Woody carbon in the dry tropics:

Biodiversity, structure, environment

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My background

- Applied functional ecologist
  - Ecosystem productivity, biogeography, structure
  - Tropical savannas, dry forests, temperate woodlands
- PhD (2021) at the University of Edinburgh
  - Biodiversity and ecosystem function in African savannas
- Post-Doc (2021-now) SECO: dry tropical carbon dynamics
  - Global multi-network plot analyses
  - Where and why is woody biomass changing?
  - How does biogeography affect responses to change?
  - https://blogs.ed.ac.uk/seco-project/

Open savanna, southwest Angola

Ancient woodland, North Yorkshire, UK

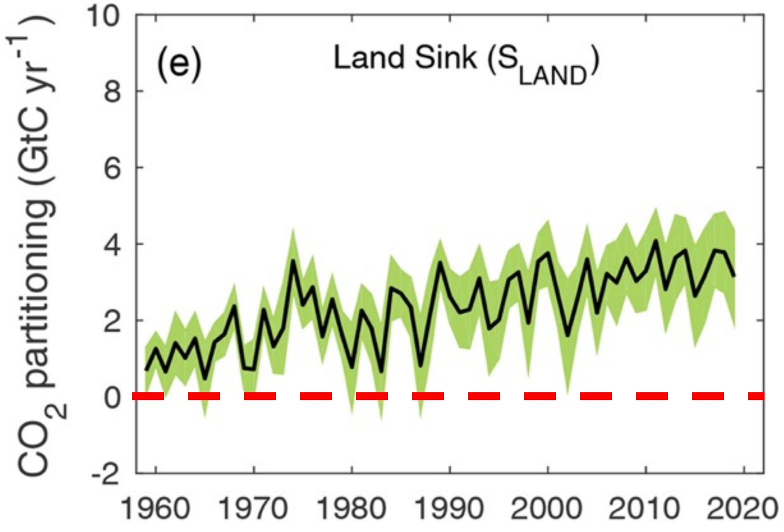
Motivations and approach

Grand challenges:

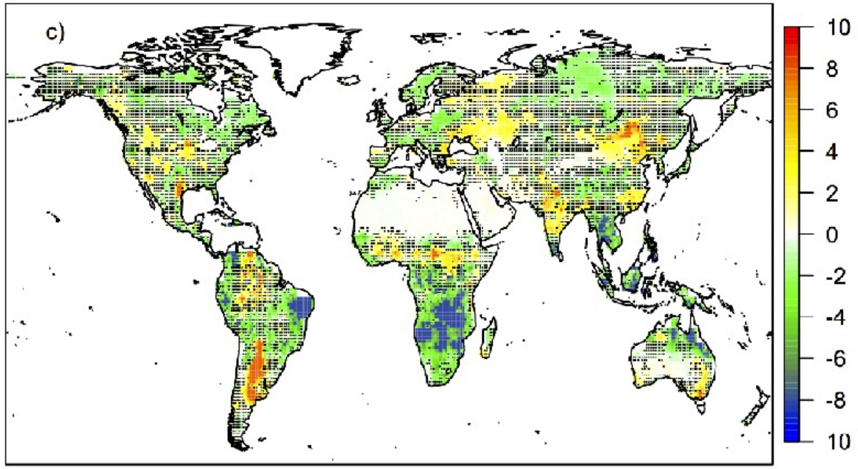
1. What is the role of terrestrial vegetation in global biogeochemical cycles?

- Long term demographic data.
- Environmental and geographic variation in carbon dynamics.

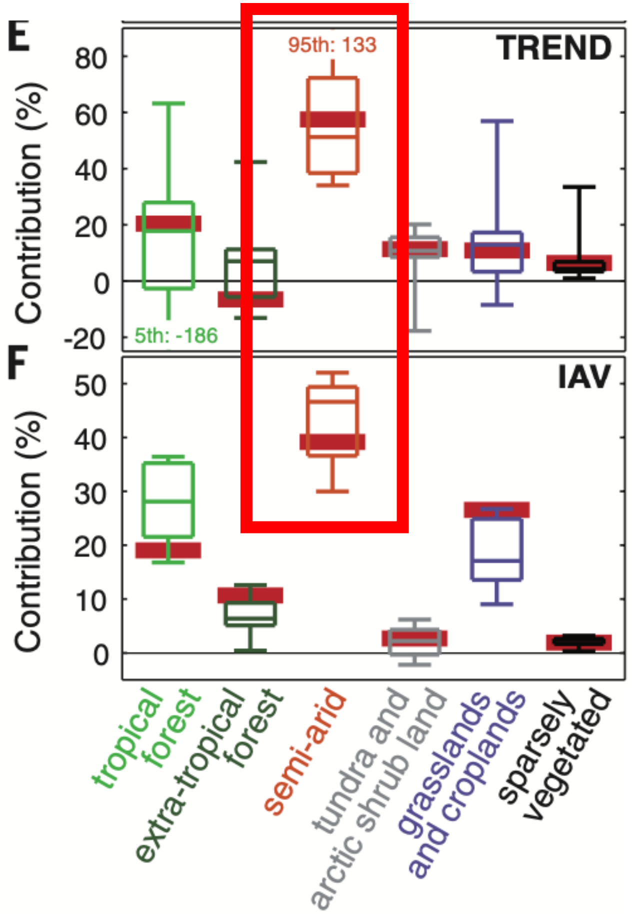
Models: increasing terrestrial carbon sink



Spatial variability in carbon flux trend



Uncertainty in trend and inter-annual variability of carbon sink



Ahlstrom et al. (2015), Sitch et al. (2015), La Quere et al. (2020)

Motivations and approach

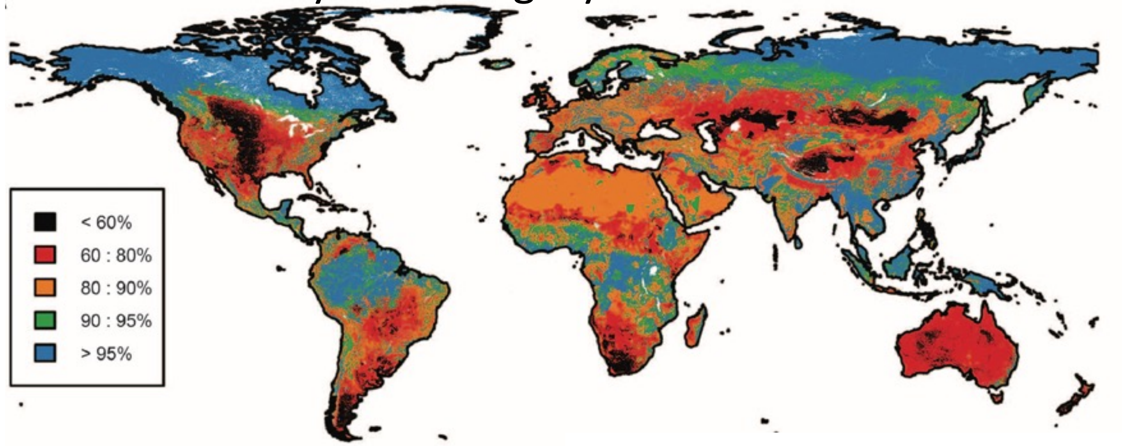
Grand challenges:

2. How do biodiversity, biogeography and environment jointly affect ecosystem structure and function?

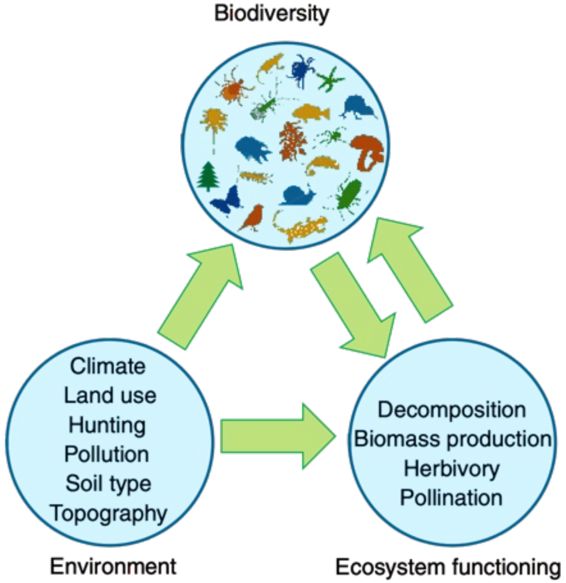
- Remote sensing
- Global plot networks
- Modern field techniques

Ecosystem integrity is under threat

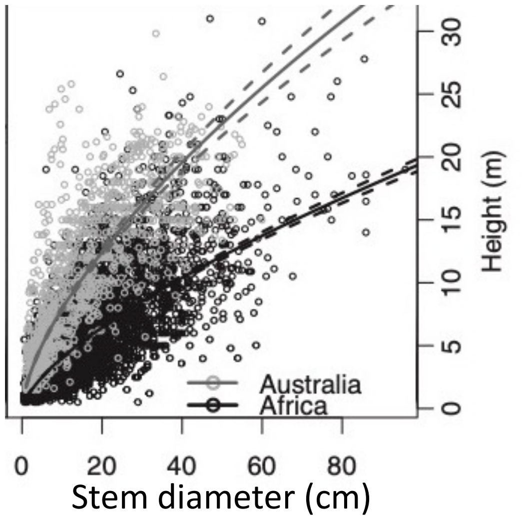
Ecosystem integrity (%)



Complex biodiversity-function feedbacks



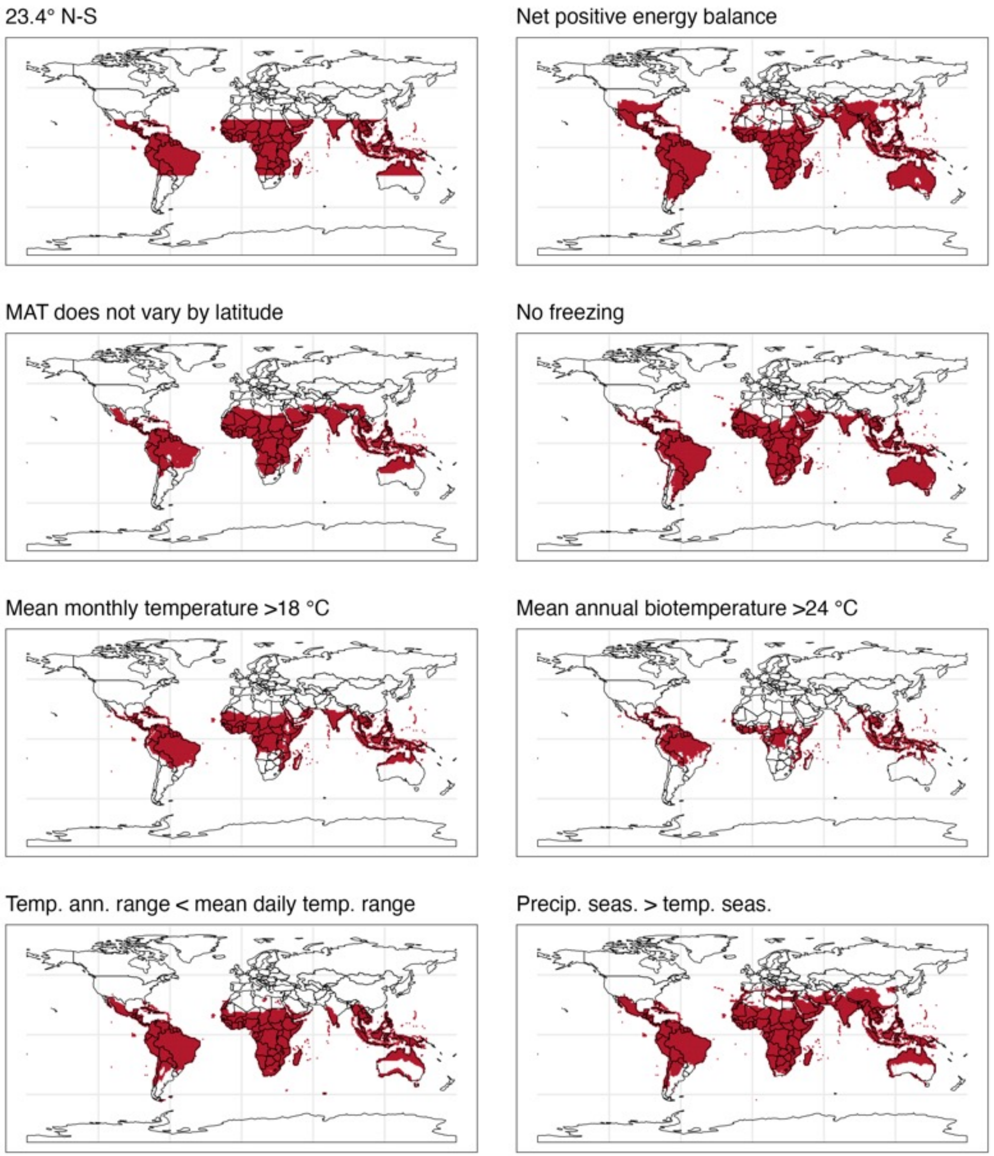
Biogeographic mediation of structure and function

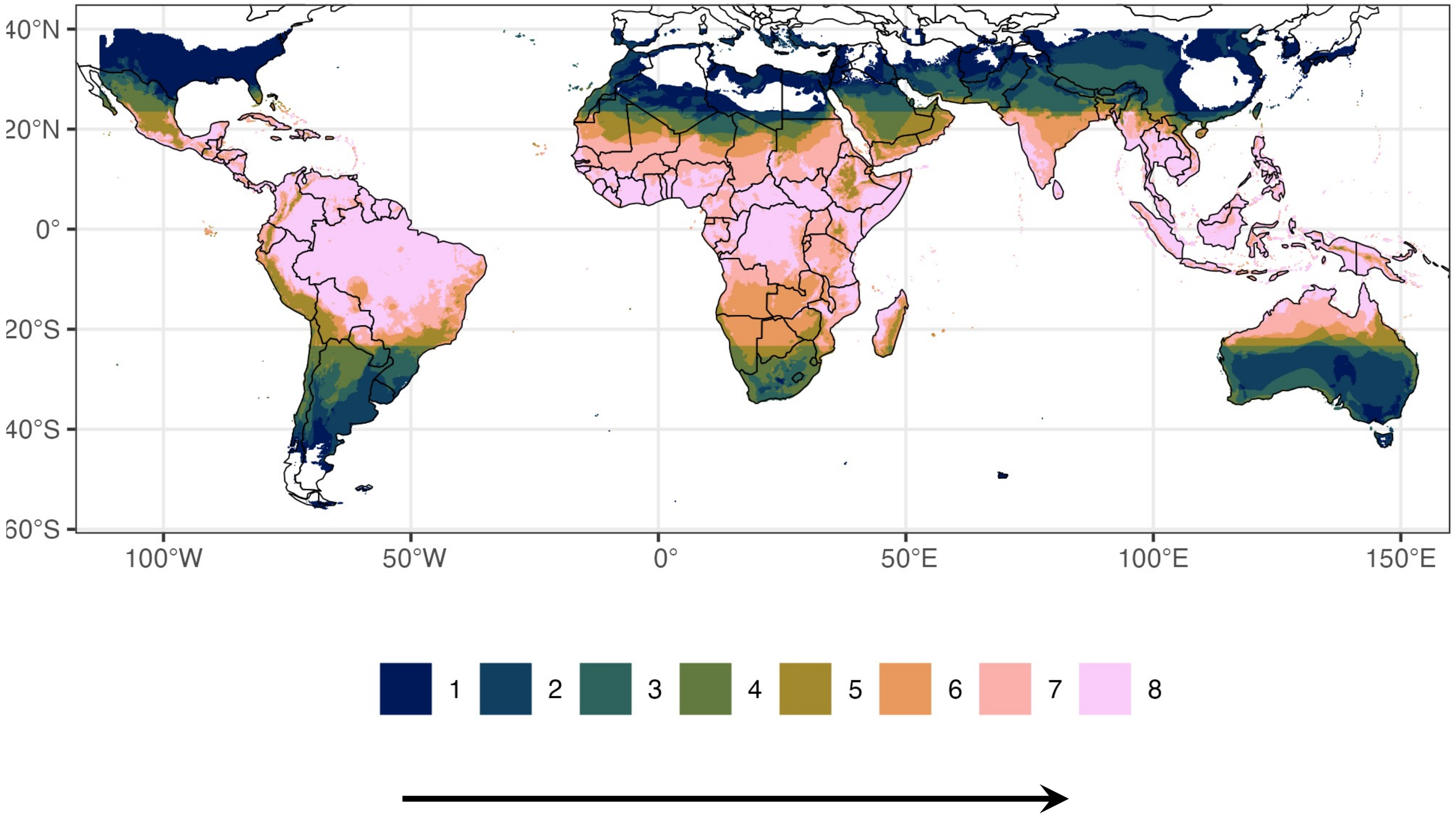


Newbold et al. (2016), van der Plas (2019), Moncreiff et al. (2014)


Dry tropical vegetation
and global change

Where are the (dry) tropics?



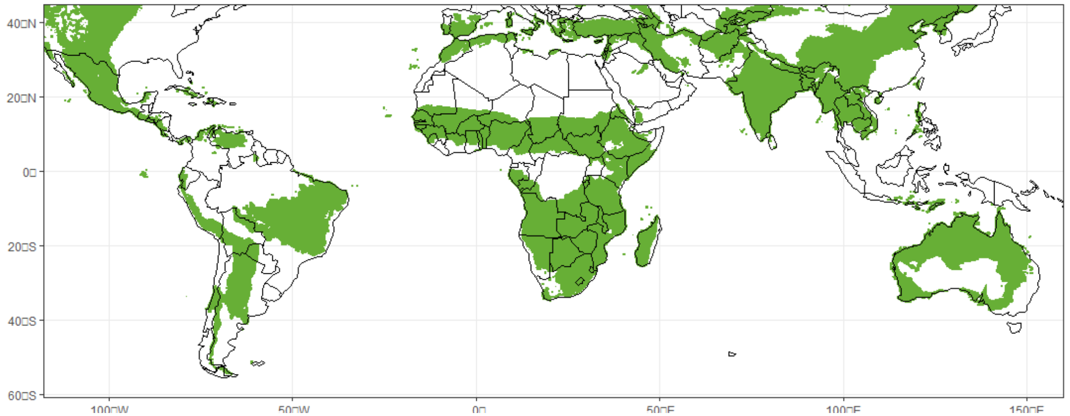


Increased "tropicality"

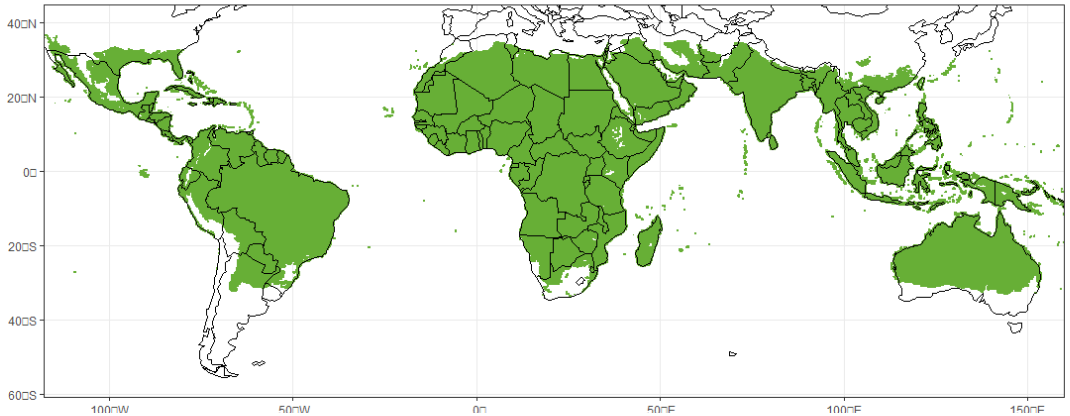
Feeley and Stroud (2018)

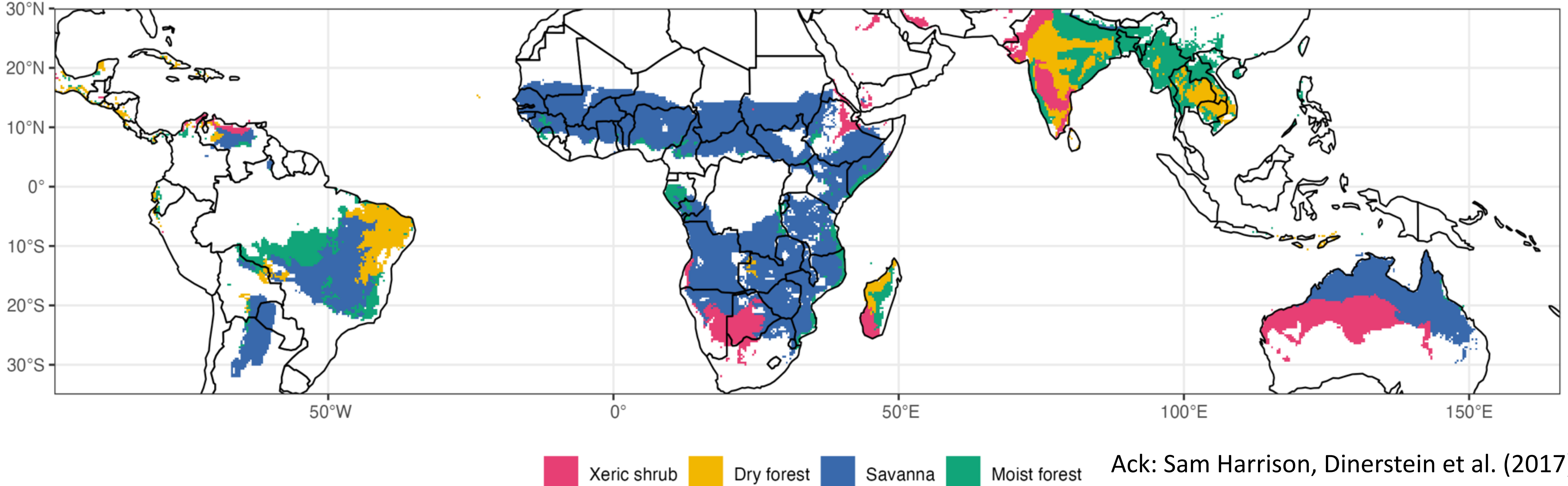
Where are the (dry) tropics?

