediterranean elevation gradients.

Environmental signals in plant traits: A dichotomy of soil and climate driven traits

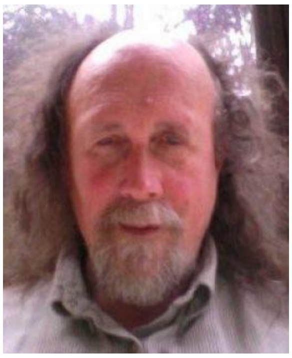
Selected talk
Session 2
10:45–11:00
Poster 22

J. S. JOSWIG, B. REU, R. RICHTER, J.S KATTGE, N. RÜGER, C. WIRTH, M. D. MAHECHA

Max-Plack-Institute for Biogeochemistry, Hans-Knöll-Str. 10, 07745 Jena, Germany

The relative contribution of the environment in modulating plant form and function across large spatial scales is often poorly quantified or understood. We address this issue by means of a comprehensive analysis on the environmental signal in global plant traits. The fact that plant traits, which reflect plant form and function, strongly covary, implies that the environmental signal jointly affects a multitude of traits. Here, we seek to disentangle the relative contribution of the soil versus climate signal in multiple plant traits that can be broadly classified into plant size traits and leaf economic spectrum (LES) traits, thereby systematically scrutinising environment-trait relationships. To achieve these objectives, we compile a dataset of 18 different traits, jointly with climate and soil predictor variables, and aggregate all data streams to ecologically homogenous 'ecoregions'. A variable selection algorithm applied to all predictor variables in tandem with a regression model is used to explain each trait mean per ecoregion.

We find that size traits can be explained better than LES traits, and climate is generally more important than soils at very large spatial scales. However, this is not true for all traits: the analysis unfolds a dichotomy between climate-driven size traits and soil-driven LES traits.



Leaf traits and environment: Towards a comprehensive theory derived from biophysical and eco-evolutionary constraints and supported by field measurements

S2.3

IAIN COLIN PRENTICE[1,2,3], NING DONG[2,4,5], ATSAWAWARANUNT KAMOLPHAT[1,4], SANDY P. HARRISON[4], TREVOR F. KEENAN[6], NICHOLAS G. SMITH[6], BENJAMIN STOCKER[1,7], HENRIQUE F. TOGASHI[2], HAN WANG[2,3], IAN J. WRIGHT[2], YANZHENG YANG[8,3], SHUANGXI ZHOU[2,9]

11:00–11:30

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Leaf morphometric and photosynthetic traits are a current focus for both field observational programmes and next-generation terrestrial ecosystem modelling. However, research in both fields to date has been largely empirical. An alternative approach outlined here will be shown to yield key generalizations that should form the basis in future both for more realistic interpretations of data, and for more reliable and robust models. This approach combines biophysical constraints and eco-evolutionary optimality considerations to make explicit, quantitative, testable predictions about trait-trait and trait-environment relationships. Analysis of trait data from long environmental transects has shown that there is largely independent variation in leaf area, photosynthetic capacity, air-to-leaf CO_2 drawdown (c_i:c_a ratio) and quantitative traits that relate to the leaf economic spectrum, including specific leaf area (SLA) and leaf dry matter content. All four dimensions of trait variation can be related theoretically to aspects of the physical environment: maximum leaf area via energy balance theory and the observed phenomenon of biophysical temperature homoeostasis; photosynthetic capacity via the co-ordination hypothesis, linking the enzymatic and electron-transport limited photosynthetic rates; the c_i:c_a ratio via the least-cost hypothesis, which postulates that plants minimize the combined unit costs of maintaining photosynthetic and water transport capacities; and SLA through its relationships to leaf thermal inertia and growing-season length. The theory has many potential applications. One of these is a model for primary production that has no free parameters and is independent of plant functional types. Another is a possible explanatory framework for aspects of functional diversity among co-existing plants.

There and back again: A model-data assimilation tale

S2.4

<u>MICHAEL DIETZE</u>, ALEXEY SHIKLOMANOV, ELIZABETH COWDERY

17:30–18:00

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Trait data play a critical role in the calibration of process-based models because they can directly estimate individual parameters or processes and provide an important constraint on the biological realism in subsequent assimilation of ecosystem-level data. But trait data estimates have uncertainty, variability, and across-trait covariances that need to be accounted for when informing models. Here we build on our previous hierarchical Bayes trait meta-analysis by presenting a hierarchical multivariate and multi-PFT trait analysis that allows us to account for differences in trait covariance within-vs across-PFTs. We find that previously reported across-PFT relationships are generally not appropriate to apply within PFTs, but that there is an important capacity to borrow-strength across-PFTs to help constrain data-limited PFTs. Biome and leaf type best explained the variability in within-PFT trait correlations, but most of the variability was unexplained by any aspect of PFT definitions. We next demonstrate that these hierarchical Bayes approaches can be extended to simple sub models, such as enzyme-kinetic photosynthesis, plant allometries, and leaf radiative transfer, whose parameters are often treated like traits. Building on this understanding of trait variability, we use of process-model uncertainty analysis to identify which trait uncertainties contribute most to model predictive uncertainty. Examples are provided from multiple biomes of how model-driven uncertainty analyses can inform subsequent iterative rounds of trait data collection, synthesis, and model improvement. Finally, it is shown that sampling designs for collecting data across multiple traits can be optimized to maximize model uncertainty reduction while accounting for fixed and marginal measurement costs and trait correlations. In conclusion, the iterative loop between process-based modeling and studies on plant trait covariation represents an important opportunity for advancing ecosystem science and improving carbon cycle projections.

Biome-scale patterns in tundra plant traits and warming-induced change over time

S2.5

ISLA H. MYERS-SMITH[1], ANNE BJORKMAN[2], HAYDN THOMAS[1], THE TUNDRA TRAIT TEAM[3]

18:00–18:30

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Rapid climate warming in Arctic and alpine regions is leading to dramatic changes in plant communities. Despite documented shifts in community composition, the consequences of vegetation change for tundra ecosystem functioning remain largely unknown. Since traits link to function, to improve predictions, we first need to quantify tundra trait change.
We integrated 27 years of vascular plant community vegetation surveys for 118 locations (alpine + Arctic) with more than 50,000 plant trait observations – the Tundra Trait Team database. We first explored whether tundra trait data are constrained along the same axes as global trait data. We tested the biome-wide relationships between temperature and intra- and inter-specific trait variation for key plant functional traits. We additionally quantify temporal trait change from geographic temperature-trait relationships and community composition change.
We found that tundra plants exhibited a two-axis spectrum of plant form and function, consistent with global findings, but that only traits associated with plant morphology, and not resource acquisition, were constrained relative to other biomes. We found strong community-level (interspecific) temperature-trait relationships for SLA, height, and leaf dry matter content, driven largely by species turnover over space, while temperature-trait relationships for leaf nitrogen and leaf area varied by moisture availability. Despite strong temperature-related spatial gradients and substantial warming over time at most sites, only community canopy height increased consistently over time.
Our results suggest that trait change is already underway in the temperature-limited and warming tundra biome, but that future shifts in many traits will likely occur slowly and will depend on the rate of immigration of species from warmer climates and trends in moisture availability. We conclude that incorporation of the mechanisms underlying trait shifts and new data collection are necessary for improved predictions of tundra vegetation change and ecosystem feedbacks to climate warming.

Session 3: Trait tradeoffs and covariation
Chair: Jens Kattge

Trait trade-offs and covariation – a brief overview

S3.1

09:15–09:45

IAN WRIGHT

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Researchers may have various objectives when setting out to measure plant traits – the morphological, chemical and physiological properties of tissues and organs. For example, a researcher might be investigating some particular species or interaction between organisms. Or, using traits as a means to index species along a spectrum of ecological strategy. Or, gathering data so as to better represent a key process in a terrestrial ecosystem model. Perhaps they have something quite different on their mind? In any case, in common to these pursuits it is tremendously valuable to understand how much the traits of interest vary (e.g. within species, among species or between vegetation types), and how – and why – the focal traits vary with other plant properties. In this overview talk for the 'Trait trade-offs and covariation' session I introduce some key ideas in this research area, give a sense of where the field is at now, and outline key challenges. For example, are 'fast' leaf traits necessarily correlated with 'fast' root traits? What about the traits of sapwood and bark? Are concepts like 'fast' and 'slow' meaningful for these tissues? What is the role of biomass allocation to different tissues and organs in influencing relationships between their traits? Just taking a single organ – leaves – how many key dimensions of variation are there? Concepts like a 'leaf economic spectrum' (LES) have been useful, but what is the relationship of the LES to variation in, say, leaf size – a trait that varies far more widely than any LES trait? How many key dimensions of trait variation are there for, say, roots, the least-studied part of the plant? What is the potential for understanding these various issues via cost-benefit or optimality frameworks?

Collaborative science to investigate above- and belowground intraspecific trait variability at continental scale

S3.2

ISABELLE AUBIN[1], BRIGHT B. KUMORDZI[2], FRANÇOISE CARDOU[1,3], BILL SHIPLEY[3], CYRILLE VIOLLE[4], JILL JOHNSTONE [5], MADHUR ANAND [6], ANDRE ARSENEAULT [7], WAYNE BELL[8], YVES BERGERON[9], MAXIME BROUSSEAU[10], LOUIS DE GRANDPRÉ[11], SYLVAIN DELAGRANGE[12], NICOLE FENTON [9] DOMINIQUE GRAVEL[3], ELLEN S. MACDONALD[13], BENOIT HAMEL[8], MORGANE HIGELIN[9], FRANÇOIS HÉBERT[14], NATHALIE ISABEL[11], AZIM MALLIK[15], ANNE MCINTOSH[16], JENNIE MCLAREN[17], CHRISTIAN MESSIER[12], DAVE MORRIS[18], NELSON THIFFAULT[2,19], JEAN-PIERRE TREMBLAY[10], ISABELLE BOULANGEAT[20], ALISON D. MUNSON[2]

09:45–10:15

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The difficulty of collecting ecological data systematically at wide scales represents an important limitation to the advancement of our understanding of plant communities. In particular, our lack of knowledge surrounding trait intraspecific variability (ITV) has recently come into sharp focus. Understanding ITV at wide scales involves systematic sampling across entire species ranges for several traits; prohibitive logistical constraints have therefore resulted in only a handful of studies at

this scale, with a focus on leaf traits. However, without range-wide variability estimates, trait information from local measurements or databanks remains without context. I report on the use of a collaborative science approach to overcome these challenges, and explore how it can provide a backbone for research questions that are beyond the capabilities of individual laboratories.
The Co-VITAS project united the efforts of 23 research teams across Canada to investigate the response of leaf and root traits of six widely-distributed boreal and temperate understory species to changes in environmental conditions at the continental scale. Following standardized methods, participants simultaneously sampled 827 populations across 80 forests sites and along a climatic gradient spanning 5000 km. We were able to characterise range-scale ITV for our six study species, and to look for common patterns across scales and among the primary drivers of ITV. Investigating above- and belowground trait covariation we found that, in contrast with expected synchronous trait variability, the magnitude of ITV differed across spatial scales between leaf and root traits. Zooming in on the logistical aspects of carrying out this project successfully, I discuss some of the lessons learned along the way. In addition to providing much-needed information on ITV patterns at different scales, environmental conditions and among traits, this project showcases how a collaborative research approach can bring significant benefits to individual researchers, contribute to greater data sharing, and accelerate advances in understanding.

Traits on trial: Within-species trait variation challenges our understanding of the causes and consequences of trait variation and covariation

Selected talk
Session 3
10:15–10:30

Poster 2

<u>LEANDER D. L. ANDEREGG</u>[1,2], LOGAN T. BERNER[3], GRAYSON BADGLEY[2], BEVERLY E. LAW[3], JANNEKE HILLERISLAMBERS[1]

[1]Department of Biology, University of Washington, Seattle, WA, USA; [2]Department of Global Ecology, Carnegie Institute for Science, Stanford, CA, USA; [3]Department of Forest Ecosystems and Society, Oregon State University, Corvallis, OR, USA

Functional traits have great potential to stimulate a predictive ecology, providing scale-free tools for understanding ecological interactions, community dynamics and ecosystem function. Yet their utility lies in four key assumptions: 1) that most trait variation lies between rather than within species, 2) that global patterns of trait covariation are the result of universal evolutionary or physiological trade-offs that are independent of taxonomic scale, 3) that traits respond predictably to environmental gradients and 4) that traits have some link to organismal performance and fitness. We use an extensive dataset of within-species foliar trait variation in North American conifers combined with a global dataset of between-species trait variation to test these key assumptions. We examine three traits central to the leaf economics spectrum, leaf mass per area (LMA), leaf lifespan, and leaf nitrogen content (per mass or per area), and quantify patterns of trait variation and trait covariation at taxonomic scales ranging from within-species to between families. We also test whether site environmental variables reliably predict geographic trait variation within species, and ask whether foliar traits explain geographic variation in relative growth rates. We find that log-transformed LMA, leaf lifespan, and mass-based nitrogen content do vary primarily between rather than within species, though area-based leaf nitrogen content varies enormously within individual species (>30% of global variation is within-species). We also find that LMA and leaf lifespan consistently correlate with mass-based leaf nitrogen across taxonomic scales. However, we find surprisingly different patterns of trait covariation between leaf lifespan, LMA, and area-based nitrogen content within versus between species. The positive global relationship between leaf lifespan and LMA disappears or reverses directions within-species, while the relationship between LMA and area-based nitrogen becomes stronger and steeper within-species. In North American conifers, we find weak and often inconsistent intra-specific relationships between site environmental factors and foliar traits, and no relationship between tree growth rate and any foliar trait other than leaf lifespan. Taken together, our results challenge the ‘scale-free’ nature of our current understand of the mechanisms driving trait covariation. However, our results demonstrate the potential power if intra-specific trait variation to deepen our understanding of the causes and consequences of functional trait variation.

