**Title:** Vulnerability of tree growth to precipitation in Thailand

**Authors**

# Abstract

# Introduction

Tropical tree woody growth is a key component of aboveground productivity and affects the global carbon carbon cycle, but its sensitivity to ongoing global change is poorly understood.  
- Woody growth has long-lasting effects on the terrestrial carbon pool but is sensitive to interannual variation in temperature and precipitation.  
- Extreme events like drought, with temperature and precipitation outside normal ranges that can lead to growth reductions that varies across species and individuals (Bennett *et al.*, 2015; McGregor *et al.*, 2021).  
- the extent of this variation in drought responses is poorly understood.  
- with changing climate patterns across the global tropics, including novel climatic regimes (Dahinden *et al.*, 2017), there is a need to understand the drivers of this variation, to be able to predict and respond to forest responses to drought.

Growth reductions from droughts are difficult to estimate reliably from whole-plot inventories.  
- Droughts are different but generally leads to low soil moisture, low water tables, vapour pressure, high temperature. - Results in thermal stress, evaporative loss, leaf turgor loss, embolism/cavitation  High mortality and growth reductions across global forests, including the tropics  
- Inventory data are often not at annual scales; smooths over drought/no-drought period.  
- Reductions are often small (<1 mm), and difficult to detect with tape measurements.

Tree species in seasonally dry forests have diverse allocation strategies and traits which can result in differential sensitivities to drought  
- Drought events can be different from each other, but generally lead to low soil moisture, low water tables, low vapour pressure and high temperature (Chitra-Tarak *et al.*, 2021).  
- Results in thermal stress on tissues, evaporative loss, leaf turgor loss and cavitation.  
- Species can be conservative or acquisitive in water and nutrient uptake; differential allocation to growth/survival.  
- Species with drought tolerant traits like deep roots, more negative turgor loss point and … are more resistant to drought (Kunert *et al.*, 2021; **refs?**).  
- Some evidence that both understory and emergent species can have reduced survival during drought (Machado *et al.*, 2023).  
- Deciduous species, with shorter duration with leaves can have acquisitive strategies during leaf on (De Souza *et al.*, 2020).  
- Strategies also affects species distribution with evergreen species covarying with soil moisture (Kunert *et al.*, 2021) and potentially affecting survival and growth.  
- Many hydraulic-related traits vary with tree height (Vinod *et al.*, 2023), including the frequency of dry season deciduous leaf loss – both within species and at the community level (**condit\_ref?**; **meakem?**).

Within species, size, exposure and location can affect sensitivity to drought.  
- Large trees tend to undergo greater growth declines during drought compared to smaller trees (e.g., Bennett *et al.*, 2015; McGregor *et al.*, 2021; Anderson-Teixeira *et al.*, 2022).  
- It remains poorly understood the extent to which this is shaped by tree size itself, crown exposure, water access, and traits that tend to covary with size (e.g., decidiousness) – all of which interact to shape drought resistance (Fig. 1).  
- There is theory and evidence that tree size itself matters.  
- Theoretically, we expect that greater height makes trees more vulnerable to drought based on the physics of hydraulic flow through a porous medium, as described by Darcy’s law (Fernández-de-Uña *et al.*, in press; **mcdowell\_darcy\_2015?**). - Height… (Olson *et al.*, 2018; see refs in Vinod *et al.*, 2023; **couvreurWaterTransportTall2018?**). - As tree size increases, leaves exert lower control over hydraulic resistance (**wolfe\_leaves\_2023?**). - Chen *et al.* (2022)  
- There is theory and evidence that crown exposure matters (Scharnweber *et al.*, 2019; Vinod *et al.*, 2023; **refs\_in\_?** vinod\_thermal\_2023). - Microclimate buffering leads to cooler, moister understory air (Vinod *et al.*, 2023). - Soils under closed canopies would also be cooler during hot times of the year (**lembrechts\_global\_2022?**). - Reduced evaporative demand would also make them moister, and this might be added to by hydraulic redistribution. - Trees with exposed crowns suffered significant crown dieback at greater rates in the 2012-16 CA drought (Ma *et al.*, 2023).  
- Water access….  
- Larger trees have larger root systems, but do not necessarily access deeper water (**ref\_from\_Panama?**)  
- Even when trees are accessing deeper water, this does not mean that they’re in better shape during drought. Rather, trees that rely on regular access to deep water may be more vulnerable during severe droughts when those sources are depleted (Chitra-Tarak *et al.*, 2021).  
- indeed, there is evidence that trees near streams undergo greater growth declines (McGregor *et al.*, 2021) and increases in mortality (**zuleta?**) during drought - rather than necessarily helping during drought, water access will shape the size and traits of species living in habitat, with stream habitats tending to have larger trees (**ref?**) and more evergreen trees, and also their average growth rate