>6 hot months (>18 °C average temperature)



≥3 dry months (<30 mm rainfall)





Ack: Sam Harrison, Dinerstein et al. (2017)

Half of the global tropics is seasonally dry

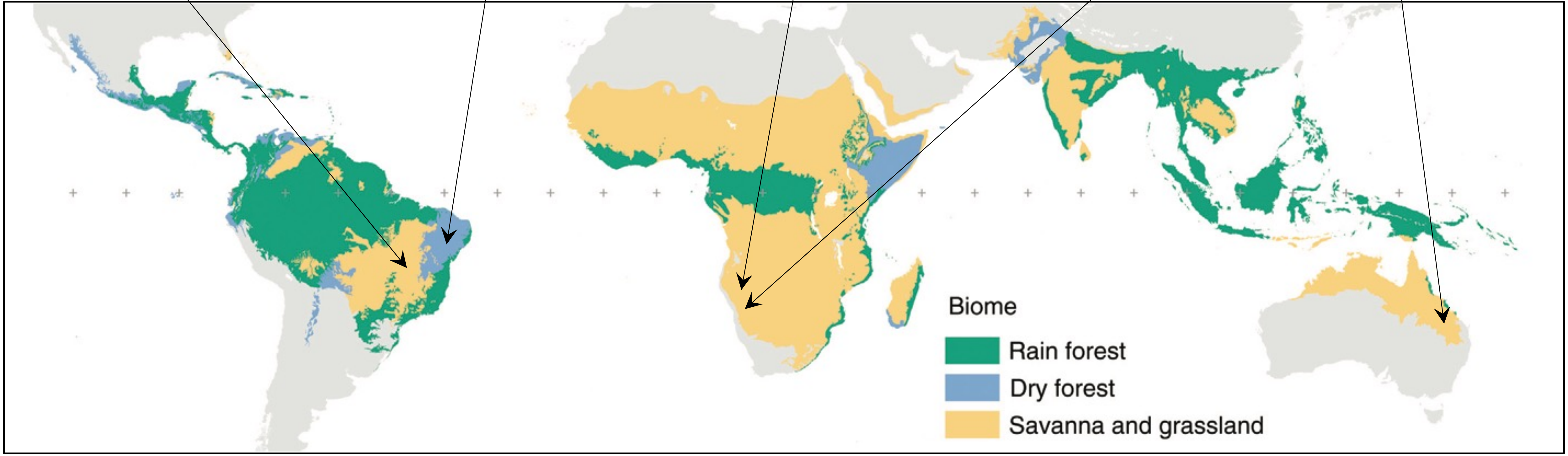
Cerrado,
Brazil

Caatinga,
Brazil

Miombo,
Angola

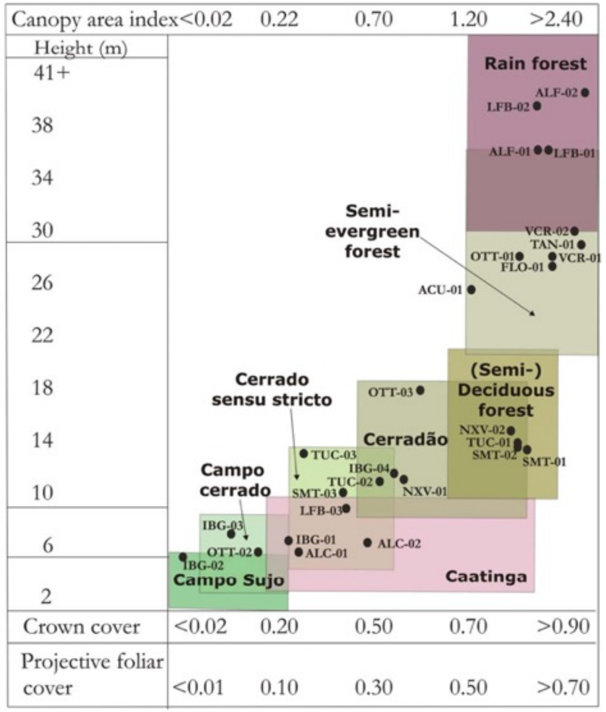
Mopane dry forest,
Namibia

Eucalypt savanna,
Australia

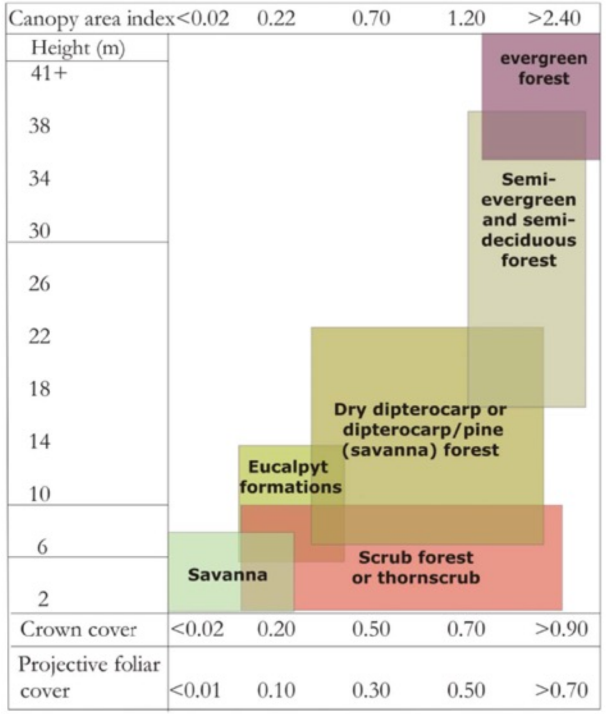


Pennington et al. (2018), after Olson et al. (2001)

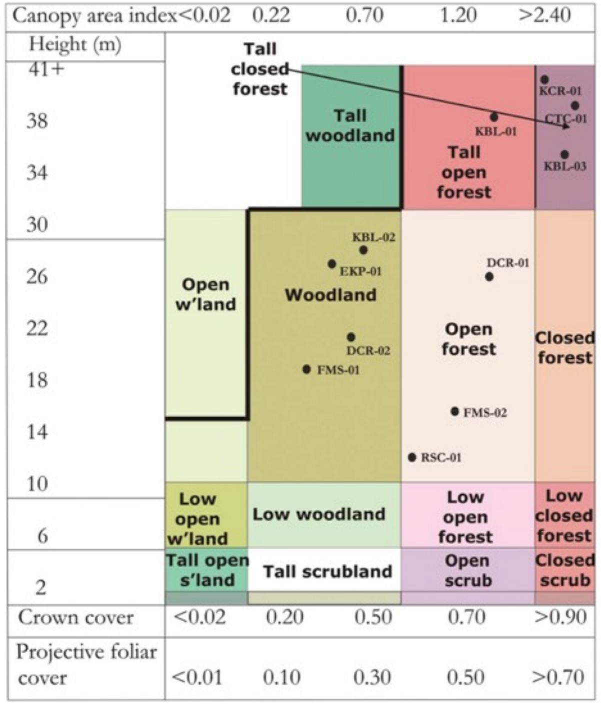
How variable are dry tropical biomes?



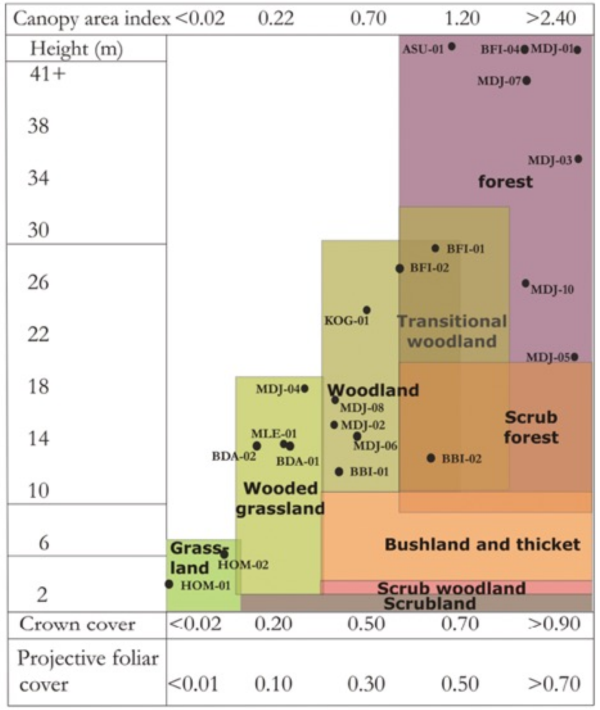
South America



South-East Asia



Africa

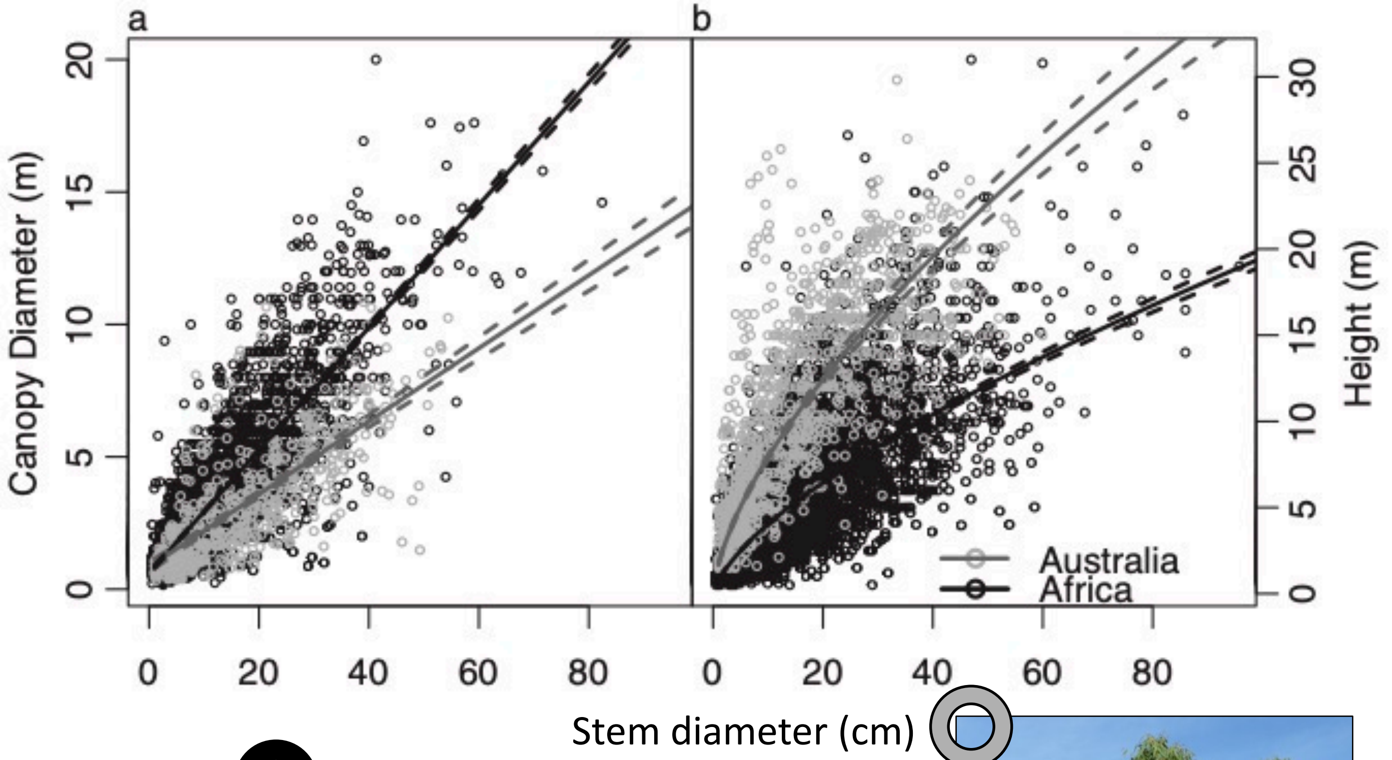


Australia

Torello-Raventos et al. (2013)

Biogeography, continent effects

- Wide crown miombo vs. tall and skinny eucalypt savanna (Moncrieff et al. 2014).
- Nitrogen fixers, mycorrhizae might increase growth rates in more arid ecosystems (Pellegrini et al. 2016).



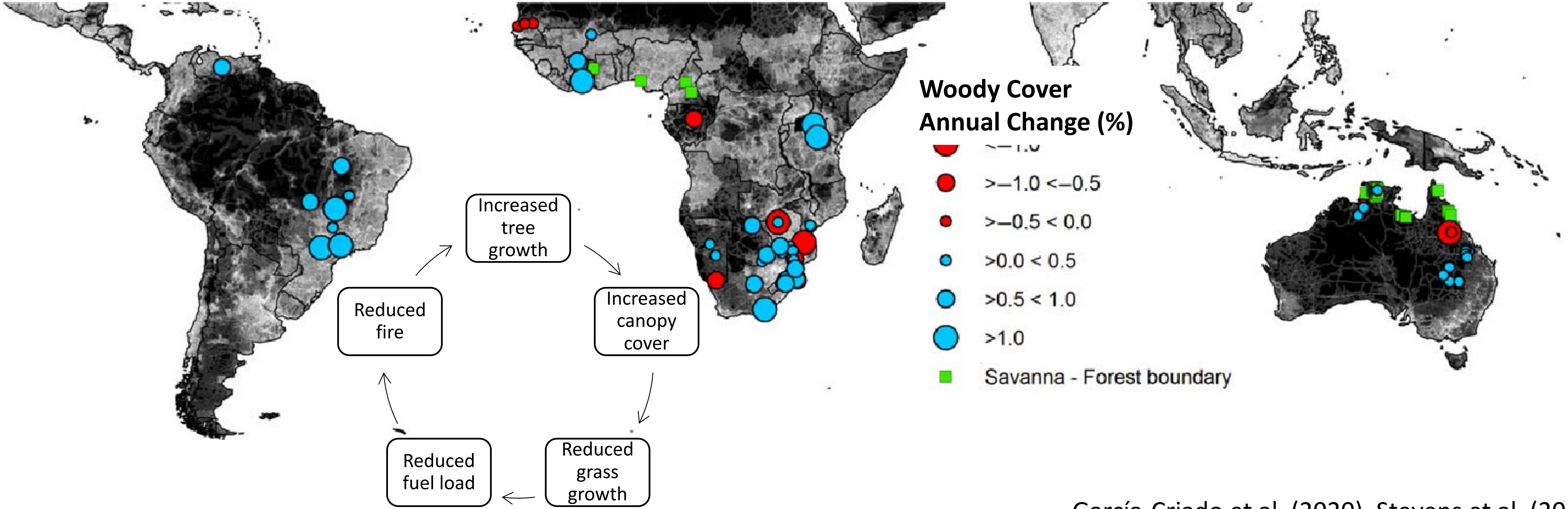
How does variation in species composition and function affect ecosystem function?

Which groups contribute most to biomass turnover / persistence?

Moncrieff et al. (2014)

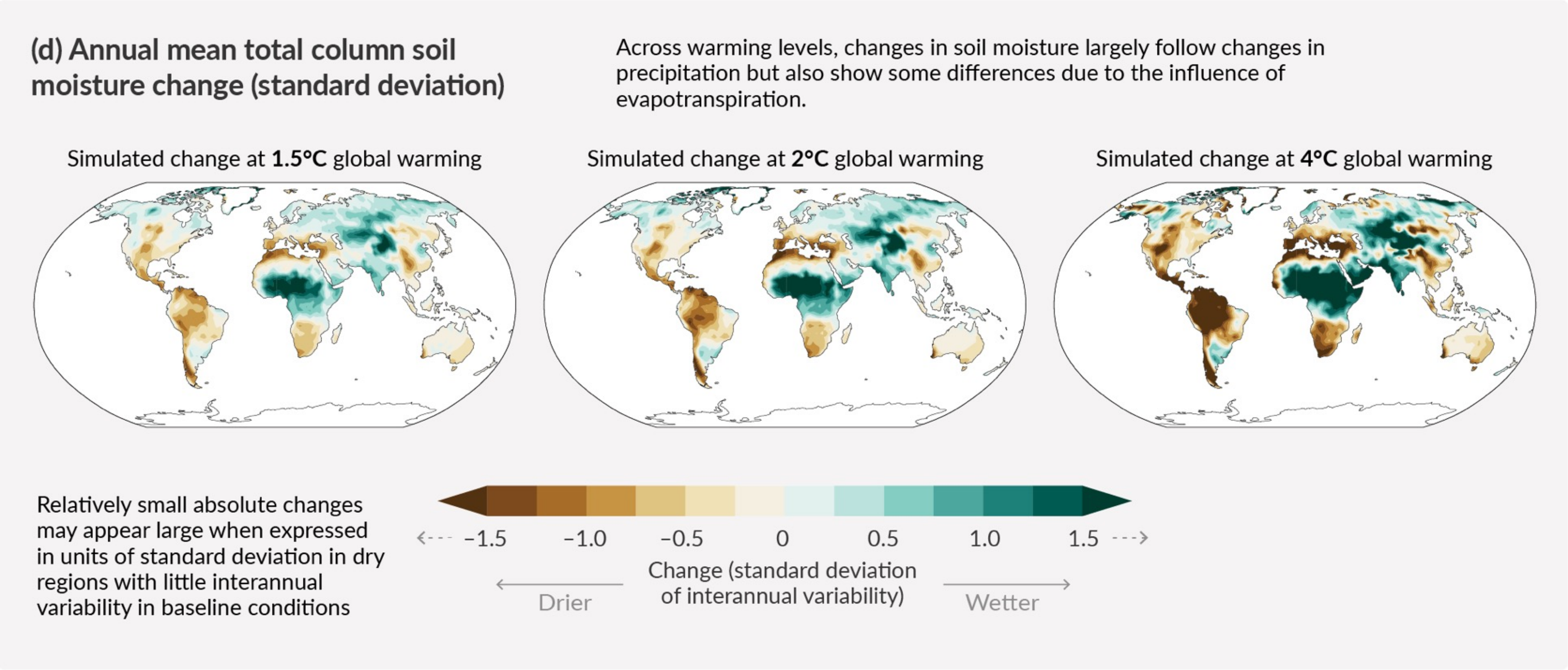
Woody encroachment, CO_2 fertilisation

- Expected to boost tree growth, especially in savannas.
  Trees can benefit from higher CO_2 while grasses cannot.
- Is this pervasive across other dry tropical vegetation like dry forests? Areas with lower rainfall?
- Rate of encroachment greater in African than Australian savannas



García-Criado et al. (2020), Stevens et al. (2016)

Warming and drying trend

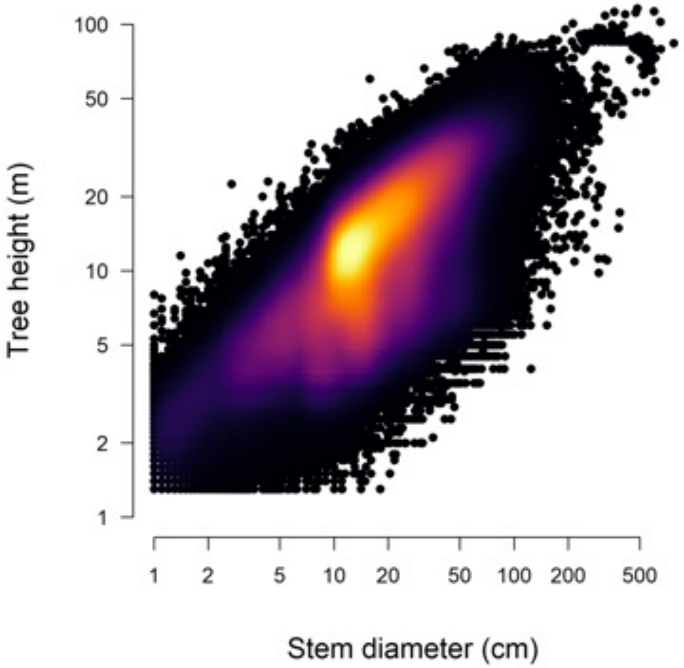


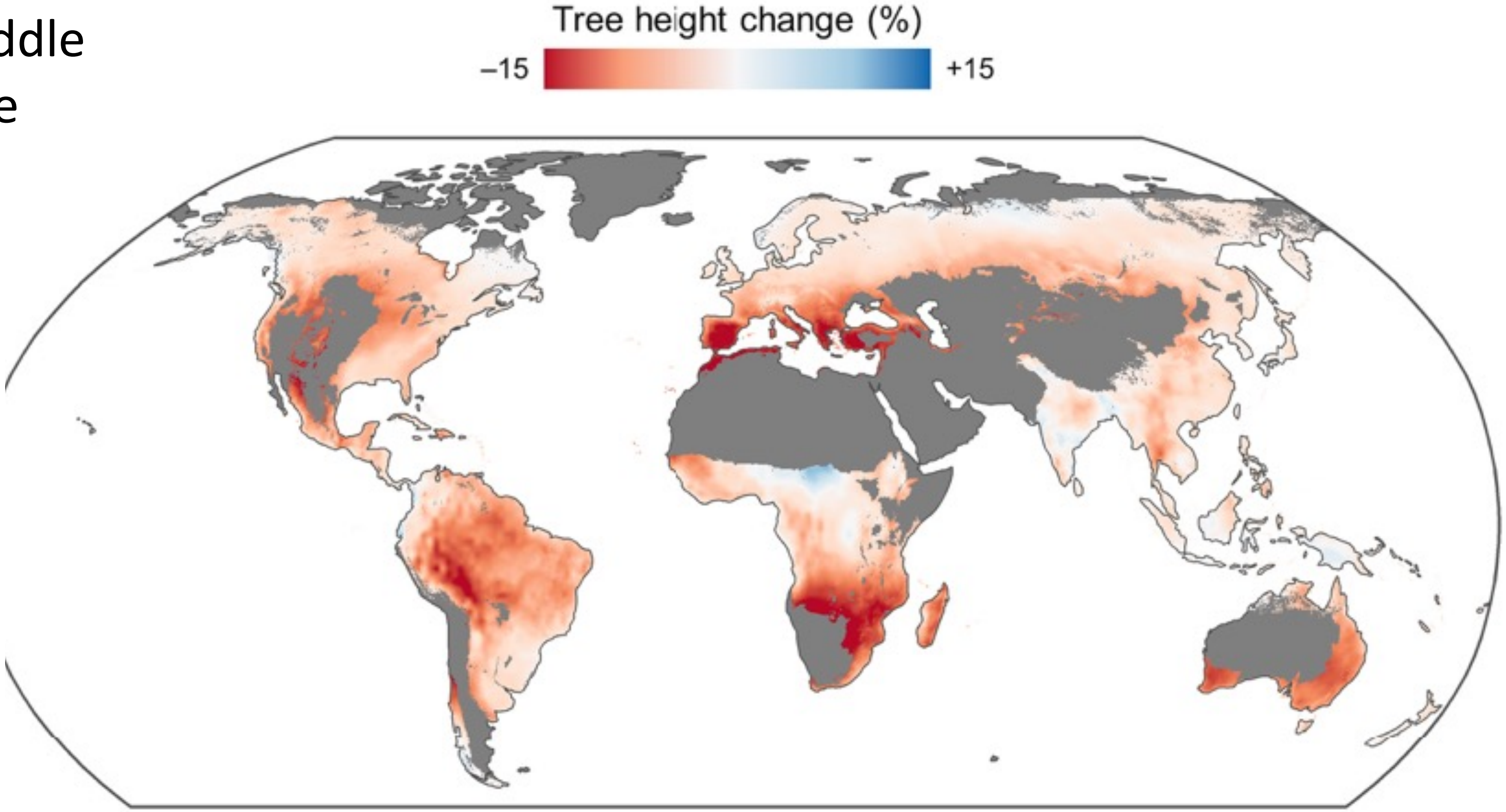
IPCC Chap. 3 (2021)

Drying and warming → reduced tree height

Projected relative tree height change under SSP 245 “Middle of the road” climate change pathway.