Tough leaves, weak roots? Trait trade-offs and covariation with declining soil fertility.

S3.3

<u>ETIENNE LALIBERTÉ</u>[1,2], HANS LAMBERS[2]

11:00–11:30

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It is widely recognised that the leaf economics spectrum is a leading dimension of plant functional variation, and that this spectrum is linked to soil fertility. For example, many field studies have shown that low fertility favours plants that use nutrients (e.g. nitrogen, N; phosphorus, P) very efficiently in well-defended leaves (e.g. high leaf dry matter content) that have long lifespan, whereas the opposite pattern is found at high fertility. By contrast, our knowledge about variation in root traits governing nutrient acquisition is much more limited, in large part because those traits are considerably harder to study. In this talk, I ask whether root traits should be expected to covary with leaf traits across plant species and soil fertility gradients. I will present results from field studies on plant trait variation conducted on a series of long-term, retrogressive soil chronosequences in south-western Australia. These chronosequences represent exceptionally strong natural gradients of soil fertility and are located within a global plant biodiversity hotspot, making them valuable model systems to study trait-environment linkages. Our results have led us to hypothesise that very low nutrient availability (particularly of P) favours plants with long-lived, well-defended leaves that maximise P-use efficiency, but short-lived fine roots that maximise P acquisition and are poorly defended against soil-borne pathogens. We discuss the potential implications of this root trait trade-off for the maintenance of plant diversity in P-impoverished ecosystems.

Towards a multidimensional root trait framework: From trait correlation to integration

S3.4

MONIQUE WEEMSTRA[1,2,3], LIESJE MOMMER[2], ERIC VISSER[4], JASPER VAN RUIJVEN[2], THOMAS KUYPER[5], GODEFRIDUS MOHREN[1], FRANK STERCK[1]

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11:30–12:00

Based on their leaf functional traits, species can be coordinated along a leaf economics spectrum (LES). One end of this spectrum includes species with acquisitive leaves that allow fast carbon gain and plant growth, whereas the other end includes species with conservative leaves that allow them to survive in adverse environments. As such, leaf traits are useful proxies of larger scale ecological characteristics and processes, such as plant fitness. By analogy, fine-root traits are hypothesized to match leaf traits along a parallel root economics spectrum (RES): it is expected that acquisitive leaves require acquisitive roots for rapid water and nutrient supply.

However, our literature review on the fine roots of trees reveals no consistent evidence of an RES mirroring an LES; root traits are neither clearly correlated to each other in acquisitive or conservative trait syndromes, nor to assumingly parallel acquisitive or conservative leaf traits. We argue that, in contrast to leaves, fine roots are not optimized for the uptake of a single resource, and also have to withstand additional soil-environmental constraints. Therefore, plants have developed multiple belowground uptake strategies that are not necessarily the most efficient in terms of resource economics, but do allow them to deal with complex soils.

We use a mechanistic, whole-tree growth model that integrates different above- and belowground traits to explore the effects of such different root trait strategies on tree fitness. Our model simulates tree carbon gain based on the carbon costs and benefits of variation in fine-root mass, SRL and root lifespan. Our model demonstrates how trees with different belowground traits – that are not generally studied in the context of an RES – may perform similarly. Furthermore, it shows how an integrative rather than a correlative approach contributes to understanding the role of fine-root traits in plant fitness.

Harder, better, faster, stronger? Trait representation in the Community Land Model Version 5.0

S3.5

ROSIE FISHER

12:00–12:30

rosieafisher@gmail.com

Climate and Global Dynamics, National Center for Atmospheric Research, 1850 Table Mesa Drive, Boulder CO 80305, USA

Version 5 of the Community Land Model (CLM5.0) was recently frozen, incorporating numerous new process representations, motivated in part by the need for closer connection between plant trait observations and model properties. The new processes include plant hydrodynamics, a heavily modified representation of the fixation and uptake of nitrogen, based on an economic framework, prognostic optimal plant photosynthetic capacity, the Medlyn representation of optimal stomatal conductance, updated plant respiration, snow hydrology, aquifer dynamics and the optional use of plant demographics. In this talk I will discuss 1) opportunities for linking the new model to plant trait tradeoff syntheses, 2) the sensitivity of model output to parametric variation in plant traits, and 3) efforts and residual challenges in automated calibration of poorly constrained parameters.

Session 4: Predicting plant traits in response to changing environmental conditions

Chair: Stephen Sitch

Plant trait concepts for a next generation of global models **S4.1**

PETER VAN BODEGOM **13:45–14.15**

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Institute of Environmental Sciences, Leiden University, the Netherlands

The high spatial and interspecific variability of plant traits and the importance of this variability for explaining patterns in ecosystem functioning is increasingly accepted and understood. As a response to this raised awareness, last decades has seen the development of a number of approaches to account for trait variability in e.g. dynamic global vegetation models (DGVMs). Empirical models of trait-environment relationships, inspired by habitat filtering concepts, have been incorporated in DGVMs as a way to quickly build upon and allowing comparisons to the existing DGVMs. Analyses of model comparisons based on these approaches have shown the critical importance of spatial trait variability on ecosystem functioning variability. At the same time, trait-environment relationships tend to be unable to explain most or even all variation in (community mean) traits. This suggests that alternative strategies are an additional mechanism causing trait variation. Eco-evolutionary models aim at understanding the selection and expression of co-existence and alternative strategies. Simplified eco-evolutionary models and DGVMs inspired by eco-evolutionary principles have been developed and may be closer to the ecological mechanisms involved. However, these models impose particular trait trade-offs, which may not be hardwired in a future climate. Also predicting the temporal dynamics in trait expression may be less straightforward when using these approaches. The temporal dynamics in community mean trait values is likely driven by a combination of plasticity, genetic adaptation and species turnover. The relative importance of these processes as well as the importance of trait trade-offs in determining these processes may have to be understood better as a next step to predict plant traits in response to changing environmental conditions.

Impact of using trait-informed plant functional types in a dynamic global vegetation model

S4.2

<u>ANNA B. HARPER</u>[1], ANDY WILTSHIRE[2], STEPHEN SITCH[3], PETER COX[1], LINA MERCADO[3], PETER VAN BODEGOM[4], LIENEKE VERHEIJEN[5]

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14:15–14.45

Dynamic global vegetation models (DGVMs) are used for studying historical and future changes to vegetation and the terrestrial carbon cycle. JULES (the Joint UK Land Environment Simulator) represents the land surface in the Hadley Centre climate models and in the UK Earth System Model and includes the dynamic vegetation model TRIFFID. JULES has been revamped to include an expanded set of plant functional types (PFTs) to better represent the range of leaf lifespans and metabolic capacities that exists in nature, capitalizing on the expanding information on plant traits available for global ecosystems. The new set of PFTs distinguishes between evergreen and deciduous trees and shrubs, and between tropical and temperate broadleaf evergreen trees. Data from the TRY database was used to calculate new parameters controlling the relationship between leaf nitrogen and the maximum rate of carboxylation of Rubisco (V_{cmax}), to update the leaf turnover and growth rates to include a trade-off between leaf lifespan and leaf mass per unit area (LMA), and to calculate the amount of nitrogen in roots and stems.

In this talk, I will show the improvements in the carbon cycle with the updated trait-based physiology and expanded set of PFTs. JULES is better able to represent gross and net primary productivity and the distribution of global vegetation. A future direction for research is the inclusion of trait-climate relationships. Using regressions between V_{cmax}, LMA and climate variables, the model is able to predict adaptive responses of vegetation to climate change. Impacts on the future carbon cycle will also be discussed.

Scaling from functional traits to demographic strategies

Selected talk
Session 4
14:45–15:00
Poster 48

<u>N. RÜGER</u>[1, 2], R. CONDIT[2], D. PURVES[3], B. ROSENBAUM[1], S.J. WRIGHT[2], C. WIRTH[1, 4]

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Scaling from functional traits to ecosystem dynamics and functions requires accounting for the intermediate level of species demographic rates (growth, survival, recruitment). However, it is unclear how well species demographic strategies can be predicted from easily measurable morphological traits. We identified the demographic strategies of 290 tropical tree and shrub species by performing a novel weighted PCA on nine demographic rates accounting for tree size and light availability (growth and survival in four canopy layers, number of sapling recruits). The most important demographic dimension was a general trade-off between growth and survival in all canopy layers corresponding to a fast-slow continuum of life-histories (42% explained demographic variation). The second dimension (21%) distinguished species with fast growth and high survival in all canopy layers, but low recruitment rates ('long-lived pioneers'), from the opposite ('short-lived breeders'). Slow species had high wood density, seed mass and small adult stature. The long-lived pioneer syndrome was associated with tall stature. Morphological traits explained about 50% of interspecific variation along both axes. Thus, using trait-based demographic strategies seems to be a promising route to 'diversify' dynamic vegetation models.

Projecting traits, communities and functional diversity: Novel approaches to ecosystem modeling

S4.3

<u>SIMON SCHEITER</u>[1], LIAM LANGAN[1], MIRJAM PFEIFFER[1], CAMILLE GAILLARD[1], DUSHYANT KUMAR[1], CAROLA MARTENS[2], STEVEN I. HIGGINS[3]

15:30–16.00

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The ability to project patterns of traits, community composition and diversity is an important challenge in ecology and it is required to understand how climate change, disturbances and land use may influence vegetation. Dynamic vegetation models are powerful tools to investigate vegetation under past, present and future conditions and at large temporal and spatial scales. Yet, their ability to simulate community composition and diversity is often constrained by their representation of vegetation using static plant functional types. Here, we present a novel dynamic vegetation modeling approach, the aDGVM2. Plants in the model are characterized by an individual combination of trait values; traits are linked by trade-offs. Successful plant strategies can pass their trait values to the next generation and persist, whereas unsuccessful strategies are filtered out. The aDGVM2 assembles plant communities that are well adapted to biotic and abiotic conditions. This approach allows to simulate trait patterns, vegetation distribution and diversity and to study the process driving these patterns. In a sequence of model applications, we show how aDGVM2 can contribute to our understanding of vegetation dynamics in tropical grass-tree systems. (1) The aDGVM2 can simulate the distribution of traits characterizing drought tolerance and leaf phenology as well as forest-savanna biome boundaries in Amazonia; these patterns are driven by plant rooting strategies, fire and climate change. (2) Fundamental trade-offs between growth and water uptake can explain the distribution of shrub dominated ecosystems in Africa. (3) Grass community composition is influenced by herbivory and the model can be used as a tool to develop management policies. The aDGMV2 requires links between trait data and modeling and it provides a framework to integrate Earth system modeling, functional ecology and socio-ecology.

Prediction of plant traits and future climates in an Earth system model

S4.4

PETER THORNTON[1], VERITY SALMON[1], COLLEEN IVERSEN[1], DANIEL RICCIUTO[1], ETHAN BUTLER[2], PETER REICH[2]

16:00–16.30

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Earth system models present an interesting end-case for the consideration of how to understand, represent, and predict plant trait variation in response to environment. Earth system models are costly to construct, to execute, and to analyze. As the speed of a single computer processor grows and larger and more capable many-core systems are invented and brought online, the spatial and temporal resolution and mechanistic complexity of Earth system models have also increased. Our most capable model versions therefore always seem to operate on the edge of computational feasibility. This imposes important constraints on all components and sub-components of an Earth system model: structure and function at every level must serve the purpose of the top-level system, which in many cases is to provide predictions of future climate given specified external forcings. Many plant traits are observed to vary strongly and predictably in response to variation in their growth environment, but not all observed trait variation is demonstrably linked to predictability in the climate system. One approach to representing the co-evolution of plant traits and the climate system focuses on model parsimony: plant traits that have important interactions with the climate system are included, with as many of these as possible being treated as emergent properties of the fundamental vegetation model state variables. Examples of this type of trait include plant height, biomass, annual growth rate, leaf area, photosynthetic rate, or size of carbon storage pools. Other plant traits must be prescribed as empirical constants or functions of environmental gradients. Examples in this category include specific leaf area, base rates for autotrophic respiration, allometry, carbon:nutrient stoichiometry, stomatal density, and controls on timing of tissue growth and senescence. Using global plant trait datasets and recent data collection, we provide examples of both emergent plant traits, useful for model evaluation, and intrinsic plant traits, which require parametric constraints. We also demonstrate an approach that uses formal uncertainty quantification methods to assess the relevance of various plant traits to climate system variability.

