Drought in tropical forests

The role of tree height and wood density for hydraulic efficiency, productivity and vulnerability to cavitation of trees along a lowland precipitation gradient

Roman Link

Department of Plant Ecology and Ecosystem Research
Georg August University of Göttingen

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Structure of my PhD project

- **Chapter 1:** Predicting radial sap flow profiles from Costa Rican tropical dry forest species
- **Chapter 2:** Predicting plant vulnerability to embolism in Costa Rican humid tropical forest species
- **Chapter 3:** Relationship between productivity, structural and functional, wood anatomical and hydraulic traits of tropical forest species from Costa Rica

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- **Bonus Chapter:** Maximum-likelihood estimation of xylem vessel lengths

Structure of this presentation

1. Introduction
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5. Maximum-likelihood estimation of xylem vessel lengths: **Not in the focus of this presentation!**

Introduction

- Basics about plant water relations
- Why is it important to know about drought effects in the tropics?

Main research questions

- This one's gonna be tough

Design of the study

- 5 research sites along a rainfall gradient on the Pacific shoreline of Costa Rica
- Gradient from tropical dry forest to humid tropical lowland forest
- Based on existing research sites of the **Instituto Tecnológico de Costa Rica**

Design of the study

- At each of the 5 research sites:
  - 8 species representing a gradient in tree height and wood density
  - 5 replicates per species

  $\Rightarrow$ 40 trees per site, 200 trees in total
- Field measurements of temperature, relative humidity and precipitation

Problems with the design

- Opportunistic use of pre-existing plots
- Different plot sizes and numbers at each site
- Differences in historic land use (pristine primary forest vs. disturbed primary forest vs. secondary forest)

→ Plot-based comparisons are difficult

⇒ Not that important for our (eco-physiological) research questions, but limits usability of plot network for other studies

First chapter: radial sap flow profiles

Sap flow measurements:

- Practical limitations → only in dry forest (Horizontes)
- 4 measurement campaigns of ± 1 week during rainy season of 2015
- 40 trees of 8 species
- measured with the Heat Field Deformation (HFD) method

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Heat field deformation sensors

Working principle:

- 1 heater and 3 temperature sensors inserted into wood
- Heater heats constantly with known caloric input
- Sap movement → faster heat transport in flow direction
- Temperature differences between sensors are used for estimation of sap flux density at different depths

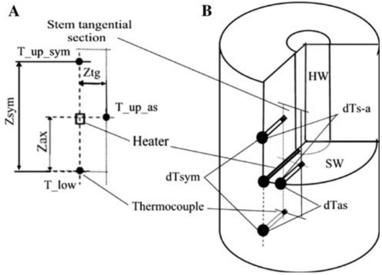

Image source: Nadezhdina et al., 2012

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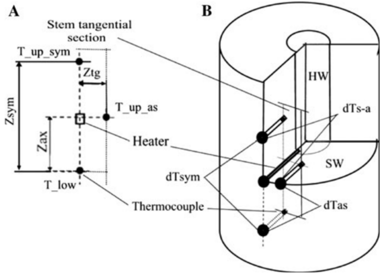

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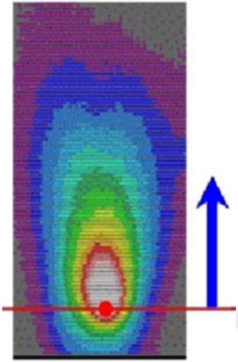

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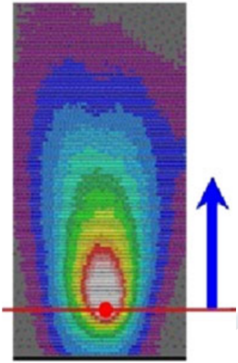

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Heat field deformation sensors

- Original idea: Comparison of sap flow and plant water use between species with different trait combinations