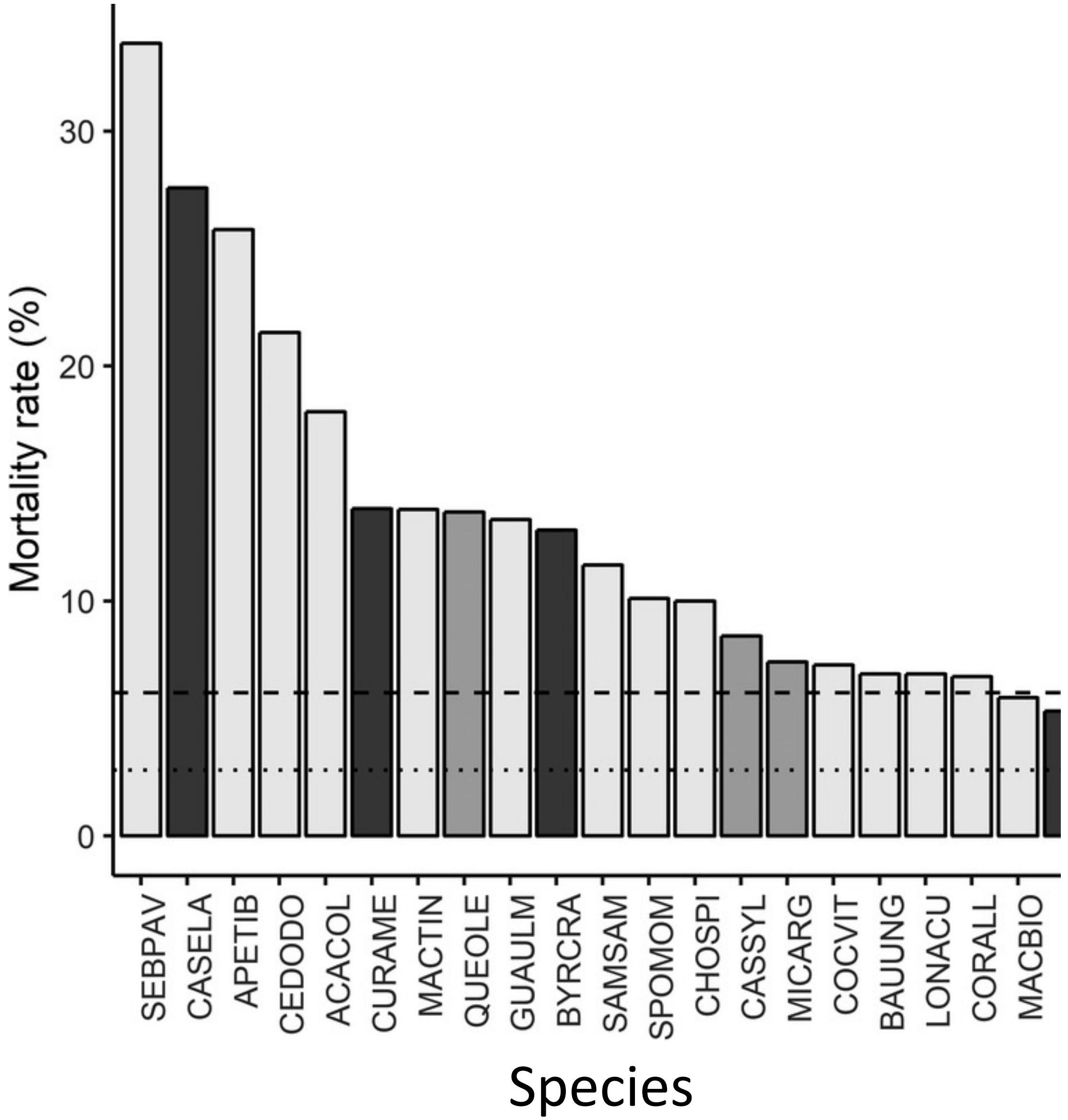
“Tallo” tree allometry database

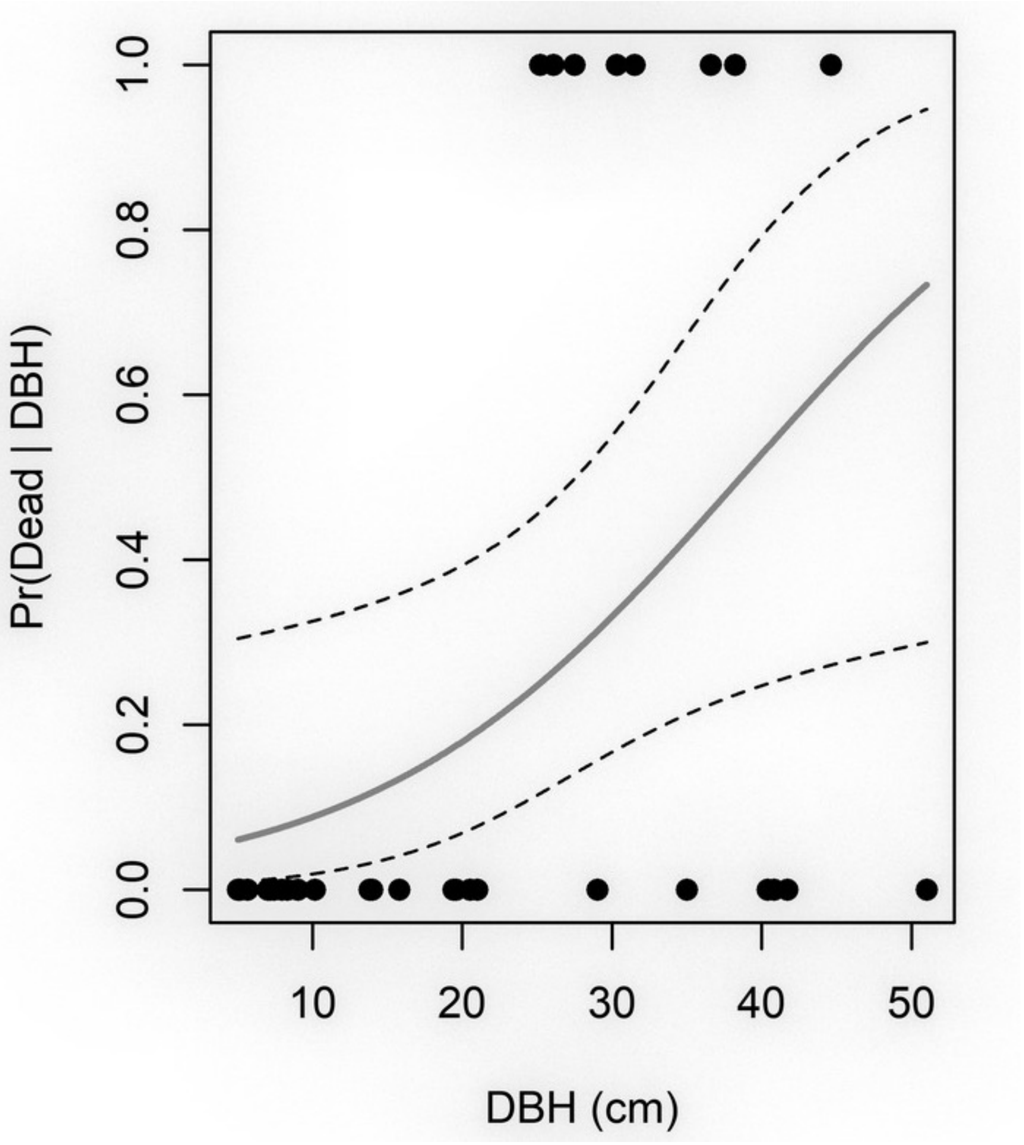




Jucker et al. (2022)

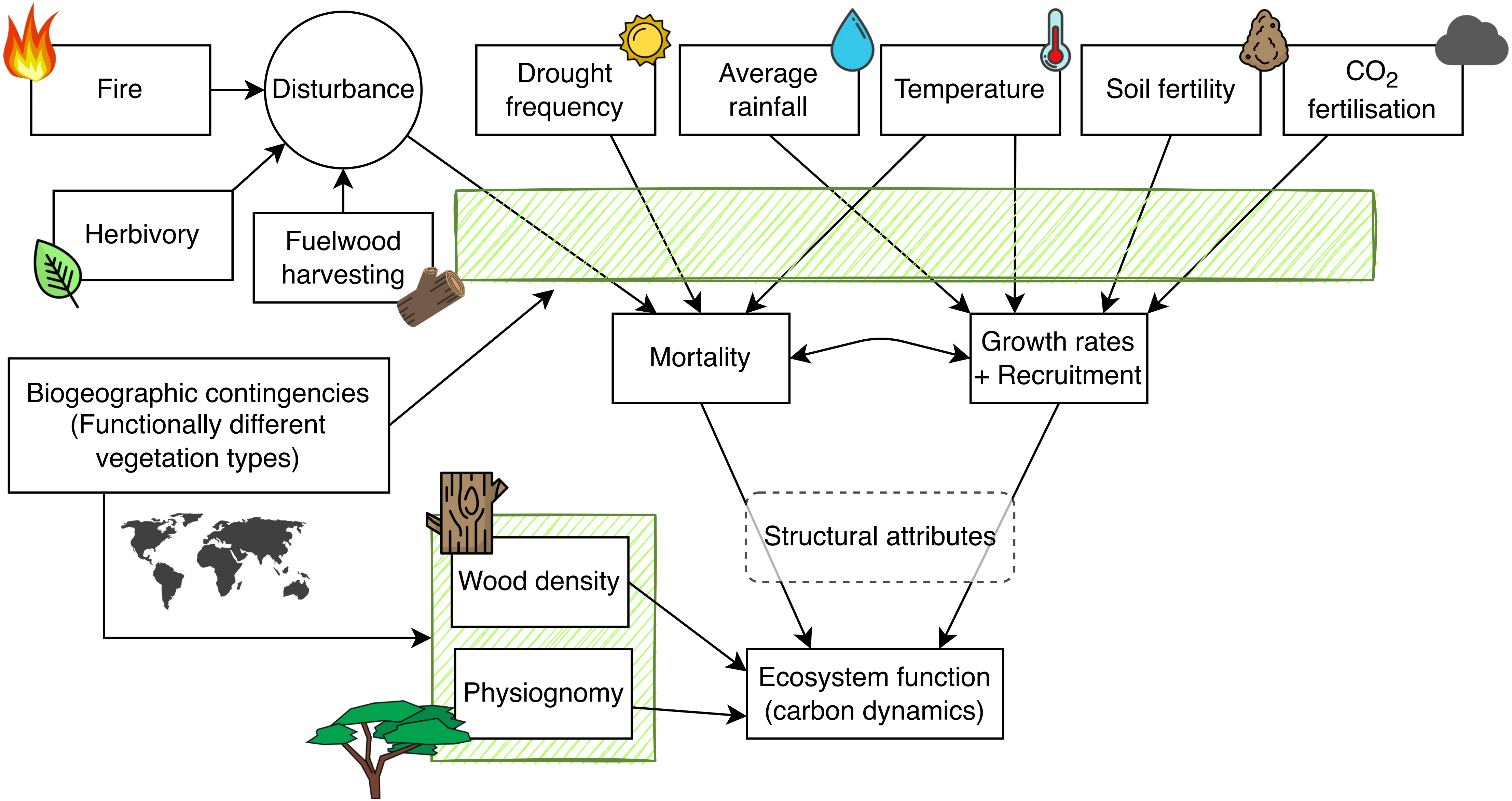
Warming and drying trend





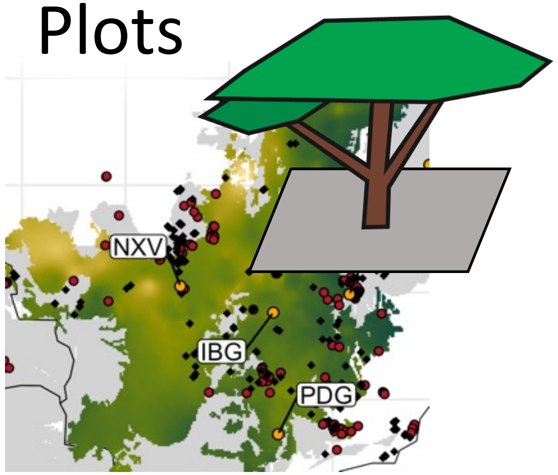
Powers et al. (2020)

Drivers of biomass (change) in the dry tropics

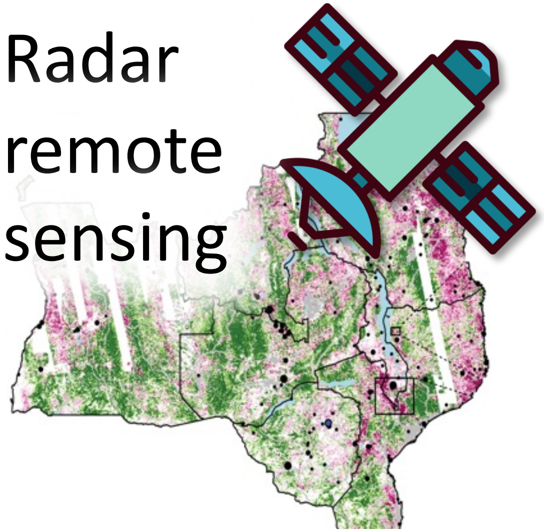


The SECO project: Methodological approach

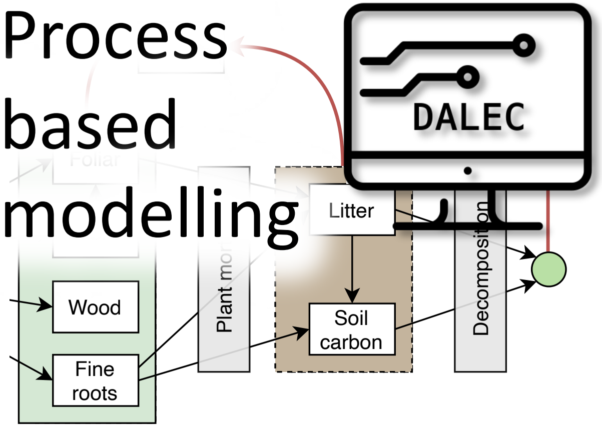
Plots



Radar remote sensing



Process based modelling

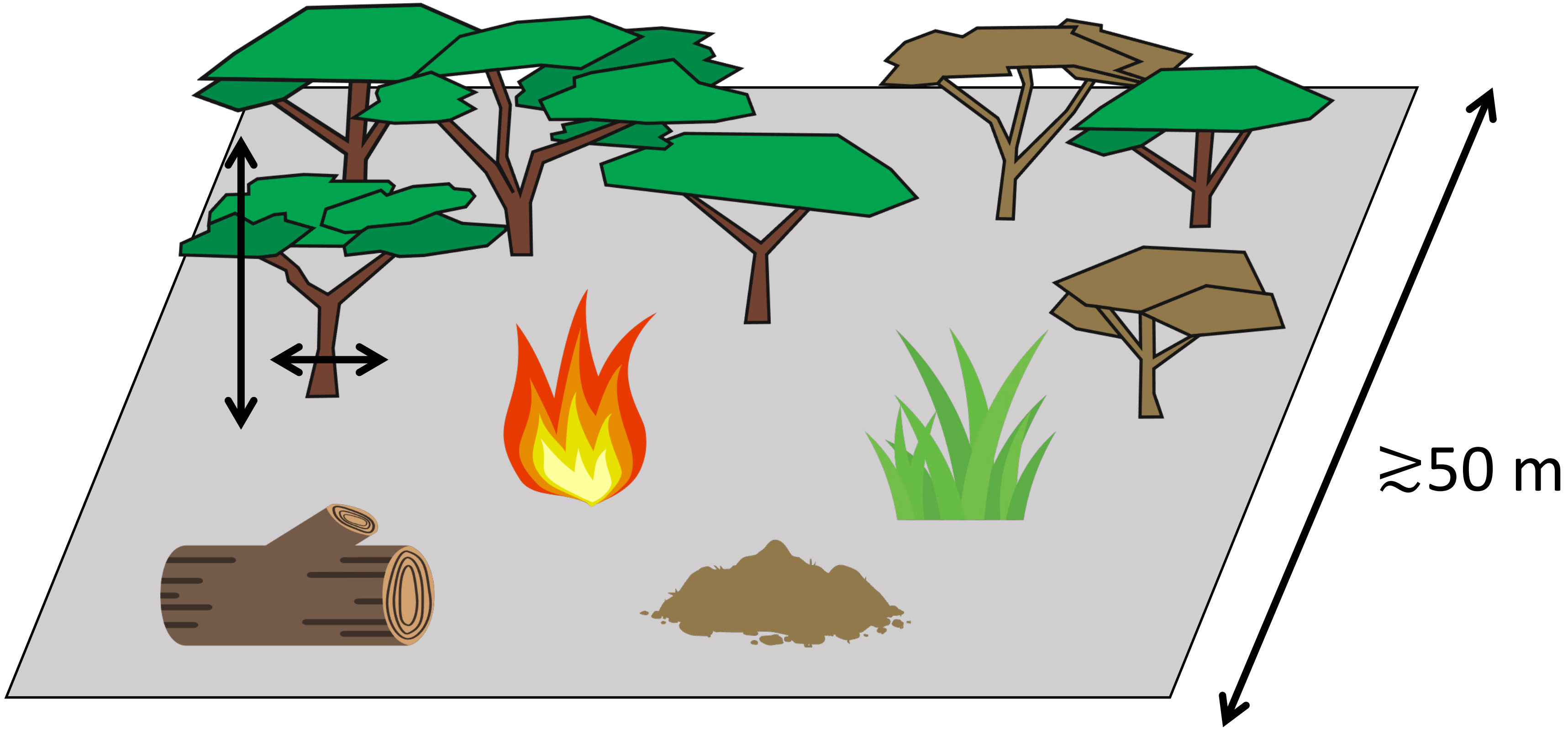


Plots provide:

- Individual-level rates of growth and mortality
- Species composition and community structure
- Infrastructure to collect auxiliary data –
  plant traits, phenology, soil, woody debris, herbaceous biomass etc.
- Woody biomass stocks and canopy structure to calibrate remote sensing

PI: Dr. Casey Ryan (Univ. of Edinburgh)

What's in a plot?