Poster Abstracts

P=poster abstract. S=speaker abstract. Bold=presenting author

Poster Abstracts

Poster abstracts are ordered alphabetically by presenting author (underlined).

P1 Plant traits and tree functional groups in Brazilian Atlantic Forest

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The aiming to predict vegetation responses to land use and global changes based on terrestrial ecosystem functions, especially in tropical ecosystems, has revived the concept of plant functional traits, which are also used along forest successional gradients to better understand tropical forest structure and function. Besides efforts to identify useful, soft and scale up traits, there is still a demand for new variables and approaches. We explored the plant functional groups along a forest succession by examining 6 plant traits (SLA, WUE, CN, BD, d15N, NRA) in two successional stages in Brazilian Atlantic Forest. Results show significant differences among the sites and correlation of CN with SLA and d15N. Based on these traits was possible to define 6 tree functional groups (TFG). The first component axis was defined by high potential to assimilate nutrients including nitrate from soil, larger leaves with little investment in structure and efficiency in water use. The second component indicated long-lived strategies, represented by the high BD and high leaf C. Tree strategies varied on a continuum from short-term nitrogen gain to higher leaf longevity and biomass. Traits were good predictors of plant performance and discriminate among plant communities. Supported by Biota-FAPESP/NERC-RCUK, PELD/FAPESP/CNPq

P2 Traits on trial: Within-species trait variation challenges our understanding of the causes and consequences of trait variation and covariation

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Functional traits have great potential to stimulate a predictive ecology, providing scale-free tools for understanding ecological interactions, community dynamics and ecosystem function. Yet their utility lies in four key assumptions: 1) that most trait variation lies between rather than within species, 2) that global patterns of trait covariation are the result of universal evolutionary or physiological trade-offs that are independent of taxonomic scale, 3) that traits respond predictably to environmental gradients and 4) that traits have some link to organismal performance and fitness. We use an extensive dataset of within-species foliar trait variation in North American conifers combined with a global dataset of between-species trait variation to test these key assumptions. We examine three traits central to the leaf economics spectrum, leaf mass per area (LMA), leaf lifespan, and leaf nitrogen content (per mass or per area), and quantify patterns of trait variation and trait covariation at taxonomic scales ranging from within-species to between families. We also test whether site environmental variables reliably predict geographic trait variation within species, and ask whether foliar traits explain geographic variation in relative growth rates. We find that log-transformed LMA, leaf lifespan, and mass-based nitrogen content do vary primarily between rather than within species, though area-based leaf nitrogen content varies enormously within individual species (>30% of global variation is within-species). We also find that LMA and leaf lifespan consistently correlate with mass-based leaf nitrogen across taxonomic scales. However, we find surprisingly different patterns of trait covariation between leaf lifespan, LMA, and area-based nitrogen content within versus between species. The positive global relationship between leaf lifespan and LMA disappears or reverses directions within-species, while the relationship between LMA and area-based nitrogen becomes stronger and steeper within-species. In North American conifers, we find weak and often inconsistent intra-specific relationships between site environmental factors and foliar traits, and no relationship between tree growth rate and any foliar trait other than leaf lifespan. Taken together, our results challenge the 'scale-free' nature of our current understand of the mechanisms driving trait covariation. However, our results demonstrate the potential power if intra-specific trait variation to deepen our understanding of the causes and consequences of functional trait variation.

P3 Thermal acclimation of leaf respiration and related changes in structural and physiological traits in tropical and temperate tree species

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Plants can acclimate to variation in temperature but the precise mechanisms remain unclear. Plants adjust leaf traits for structure, N use, and physiology, but it is unclear which trait is related to acclimation the most. We examined which of the traits are related to the acclimation of leaf dark respiration and if the relationship differs among species or biomes. We choose six tree species from temperate and four from tropical biomes and grew them in 5 °C warmer and colder temperature relative to the mean annual temperature of their biome. We measured leaf respiration rate at a common temperature and the traits for structure (leaf mass per area), N use (N concentration, fraction of N in protein, and fraction of protein in mitochondria), and physiology (mitochondrial cytochrome and alternative oxidase content). We found that acclimation was related to changes in leaf mass per area and to cytochrome oxidase content, but not to changes in N concentration, protein, mitochondria, nor alternative oxidase. Temperate species adjusted leaf mass per area whereas tropical species did not. Some species did not acclimate. These results suggest that acclimation is related to leaf structure and mitochondrial capacity, but the relationships differ among biomes.

P4 Does mesophyll conductance scale with photosynthetic capacity?

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There is a growing concern about the accuracy of the biochemical model of C_3 photosynthesis in estimating maximum capacity of Rubisco (V_{cmax}) when mesophyll conductance, g_m, is ignored. Using a combination of leaf gas exchange and carbon isotope discrimination measurements, we estimated g_m of several Australian tropical and temperate rainforest trees. The tropical trees generally had both lower photosynthetic rates (4.5-14.3 µmol m^{-2} s^{-1}) and g_m (0.09-0.32 mol m^{-2} s^{-1} bar^{-1}) compared to the temperate trees (photosynthetic rates 5.4-27.3 µmol m^{-2} s^{-1}, g_m 0.08-0.47 mol m^{-2} s^{-1} bar^{-1}). All species fell on a common photosynthesis - g_m relationship and the CO_2 drawdowns imposed by stomatal and mesophyll conductances were independent of g_m. g_m did not relate with leaf mass per area or leaf nitrogen in our study species. We discuss our findings in the context of global trait relationships and we propose that g_m can be better inferred from photosynthesis rather than leaf structure or nutrient composition.

P5 Do rhizomes fit the plant economic spectrum?

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Large-scale comparisons have shown that that leaf and stem traits are coordinated in the plant economic spectrum ranging from plants with fast growing organs and high demands for nutrients to plants with slowly growing organs and low nutrient demands. In herbs, perennial stems are located belowground (rhizomes) and are therefore freed from selection pressure on mechanical properties and can serve as large deposits of nutrients and carbohydrates. It is not well known to what extent they are also involved in the plant economic spectrum. We therefore examined relationships of rhizome parameters, namely longevity, diameter, length and volume of annual increment, with whole-plant traits such as plant height, and specific leaf area (SLA), and environmental gradients for herbs of Central Europe. Plants in productive conditions were characterized by large annual increments of rhizomes and low rhizome longevity in contrast with plants from more stressful conditions. The longest lateral spread per year was recorded in tall plants from moist and nutrient rich soils; at the same time, these plants had also the thinnest and least persistent rhizomes and the highest SLA. After filtering out effect of plant height the relationship between lateral spread and environmental conditions disappeared indicating that lateral spread is function of plant size. Rhizomes therefore fit to plant economic spectrum observed on other organs. To assess role of rhizomes in plant economy, future comparative studies should focus on nutrient resorption and decomposition rates of rhizomes.

P6 A decision support system for optimizing urban ecosystem services based on species choice

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The combination of population increase, urbanisation and climate change poses challenges for a healthy living environment in the future. Through the delivery of ecosystem services (ESS), urban green plays and will play an increasingly important role in keeping urban areas sustainable. This implies that urban green has to be stable throughout time, adapted to climate change and has to deliver ecosystem services. Biodiversity, and more specifically functional diversity (FD) (the value and range of functional traits), is believed to be the most important driver of ecosystem stability and ecosystem functioning. Maximizing the functional diversity of the species ensemble used in urban green will therefore maximize the delivery of ESS, now and thanks to stability also in the future. Despite this knowledge, current species choice is mostly based on aesthetics, economics and tradition. Also, environmental conditions, such as light intensity and soil pH, are often neglected, leading to the use of unsuitable species thus creating an unstable and less performing ecosystem. Therefore, this project intends to create a decision support system that will calculate the ideal species choice for urban green, meaning the one with the highest FD and thus a maximum delivery of ESS, taking into account the environmental conditions.

P7 Influence of microtopographic gradients and belowground functional traits in determining tropical reforestation success

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Early establishment and sapling growth is a key phase in ensuring cost-effective reforestation success with related biodiversity outcomes. Therefore, species selection must consider the interaction between plant functional traits and the often-challenging and heterogenous biophysical environment of degraded landscapes. In this study, we examined how microtopography (slope) results in spatial heterogeneity of soil nutrients, especially phosphorus (P) in a degraded tropical pasture-landscape in Queensland, Australia. We then explored how this small-scale heterogeneity influences the growth of two native tree species *Cardwellia sublimis* (Proteaceae) and *Flindersia brayleyana* (Rutaceae), which differ in key nutrient-acquisition strategies. The proteaceous *C. sublimis* was found to be buffered from possible P limitation in degraded soils due to its effective P acquisition by cluster roots. In contrast to *C. sublimis,* which showed no difference in growth after 5 years across a range of soil conditions, *F. brayleyana* was found to be highly responsive to soil conditions with increased growth in low-slope, higher P availability areas. The ability of *F. brayleyana* to take advantage of high soil P levels, including the development of leaves with a higher P concentrations, resulted in an apparent switch in competitive advantage between these two species across the landscape.

P8 Brown world forests: Increased ungulate browsing keeps temperate trees in recruitment bottlenecks in resource hotspots

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Plant biomass consumers (mammalian herbivory and fire) are increasingly seen as major drivers of ecosystem structure and function but the prevailing paradigm in temperate forest ecology is still that their dynamics are mainly bottom-up resource-controlled. Using conceptual advances from savanna ecology, particularly the demographic bottleneck model, we present a novel view on temperate forest dynamics that integrates consumer and resource control. We used a fully factorial experiment, with varying levels of ungulate herbivory and resource (light) availability, to investigate how these factors shape recruitment of five temperate tree species. We ran simulations to project how inter- and intraspecific differences in height increment under the different experimental scenarios influence long-term recruitment of tree species. Strong herbivore-driven demographic bottlenecks occurred in our temperate forest system, and bottlenecks were as strong under resource-rich as under resource-poor conditions. Increased browsing by herbivores in resource-rich patches strongly counteracted the increased escape strength of saplings in these patches. This finding is a crucial extension of the demographic bottleneck model which assumes that increased resource availability allows plants to more easily escape consumer-driven bottlenecks. Our study demonstrates that a more dynamic understanding of consumer–resource interactions is necessary, where consumers and plants both respond to resource availability.

P9 Strong relations among the diversity of single traits suggests important applications for managing forests while promoting their multi-functionality

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It is currently accepted that a greater functional diversity (FD) often improves ecosystem functions and resilience to environmental changes because of a complementary resources use and larger diversity of responses, respectively. The multi-functionality of ecosystems mostly depends on the occurrence and value of different traits, however there is a scarce knowledge of how the FD of a single trait correlates with the FD of other traits. Understanding these correlations would be of how value as it would support a more efficient forest management. We used forest inventory data from France, Italy, and Spain and trait data from published sources to calculate and correlate the FD of different traits, i.e. specific leaf area (SLA), maximum height (MH), wood density (WD), seed dry weight (SDW), percentage of hydraulic conductivity lost (PLC) and hydraulic safety margins (HSM,) across forested plots. Results show strong relations among the FD of some traits (HSM, WD and MH), whereas these correlations are weak at species level. In addition, the main axis of FD variation composed of HSM, WD, MH, and PLC explained 62% of variance. Results suggest that forest management practices to increase diversity for one single trait would also entail a larger diversity for other traits, potentially improving ecosystem's multi-functionality.

P10 On the adaptive value of phenotypic integration in leaves

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Plants must invest their limited resources in multiple functions, suchs as carbon assimilation and defence against herbivores. Natural selection should promote the expression of the most efficient combination of leaf traits acting on the pattern and magnitude of correlations (phenotypic integration). We first explored the variation of foliar integration in five populations of the tropical shrub *Turnera velutina*, along a precipitation gradient. Second, we assessed the adaptive value of phenotypic integration in an experimental population established in a coastal sand dune. We determined genotypic variation for foliar integration and its relationship with plant fitness. We detected differences in correlation patterns and phenotypic integration among populations, which was possitively associated with flower and seed production. This work constitutes the first report on the geographic variation and natural selection on the phenotypic integration of foliar traits.