Heat field deformation sensors

- Problem: newer research indicates that
  a) The mechanistic explanation of the HFD method (Nadezhdina et al., 2012) is flawed (Vandegehuchte et al., 2012)
  $\rightarrow$ species-specific calibration likely necessary in most cases
  b) Calibration parameters are not consistent within species (Fuchs et al., 2017)

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Short communication

Interpreting the Heat Field Deformation method: Erroneous use of thermal diffusivity and improved correlation between temperature ratio and sap flux density

Maurits W. Vandegehuchte*, Kathy Steppe

Laboratory of Plant Ecology, Faculty of Bioscience Engineering, Ghent University, Coupure links 653, 9000 Gent, Belgium

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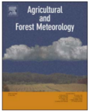

Calibration and comparison of thermal dissipation, heat ratio and heat field deformation sap flow probes for diffuse-porous trees

CrossMark

Sebastian Fuchs, Christoph Leuschner, Roman Link, Heinz Coners, Bernhard Schuldt*

Plant Ecology, Albrecht von Haller Institute for Plant Sciences, University of Goettingen, Untere Karspüle 2, 37073 Goettingen, Germany

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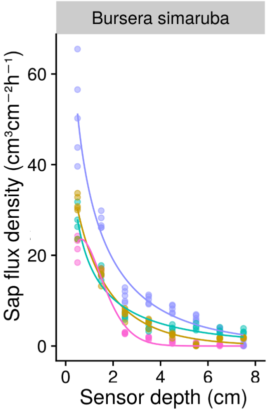
$\Rightarrow$ **Decision for analysis: focus on radial gradients of sap flux**

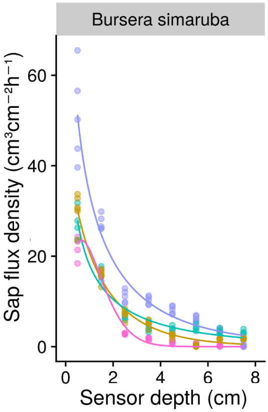
Research questions & hypotheses



- For studies of water use radial gradients in sap flow are very important, but only few methods take it into account
- Species specific measurements are problematic in the tropics

⇒ **Question:** Is it possible to predict the shape of the radial sap flow profile based on tree traits?

Research questions & hypotheses



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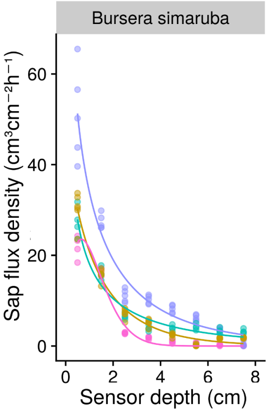

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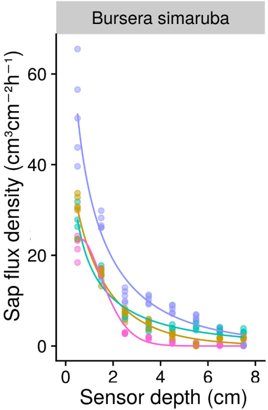

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⇒ **Hypothesis:** The shape of the radial sap flow profile is related to **wood density** and **tree height**

Data analysis

- Modeled with **Bayesian nonlinear hierarchical model**
  - **First stage of the model:** Nonlinear relationship between sensor depth and predicted flux density modeled by density function of the Weibull distribution
  - **Second stage of the model:** Parameters of the Weibull distribution modeled as a function of wood density, tree height and their interaction, accounting for species and stem specific random variation
  - Model fitting with **Stan modeling language**

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  - Model fitting with **Stan modeling language**
- Model still need tunings → shown results are from preliminary model based on R package `nlme`

Model equations of the preliminary model

Model equation

- $SFD_{ijk} \sim \mathrm{Normal}(\mu_{ijk}, \sigma_{ijk})$
- $$\mu_{ijk} = c_{jk} \cdot \mathrm{Weibull}(depth_{ijk} | \lambda_{jk}, K_{jk}) = c_{jk} \cdot \frac{K_{jk}}{\lambda_{jk}} \cdot \left(\frac{depth_{ijk}}{\lambda_{jk}}\right)^{K_{jk}-1} \cdot \exp\left(-\left(\frac{depth_{ijk}}{\lambda_{jk}}\right)^{K_{jk}}\right)$$