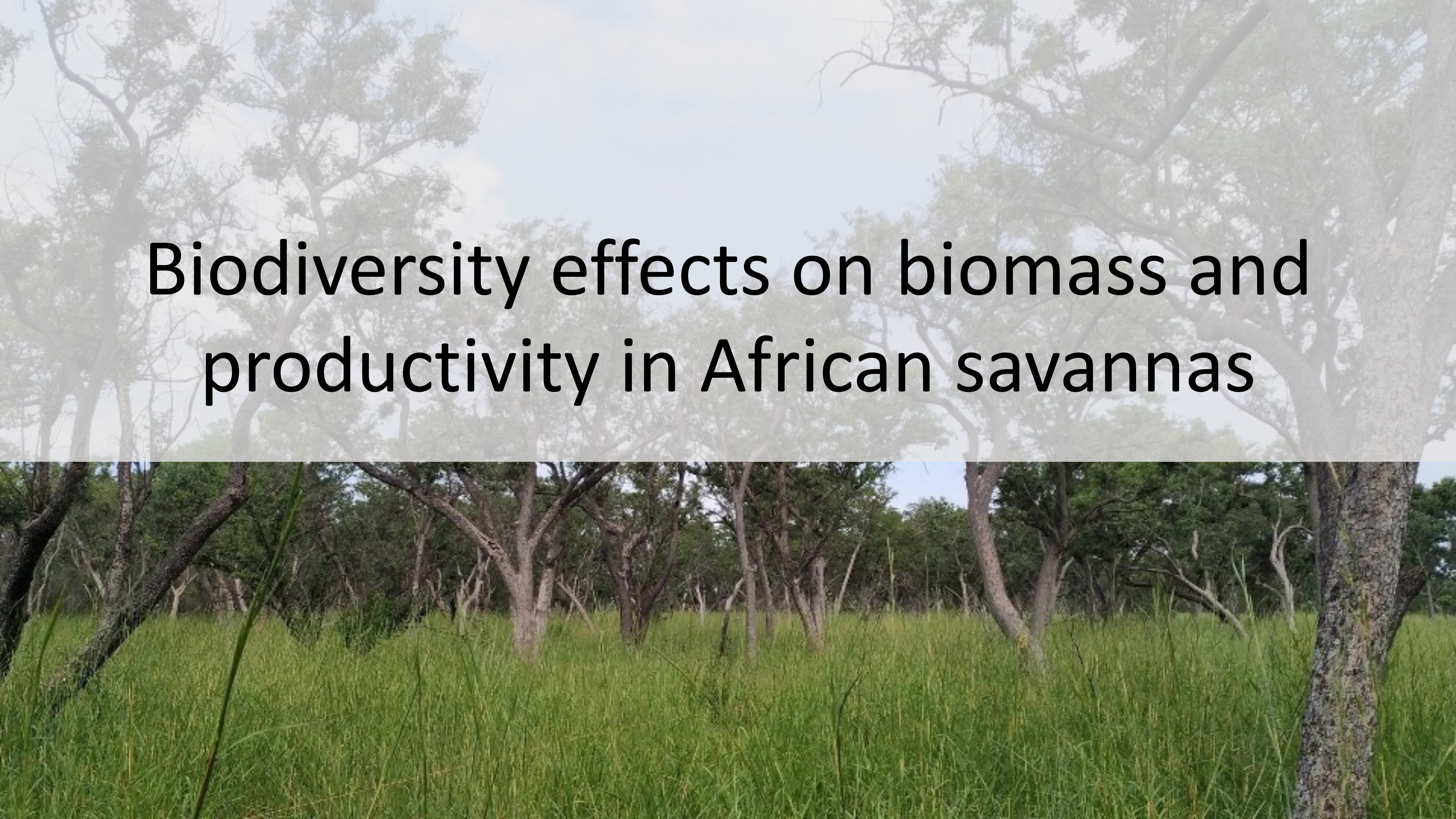


All woody stems >5 (or 10) cm diameter are tagged

- Tree species
- Stems within a tree
- Stem diameter
- Stem height
- Coarse woody debris
- Fire disturbance regime
- Soil carbon and nutrients
- Herb. biomass and comp.
- Tree mortality
- Leaf phenology

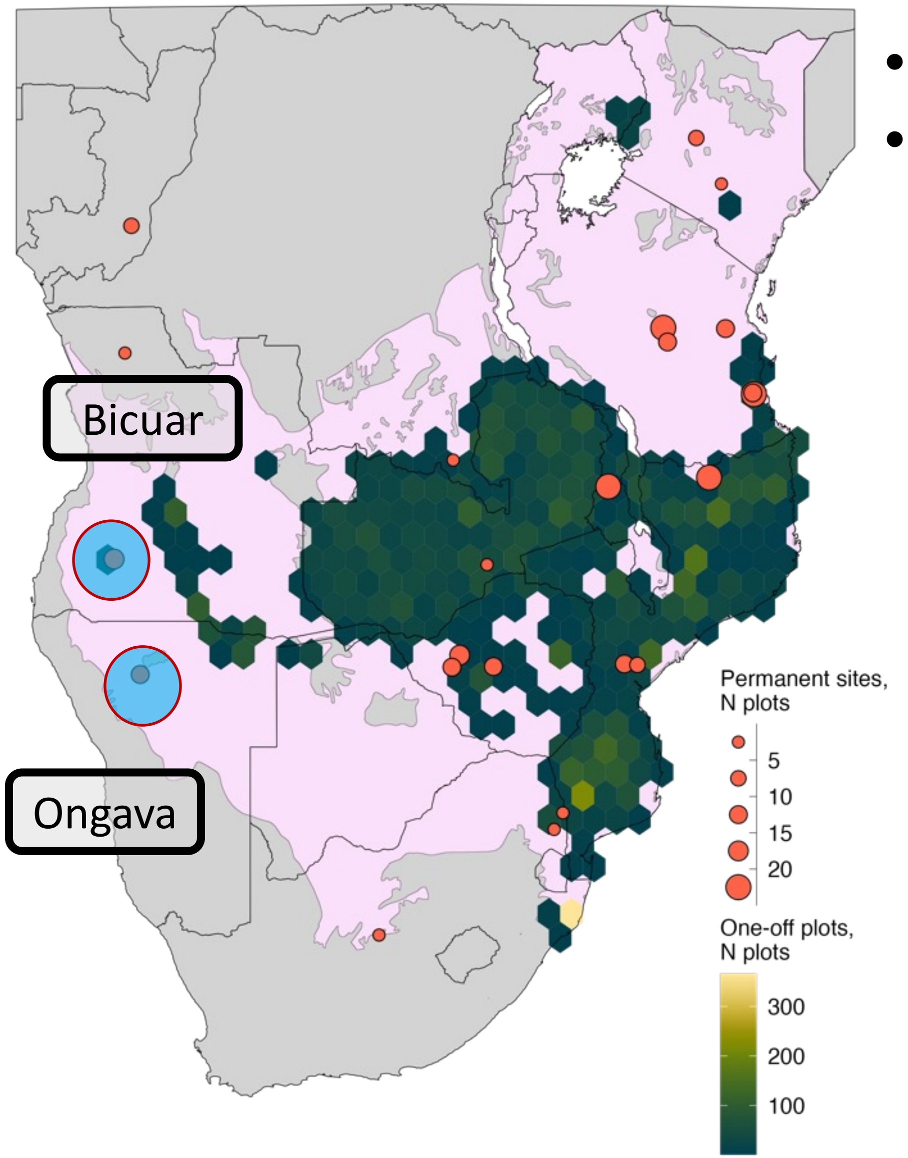
SEOSAW (2020), ForestPlots.net (2021), Hutley et al. 2011)

Biodiversity effects on biomass and productivity in African savannas



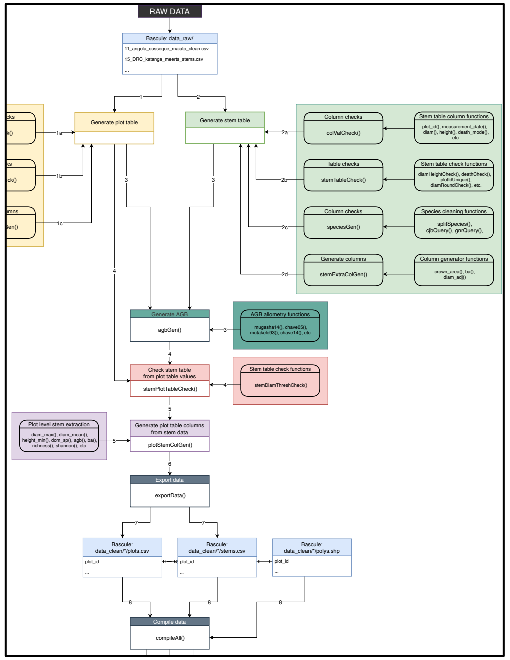
SEOSAW: plots in African woodlands

Socio-Ecological Observatory for Studying African Woodlands

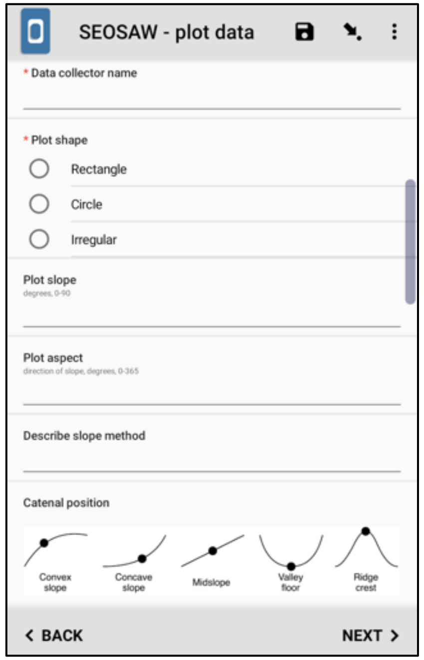


- 325 permanent plots
- 9702 one-off plots

Data processing



Digital data collection



Accessible documentation

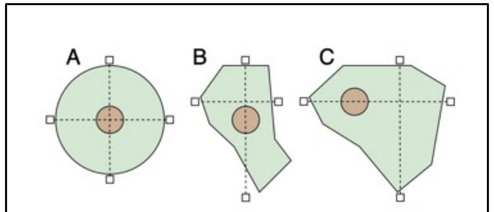


Figure 3: Schematic diagram showing a top-down view of tree canopies, with the trunk marked in brown, demonstrating measurement of perpendicular tree canopy diameters (dashed lines). Note that for trees B and C, the maximum diameter extents do not overlap the tree trunk.

Canopy volume of angiosperm trees is mostly modelled as an ellipsoid using perpendicular canopy dimensions (a and b), and the canopy depth (c):

$$V = \frac{4}{3}\pi abc \qquad (8)$$

SEOSAW recommended sampling strategy

Measure trunk diameter on every stem >5 cm DBH and tree height on every tree with at least one stem >5 cm DBH.

Measure perpendicular canopy diameters and canopy depth on all living trees with at least one stem >20 cm DBH.

5 Woodland canopy traits

Woodland canopy traits can be used to understand the understorey light environment, tree-tree competition, estimate productivity, and are useful to ground-truth remotely sensed data such as airborne LiDAR or tree-cover data products. Woodland canopy traits are collected at the scale of the woodland landscape, rather than the individual tree level.

Table 1: Common woodland canopy trait metrics.

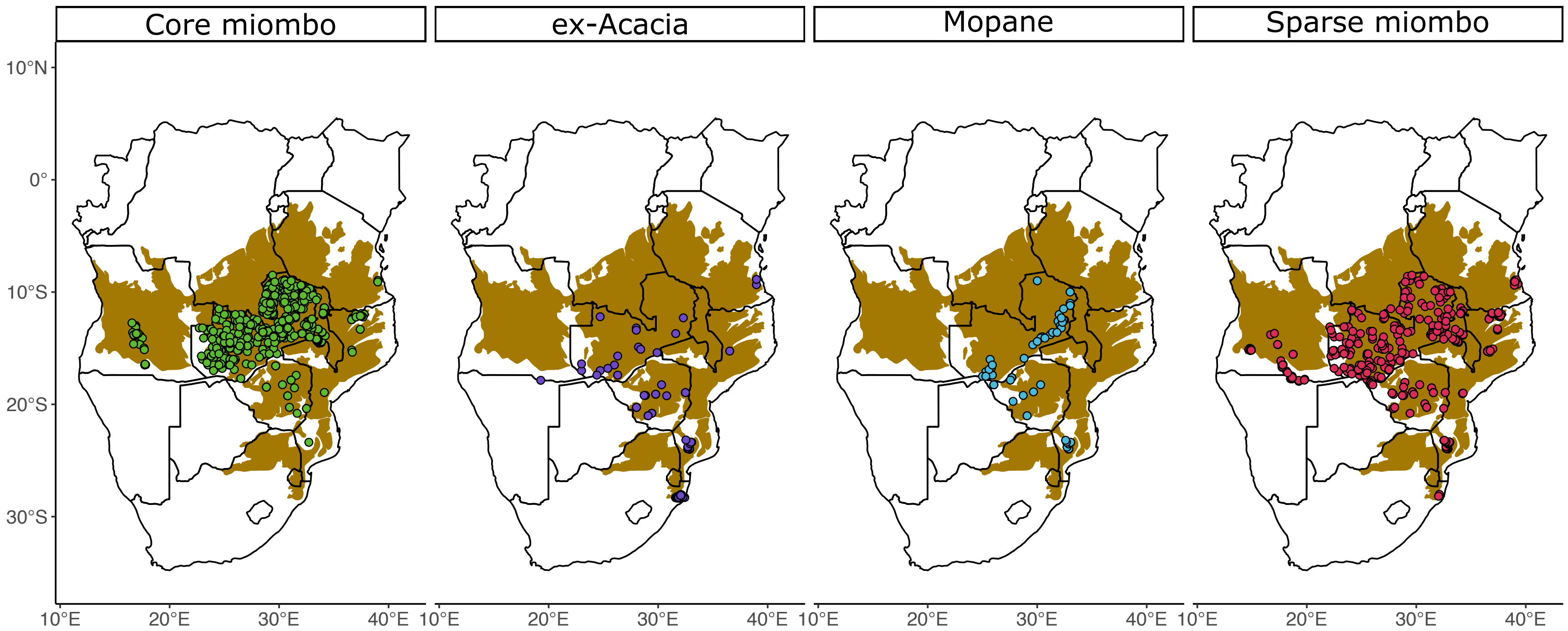
Metric	Unit	Description
Gap fraction	%	Proportional coverage of plant canopy material as viewed from a single point with some given angular field of view. Canopy closure = 1 - gap fraction.
Canopy cover	%	Proportional coverage of plant canopy material per unit ground area covered.
Leaf Area Index	$m^2\ m^{-2}$	Single-sided area of leaf (LAI) per unit ground area .

SEOSAW (2021) https://seosaw.github.io/

Determinants of woody biomass in African savannas

How do biodiversity and environment jointly affect woody biomass in African savannas?

SEOSAW



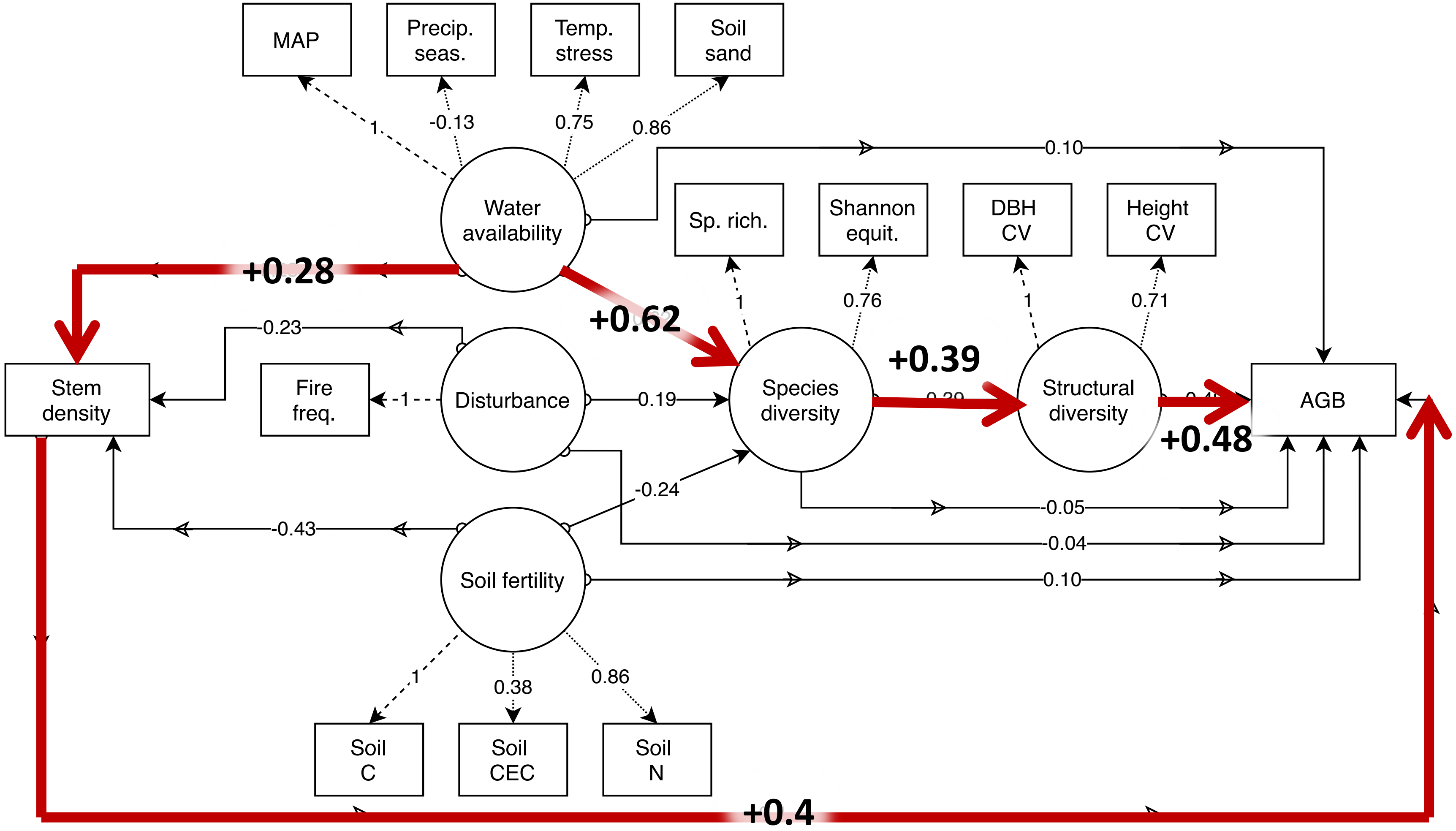
Godlee et al. (2021) *New Phytologist*

Determinants of woody biomass in African savannas

1. Water availability drives biomass via species diversity and stem density

2. Structural diversity as an axis of niche differentiation

3. Bootstrapping: Stem density mediates species diversity – biomass relationship



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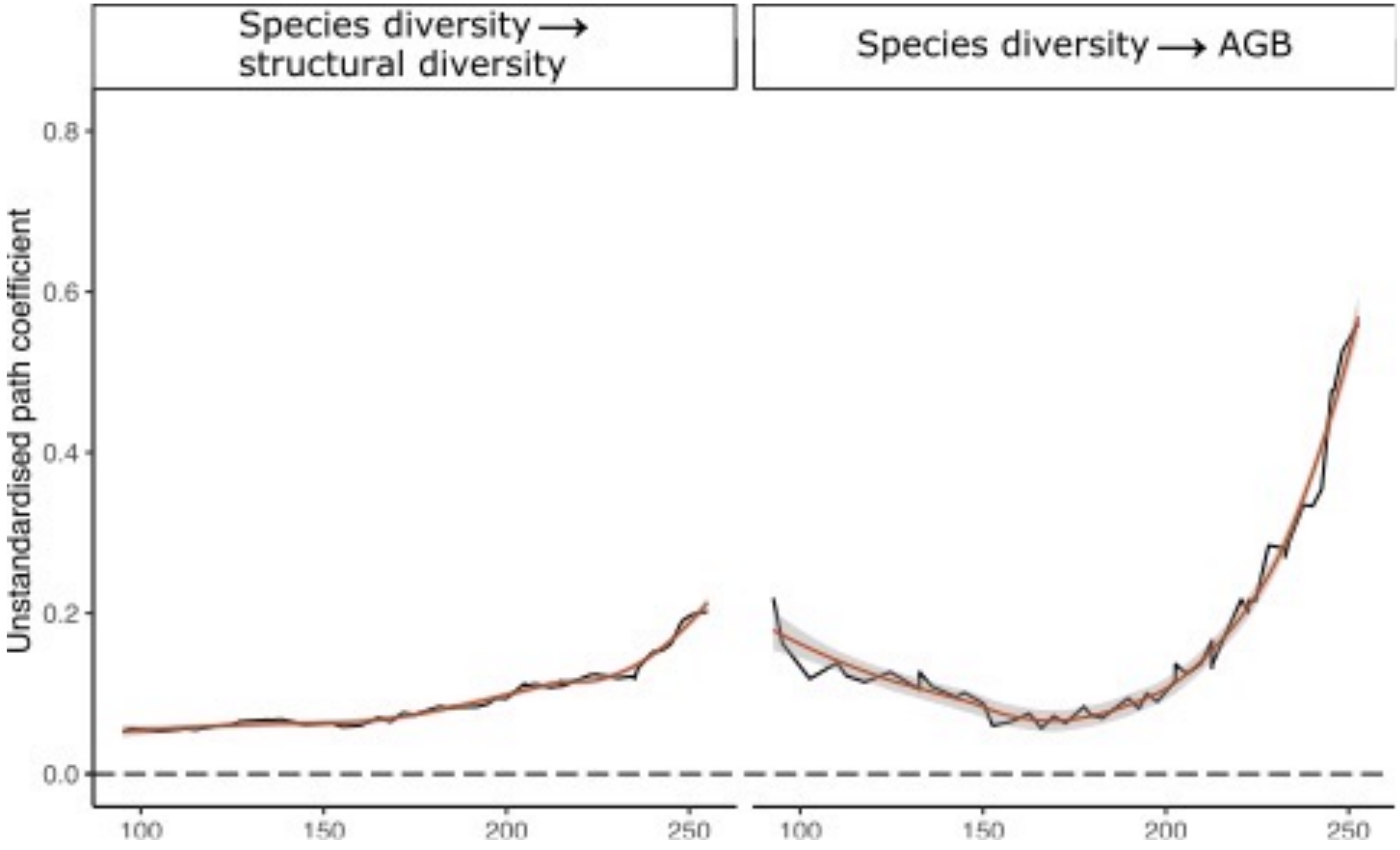
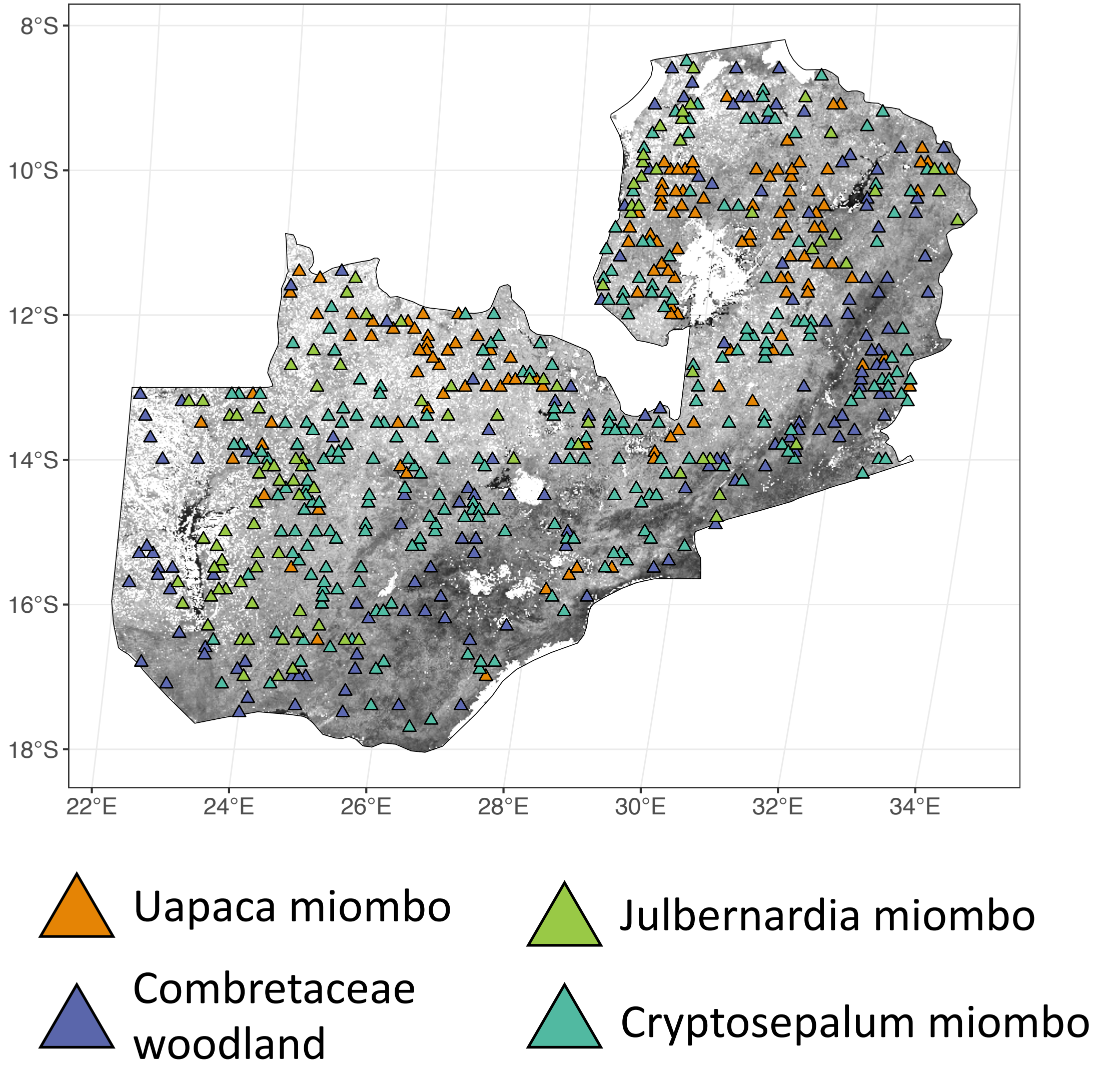