P11 New insights into the covariation of stomatal, mesophyll and hydraulic conductances from optimisation models incorporating non-stomatal limitations to photosynthesis

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Optimisation models of stomatal conductance (g_s) show considerable promise in explaining observed stomatal behaviour in terms of cost-benefit trade-offs. However, while the benefit of stomatal opening through increased CO_2 uptake is clear, currently the nature of the associated cost(s) remains unclear. We explored the hypothesis that leaf photosynthesis is maximised with respect to g_s, where the cost of stomatal opening arises from non-stomatal reductions in photosynthesis induced by leaf water stress. We analytically solved two cases, PGEN and MES, in which stomatal opening leads to reductions in, respectively, photosynthetic capacity and mesophyll conductance (g_m). Both PGEN and MES predict the same one-parameter relationship between the intercellular-to-atmospheric CO_2 concentration ratio (c_i/c_a) and vapour pressure deficit (D), viz. $c_i/c_a \approx \xi/(\xi + \sqrt{D})$, as that obtained from current optimisation models, with the novel feature that the parameter ξ is determined unambiguously as a function of a few plant and environmental variables including soil-to-leaf hydraulic conductance. MES also predicts that the ratio g_s/g_m is closely related to c_i/c_a and is thus similarly conservative. These results are consistent with observed stomatal behaviour, give rise to new testable predictions, and provide new insights into the covariation of stomatal, mesophyll and hydraulic conductances.

P12 Tree-ring based functional traits develop coherently with stand structural complexity in a network of old-growth European beech forests

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The long–term understanding of forest patterns and processes often requires chronosequences, generally established using structural or age conditions as proxies of ecological processes. Nonetheless, in late-successional multi-aged forests the chronosequential ranking is difficult, since stand age carries little information, and time since last stand-replacing disturbance cannot be easily determined.
Tree-ring metrics describing the intensity/time distribution of ecological processes (e.g. disturbance/suppression history, canopy accession, growth trajectories) were used to quantify functional traits connected to the advancement of old-growth status, and compared to established structural metrics, in a network of old-growth and managed European beech forests in the Alps and Apennines.
Tree-ring functional metrics were site dependent, as biogeoclimate affects turnover rates and constrains the onset and recovery rate of old-growth attributes. Trees in well-conserved primary old-growth forests experienced several and long suppressions, and the highest complexity in recruitment history, canopy accession, growth trajectories. The most informative metrics were condensed in a Naturalness Score (NS) to provide a synthetic functional ranking of forests. NS varied coherently with structural complexity, which represented stand dynamics more closely than traditional biomass-related metrics.
Tree-ring inferred functional traits link plant ecology to ecosystem structure, providing a tool to describe forest dynamics under variable environmental conditions.

P13 Leaf traits and environmental factors: Searching for relationships for tropical forests and savannas

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Forests and savannas, given its extension and biomass, are two important vegetation types from tropical landscapes. Previous studies have focused on how functional diversity can be used to mechanistically explain the functioning of such ecosystems, and therefore, the observed spatial distribution. Here we present an evaluation of leaf functional traits from 60 research sites comprising high biomass forests to low biomass savannas, from South America, Africa and Australia. As functional traits, we evaluate leaf photosynthetic capacity, nitrogen and phosphorus content and mass to area ratio. The variability of those traits is evaluated regarding site-specific environmental variables related to soil (nutrient availability, clay/sand/silt content), climate (dry season length, potential evapotranspiration, mean temperature, etc.) and community parameters (basal area, canopy height, species diversity). Results indicate weak relationships among parameters, therefore suggesting a general lack of deterministic relationships between leaf traits and environmental drivers. Previous studies encompassing broad vegetation categories, including temperate vegetation has suggested a coupling of leaf traits and soil or climate parameters, but apparently, such relationships are less prominent on more limited spatial scales, interestingly more so for tropical systems. One possible reason for tropical vegetation to exhibit loose relationships is the usual high diversity of phylogenetic lineages.

P14 Hydraulic Safety vs growth rate trade-off determines tropical tree productivity

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Faster growth in tropical trees is usually associated with higher mortality rates, but the mechanisms underlying this relationship are poorly understood. In this study, we investigate how tree growth patterns are linked with environmental conditions and hydraulic traits, by monitoring the cambial growth of nine tropical cloud forest tree species from bark and xylem diameter change data. We find that fast-growing trees have lower xylem safety margins than slow-growing trees and this pattern is not linked to differences in stomatal behaviour or environmental conditions when growth occurs. Instead, fast-growing trees have xylem vessels that are more vulnerable to cavitation and the wood has lower density. Our results suggest that vulnerability to hydraulic failure is likely to explain the growth-mortality trade-off in tropical trees, thus determining important life history differences. We propose that this growth-xylem vulnerability trade-off represents a wood hydraulic economics spectrum similar to the classic leaf economic spectrum, whereby fast-growing species have a faster xylem turnover associated with lower hydraulic safety margins, whilst slow-growing trees preserve their xylem for longer periods thanks to larger hydraulic safety. These findings are important in furthering our understanding of xylem evolution, productivity and mortality of tropical trees.

P15 Reproductive phenology as a functional dimension in plants

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Phenology, the study of seasonal timing of events in nature, has long been known to play a key role in the matching of organisms to their environment. Yet, it has been largely ignored in trait-based research. Here, we focus on three phases of reproductive phenology in plants - time of flowering, time of seed dispersion and length of the seed maturation period - , to ask how (1) these three traits vary across species, and (2) these different phases relate to the major traits involved in the recently identified global spectrum of plant form and function (Díaz *et al.* 2016, *Nature*, 529: 167).
Traits describing reproductive phenology, together with reproductive plant height, seed mass and traits involved in the leaf economics spectrum were compiled for 135 herbaceous and small woody species growing under Mediterranean climate conditions. We show that (1) all three phenological traits span a wide range of values and co-vary across species, (2) phenological traits correlate with reproductive plant height and seed mass, but not with leaf traits.
By showing how phenology relates to other dimensions of plant functioning, this study allows one to put back this key axis of variation into the broader context of functional strategies.

P16 Legume dominance across successional and rainfall gradients in the Neotropics

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The nutrient demand of regrowing tropical forests may be partly satisfied by nitrogen-fixing legumes trees, but currently-available estimates of legume dominance are biased towards the wet tropics. Here we examine a network of dry and wet Neotropical forest plots to show how the distribution of Fabaceae is affected by both recovery from disturbance and large-scale environmental gradients. Compared to wet forests, legume species are far more abundant in dry forests during early successional stages and maintain their dominance in older forests. Those legumes that are most abundant also have smaller leaflets, which implies that species favored in early successional dry forests are able to minimize water loss during C acquisition and reduce of the costs of the recurrent post-dry season leaf-flush. Our analyses establish firmly that the ecological success of legume trees is nowhere more important than in the dry Neotropical biome, especially following disturbance. Our study further underscores the fact that habitats across rainfall gradients host taxa with different traits and divergent evolutionary histories, which translate into divergent biogeochemical cycles. Spatially explicit estimates of nitrogen fixation for tropical biomes should account for the proportional abundance of legumes across rainfall and successional gradients.

P17 Intraspecific shifts of xerophytic grasses along the leaf economic spectrum in response to long-term vertebrate herbivory

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The leaf economic spectrum (LES) assumes the existence of a multidimensional space with a main variation axis (from 'conservativeness' to 'acquisitiveness') along which all vascular plants are distributed. There is debate as to whether sustained herbivory selects for increasing acquisitiveness or conservativeness. We studied whether long-term ungulate herbivory promotes shifts along the LES of populations of the same species. Our study system was the semi-arid Chaco forest-shrubland of Central Argentina, where we identified, for each of six native grasses, close populations subjected to long-term ungulate herbivory or free from it. In each population, we measured LES-relevant foliar traits: leaf area, specific leaf area, leaf toughness and leaf dry matter content. We found intraspecific pattern of LFT correlation to be qualitatively consistent with the LES. Herbivory led to a more acquisitive leaf syndrome in all species. In some cases, we also observed a change in slope, that is, a change in the arrangement of traits in multivariate space. This suggests that long-term herbivory could be changing not only the position of populations on the LES but also the patterns of resource allocation, involving e.g. differences in photosynthetic rates as a function of differential resource allocation and metabolic activity.

P18 Alternative plant strategies influence the relationship between plant traits and net primary productivity

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Net primary productivity (NPP) is a fundamental ecosystem measurement of how much carbon is allocated to growth in a given ecosystem and is a key parameter in vegetation and climate models. Improving estimates of NPP is critical to understanding and predicting future C stocks; however, it is logistically unrealistic to directly measure the total growth of vegetative biomass over large spatial and temporal scales. One approach to predict NPP is to apply continuous plant traits that are related to differences in NPP. Despite a strong theoretical framework, few empirical data quantitatively link plant traits to NPP directly. Here, we assessed the ability of 14 traits to predict NPP (total oven-dried biomass in g day^{-1}) in 29 herbaceous *Asclepias* species grown under common garden. We identified four plant strategies defined primarily by gas exchange, leaf nitrogen and biomass allocation among leaves, stems and roots. Although some traits generally predicted NPP across all species, most trait-NPP relationships were context dependent based on differences among plant strategies. Our results suggest that some commonly used traits have limited general predictive ability in part because similar NPP can be achieved via alternative plant strategies based on leaf-level and whole-plant tradeoffs.

P19 Invasive species differ in key functional traits from native and non-invasive alien plant species on Marion Island

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Invasive species are a major conservation threat. A need exists to fully understand which factors have allowed invasive species to become successful to inform invasion risk and reduce future invasions. We used a functional trait-based approach to ascertain whether specific traits make invasive species successful to the Sub-Antarctic region. We compared the functional traits of invasive plant species to those of indigenous and non-invasive alien plant species on Sub-Antarctic Marion Island. Invasive species were characterized by traits that indicate enhanced resource acquisition and competitive vigour compared to indigenous and non-invasive alien species. This may explain what drives the success of invasive plant species on Marion Island. Compared to invasive species, indigenous species invested in physically tougher leaves and more resilience against freezing. These defence traits are expected become less important for continuing fitness as conditions become milder on Marion Island due to climate change, placing the native flora at a disadvantage to the alien flora. Our functional approach indicates that plant traits can be used to predict invasion potential, and suggests that invasive species on Marion Island will become more successful under a climate change scenario.

P20 Plant traits as floodplain management aid?

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Floodplains of regulated rivers often fulfil several functions, like providing water safety during high river discharges and as nature areas. Understanding how vegetation development is steered, may aid in optimizing different floodplain functions. Because traits are believed to couple processes to traits and vice versa, the trait concept may proof eventually useful for river management issues. However, is this indeed the case? The objective of this study is therefore to determine if easy measurable traits do reveal the steering mechanisms in observed vegetation patterns in floodplains of regulated rivers.

In each of three Dutch floodplains, ten 1 m^2 plots were marked and soil moisture and composition was measured. The vegetation was mapped and for species covering more than 15% of a plot, leaf traits (mass, area, C, N and P) were determined. The Turboveg software supplied the categorical traits of all the mapped plant species.

All plots were dominated (coverage >15%) by hemicryptophytes, but their measured leaf traits depended on the moistness and nutrient status of a plot. Known relations between leaf traits and photosynthetic capacity linked drier and less nutrient rich plots to lower photosynthetic capacity and therefore reduced biomass production per time. However, how this and other traits may relate to floodplain roughness and biodiversity is still being analysed.

P21 Intra-specific adaptive variation in anatomical traits of Scots pine (*Pinus sylvestris* L.) needles along a temperate-boreal transect

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Evergreen leaves functioning in cold habitats require structural modifications enhancing stress resistance and supporting increased longevity. To identify traits that may be adaptive in cold environments, we studied intra-specific variability in needles of Scots pine (*Pinus sylvestris* L.) along a 1900 km temperate-boreal transect in Europe, encompassing mean minimal winter temperatures between -4.0°C and -19.9°C. Needles from cold sites lived longer, were shorter and had higher leaf mass-per-area (LMA, g m^{-2}) and leaf density (LD, g cm^{-3}), had narrower tracheids, thicker epidermal cells and wider resin ducts occupying larger fraction of needle volume than needles from warmer sites. We further examined the same traits in adult trees or juvenile seedlings originating from sites differing in thermal minima and grown in common gardens. Correlation of several key traits (e.g., needle length, LMA, tracheid diameter, size and volume fraction of resin ducts, but not needle longevity) with original site temperature persisted under common garden conditions suggesting that these trait patterns were genetically fixed as a result of past selection. Thus, both plastic modifications and genetically fixed adaptations contributed to scleromorphic needle phenotypes associated with cold, nutrient poor conditions of high latitudes.
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P22 Environmental signals in plant traits: A dichotomy of soil and climate driven traits

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The relative contribution of the environment in modulating plant form and function across large spatial scales is often poorly quantified or understood. We address this issue by means of a comprehensive analysis on the environmental signal in global plant traits. The fact that plant traits, which reflect plant form and function, strongly covary, implies that the environmental signal jointly affects a multitude of traits. Here, we seek to disentangle the relative contribution of the soil versus climate signal in multiple plant traits that can be broadly classified into plant size traits and leaf economic spectrum (LES) traits, thereby systematically scrutinising environment-trait relationships. To achieve these objectives, we compile a dataset of 18 different traits, jointly with climate and soil predictor variables, and aggregate all data streams to ecologically homogenous ’ecoregions’. A variable selection algorithm applied to all predictor variables in tandem with a regression model is used to explain each trait mean per ecoregion.
We find that size traits can be explained better than LES traits, and climate is generally more important than soils at very large spatial scales. However, this is not true for all traits: the analysis unfolds a dichotomy between climate-driven size traits and soil-driven LES traits.