Parameter models

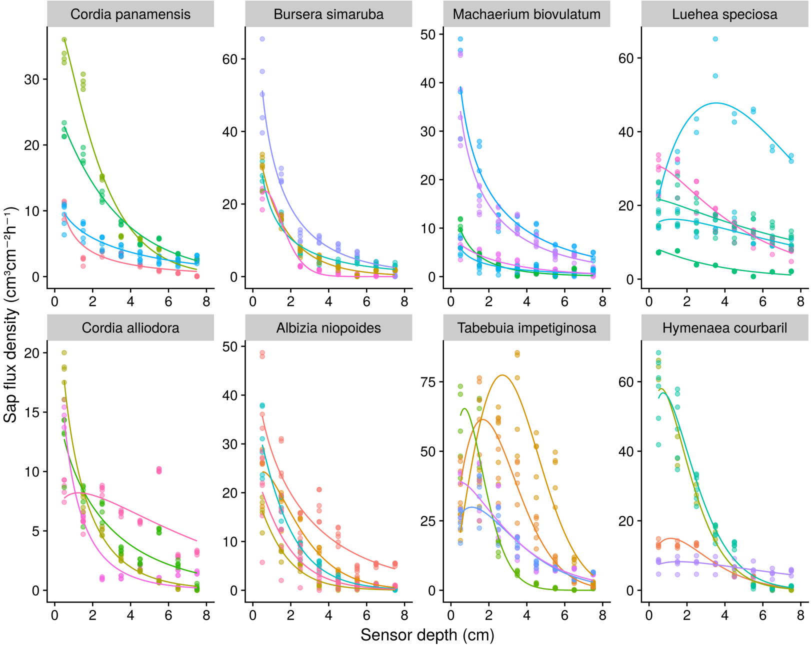
- $\lambda_{jk} = \exp(\beta_{\lambda 0} + \beta_{\lambda 1} \cdot WD + \beta_{\lambda 2} \cdot H + \beta_{\lambda 3} \cdot WD \cdot H + \epsilon_{j_\lambda} + \epsilon_{k_\lambda})$
- $K_{jk} = \exp(\beta_{K0} + \beta_{K1} \cdot WD + \beta_{K2} \cdot H + \beta_{K3} \cdot WD \cdot H + \epsilon_{j_K} + \epsilon_{k_K})$
- $c_{jk} = \exp(c_0 + \epsilon_{j_c})$

Random effects

- $\epsilon_j \sim \mathrm{MultiNormal}(0, \Sigma_j)$
- $\epsilon_k \sim \mathrm{MultiNormal}(0, \Sigma_k)$

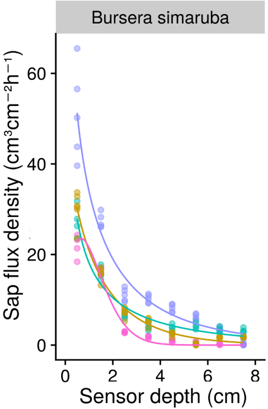
Variance covariates

- $\sigma^2_{ijk} = \sigma^2_0 \cdot \exp(2 \cdot \delta \cdot \mu_{ijk})$


Cordia panamensis
Bursera simaruba
Machaerium biovulatum
Luehea speciosa
Cordia alliodora
Albizia niopoides
Tabebuia impetiginosa
Hymenaea courbaril
Sap flux density (cm³cm⁻²h⁻¹)
Sensor depth (cm)

Preliminary results I - predicted profiles

- Model explains a large part of the observed variance in the dataset (conditional pseudo-$R^2 = 0.918$)
- Most of this variance is explained by random differences between species and stems (marginal pseudo-$R^2 = 0.329$)