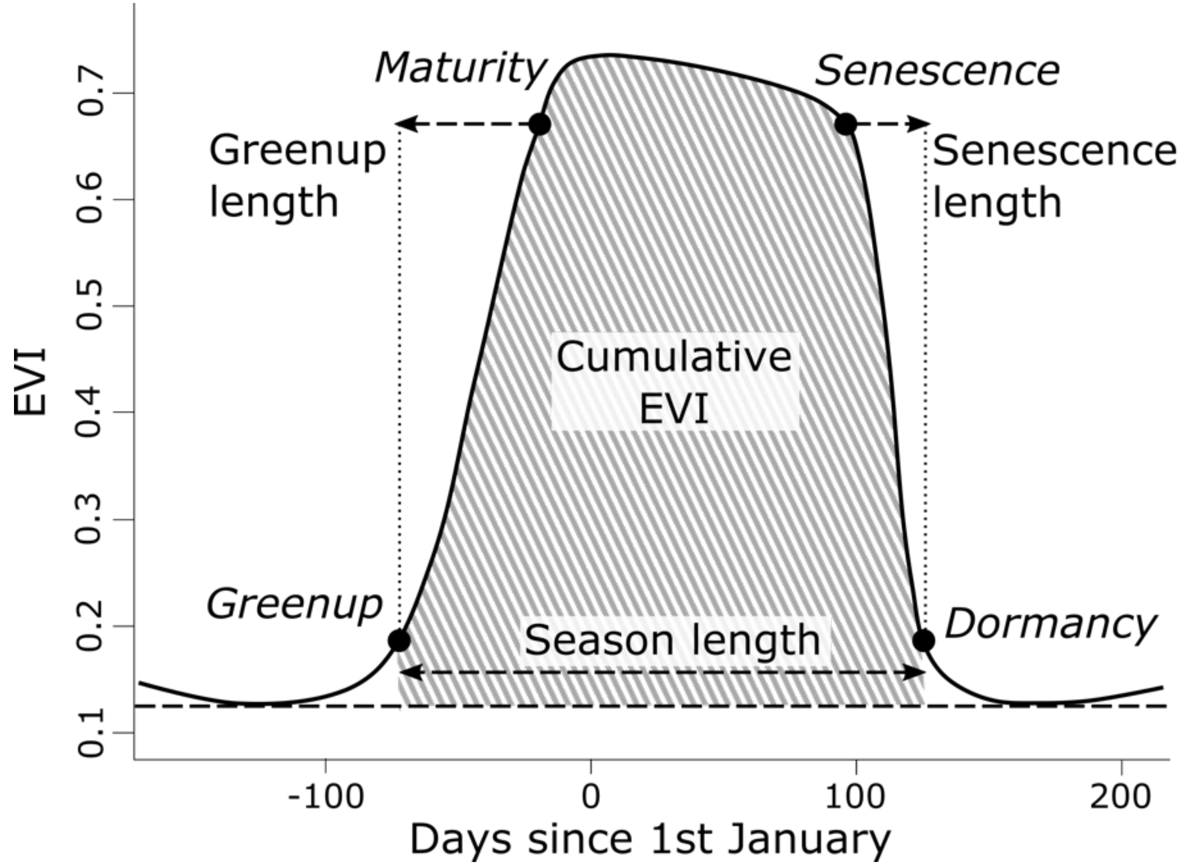
Godlee et al. (2021) *New Phytologist*

Linking land surface phenology and diversity

Zambian Integrated Land Use Assessment – 617 plots

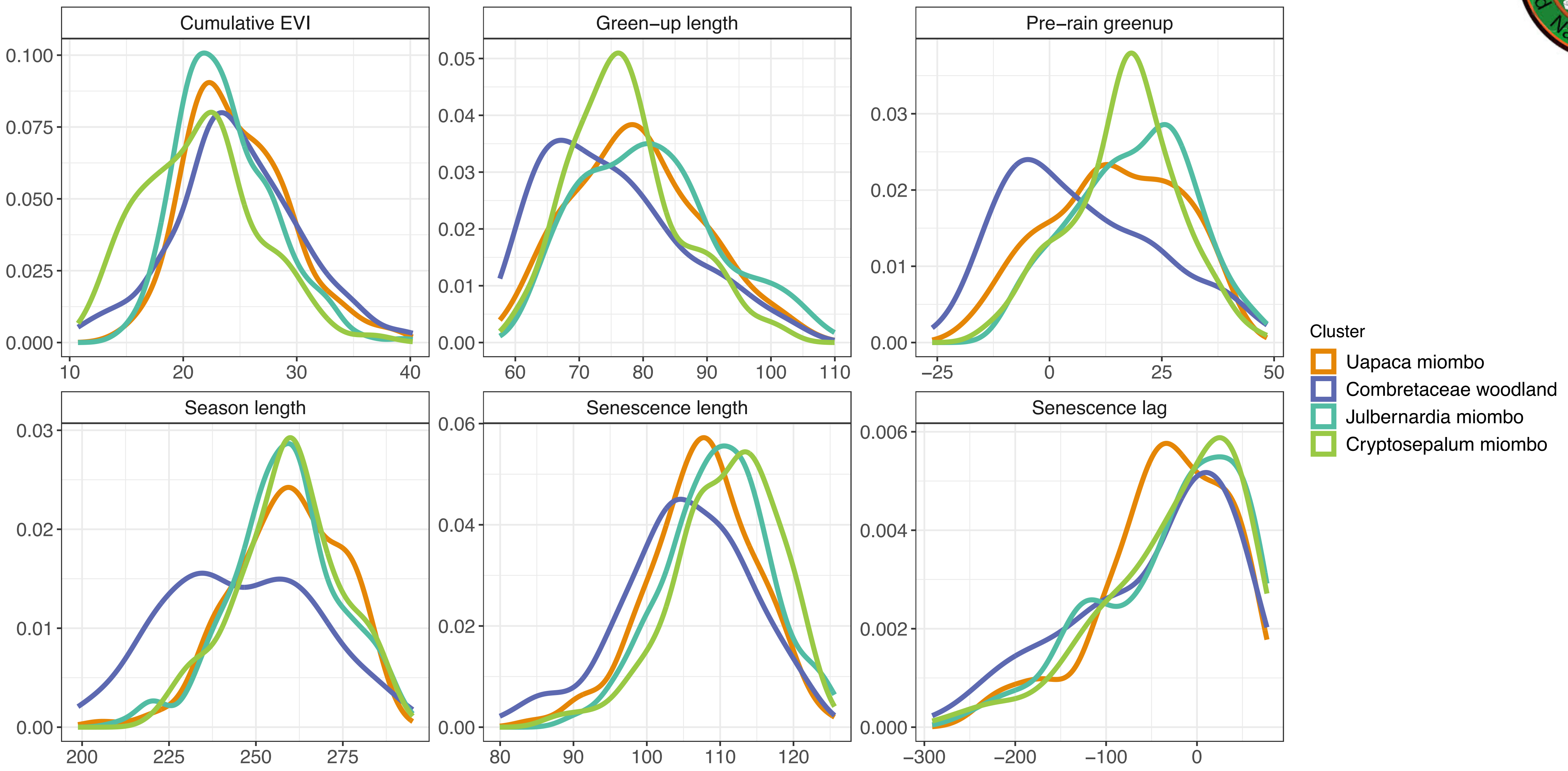


MODIS land surface phenology time series
EVI – Enhanced Vegetation Index



Godlee, Ryan, Siampale & Dexter (in revision Mar 2023) *Journal of Ecology*

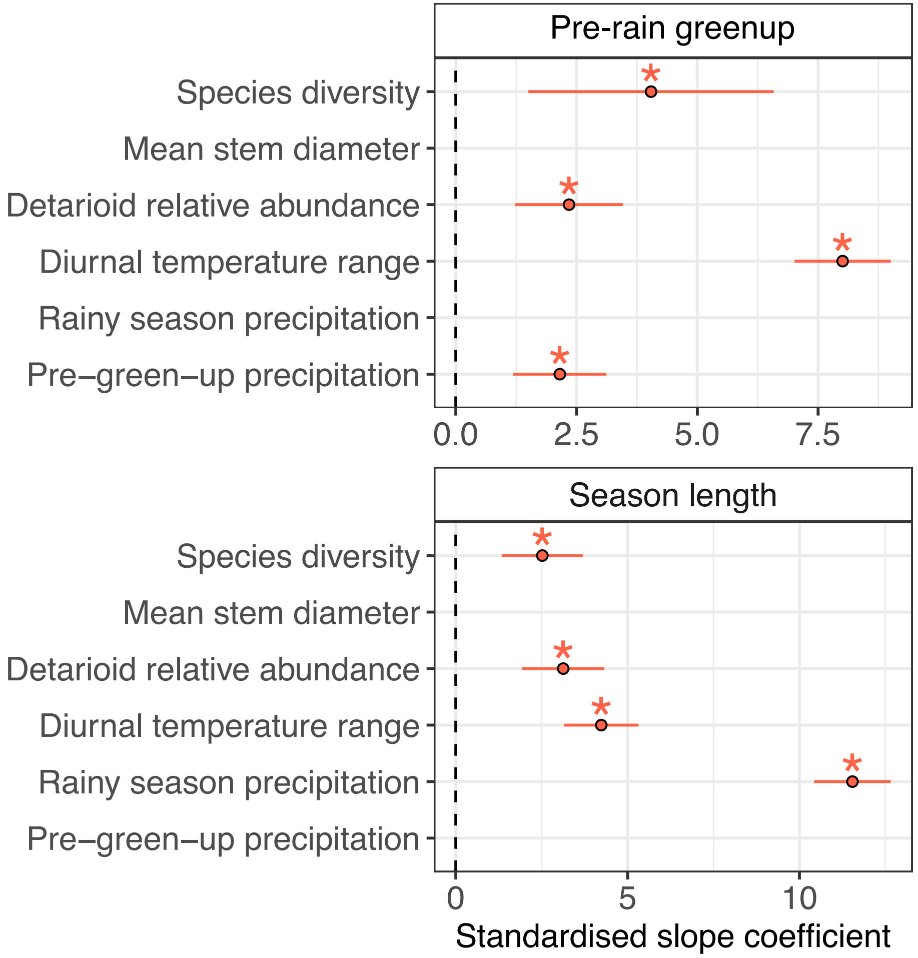
Linking land surface phenology and diversity

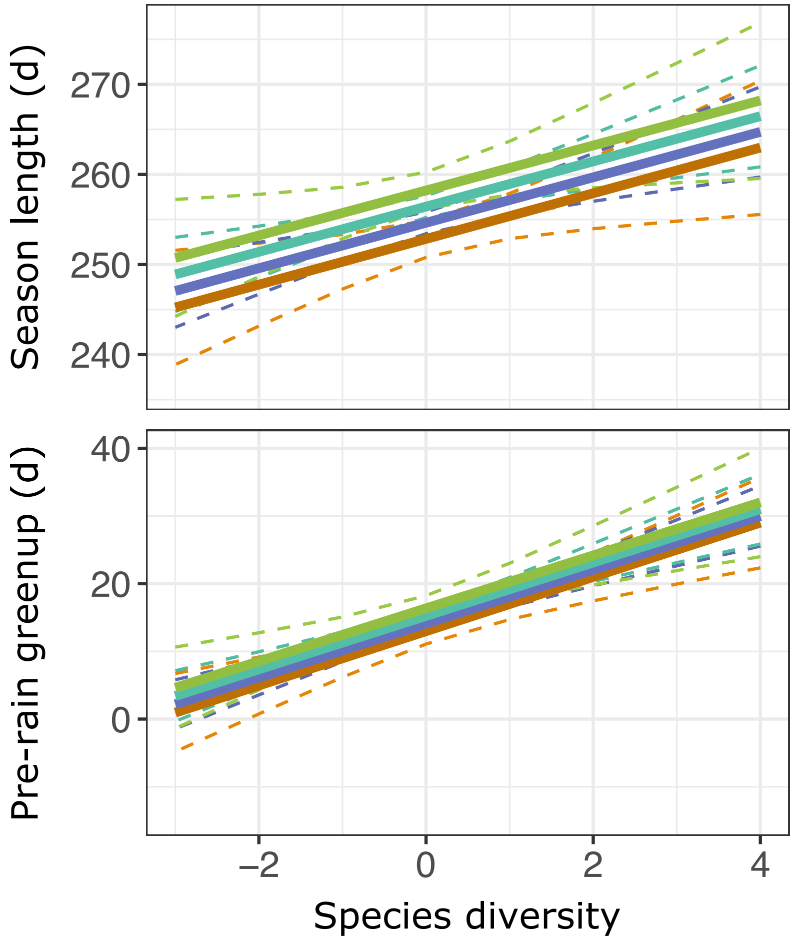


Godlee, Ryan, Siampale & Dexter (in revision Mar 2023) *Journal of Ecology*

Linking land surface phenology and diversity

Tree species diversity and detarioid legume abundance associated with longer growing season length, earlier pre-rain greenup.





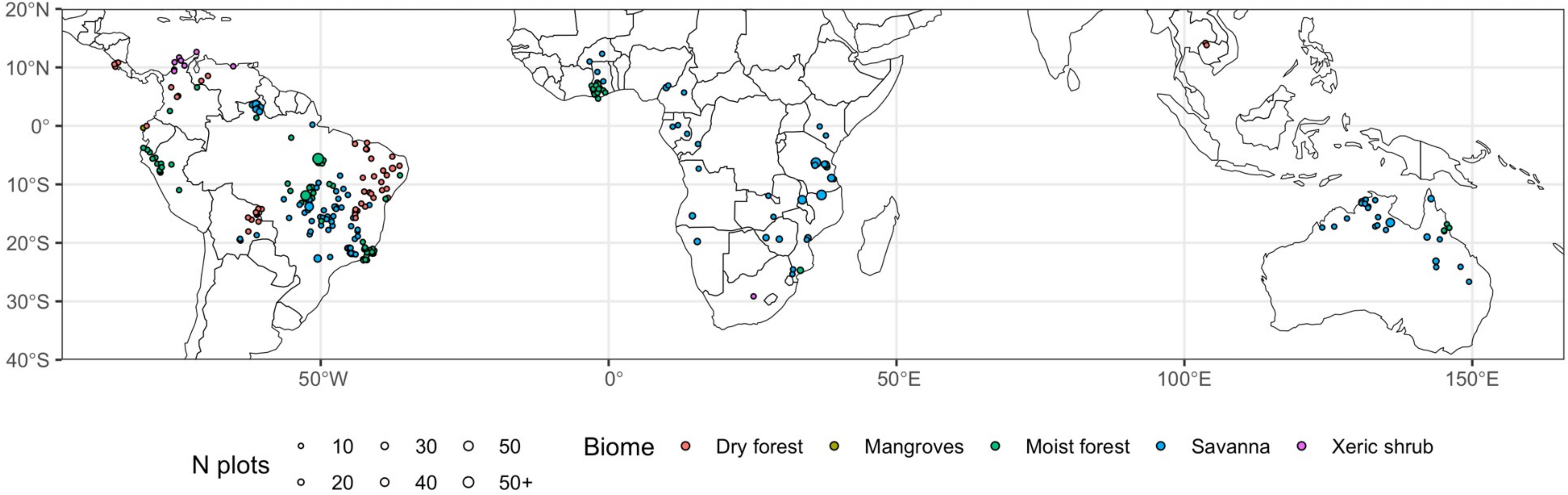
Godlee, Ryan, Siampale & Dexter (in revision Mar 2023) *Journal of Ecology*


Structural traits and vital rates
across the dry tropics

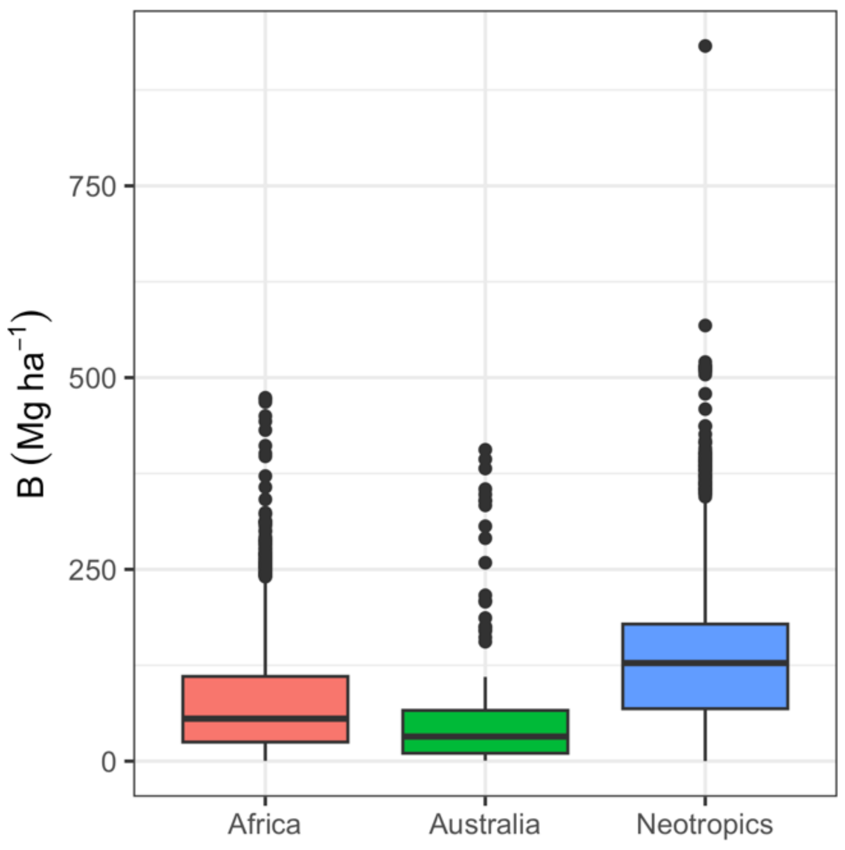
Structural traits and vital rates across the dry tropics

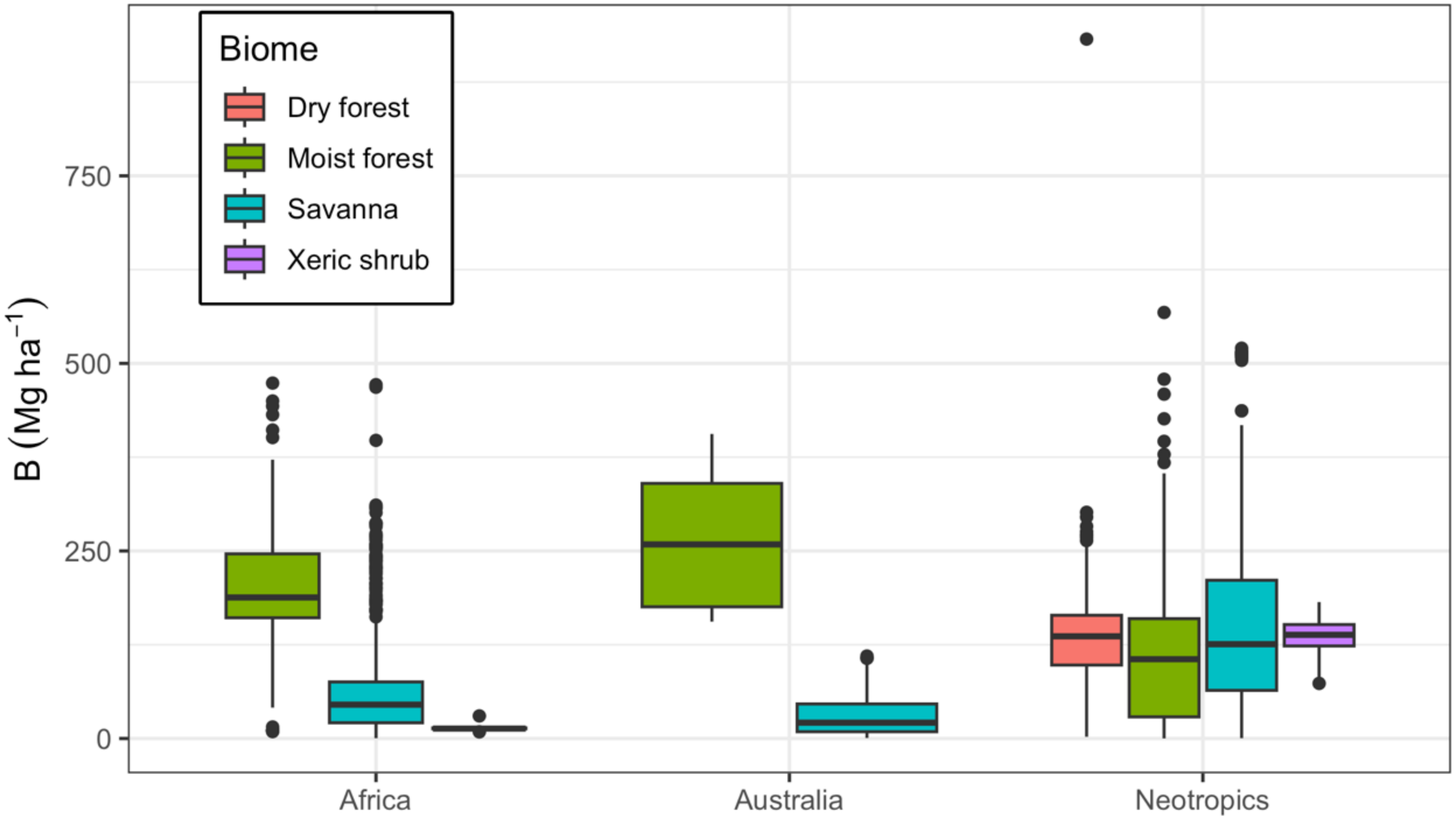
639 plots with >1 census since the year 2000