P23 Global leaf trait estimates biased due to plasticity in the shade

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The study of leaf functional trait relationships, the so-called leaf economics spectrum, is based on the assumption of high-light conditions. Owing to the exponential decrease of light availability through canopies, the majority of the world's vegetation exists in at least partial shade. Plant functional traits vary in direct dependence of light availability, with different traits varying to different degrees. This means that the derived trait relationships of the global leaf economic spectrum are probably dependent on the extent to which observed data represent high-light conditions. Here, using an extensive worldwide database of within-canopy gradients of key physiological, structural and chemical traits, we show that: (1) accounting for light-driven trait plasticity can reveal novel trait relationships, particularly for highly plastic traits; and (2) a large proportion of leaf traits in current global plant databases reported as measured in full sun were probably measured in the shade. The results show that even though the majority of leaves exist in the shade, along with a large proportion of observations, our current understanding is too focused on conditions in the sun.

P24 Invasion of *Asclepias syriaca* in sandy grasslands – a trait-based analysis

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Exploration of the effects of invasions on native flora is crucial to plan effective grassland conservation strategies. Here we demonstrate the effect of *Asclepias syriaca* (milkweed) on sandy vegetation. The direction of this effect is not obvious as milkweed is a competitive invasive species, but former papers reported no effects of this invader on the natural vegetation. This ambiguity suggests that there is a need to further tests. To explore its effect on the native flora, we studied late-successional sandy old-fields invaded by milkweed in Hungary. We performed trait-based analyses to identify the most sensitive species groups. We found that there was no effect of milkweed on total species richness; however, it had a negative effect on the cover of native grassland species. This effect was the most pronounced in case of species with low SLA, low seed weight and low clonal spreading ability (i.e. low competitive ability). Our findings indicated that late-successional sandy grasslands invaded by milkweed form undesirable ecosystems and the invasion of milkweed can delay the colonisation of native grassland species and arrest the succession in an undesirable stage. Thus, the control of milkweed is crucial for the protection of the native sandy flora.

P25 Do functional trait syndromes predict life-history strategies?

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A key assumption of the use of 'functional' traits in plant ecology is that these traits can be used to predict the fitness of species in terms of vital rates and population performance. Plant life-history strategies are critical in determining whether species will persist, spread or face extinction under changing environmental conditions. Recent research findings have revealed the extent of covariation among plant functional traits, with evidence of 'trait syndromes' characterized by the co-occurrence of groups of traits. Concurrently, population demographers have described key axes of covariation in plant life-history strategies. Relationships between single plant traits and vital rates have been previously demonstrated, but these relationships explain relatively little variation across species and environments.

Our research differs from previous work by focusing on the association between multivariate 'trait syndromes' and complete life-history strategies (i.e. combined schedules of growth, survivorship and reproduction). This work capitalizes on recent international collaborative databases (TRY, BIEN and COMPADRE) bringing together detailed data on traits and demography for hundreds of plant species globally. This combined approach will ultimately enhance our understanding of relationships between traits and population performance, leading to better predictions about the persistence and spread of species under environmental change.

P26 Plant morphology versus plant traits: which is a better predictor for species optima along disturbance gradients?

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Belowground plant organs can serve as an adaptation to disturbance as they bear reserve buds and store resource which enable plant to survive and recover aboveground parts. Although there is a large diversity of belowground bud bearing organs (e.g. rhizomes of different types, bulbs etc.), we have only anecdotal evidence whether and how they differ in resprouting ability and how they determine plants niche in respect to disturbance gradients. We therefore examined morphological types of belowground plant organs as predictors of species' response to disturbance, and compared their predictive power with plant traits known to determine species disturbance niche (bud bank depth, bud bank size, clonality, lateral spread). In addition, we examined to what extent these traits are determined by the morphological type of the belowground organ that bears them. We found that individual plant traits (namely lateral spread and bud bank size) were better predictors of plants disturbance niche than type of the bud bearing organ. However, there was still significant difference among individual morphological types in their ability to survive a disturbance event, with aboveground stolons and adventitious root sprouting ranking highest. Morphologically determined Bud bearing organs represent phylogenetical constraints on plant body plans, but have similar function in response to disturbance.

P27 Widely distributed native and alien plant species differ in arbuscular mycorrhizal associations and related functional trait interactions

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We are interested to know whether the area of occupancy of plant species in Germany differed among origin status (natives, archaeophytes, neophytes), arbuscular mycorrhizal (AM) status (obligate, facultative, non-mycorrhizal) and specific functional traits. Main effects and up to three-way interactions were incorporated. Functional traits were chosen with respect to potentially high energy costs, i.e. plants' carbon cost for retention of the symbiosis. AM status significantly explained the area of occupancy of native species and neophytes, with facultative mycorrhizal species occupying the largest area in both groups. This relationship was absent for archaeophytes. Significant trait interactions between AM status and other plant functional traits were almost exclusively detected for neophytes. Whereas facultative mycorrhizal neophyte species benefit from trade-offs with other traits related to high C cost, such trade-offs are almost absent in case of natives. This indicates that natives and neophytes benefit differently from the symbiosis, i.e. that neophytes might be less responsive towards native AM fungal partners or that it needs time to establish similar relationships between neophyte plant species and native fungal symbionts.

P28 Improved representation of photosynthetic temperature acclimation and adaptation in Earth system models

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Temperature dependence of leaf photosynthesis (A_n-T response) is a key determinant in modelling plant growth. Hence, the way that any Earth System Model (ESM) handles the A_n-T response is critical. It is known that there are differences in the optimum temperature for net photosynthesis (T_{opt}) across species. However, it's unknown how much each of the underlying component processes (biochemical, stomatal and respiratory) contribute to these differences in optimum. Additionally, it is unknown whether differences across species are largely genetic (adaptation) or plastic (acclimation). In this study, we hypothesise that T_{opt} is more strongly related to climate of origin than growth environment, and that all three component processes contribute to differences in T_{opt}. We analyse the photosynthetic temperature response of more than 50 tree species from different plant functional types across tropical to boreal biomes. Our focus is on 1) identifying key mechanisms (component processes) responsible for photosynthetic temperature acclimation and adaptation and 2) how to represent these component processes in ESMs. We found that T_{opt} was strongly correlated with both temperature at seed origin and the prevailing growth temperature, suggesting that both adaptation and acclimation were important drivers. Our overall aim is to provide improved A_n-T response functions for models that incorporate both species differences and responses to short-term changes in growth temperature.

P29 Assessing the response of highly diverse tropical ecosystems to climate change with the CAETÊ model: heuristic and first results

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While employing standard plant-functional types (PFTs) Dynamic Global Vegetation Models (DGVMs) have a limited capacity to support the investigation of questions addressing the enormous diversity of plants and their traits found in the tropics, such as how tropical forest trees will respond differently to increasing atmospheric CO_2 concentration. Here we present the Carbon and Ecosystem Trait-based Evaluation (CAETÊ) model, the model structure and analysis of results of which are focused majorly on possible changes of frequency distribution of key plant traits and associated tradeoffs, both of which ultimately shape ecosystem-scale properties. First model results reveal that ecosystem fluxes such as gross primary productivity and net primary productivity as well as functional richness patterns are better represented with the increase in the number of plant-life strategies (PLS), stabilizing around n(PLS)=500. Our preliminary conclusions are that the variation of trait values allows a more efficient establishment/occupation of ecosystem spaces by plants, even though trait values are constrained to an observed range within CAETÊ, preventing the representation of unrealistic ecosystems.

P30 Fine-root response to experimental warming in an ombrotrophic peatland

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Peatlands are long term reservoirs of carbon (C) and the magnitude and mechanisms of increased C losses from peatlands due to global change are poorly understood. Ephemeral fine roots regulate ecosystem C and nutrient cycling and may be the first to respond to increasing temperatures. Ecosystem warming could increase nutrient cycling rates and decrease belowground carbon allocation. Fine-root traits and rooting depth distribution may also respond to changes in water and nutrient availability. We will present results from the first two years of warming at SPRUCE (Spruce and Peatland Responses Under Climatic and Environmental change), a whole ecosystem warming and elevated CO_2 experiment in an ombrotrophic peatland. Ingrowth cores were used to study changes in woody fine-root traits, chemistry, and production along a temperature treatment gradient (0, +2.25, +4.5, +6.75 and +9 °C above ambient). We observed a 3-fold increase in total fine-root production in the +2.25 and +4.5 °C above ambient treatments. Results also varied by plant functional type (PFT) wherein warming response of root production was unimodal in trees and linear in shrubs. Our results highlight non-linear and PFT-specific warming responses that will be useful to parameterize belowground components of peatland models.

P31 Traits influence the role of trees on ecosystem services: phytostabilization of trace elements and carbon sequestration

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Functional traits of trees affect soil functions and ecosystem services in different ways. Here we studied a restored land affected by a mine-spill in SW Spain. We analysed morphological and chemical traits on leaves and roots of seven afforested tree species with contrasted leaf habit. We evaluated two ecosystem services: 1) the regulation of soil quality by immobilization of trace elements (phytostabilization), and 2) the mitigation of climate change by C sequestration. A main trend of trait variation was associated with higher SLA and SRL, and lower leaf C:N in deciduous species, while a secondary trend separated *Populus alba* with higher leaf Cd concentration. The retention of trace elements on the roots was higher for *Fraxinus angustifolia* and *Celtis australis* favouring the phytostabilization process, while the high transfer of Cd to leaves of *Populus alba* (above toxicity levels) favoured its mobilization, adding a risk for herbivores. In general, soil underneath all tree species accumulated more organic matter than in non-afforested sites, due to a higher litter input and a lower respiration rate. *Ceratonia siliqua* showed a higher C accumulation in the forest floor, a relatively low C:N, and a high soil C density; all favouring C sequestration.

P32 Nitrate reductase activity as a new leaf trait to assess nutrient assimilation

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The highly biodiverse Tropical Forests represent the largest contribution to Earth's productivity but are extremely threatened by human activity. Plant functional traits could represent ecological strategies and determine the response of plants to environmental factors. However, nitrogen is usually only addressed in plant traits approaches in the form of dry mass basis total N. We propose the inclusion of the nitrate reductase activity as a functional trait to evaluate N uptake by plants. We compared 6 specific traits in two successional stages sites in the Brazilian Atlantic Forest. Results showed differences along successional stages and correlation of NRA with A_{maxa} and N. Including ANR, 6 plant groups formed a fast-slow spectrum where extremes were: species with high photosynthetic capacity, leaf nitrate assimilators and low investment in structure (PC1) and high construction cost, tolerance to water limitation (LMDC) and C (PC2). When NRA was removed, the cophenetic correlation reduced 4% and we noticed a decreased in the importance of N and photosynthesis. We conclude that NRA should be added in leaf traits studies, especially because it is a soft trait, easily field measured and has high potential to highlight 'fast' species or strategies (pioneer or early successional). Supported by Biota-FAPESP/NERC-RCUK.

P33 Disturbance is an important factor in the evolution and distribution of root-sprouting species

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Root sprouting (RS) in plants has been considered a morphological curiosity. However, data of the Central European flora show that RS occurs in 10% of species. These species are independent of a stem-derived bud bank (BB) in their resprouting. As sprouting from roots has been hypothesised to help plants survive disturbance, we used a data set of 2914 Central European species to perform comparative analyses of RS occurrence in disturbed habitats, evolution of RS in response to disturbance, and RS distribution among plant lineages. We confirmed that RS ability is more frequent in plants growing in disturbed habitats, especially in annuals and clonal species. Disturbance severity is the most important factor determining RS species distribution, whereas disturbance frequency plays a smaller role. RS is phylogenetically less conservative than sprouting from the stem-based belowground BB and thus can be easily acquired or lost in evolution. Evolution of RS seems to be driven largely by occurrence in disturbed habitats, and has appeared/disappeared independently of the presence of a stem-derived BB. Root sprouting is hence a more important ecological trait than hitherto assumed. It constitutes an independent route of response to severe disturbance and its ecology and evolution differ from stem-based clonality.