-High Crown exposure makes trees more vulnerable to drought, but drought deciduous habit or perennial water access allows them to escape this  
-Disentangling the effects of tree size, crown exposure, water access, and deciduousness on drought sensitivity

Here we use a 14-year record of dendrometer band measurements in seasonally dry forest in Thailand to test the vulnerability of tropical tree growth to drought. We expect variation in drought sensitivity (growth in drought year/growth in a previous year with normal rainfall) across trees. We ask: i) How much do species vary in drought sensitivity? ii) How does deciduousness influence the drought sensitivity of a species? iii) How much of the intraspecific variation is explained by tree height *per se*, crown exposure and the habitat of the tree (proxy for water and nutrient availability). We hypothesise that growth during drought is affected by:

* **habitat** : water availability is a key driver of tropical tree growth (Wagner *et al.*, 2012).
* **leaf habit** : drought resistance is higher in deciduous species because of leaf strategies that minimise water loss during months of high vulnerability. Deciduous and evergreen species have differential sensitivity to drought (De Souza *et al.*, 2020).
* **tree size** : larger trees face higher risk of mortality during drought, as well as greater growth reductions (e.g., Bennett *et al.*, 2015; McGregor *et al.*, 2021; Anderson-Teixeira *et al.*, 2022).
* **exposure** : trees with higher exposure because of their canopy position have lower drought resistance than trees with lower exposure due to the direct effects of temperature and vapour pressure deficit.
* **competition** : trees in denser stands have lower drought resistance than trees in sparser stands because of more intense competition for groundwater. Differences in rooting depths could add complexities to this effect, however, we do not have direct measures that could test this effect.
* **exposure x size** : While larger trees are likely to have uniform high exposure, smaller trees can have high or low canopy position based on stand characteristics (stand density, presence of a canopy gap etc.) Drought resistance of smaller trees with high exposure is expected to be lower than that of trees with low exposure because of the direct influence of temperature and light that could lead to cavitation. (BCI light x size interaction in Rüger *et al.* (2011))
* **leaf habit x exposure** : species canopy strategies along with their leaf habit could exacerbate or counteract drought vulnerability (Rahman *et al.*, 2019). Under high exposure, deciduous species are potentially more drought resistant than evergreen species, while the pattern could be less clear under low exposure.
* **leaf habit x habitat** : tropical evergreen and deciduous species have different habitat preferences (Kunert *et al.*, 2021) that could affect their drought resistance.
* **habitat x exposure** : trees with high exposure in upland habitats are expected to have lowest drought resistance because of the compounding influence of abiotic stressors.

# Methods

ForestGEO data (Anderson-Teixeira *et al.*, 2015)

***Sites and data***

*Huai Kha Khaeng plot* - location - annual precipitation - ecosystem type/association - long-term trends from (**vlam?**) et al etc

*Resistance* - Dendrometer band measurements - census protocol - Calculated DBH at each instance from first DBH and window size using Condit’s functions. - Removed measures with large decimal errors, potential band misID, large outliers (> 3 SD). - calculated increments for each individual for each census year using dendroband data and tape measurement - tape measurement does not have accuracy required to measure this effect, but used tape increments to detect outliers. - removed all increment measurements with more than 0.5 cm deviation from the 1:1 line for dendro and tape increments - For each drought year, used drought-year increment. - for each tree, long-term growth was calculated as the mean growth across 20 years of full-plot censuses - Resistance - ratio of drought-year increment to long-term growth for each individual tree

*Tree size* - calculated DBH for at the start of the drought year from dendrometer band window

*Deciduousness* -data from Williams *et al.* (2008). -Leaf phenology score - mean proportion of crown loss. -Continuous scale from 1 to 4, where 4 is maximum crown loss or deciduousness. -One value per species. - 7 species out of the top 51 species in the dendroband census have no values. (currently excluded from analysis but can fill these with best estimates and add them back in)

*Exposure* - crown illumination index for each individual, collected at each dendrometer band census - categorical variable with values 1 to 5 where 1 is least exposed and 5 is most exposed

*Topographic Wetness Index* - calculated from topography - estimate of water availability at a location

***Models***

For individual stems, we modelled drought resistance as:

# Results

# Discussion

# References

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