Across Neotropics, Africa, Asia (only 4 plots!), and Australia



Variation in woody biomass among continents

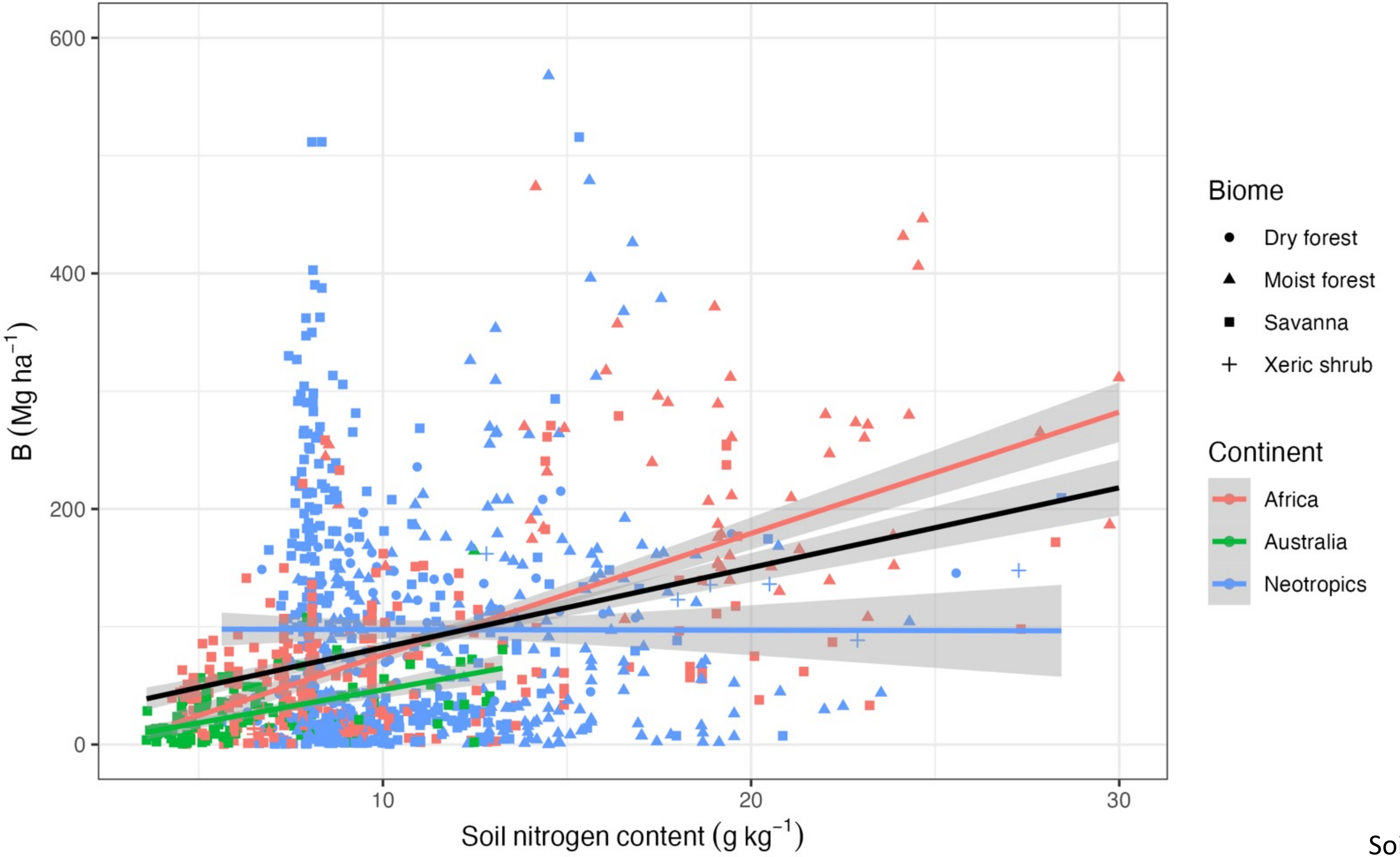




Woody biomass and moisture availability

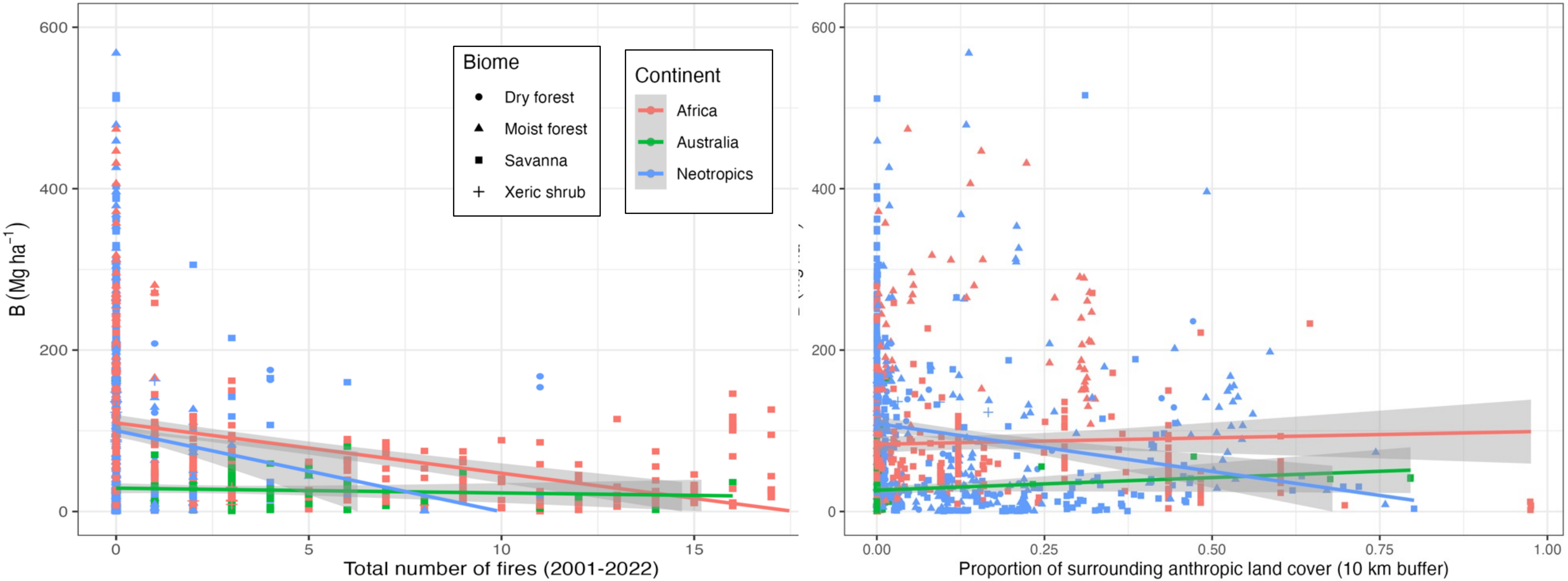
ERA-Land: Muñoz-Sabater et al. (2021)

Woody biomass and soil nutrient content



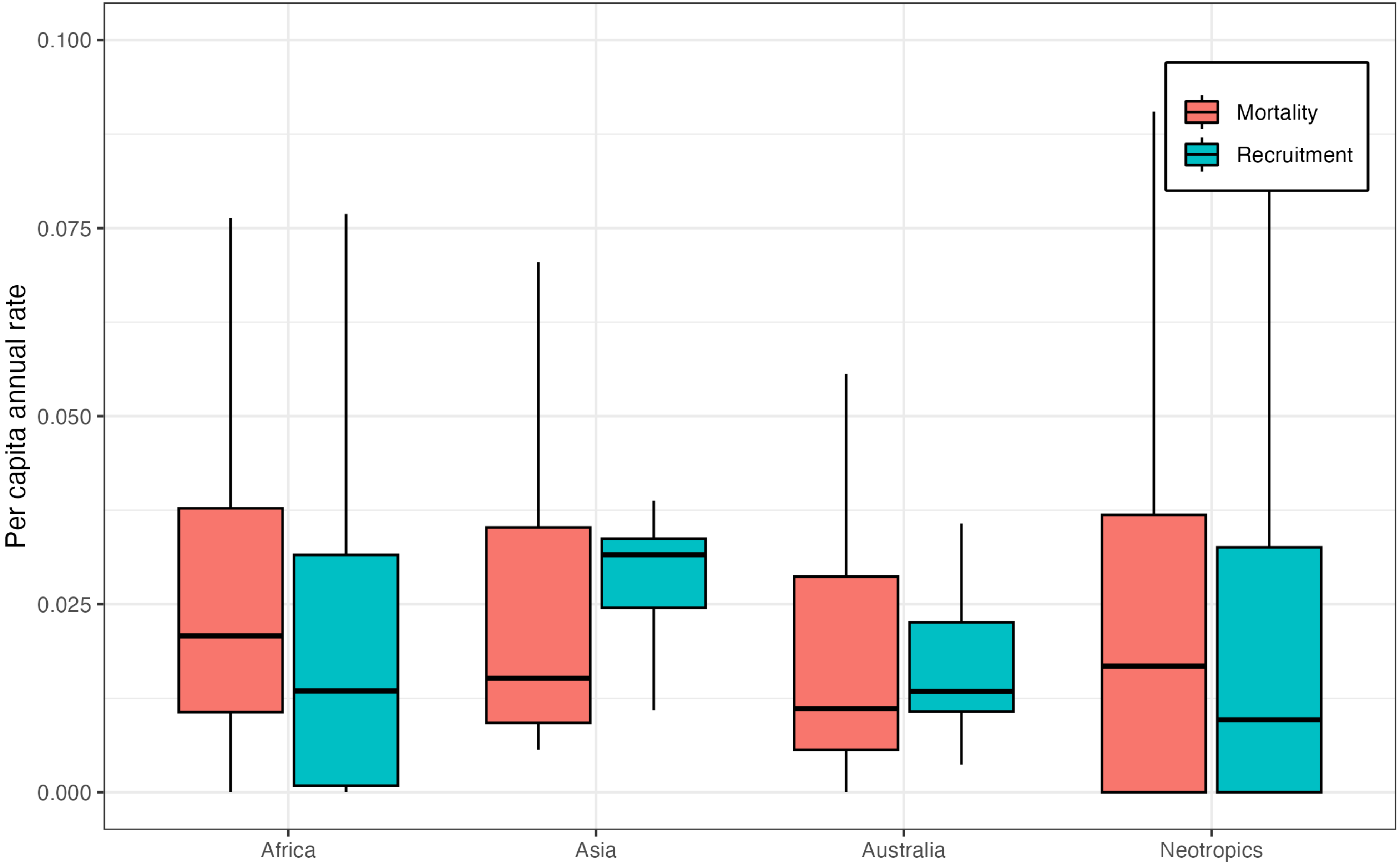
SoilGrids: Poggio et al. (2021)

Woody biomass and disturbance



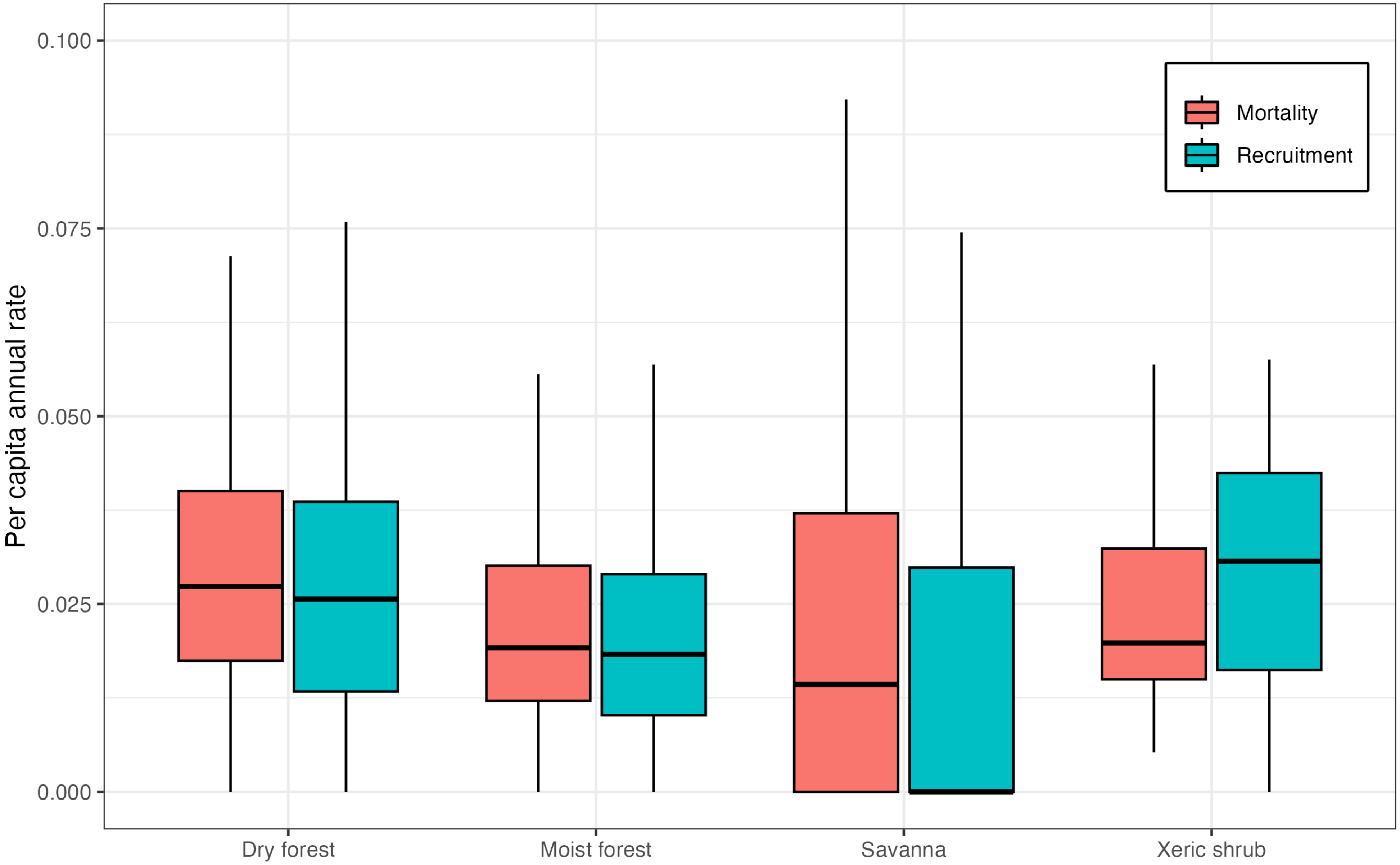
MODIS MCD64A1: Giglio et al. (2015); Copernicus LandCover: Buchhorn et al. (2020)

Variation in vital rates among continents



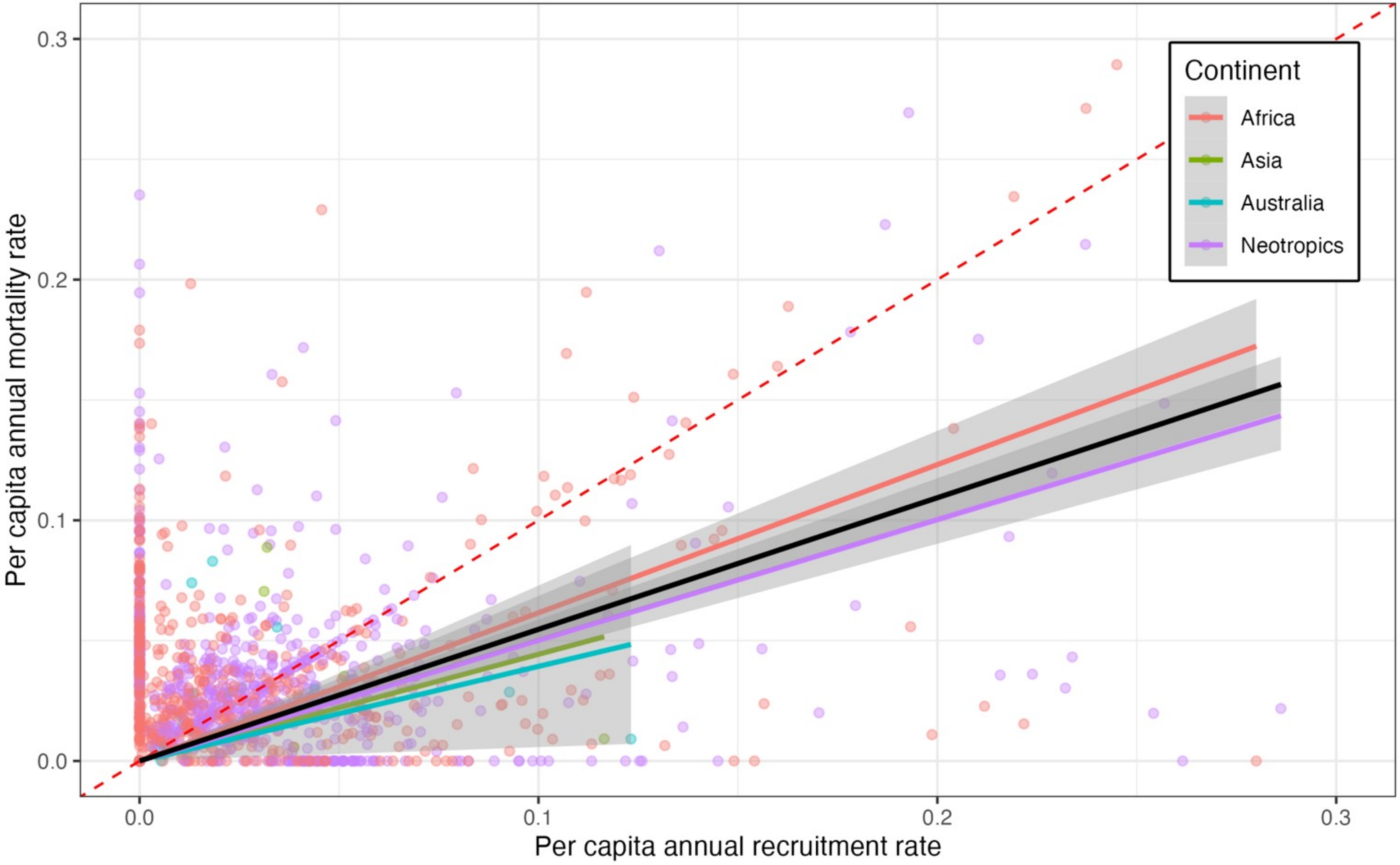
Kohyama et al. (2018)

Variation in vital rates among biomes



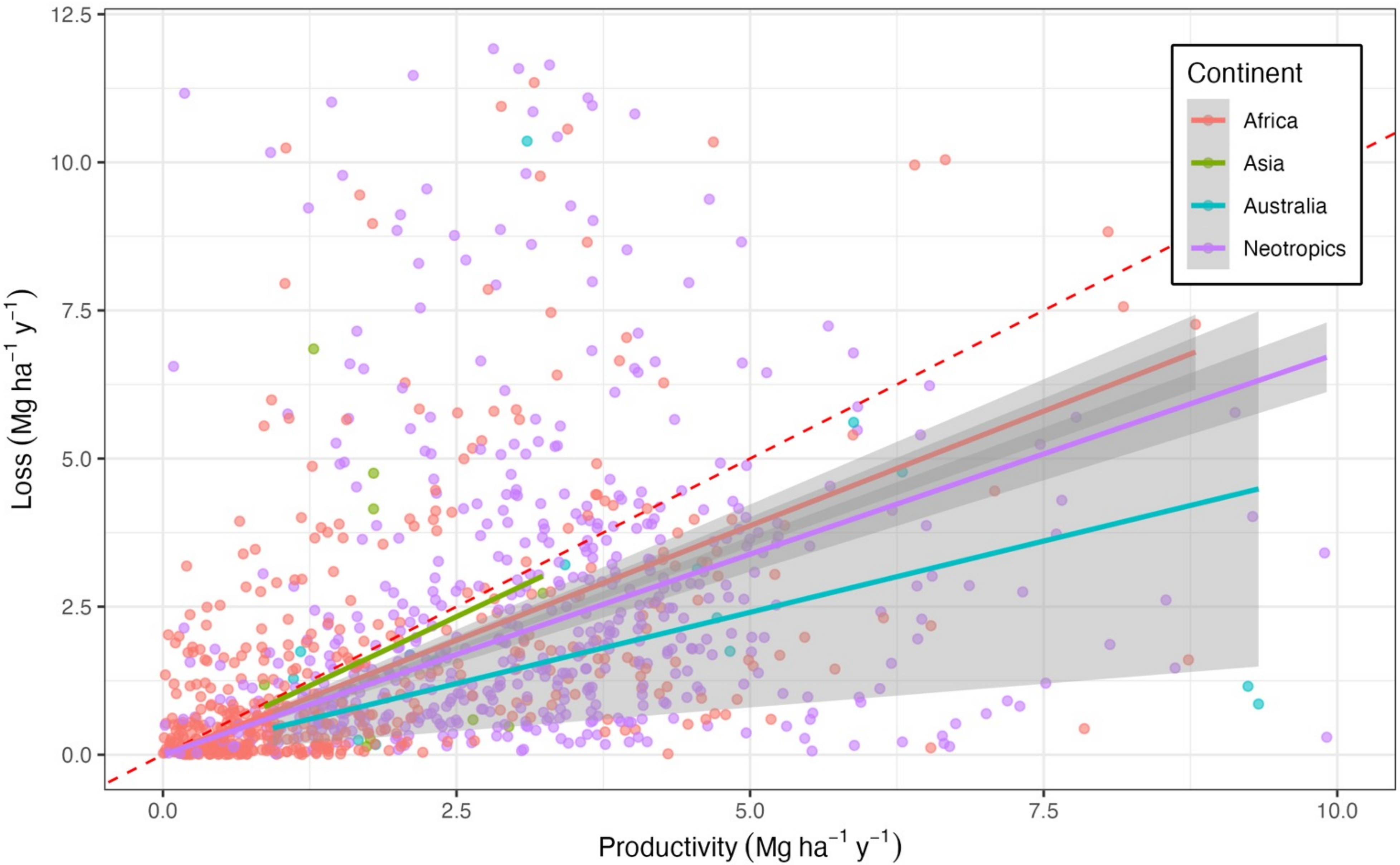
Kohyama et al. (2018)