P34 Wood and leaf chemical traits associations are mostly mediated by species effects

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According to the plant economic spectrum, trees should present an ecologic trade-off between carbon investment and nutrient usage in multiple plant organs. Nevertheless, this association can be determined by the species or by the environment where the plant grows. In the present study, we analysed element concentration in branches and leaves of tropical Amazonian trees. We assessed the chemical inter-organ relation between traits in both organs by using multilevel models in order to disentangle the species effect from the environmental effect on the mean trait variation. Some traits were significantly associated between the two organs and these scaling relations were controlled only by the species identity. The environmental effect played a significant role only for Ca association between organs. By using the species effect to evaluate scaling relationships between organs we infer how tropical species developed coupled responses between wood and leaf in order to manage essential nutrients within their structures. We also show the potential osmotic role of cations locked up in the woody tissues of those trees.

P35 Temperature and Precipitation distributions of Andean species: Do they differ by successional stage?

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Tropical Andean forests host the highest plant biodiversity on Earth. Current rates of warming are three times higher than elsewhere in S. America. Therefore, climate change together with invasive migration by lowland species pose significant challenges to the diversity and functioning of montane forest in the future. There is now evidence for warm-edge range contraction in some high elevation tree species, suggesting a strong response to recent warming. Understanding their current temperature and precipitation distributions should provide insights into their current climatic thresholds. Here we create temperature and precipitation distributions of the most dominant Andean species in Colombia -from 63,198 collection records- and we ask whether the minimum, optimum and maximum of these distributions differs across successional stages and whether there any differences in such distributions across species of the same genera. Our highlight result is that optimal and minimum temperature and precipitation differ across successional stages. Given the predicted rates of climate change, In the absence of thermal acclimation, our results imply largest losses under RCP2.6 and 8.5 for intermediate successional species, which are the species that store the highest amount of carbon in current Andean forests.

P36 Light requirements direct the response of boreal forest understorey plants to forest cuttings

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We analysed the driving forces of temporal change in the cover of boreal forest plant species in Finland over 21 years (1985–2006). Our study focused on the effects of forest cuttings of different intensity, i.e. regeneration cuttings (RC, e.g. clear cuttings) and intermediate cuttings (IC, mostly thinnings), on 11 common understory species (including vascular plants, mosses and lichens) and their recovery after cuttings. Linear models were applied in explaining the change in the cover of plant species. The plant species displayed contrasting responses to RC and IC in accordance with their light demand, which also accounted for their recovery rate after cutting disturbance. Species-specific responses to cuttings showed considerable variation within plant functional groups (e.g. dwarf shrubs, herbs, mosses). In general, early successional light-demanding species increased and late successional shade-tolerant species decreased after RC. IC favoured all but the most light-demanding species. The advantage IC provide for certain semi-light species (e.g. *Vaccinium vitis-idaea*) may cause homogenization in plant communities. Cuttings determined the principal change in vegetation, while only slight signals of the effect of climate warming were found in few species. The legacy of forest management deserves special attention when e.g. tracking the effect of global change on vegetation.

P37 Understanding similarities and differences in intrapopulation trait integration of coexisting tree species: Consistent hydraulic relationships amidst widely different integration patterns

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General relationships among functional trait have been identified across species, but it remains largely unknown whether they reflect constraints or adaptation. Comparing species' intrapopulation trait correlations allows us to test these processes. We study similarities and differences in intrapopulation trait integration among locally coexisting tree species to test the hypotheses that (i) the intrapopulation integration of functional traits is largely shaped by fundamental trade-offs or constraints, and (ii) differences among species reflect adaptation to different environmental niches. We compare pairwise and multivariate correlations of seventeen functional traits within and among temperate tree species. These traits fall into three well-established trade-off dimensions characterizing interspecific relationships among physiological functions: resource acquisition and conservation, sap transport and mechanical support, and canopy architecture.
Three dimensionally independent trait pairs are correlated within all populations: K_S-Lumen Fraction, K_{BRANCH}-Lumen Fraction and LMA-δ13C. For all other traits, intrapopulation integration of functional traits is weak, species-specific and distinct from interspecific integration. Surprisingly, species intrapopulation integration is related to neither phylogeny nor environmental niche.
The results suggest the existence of a 'template' on tree functional design centered on sap transport that includes leaf and xylem traits, point to a minimal role of fundamental constraints in shaping functional trait integration, highlight flexibility in plant functional design, and suggest that interspecific integration is mainly shaped by processes acting at the species scale.

P38 Trait dimensionality and community assembly in a semi-arid grassland: Covariance and utility of traits related to leaf economics, resource acquisition, and tolerance of drought and grazing

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The nature of variation among functional traits in plant communities determines niche differentiation and community assembly, yet the dimensionality of plant trait variation is poorly known because most studies of plant communities measure just a few traits. To understand plant community assembly and the evolutionary and environmental constraints on plant function, studies must broadly characterize the dimensionality of trait variation among plant species, including synergies and trade-offs among traits related to different functions. We characterized variation among a diverse set of plant functional traits in a semi-arid, mixed-grass prairie of North America. For ~35 species, we measured a suite of leaf and root economic traits and traits related to tolerance of both drought and cattle grazing. Then we used simple and multiple regression to describe covariation among these traits and the role of plant traits in predicting community assembly (i.e., relative abundance of each species) and plant phenology. We also evaluated traits as predictors of plant responses to environmental change, including elevated CO_2, warming, drought, and increased grazing. Preliminary results suggest: 1) most pairwise relationships among traits are weak, 2) multivariate synergies and tradeoffs exist, and 3) community assembly and plant phenology are best explained by multiple traits (>3).

P39 Macro-dynamics of stomatal conductance in woody vegetation across seven biomes

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Stomata are at the interface between biosphere and atmosphere, regulating carbon uptake and water loss through stomatal conductance (g_s) and intrinsically linking the hydrologic and carbon cycles. However, current understanding of global g_s in natural field conditions is limited. Unlike previous research carried out under varying degrees of environmental control, we measured g_s in natural forest ecosystems across a wide range of woody angiosperms using a standardised protocol to capture natural variance and improve our understanding of macro-level stomatal functioning. We present a contemporary dataset of 4723 g_s measurements across 264 species, six major PFTs and seven biomes, exploring g_s variance in the natural environment. Individual leaf sample and species combined contribute ~60% to observed variance, PFT (8%), site (6%) and biome (2%), with environment (VPD, light and temperature) contributing just 2.5%. The dataset distribution parameters (Weibull), describing shape and slope of g_s frequency distribution, correlate strongly with species g_s plasticity and environment, demonstrating that each biome is characterized by unique interactions of physiological response and species phenotypic plasticity. This novel dataset can be used for stochastic modelling of g_s, validation of climate model g_s simulation and improve predictions of vegetation feedback on the hydrologic cycle.

P40 Informing models through empirical relationships between foliar phosphorus, nitrogen and photosynthesis across diverse woody species in Panama

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Our objective was to inform model representation of phosphorus (P) limitation of tropical forest productivity. Gas exchange and nutrient content data were collected from upper canopy leaves at two forest sites in Panama, differing in species composition, rainfall, and soil fertility. Photosynthetic parameters were derived from analysis of assimilation rate vs. internal CO_2 concentration curves (*A*/Ci), and relationships with foliar nitrogen (N) and P content were developed. The relationships between area-based photosynthetic parameters and nutrients were of similar strength for N and P and robust across diverse species and site conditions. The best relationship was further improved with the inclusion of independent data on wood density. Models that estimate photosynthesis from foliar N content would be improved only modestly with the inclusion of additional data on foliar P, but doing so may increase the capability of models to predict future conditions in P-limited tropical forests, especially when combined with data on edaphic conditions and other environmental drivers.

P41 Comparing small scale variability patterns of functional traits in an herbaceous community

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In the last decades, trait based studies raised as a novel approach in ecology, but several issues are still partially unresolved. First, the choice of the best set of traits to measure is fundamental to gain as much as possible information about plants' performance. Moreover, assessing the adequate sampling strategy is fundamental to avoid underestimation of traits variability and functional diversity indexes within a community. We measured four leaf traits, specific leaf area (SLA), osmotic potential (π), vein density (VD) and carbon to nitrogen ratio (C:N), on leaves of 32 herbaceous species of an arid meadow. We specifically aimed at: i) assessing the minimum number of plots to adequately estimate Functional Diversity (FD) and Community Weighted Mean (CWM) indices; ii) assessing traits variability within the community. 10 plots, 30x30 cm wide, represented the minimum number of plots to be sampled, since they accounted for ~99% of the total FD. On average, variability was higher in VD, π and C:N, often reported as 'hard' traits (traits difficult to measure), than in SLA. Moreover, the low correlation between traits suggest that several trade-offs observed in the global leaf economic spectrum do not necessarily hold true within plant communities at small spatial scales.

P42 What do plants grown under controlled conditions tell us about plants in the field?

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Many biologists study plants in (semi-)controlled conditions in glasshouses and growth chambers, but with the ultimate aim to understand plant functioning in the field. Controlled growth facilities allow for a reproducible environment, where plants can be grown under either 'optimal' conditions or subjected to a specific level of a stress factor. However, by doing so, conditions can become quite remote from those in the field.
We demonstrate that plants in controlled environments generally have higher RGR and SLA, but lower photosynthetic capacity and size than plants from the field. We show that the combination of a low daily light integral (DLI) and a high mean temperature are important reasons for this difference and emphasise that the 'photothermal ratio', the ratio between DLI and mean air temperature, is a relevant variable to gauge how realistic conditions applied in the lab are for those in the field. Various other options to apply more 'realistic' environments under controlled conditions are discussed.
See also: *New Phytologist* **212**: 838–855.

P43 Height-related changes in xylem hydraulics and anatomy of leader shoots of *Picea abies* trees

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During ontogeny, the increase in tree height constrains water transport in terms of safety and efficiency. The higher risk of embolism formation is driven by the extra tensile strength to the xylem water due to gravitational pressure drop. Additionally, the total root-to-leaves path length increases with negative effects to water flow due to increasing frictional forces. We investigated whether safety or efficiency is prioritized at the apex of taller trees, and which are the responsible anatomical adjustments.
We assessed the vulnerability curves and measured xylem anatomical traits of the leader shoots of *Picea abies* trees varying from 2 to 37 m of height, at two timberline sites in the Eastern Alps.
The xylem water potential triggering 50% of loss of conductivity (*P50*) significantly increased from small to tall trees; the total tracheid number and their hydraulic diameter significantly increased with tree height. A strong efficiency vs. safety trade-off was found, with xylem conductivity showing a significant negative relationship with *P50*.
Taller trees prioritize xylem efficiency vs. safety, with the xylem becoming more vulnerable to cavitation with increasing tree height. These results could represent a mechanistic explanation of why taller trees are commonly more prone to top dieback and vigour decline.

P44 Plant traits and the regulation of grassland soil functions

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Grasslands store large amounts of carbon globally. It has been shown that vegetation type and diversity affect soil properties and processes related to carbon sequestration and other soil functions, but the mechanisms remain unclear. Trait-based approaches are a promising way to understand and predict this link between plants and soil function. We will conduct a field survey in existing long-term biodiversity manipulation grassland experimental sites located in Salisbury Plain and Yorkshire Dales. We are planning to survey above- and below-ground plant traits as well as physical, chemical and microbial soil properties. Particular focus will be put on measuring a broad range of root traits, including mycorrhizal colonization and root hair length and density. We will investigate relationships between traits and soil properties to address the following questions: Are there relationships between above- and below-ground traits? Is there a resource economic spectrum of root traits? How do leaf and root traits affect soil carbon and nutrient cycling, microbial community and soil physical properties? How large are intra- and interspecific variation of plant traits?

P45 Photoreceptor-mediated responses to spectral cues are reflected in the leaf pigments and photosynthetic sufficiency of understorey plants during the seasonal evolution of forest canopies.

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In the forest understorey plant inhibit a complex light environment. Irradiance and spectral composition vary seasonally (particularly during canopy flush) and spatially, with sunflecks traversing the forest floor. Plants living in these conditions must be adapted both to exploit the opportunity provided by transient high irradiance and to maintain a positive carbon balance while under shade. We tested how photoreceptor mutants of model plant species adjust their photosynthetic capacity, leaf pigmentation, and photoprotection when subjected to artificial under-canopy spectra created by manipulating blue and UV radiation. We compared these responses to those of understorey species in various forest types. Model plants lacking perception of blue through cryptochromes and of UVB through UVR8 photoreceptor were deficient in photoprotection and their photosynthetic capacity was impeded when exposed to high light. In many understorey species, the accumulation of UV-screening phenolics was maximal during the early-spring peak in irradiance immediately prior to canopy closure rather than the later peak in the UV:PAR ratio, but various species employed alternative strategies to cope with fluctuating irradiance. The proportion of blue light received was key to the development of leaf traits that promoted effective utilisation of transient high irradiance in both model and understorey species.