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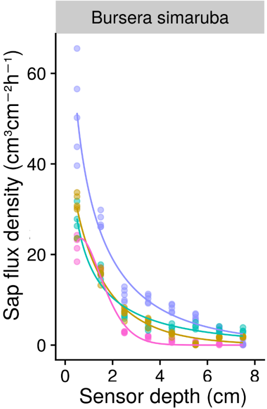
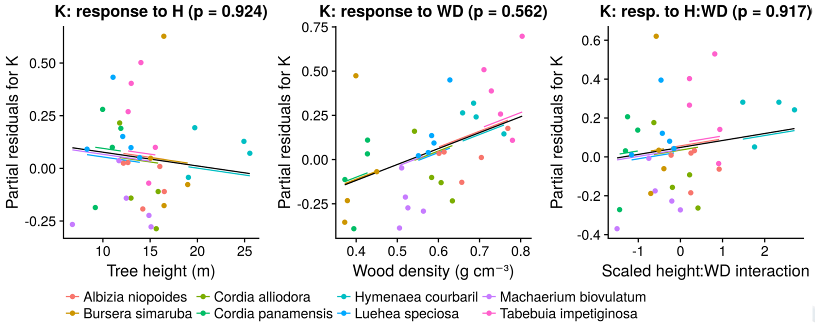
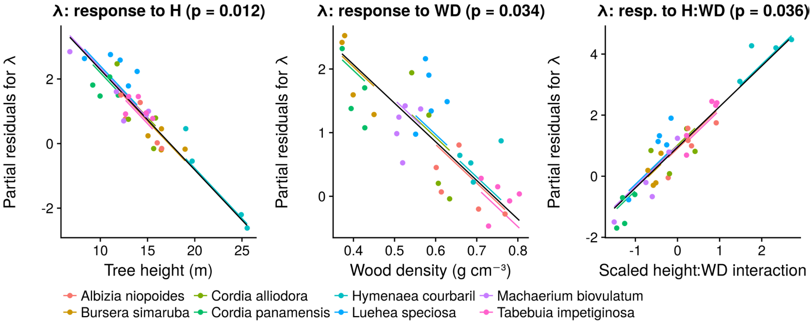


Preliminary results II - parameter models



- **Weibull shape parameter K**
  - No significant height- and wood density effects

Preliminary results II - parameter models



- **Weibull scale parameter λ**
  - Decreases significantly with tree height and wood density, but significantly less so in trees that are both large AND have hard wood

Radial sap flow profiles - conclusions

- Very good predictions possible with a nonlinear hierarchical model
- Shape of the profile significantly depends on height and wood density
- Predictive power for predictions on new trees is low because of high stem-specific variability

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Vulnerability curves

- What are vulnerability curves?
- What kind of information do they offer?

The Cavi1000

- Some photos, basic information about how it works

Research questions & hypotheses

- Plant vulnerability to embolism can be predicted by structural, functional and wood anatomical traits

Data analysis

- Non-linear Bayesian hierarchical model
- Compare to HFD model, mention Ogle et al. 2009
- ONE SLIDE!

Observed vulnerability curves

- Do not overinterprete!

Big picture

- Analyzed variables (methods section)
- Design

Growth data

- short description
- picture

Wood anatomy

- short description
- picture

Non-structural carbohydrates

- short description
- picture
- data not available so far

Research questions & hypotheses

- Lots and lots of hypotheses

Data analysis

- Short explanation of structural equation models

Meta-model & causal diagram

- figures on one or two slides

Example for SEM: Martyna's paper

- Meta-model, causal diagram & final path model

Summary

- Sap flow
- Vulnerability curves
- SEM

Thanks & goodbye

- Names of assistants (pictures?)

References

- **Fuchs S, Leuschner C, Link R, Coners H, Schuldt B, 2017.** Calibration and comparison of thermal dissipation, heat ratio and heat field deformation sap flow probes for diffuse-porous trees, *Agricultural and Forest Meteorology* **244–245**,151-161. https://doi.org/10.1016/j.agrformet.2017.04.003..