Generally, stem recruitment > mortality …



Kohyama et al. (2018)

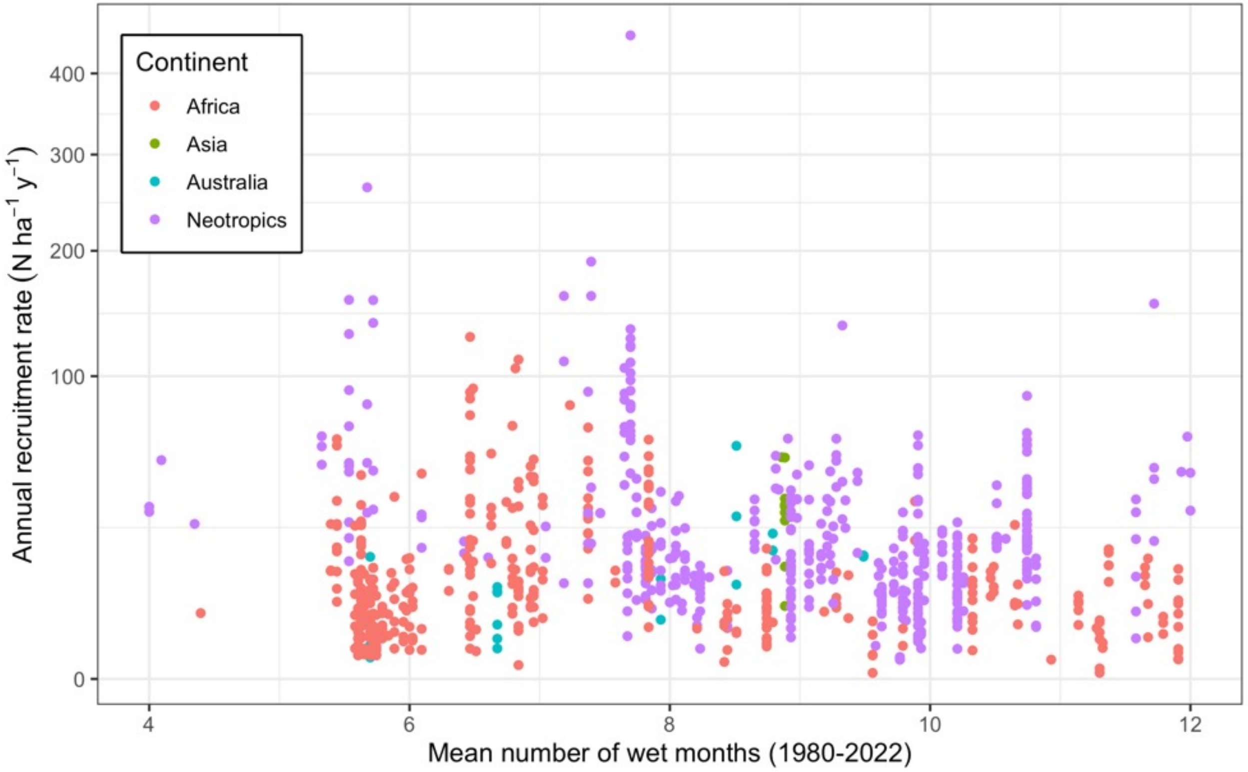
… and, biomass gains > losses



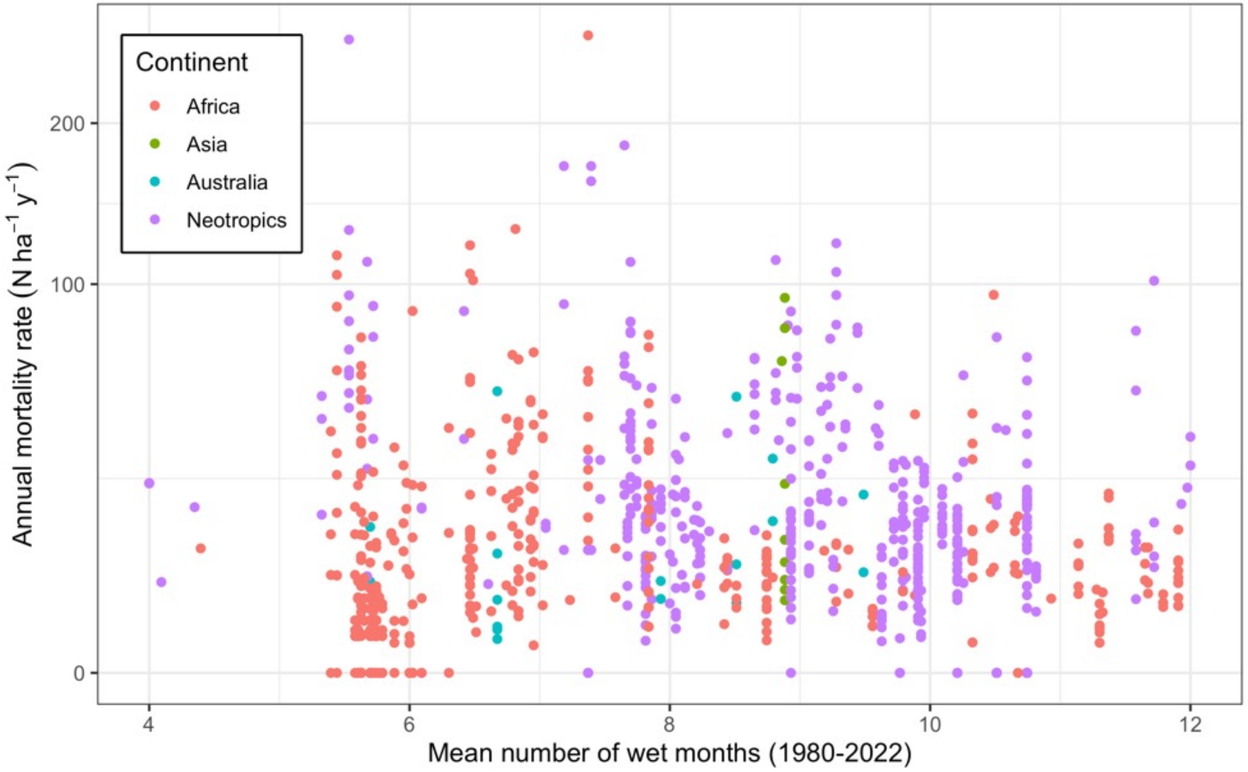
Kohyama et al. (2019)

Climate is a poor predictor of vital rates

Recruitment



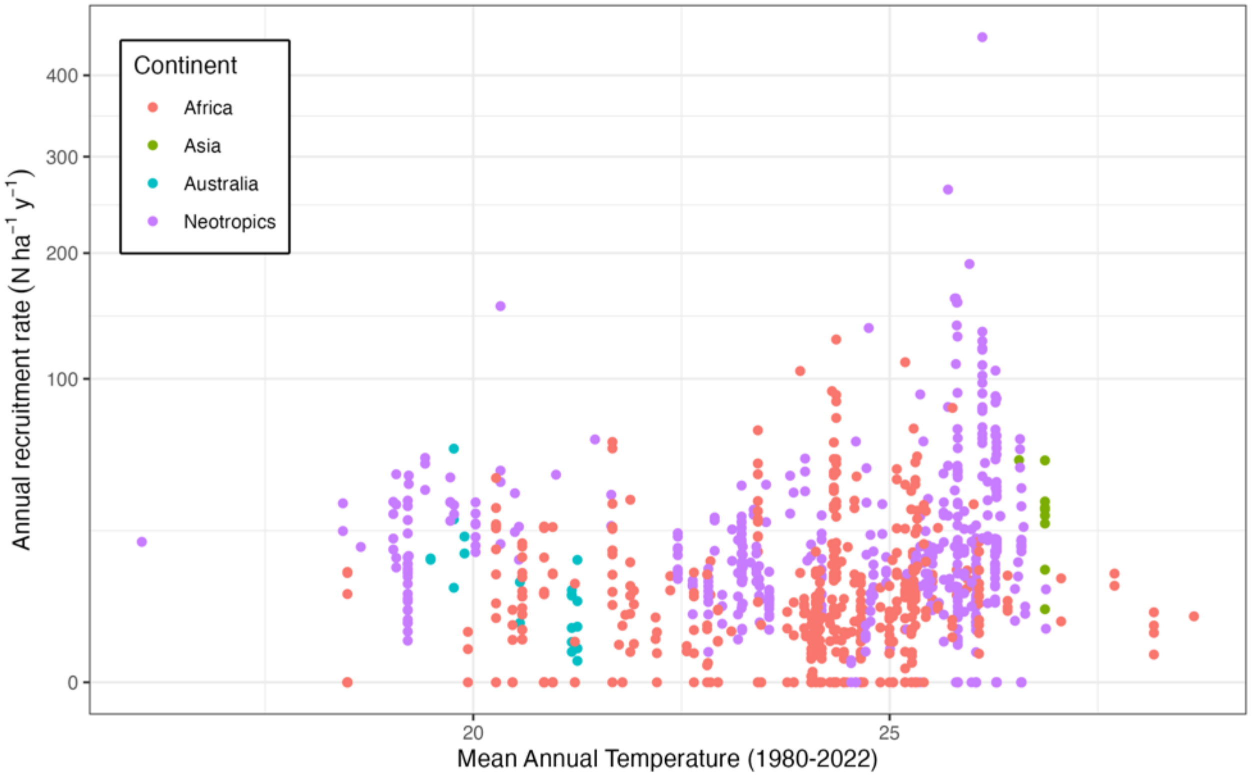
Mortality



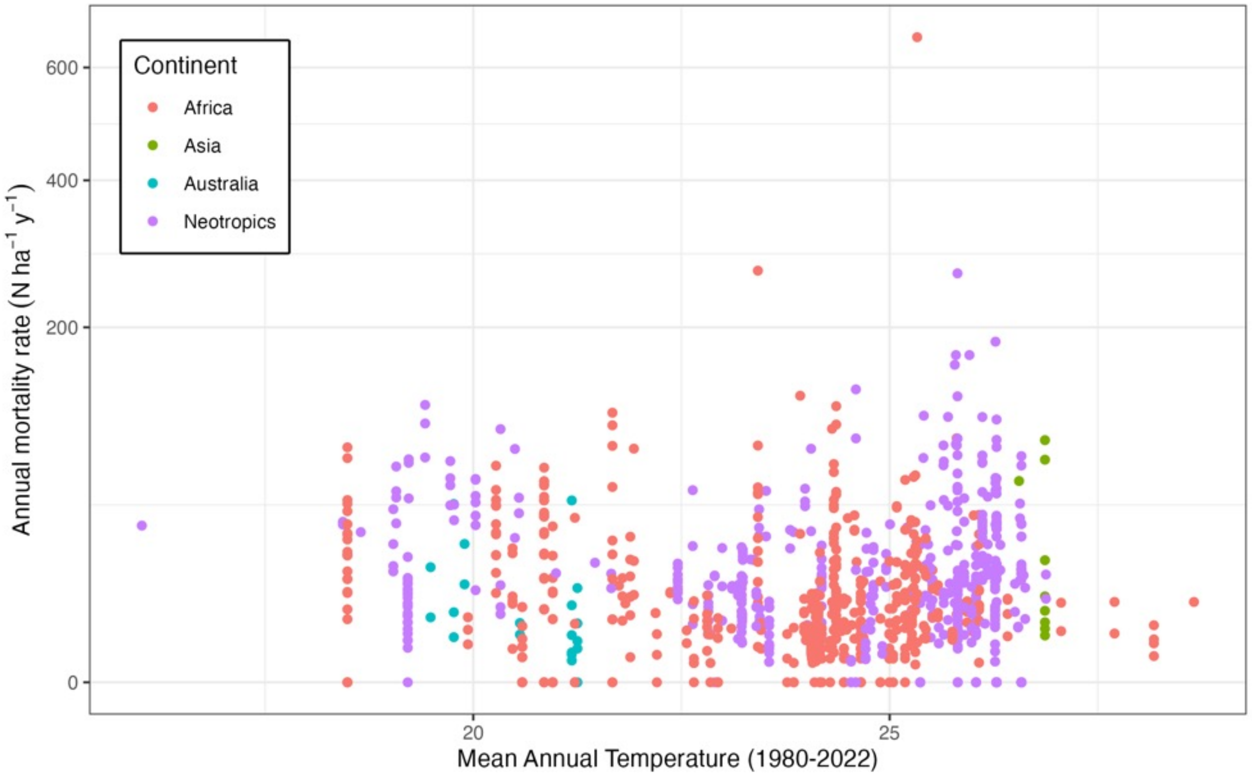
ERA-Land: Muñoz-Sabater et al. (2021)

Climate is a poor predictor of vital rates

Recruitment

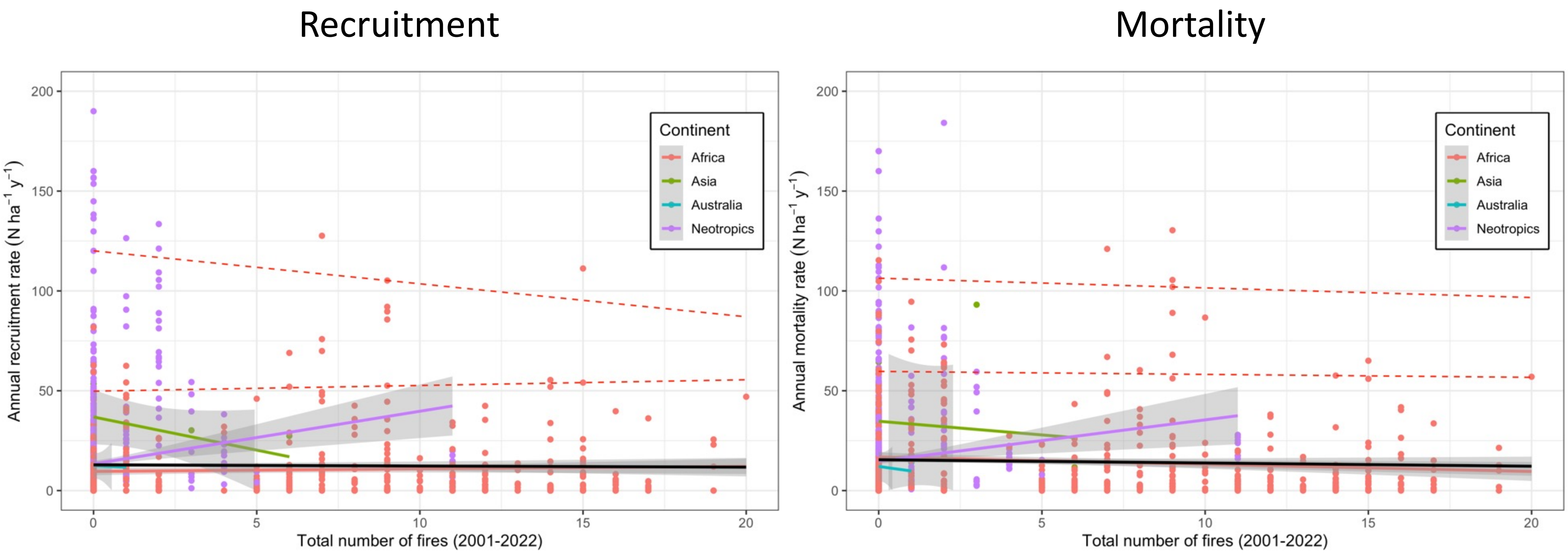


Mortality



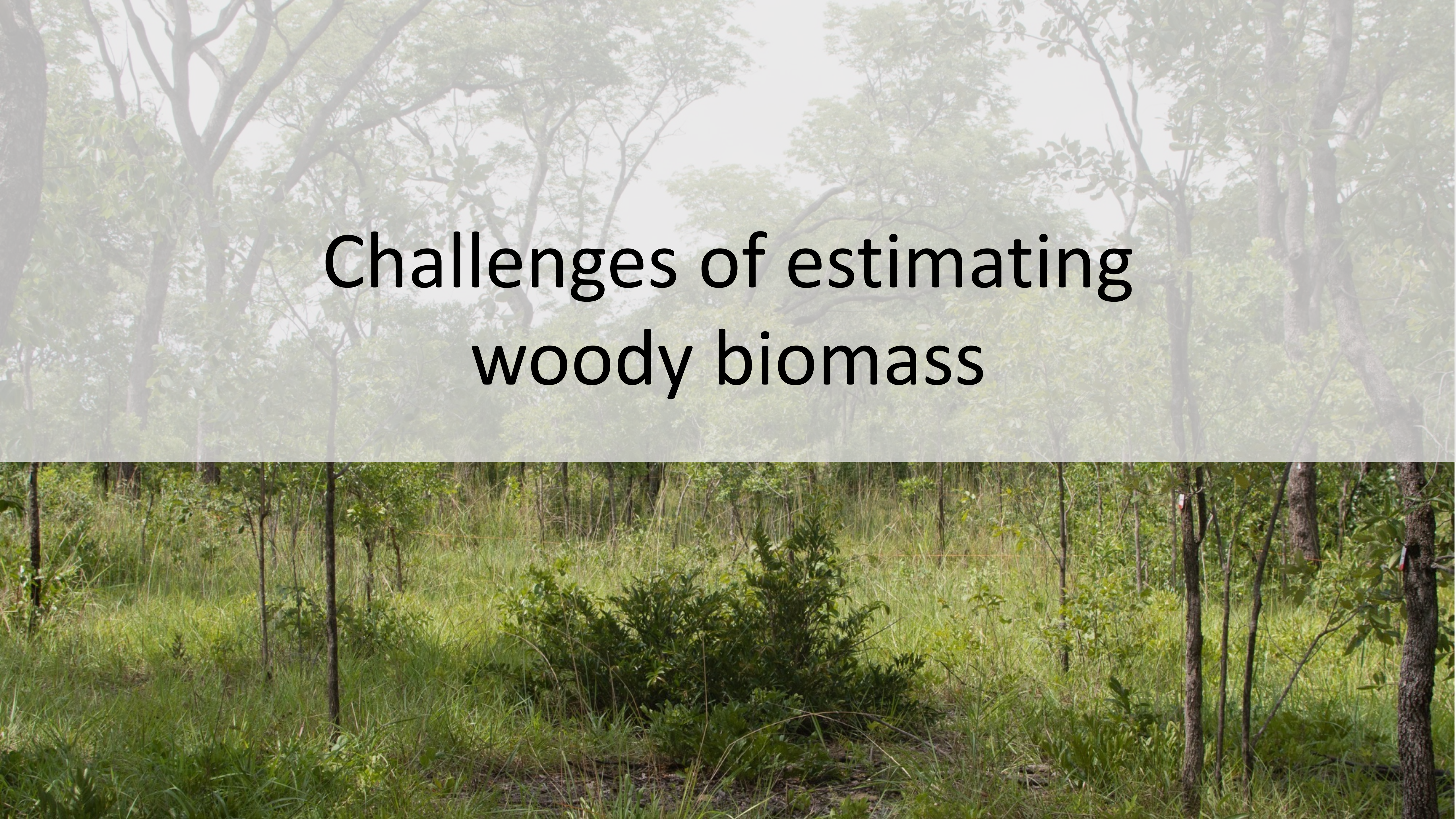
ERA-Land: Muñoz-Sabater et al. (2021)

Fire is a poor predictor of vital rates



MODIS MCD64A1: Giglio et al. (2015)

Challenges of estimating woody biomass



Estimating biomass in the dry tropics

Global Change Biology

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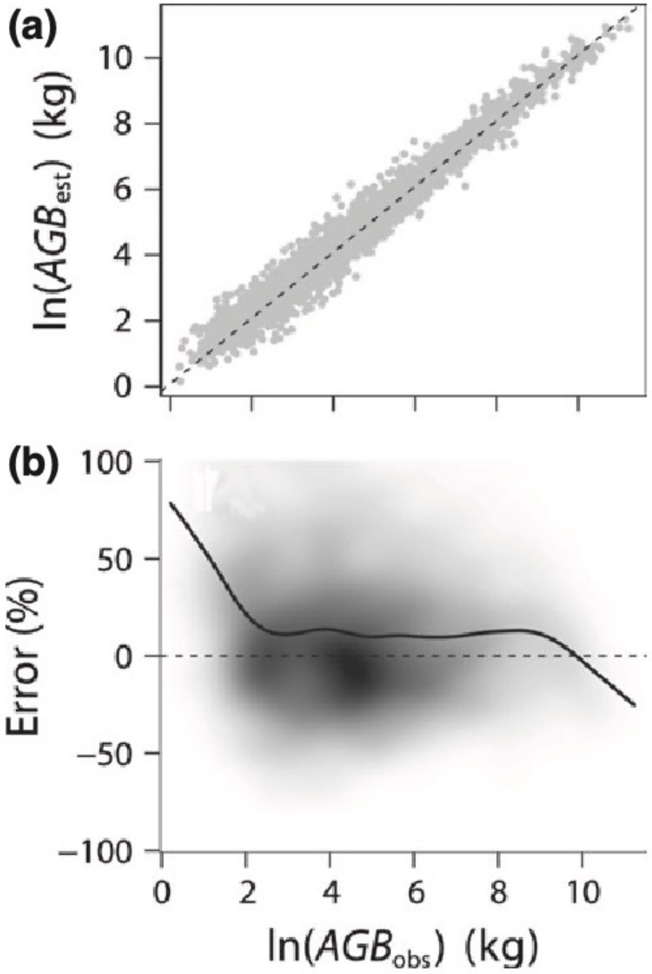
Improved allometric models to estimate the aboveground biomass of tropical trees