P46 Hydraulics constrain the scaling of the leaf economics spectrum

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Two main foci in ecology are to understand trade-offs explaining ecological strategies and to identify the critical traits of species responsible for them. A universal leaf economics spectrum (LES) has been described, spanning from conservative leaves with long life-span and slow returns on C and nutrients to acquisitive leaves with short life-span and fast returns on investment. The functional significance of this spectrum for plants remains to be completely elucidated. Here we compile trait data from ~1650 species worldwide to show that xylem water transport properties constrain the scaling of LES. We found evidence of coordination of LES with hydraulic efficiency and safety at the tissue level but also compensatory responses in terms of allocation and minimum water potentials, resulting in LES being largely decoupled from whole-plant water economics. Our results indicate that water economics need to be included to improve our capacity to scale up from the leaf to the plant in predicting vegetation changes under new climatic conditions.

P47 Fine root traits co-variations: Structural and functional relationships at the global scale

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Because fine roots perform many functions, they have to face to conflicting demands that have major ecological implications on their structure. Understanding how root structure and functions varied among species is thus a major goal in ecology. This has been largely under-considered worldwide in part because of the lack of large root databases. This study aimed to test on a large number of species fine root trait covariations among key chemical, structural and physiological traits that may reflect a trade-off between resource acquisition and conservation similar to that reported at the leaf level.
We compiled a world-wide fine-root trait dataset, featuring 1115 species from contrasting climatic areas, phylogeny and growth forms. We determined patterns of correlations among root structural and chemical traits and their relationships with two traits relating to carbon economy, root respiration and root decomposability. We then tested whether patterns of fine root trait correlations differed among functional groups, climate and growth conditions.

P48 Scaling from functional traits to demographic strategies

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Scaling from functional traits to ecosystem dynamics and functions requires accounting for the intermediate level of species demographic rates (growth, survival, recruitment). However, it is unclear how well species demographic strategies can be predicted from easily measurable morphological traits. We identified the demographic strategies of 290 tropical tree and shrub species by performing a novel weighted PCA on nine demographic rates accounting for tree size and light availability (growth and survival in four canopy layers, number of sapling recruits). The most important demographic dimension was a general trade-off between growth and survival in all canopy layers corresponding to a fast-slow continuum of life-histories (42% explained demographic variation). The second dimension (21%) distinguished species with fast growth and high survival in all canopy layers, but low recruitment rates ('long-lived pioneers'), from the opposite ('short-lived breeders'). Slow species had high wood density, seed mass and small adult stature. The long-lived pioneer syndrome was associated with tall stature. Morphological traits explained about 50% of interspecific variation along both axes. Thus, using trait-based demographic strategies seems to be a promising route to 'diversify' dynamic vegetation models.

P49 The StrateGo network: A global network for predictive functional population ecology

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Understanding the mechanisms that shape the vast variation in plant functional traits (e.g. seed mass, woody density, specific leaf area) and life history traits (e.g. longevity, reproductive output, growth rate) is fundamental for effective predictions of viability, invasions and evolutionary pressures. Recent work using functional trait approaches and life history approaches have shown remarkable similarities in the way plant diversity is structured, with two predominant axes of variation predicting upwards of 60%. Here, I discuss the 'fast-slow continuum and reproductive strategy' framework to quantify the variation in plant life history strategies worldwide, using high-resolution demographic information from 650 plant species archived in the COMPADRE Plant Matrix Database, and combine it with functional traits to demonstrate their predictive power. Basic information about the allocations to vasculature tissue (or survival) and seed mass and seed number (or reproduction) predicts population growth rate and resilience. The fast-slow continuum & reproductive strategy framework relates to the leaf economics spectrum, as specific leaf area predicts allocations to survival and reproduction. However, this approach raises relatively low R2s. I argue that this is so because the provenance of functional trait data (TRY) and demographic data (COMPADRE) for a given species differ in geographic and micro-climatic distance. The StrateGo network (https://strategonetwork.wordpress.com), a distributed network of field ecologists examining traits and vital rates at the same location and species, will improve the predictive ability of functional trait demography. I review how the StrateGo network operates, its main goals, approaches, and opportunities.

P50 Ecophysiological bases of the growth-defence trade-off in 311 Arabidopsis thaliana genotypes

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The growth-defence trade-off, source of plant diversification, can have several origins; (i) *biophysical*, through the venation network which constrains fluxes and supports the leaf, (ii) *biogeographical*, since defence strategies should be favoured at low latitudes, (iii) *genetic*, through the effects of pleiotropic genes. We measured a set of leaf traits related to defence and metabolism on 311 ecotypes of *Arabidopsis thaliana* collected globally.
More precisely, we measured traits related to resources acquisition (Specific leaf area, Leaf nitrogen content), leaf traits related to structure (resistance to cutting, thickness) and defence (glucosinolates, trichomes). We payed particular attention to the vein network study, since we hypothesized that it is an integrative trait of this trade-off.
Our results confirm the existence of a growth-defence trade-off at the intra-specific level. We show that hypothesis (i) is supported and hypothesis (iii) needs further comprehensive analysis. Hypothesis (ii) is not supported by our dataset but we show a shift in the type of defence with latitude. This study points to the need to reconsider the importance of intraspecific phenotypic variability in comparative ecology.

P51 Nitrogen cycling in tropical zones of transition – inference from leaf and soil $\delta^{15}N$ across three continents

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The ratio of stable nitrogen isotopes ($\delta^{15}N$) can act as an important indicator of ecosystem nitrogen (N) cycling and thus key ecosystem processes. Although evidence for general patterns accumulates across the globe, such as foliar $\delta^{15}N$ decreasing with increasing mean annual precipitation and decreasing mean annual temperature, as well as forests generally having a more open N cycle, a comprehensive understanding of the N cycle in tropical ecosystems is still lacking.
We present data on foliar, litter and soil $\delta^{15}N$ from 62 permanent sampling plots in tropical zones of transition where forest and savanna coexists at their relative dry and wet margins, across South America, Africa and Australia. These zones of transition are highly dynamic systems and thus good 'natural' experiments for the effects of global change on plant growth and function.
We found that foliar $\delta^{15}N$ relationships in tropical forests and savannas differ consistently across three continents with forests being mainly limited by site (soil and climate) and savannas by taxonomic identity of the tree and only few of the potentially nodulating plants being apparent fixers. Our results highlight the need for explicit analyses highlighting differences in the functioning of diverse tropical ecosystems.

P52 Leaf optical properties shed light on foliar trait variability at individual to global scales

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Recent syntheses of trait databases have contributed immensely to our understanding of global plant functional variability. However, trade-offs revealed by such syntheses, such as the leaf economics spectrum, are often not observed at smaller scales. An improved understanding of trait variation within communities, species, and individuals is critical to accurate representations of vegetation ecophysiology and ecological dynamics in ecosystem models. Spectral data from field observations and remote sensing present a widely available source of information on plant traits. The inversion of physically-based radiative transfer models (RTMs) is an effective and general method for estimating plant traits from spectral measurements. Here, we apply Bayesian inversion of the PROSPECT leaf RTM to a large database of field spectra and plant traits from a variety of biomes to identify dominant sources of variability and characterize trade-offs in plant functional traits. Our project has two major findings: (1) Optical traits related to leaf size and function (pigments, water content) occupy a separate axis of variability to traits related to leaf recalcitrance (mass per area, lignin, C:N ratio); and (2) Variability in optical traits is comparable within and among species, and the contributions of additional variables to explaining this variability are highly trait-dependent.

P53 Leaf Dry Matter Content is better at predicting above-ground Net Primary Production than Specific Leaf Area

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Reliable modelling of above-ground Net Primary Production (aNPP) at fine resolution is a significant challenge. A promising avenue for improving process models is to include response and effect trait relationships. However, uncertainties remain over which leaf traits are correlated most strongly with aNPP. We compared abundance-weighted values of two of the most widely used traits from the Leaf Economics Spectrum (Specific Leaf Area and Leaf Dry Matter Content) with measured aNPP across a temperate ecosystem gradient. We found that Leaf Dry Matter Content (LDMC) as opposed to Specific Leaf Area (SLA) was the superior predictor of aNPP (R^2=0.55). Directly measured *in situ* trait values for the dominant species improved estimation of aNPP significantly. Introducing intra-specific trait variation by including the effect of replicated trait values from published databases did not improve the estimation of aNPP. Our results support the prospect of greater scientific understanding for less cost because LDMC is much easier to measure than SLA. A paper reporting this work is in press at *Functional Ecology*.

P54 Surface saturation storage capacity of common urban green types: a predictive model based on functional traits

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Rainfall interception plays a key role in the urban hydrological balance by detaining rain water that otherwise will run-off or infiltrate. Up until now, interception studies in the urban environment have mainly focused on interception of man-made materials and urban trees because of their large water retention capacity. Smaller green types however, also have a large interception potential due to their dense biomass and widespread abundance in the urban landscape. The most important variable in determining the interception of a plant species is the surface saturation storage capacity. The surface saturation storage capacity of two shrub species, one perennial grass, one common grass mix and two green roof vegetation types were determined in a controlled greenhouse experiment and related to several plant functional traits. The most influencing plant functional traits were used to construct generic, mixed multiple linear regression models to predict the surface saturation storage capacity of several small green types. The results of this research are of interest for urban planners and hydrologists alike to get a better understanding about the potential benefits of small green types in the urban environment.

P55 Predicting photosynthetic capacity from first principles

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Photosynthesis by plants represents one of the largest uncertainties in projecting the rate and magnitude of future atmospheric carbon dioxide (CO_2) concentrations. While models of photosynthesis perform well at small temporal and spatial scales, there is a need for formulations that perform well at scales relevant for projecting future global changes. Here, we develop a theoretical model to predict photosynthetic capacity (i.e., the maximum rate of Rubisco carboxylation, V_{cmax}) and test it using a global observational dataset of V_{cmax} (>4000 datapoints at >200 sites across most of the world's major biomes). The theoretical model used climatic variables for each site to predict V_{cmax} rates using the coordination hypothesis for photosynthesis and intercellular CO_2 optimization. We found that the theoretical model could capture >60% of the variation in observed V_{cmax} values across all sites. Our findings suggest that the long-term integrated photosynthetic capacity can be well predicted from first principles of photosynthetic theory, without reliance on typical empirical parameters. Our results have implication for how we understand and model photosynthetic responses to environmental change.

P56 Global trends in biome-level plant water-use efficiency in the past 25 years from rising atmospheric carbon dioxide concentration.

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Climate change will likely alter future ecosystems functioning however the magnitude and direction of such changes are unpredictable and difficult to quantify. Uncertainties in the magnitude and direction of the physiological responses of plants to elevated CO_2 at biome level hamper modelling of terrestrial water cycling and carbon storage. One of the important physiological traits is water-use efficiency which is the key characteristics of ecosystem function that is central to the global cycles of water, energy and carbon. Many existing studies have focused on long-term centennial effects of elevated CO_2 on plant water-use efficiency of a relatively few species within narrow ecosystem range but short-term effect on much broader ecosystem coverage is unknown. Here we assessed the impact of a short-term (25 years: between 1988/89 and 2013/15) increase in CO_2 (*c*. 45 ppm) on plant intrinsic water-use efficiency inferred from leaf stable carbon isotope ($\delta^{13}C$), encompassing a broader coverage to include seven world biome and 229 woody angiosperm species. We show that the magnitude of plant intrinsic water-use efficiency change varied among biomes and plant functional types. Our finding is important because it shows that short-term increase in atmospheric CO_2 may differ among biome-plant functional type compositions.

P57 Global plant trait relationships persist at environmental extremes

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Trait based ecology offers the promise of predicting community assembly, ecosystem function, and responses to environmental change across biomes. However, development of generalizable trait theory relies on reducing the variation of life to a few simplified dimensions. There is evidence that the majority of variation in plant traits can be explained by just two axes, corresponding with growth strategy and plant morphology. However, these findings focus on global scales so may not represent all biomes equally, and ignore variation within species. Here, we use the largest tundra plant trait database ever compiled to test whether global plant trait relationships are observed in the tundra biome. We found that tundra plants exhibited a two-axis spectrum of plant form and function, consistent with global findings, but that only traits associated with plant morphology, and not resource acquisition, were constrained relative to other biomes. Trait variation was primarily explained by differences between species, rather than between functional groups or within species; however, within-species differences strongly influenced trait variation at community scales. Our findings indicate that global plant trait relationships are maintained at the edges of trait-space in the temperature-limited tundra biome, providing the basis for prediction of plant trait change with climate warming.

P58 Traditional cattle and sheep grazing: a trait-based approach

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In Europe, grassland conservation became a top priority and frequently sheep or cattle grazing are suggested as the best options for biodiversity conservation in practice. We compared the effects of cattle and sheep grazing on short-grass steppe vegetation in Hungary under various grazing intensities. We found lower taxonomic and functional diversity, and lower cover of forbs in sheep-grazed steppes compared with cattle-grazed ones. Grazing intensity had a significant effect only on species richness, while on Shannon diversity and evenness; only livestock type had a significant effect. Most single trait indices were affected by the type of the grazer; significant effect of intensity was detected only in a few cases. These findings suggest that the selection of the livestock type is more crucial in biodiversity conservation than the set of intensity. However, for proper ecosystem functioning and high trait variability, the suitable grazing intensity should also be carefully adjusted.

