Global variation in sapwood to leaf area ratio explained by optimality principles

Xu H[1,2], Wang H[1], Prentice IC[1,3], Harrison SP[1,4], Rowland L[2], Mencuccini M[5,6], Sanchez-Martinez P[5,7], He P[8], Wright IJ[9,10], Sitch S[2], Ye Q[8]

[1]Tsinghua University, China; [2]University of Exeter, UK; [3]Imperial College London, UK; [4]University of Reading, UK; [5]CREAF, Spain; [6]ICREA, Spain; [7]Universitat Autònoma de Barcelona, Spain; [8]South China Botanical Garden, China; [9]Western Sydney University, Australia; [10]Macquarie University, Australia

1. OBJECTIVES

There is a fundamental limit to the total leaf area a branch can support

The raio of sapwood to leaf area (v_H) represents resources allocation between leaf and stem, which is treated as fixed parameters for PFTs or empirical functions in DGVMs

How and why v_H varies along geographic climate gradients is poorly understood at global scale

- ✓ We propose a parsimonious model with **only one parameter** to quantify how plants mediate allocation to leaf and stem in response to temperature (T), vapour pressure deficit (D), irradiance (I_{abs}) and CO_2
- ✓ We test the model using two global hydraulic traits datasets collected at species and individual-at-site levels
- ✓ We predict v_H variation using climate data

2. OPTIMALITY HYPOTHESIS

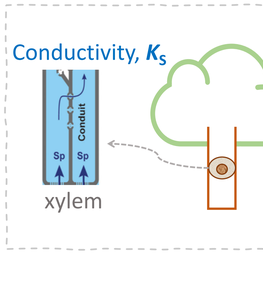
Water supply through stem = **Water loss via leaf/stomata**

$K_S \Delta\Psi_{max} v_H / h$ (Darcy's law) = $1.6\, g_s\, D$ (Fick's law)

$g_s = A/[c_a(1-\chi)]$

Compensation effect of hydrauilic efficiency (K_S)
Driving force of water potential difference ($\Delta\Psi_{max}$)

$A = m_C V_{cmax}$ ← **coordination hypothesis**
$m_C = (\chi c_a - \Gamma^*)/(\chi c_a + K)$ ← **least-cost hypothesis**

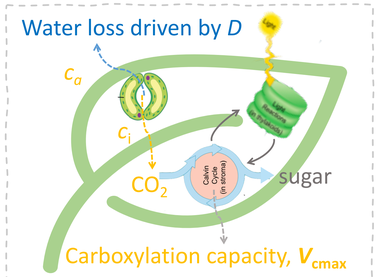


Under-extended leaf area
Water supply > Water loss

waste of hydraulic system

Over-extended leaf area
Water supply < Water loss

embolism cavitation



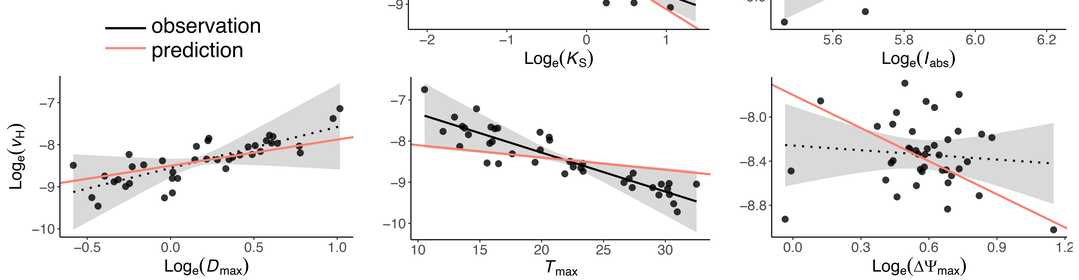
linearization

$$\mathrm{Log_e}(v_H) = \mathrm{Log_e}(I_{abs}) + 0.6\mathrm{Log_e}(D) - 0.03T - \mathrm{Log_e}(K_S) - \mathrm{Log_e}(\Delta\Psi_{max}) + C$$

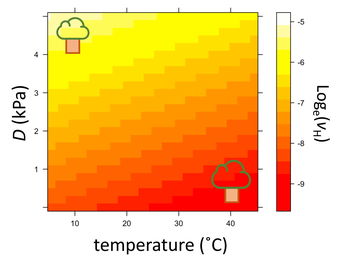
environment | hydraulics

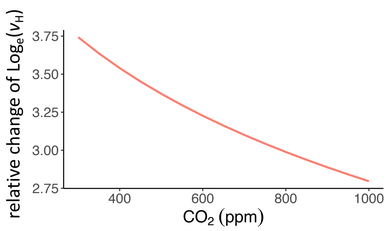
3. MODEL PREDICTION

1 Predicted trait-climate and trait-trait relationships are consistent with observed patterns

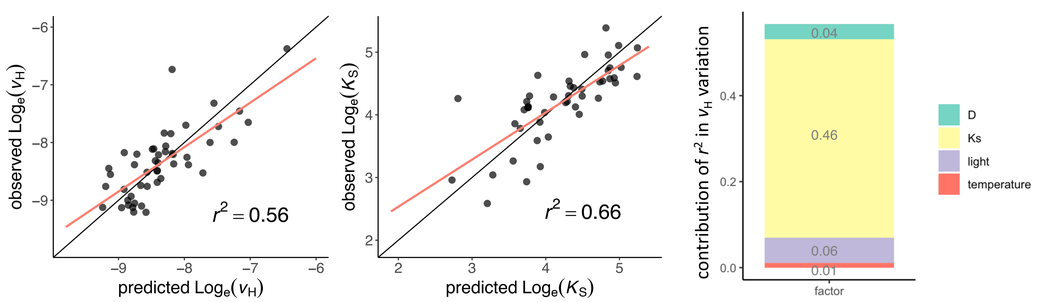


2 Under future climate condition, change in optimal v_H depends on the combining effects of increasing temperature, D and CO_2





3 Our optimality-based model predicted ~60% of v_H or K_S variations across sites



4. TAKE-HOME MESSAGES

Traits coordination

- **Hydraulic efficiency** has a huge impact on v_H value globally
- Plant allocation strategy is the outcome of coordination between hydraulic and **photosynthetic traits**

Climate effect on v_H

- Our model predicts **v_H increases with irradiance and D, decreases with temperature**, which is consistent with observed patterns
- Our model allows to **disentangle the effects of D and temperature** theoretically and reveals their opposite impacts on v_H, which emphasizes the importance of quantifying their sensitivities to predict plant allocation strategy under future climate
- Our model predicts plants have **higher total leaf area** at given sapwood area **under elevated CO_2**

Model performance

- The optimality-based model captures nearly 60% of v_H variation or 66% of K_S variation across sites

CONTACT INFORMATION

Email: xuhy19@mails.tsinghua.edu.cn
Twitter: @huiying_xu

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