P59 Global fitness maximizing approaches to evaluate the trade-offs involved in the evergreen and deciduous conundrum

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It is undisputed that variation in functional traits, like leafing strategies, drives global patterns in vegetation functioning and associated services. Despite its global significance, the challenge of building a prognostic model to understand and predict how evergreen-deciduous strategies affect plant fitness and the global distribution of these leafing strategies has, however, not been addressed. Here, we will apply eco-evolutionary principles to develop a mechanistic foundation with respect to this conundrum, evaluating trade-offs among key dynamic traits in relation to carbon and nitrogen management in trees.

To determine the traits and trade-offs that determine leafing strategy, an optimal response stand model was built. This model optimizes the allocation of C and N in order to maximize an Euler-Lotka fitness equation based on fecundity and survivorship. The C and N allocation optimization was done with an MCMC algorithm to infer trait combinations to discover which set of traits can predict fitness of evergreen and deciduous trees best. In order to explain global patterns, leaf life span was optimized through its relationship with leaf nitrogen and chemical defense properties of the leaf. Results are expected to show the best possible trait combination to predict fitness and global distribution, and are expected in April.

P60 Adaptive diversification of plant allometry in *Arabidopsis thaliana*

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Seed plants vary tremendously in size and morphology. However, the diversification of plant traits may be governed by a small set of universal biophysical laws underlied by few biological constants. According to the Metabolic Scaling Theory (MST), hydrodynamic resistance constrains several physiological traits to be mathematical functions of plant size with near constant scaling exponents across species. However, recent observations challenge the universality of the so-called allometric relationships. We assessed growth scaling and fitness traits of 451 accessions of *Arabidopsis thaliana* with sequenced genomes. We found substantial variation between accessions around the scaling exponent predicted by MST, nonetheless associated with reduced seed production. Using genome-wide association mapping, we showed that allometric variation is genetically correlated with local climate. The genes identified are related to abiotic stress response and they show molecular signatures of balancing selection that maintains high allelic diversity between populations. Strikingly, plants with extreme allometries performed better under water deficit and high temperature, which illustrates that the maintenance of intraspecific variation on growth scaling is due to opposing selection for two major components of plant fitness: seed production and resistance to abiotic stress. We thus provide an evolutionary explanation for the diversification of plant allometry within species.

P61 Can leaf net carbon gain acclimate to keep up with global warming?

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Future plants will likely face warmer and more variable air temperatures and more frequent dry conditions limiting transpiration. These changes will impact leaf temperature, which in turn directly and indirectly affects leaf net CO_2 uptake and hence plant productivity. Plants are able to adjust their physiological activity to fluctuations and long-term changes in their growing environment. Nevertheless, projected increases in temperatures will occur at unprecedented speed. Will global warming exceed the acclimation capacity of leaves, thus reducing net CO_2 assimilation? To address this question, we combined data on net photosynthetic thermal acclimation to short-term (sub-daily) and long-term (weekly to monthly) changes in leaf temperatures with a probabilistic description of temperature variability. The developed stochastic model quantifies how the mean and variability of leaf temperature affects net CO_2 assimilation as mediated by acclimation. We show that i) the projected increase in leaf temperature variability will have consequences on net CO_2 assimilation rate comparable to an increase in average leaf temperature and will increase the variability of net CO_2 assimilation rates; and ii) acclimation to changed thermal conditions can reduce the impact of the expected increase in foliar temperature, but acclimation is not sufficient in the face of more variable temperatures.

P62 Root traits across environmental gradients in Mediterranean woody communities: are they aligned along a single acquisition-conservation axis?

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Root traits play a critical role in plant resource-use strategies and ecosystem functioning, but there is great controversy regarding their identity and functionality in different dimensions of belowground functional variation. Here, we explored the level of covariation among a suite of key root traits as well as between them and two aboveground parameters related with plant function (leaf nutrients and growth rate). We also evaluated whether these patterns of trait covariation were consistent at different spatial scales and organisational levels. We collected fine roots traits of 534 individuals (of 80 woody species), sampled along a wide regional range of environmental conditions in southern Spain. In general, strong correlations among the root morphological traits (except root mean diameter) were found, as well as between them and the aboveground parameters, supporting the existence of a 'root economics spectrum'. This syndrome of root trait covariation was consistent at the different spatial scales and organisational levels. Soil nutrients and water availability were the main drivers of this root trait variation. Our results indicate that root trait variation is primarily aligned along a leading dimension related to resource economics. However, the distinct pattern of root diameter may indicate a multidimensionality of belowground traits that needs to be explored in greater depth.

P63 An influential couple: The relationship of J_{max} and V_{cmax} in photosynthetic responses to elevated CO_2

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Predictive understanding of the future terrestrial carbon sink remains elusive and is manifest in the wide variability in projections from earth system models of CO_2 fertilisation. While many biogeochemical and ecological processes contribute to this wide variability in model projections, models are highly sensitive to chloroplast-scale photosynthetic traits. For this reason, it is hypothesised that chloroplast-scale photosynthesis is an important driver of variability in model projections and that identifying drivers of variability in leaf-scale photosynthesis modelling is a needed endeavor. To investigate drivers of variability we present a novel modelling framework—the multi-assumption architecture and testbed (MAAT)—that can explicitly evaluate both parameter variability and multiple hypotheses for each process represented by the model. Commonly used by models are the different electron transport functions and limiting rate function posed by Farquhar et al., (1980) and Collatz et al., (1991). We use process and trait sensitivity analysis to show that the covariance between J_{max} and V_{cmax} is the most influential trait in simulating the response of photosynthetic carbon assimilation to CO_2. However, the covariance between J_{max} and V_{cmax} was not the most influential variable in earth-system models suggesting that a key trait covariance is being overlooked.

P64 Variation in plant response to herbivory underscored by functional traits

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The effects of herbivory can shape plant communities and evolution. However, the many forms of herbivory costs and the wide variation in herbivory pressure, including across latitudinal gradients, can make predicting the effects of herbivory on different plant species difficult. Functional trait approaches may aid in contextualizing and standardizing the assessment of herbivory impacts. Here we assessed the response of 28 plant species to simulated defoliation in a greenhouse setting by measuring whole plant and leaf level traits in control and treated individuals. Simulated defoliation reduced height but otherwise had no significant effects on any plant traits measured. However, control plant leaf-level traits were consistently predicted the log response ratio for whole plant response. The latitudinal mid-point of species' distributions was also significantly correlated with aboveground biomass and total leaf area responses, with plants with a more northern distribution being more negatively impacted by treatment. These results indicate that even in the absence of significant overall impacts, functional traits may aid in predicting variability in plant responses to herbivory and in identifying the underlying limitations driving those responses.

P65 Whole-plant biomass allocation patterns in temperate lianas

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Lianas are specialized growth forms that use neighboring plants for support. According to Darwin, this allows them to reduce biomass investment in stems and to produce additional leaf biomass. The few explicit tests of this hypothesis reported so far have either considered only aboveground biomass, attempted to excavate plants *in situ* or used small, pot grown plants. Moreover, the allometric effect of plant size on biomass allocation has seldom been considered. We conducted an outdoor cultivation experiment using large, 120 L containers and performed annual harvests to determine whole-plant biomass allocation ratios in five confamiliar temperate liana/shrub species pairs. At common plant biomass, leaf biomass fraction tended to be higher in lianas than in shrubs, accompanied by smaller stem or root fraction. Such allocation pattern in combination with higher specific leaf area in lianas resulted in their greater leaf area to plant biomass ratio, relative to shrubs. The high foliar investment in lianas was, however, sometimes only apparent in large plants. Despite variability of allocation ratios within each growth form, our results validate the Darwin's hypothesis and illustrate the mechanism of high biomass productivity in lianas.
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P66 Quantifying the effects of interacting nutrient cycles on terrestrial biosphere dynamics and their climate feedbacks (QUINCY)

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Nutrient availability plays a pivotal role in the response of terrestrial ecosystems to increasing atmospheric CO_2 and climate change. The first generation of global nutrient-carbon cycle models shows strongly diverging estimates of the effect of varying nutrient availability resulting *inter alia* from uncertainties in the representation of governing processes. The QUINCY project addresses the two most important areas in which advances in modelling are required: i) the effects of nutrient availability on photosynthesis and the partitioning of assimilates to different plant organs and respiration, and ii) the effects of rhizosphere processes on plant nutrient availability and soil organic matter turnover.
We present first results from a novel modelling approach to systematically link carbon, nutrient and water flows within the framework of a general land surface model at time-scales of minutes to decades. The model employs resource economics to predict the acclimation of hitherto constant plant traits (such as leaf internal and total N allocation) under altered environmental conditions. Carbon costs and gains also affect plant partitioning to resource (carbon, water, nutrients) uptake. Finally, the model represents a detailed framework to simulate interactions between plant below-ground carbon allocation, microbial and fungal activity, and soil organic matter decomposition.

P67 Plasticity of photosynthetic heat tolerance in plants adapted to contrasting environments across Australia

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Plants are increasingly subject to more frequent and intense heat waves, potentially causing more negative effects on photosynthetic apparatus. Currently, our ability to predict spatial and temporal variations in photosynthetic heat tolerance (P_{HT}) remains limited. With these issues in mind, we quantified seasonal variations in T_{crit} (critical temperature at which minimal chlorophyll-*a* fluorescence rises rapidly during heating, indicating photosynthetic heat damages) of 62 species at six thermally contrasting field sites across Australia. Thereafter, T_{crit} was quantified in ca. one-third of those species (sourced from locations close to the surveyed field sites) using plants grown in three temperature-controlled glasshouses. Leaf fatty acid (FA) composition was also profiled. T_{crit} was generally higher in summer than winter. Glasshouse study showed that T_{crit} acclimates to sustained changes in growth temperature. Relative abundance of some FAs were higher in warm acclimated plants. T_{crit} and the relative abundance of some FAs were higher in species adapted to hot habitats than their cool habitat counterparts. Overall, variations in FAs accounted for ca. 40% of variation in T_{crit}, suggesting a link between P_{HT} and lipid composition. These results highlight the evolutionary footprints and acclimation to the contemporary environment in determining P_{HT} of plants broadly.

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STREATHAM CAMPUS MAP GUIDE

Residences

Birks Grange Village	66 5B
Bonhay House	53 11C
Clydesdale Court	64 5C
Clydesdale Rise	65 4C
Cook Mews	69 4A
Duryard	72 2B
Garden Hill House	27 3J
Holland Hall	62 4D
Holland Hall Studios	62 4D
Hope Hall	41 7K
King Edward Court	68 5A
King Edward Studios	67 5A
Lafrowda	43 7J
Lafrowda Cottage	44 8J
Lazenby	38 7L
Llewellyn Mews	70 4A
Lopes Hall	34 6K
Mardon Hall	58 5E
Moberly	71 3B
Nash Grove	57 5D
Northfield	75 9C
Pennsylvania Court	36 6L
Ransom Pickard	35 6L
Rowe House	45 7J
St David's	51 12B
St German's	42 7K

Academic, administration and social buildings

Alexander	47 10E
Amory	29 5H
Bill Douglas Cinema Museum	7 8G
Business School Building:One	84 6I
Byrne House	37 7K
Catholic Chaplaincy	74 3A
Clayden	54 8D
Clydesdale House	63 5D
Cornwall House	32 6I
Cornwall House Swimming Pool	80 7I
Devonshire House	2 6G
Exeter Northcott Theatre	13 5F
Family Centre	59 5E
Forum	3 6G
Geoffrey Pope	20 5F
Great Hall	1 6G
Harrison	23 4H
Hatherly	6 7G
Henry Wellcome Building for Biocatalysis	19 5F
Innovation Centre	25 4I
Institute of Arab and Islamic Studies	16 5E
INTO International Study Centre	83 5G
Kay Building	24 4H
Kay House Duryard	85 1A
Knightley	55 8E
Lafrowda House	33 6J
Laver	22 4G
Library	4 6H
Mary Harris Memorial Chapel	10 7F
Newman	18 5F
Northcote House	12 6F
Old Library	7 8G
Peter Chalk Centre	17 5F
Physics	21 4F
Queen's	11 7F
Redcot	56 7D
Reed Hall	14 6E
Reed Mews Wellbeing Centre	15 5E
Roborough	8 8F
St David's Retail Services	52 11B
Sir Henry Wellcome Building for Mood Disorders Research	82 8F
Sports Park	60 4E
Streatham Court	31 6H
Streatham Farm	5 6H
Student Health Centre	86 6E
Tennis Centre	61 4E
Thornlea	48 10D
University Reception	1 6G
Washington Singer	9 8E
Xfi	30 5I