JÉRÔME CHAVE[1], MAXIME RÉJOU-MÉCHAIN[1], ALBERTO BÚRQUEZ[2], EMMANUEL CHIDUMAYO[3], MATTHEW S. COLGAN[4], WELINGTON B.C. DELITTI[5], ALVARO DUQUE[6],



$$AGB_E = e[-1.8 - 0.98E + 0.98\ln(\rho) + 2.68\ln(D) - 0.03[\ln(D)]^2]$$

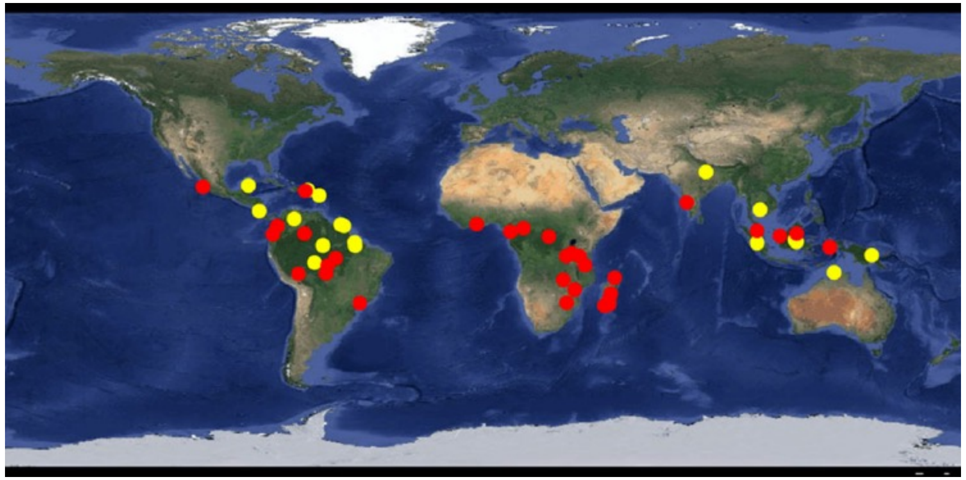
$$AGB_H = 0.0673 \times (\rho D^2 H)^{0.976}$$

D = Stem diameter

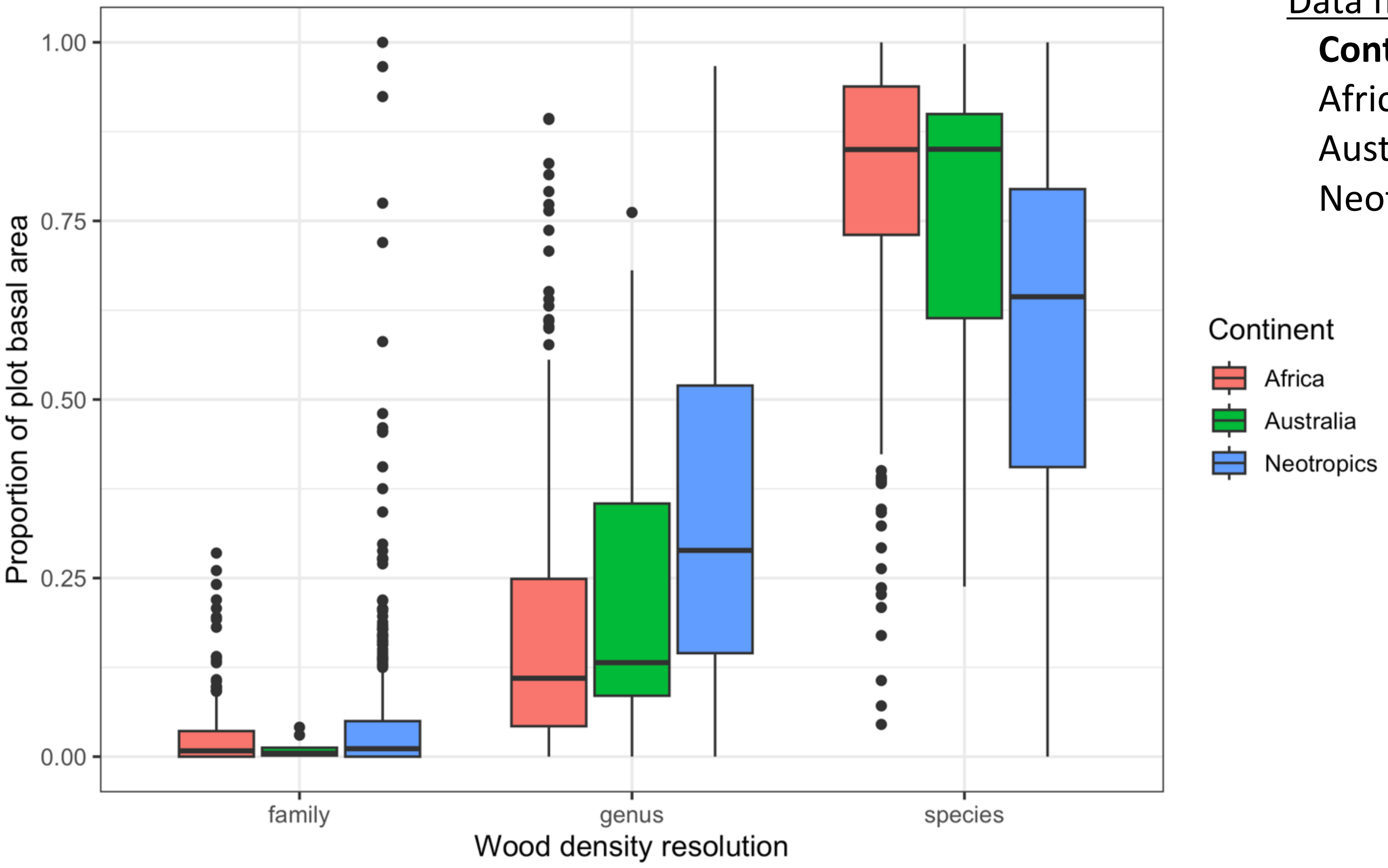
H = Stem height

ρ = Wood density

E = Environmental Stress



Wood density data availability



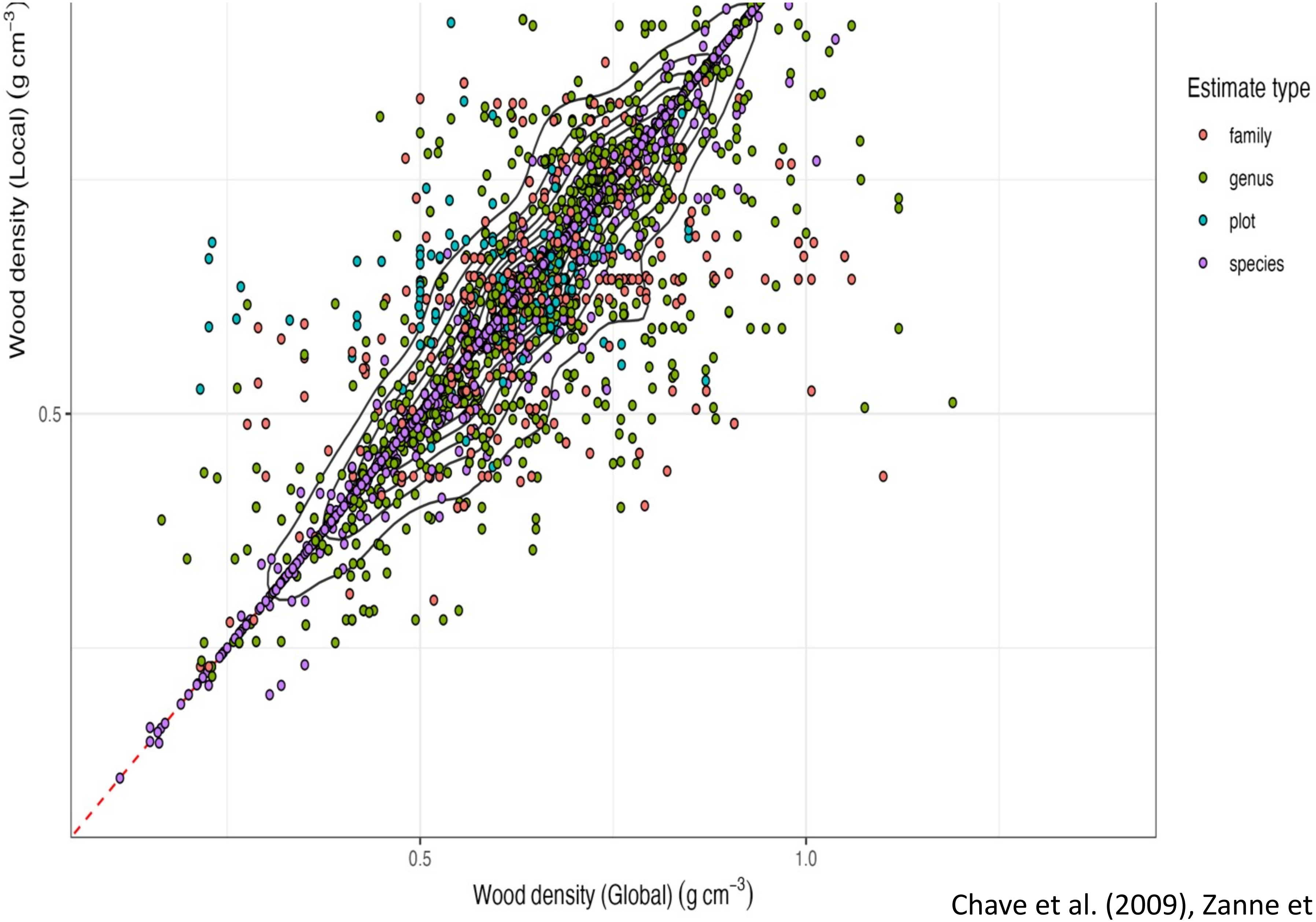
Data from Zanne et al. (2009)

Continent	N samples
Africa	3077
Australia	2238
Neotropics	5355

Mostly wet tropics

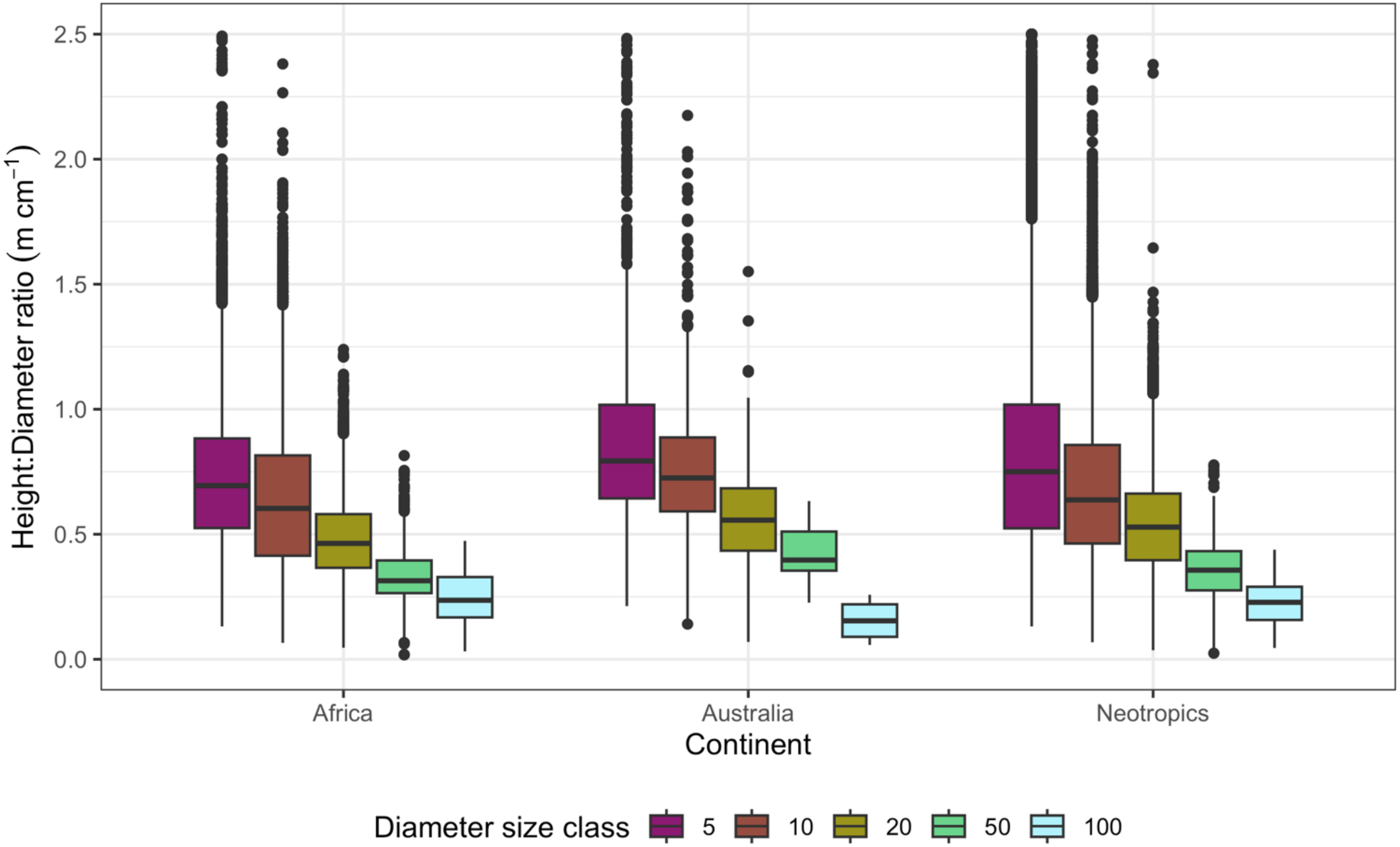
Chave et al. (2009), Zanne et al. (2009), Vieilledent et al. (2018)

Wood density data availability



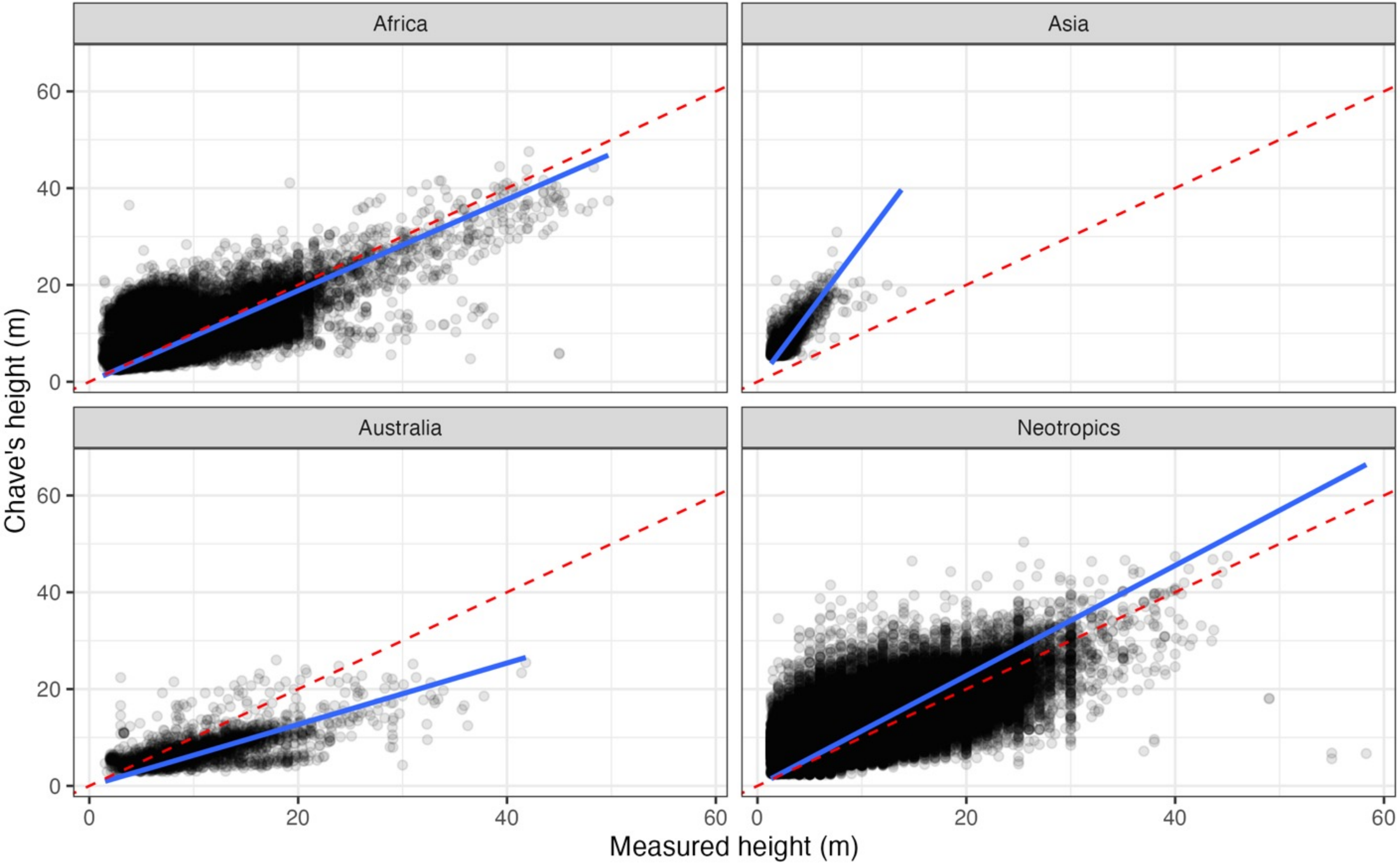
Chave et al. (2009), Zanne et al. (2009), Vieilledent et al. (2018)

Height:diameter relationships vary

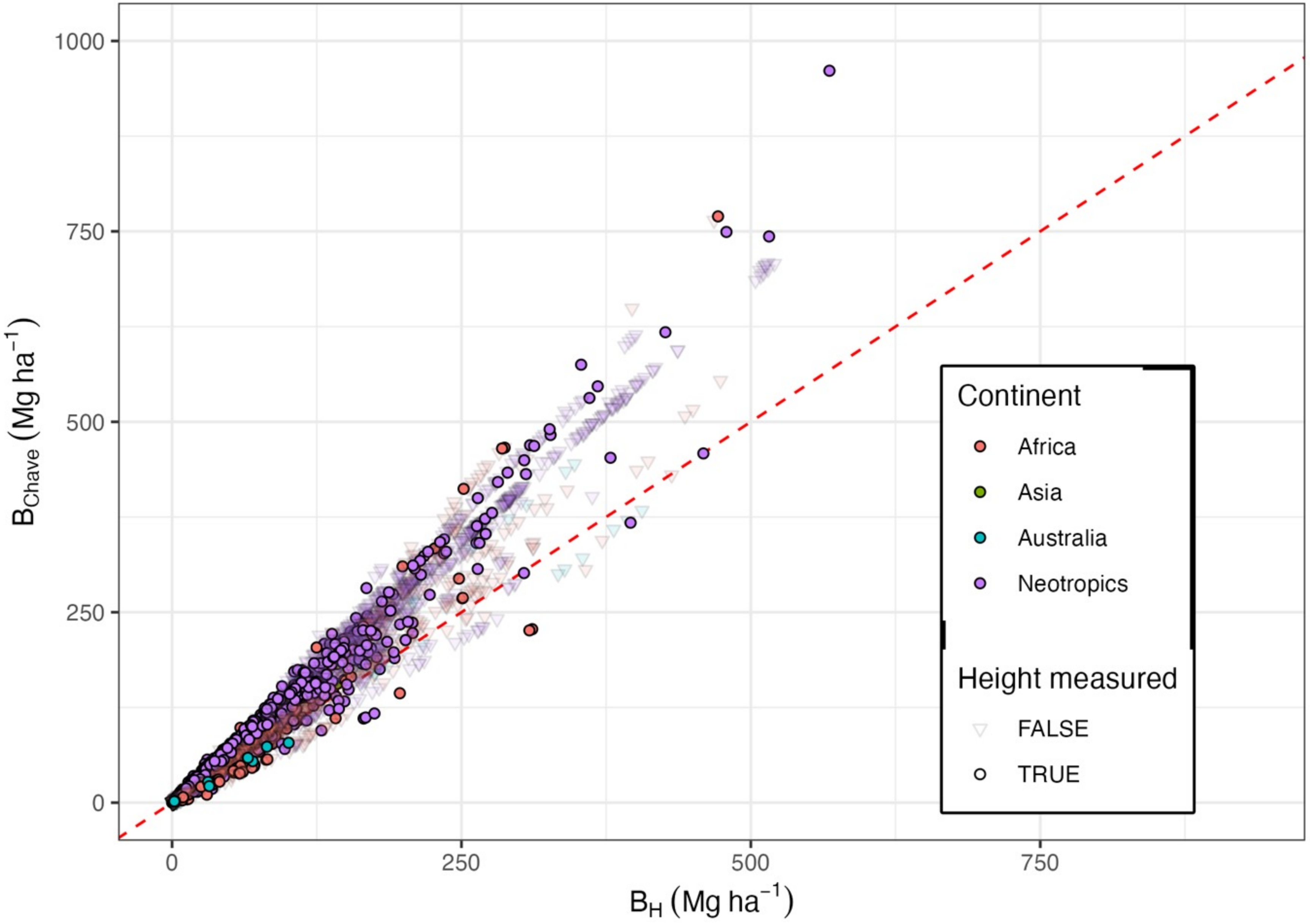


Estimating height: Is Chave's method appropriate?

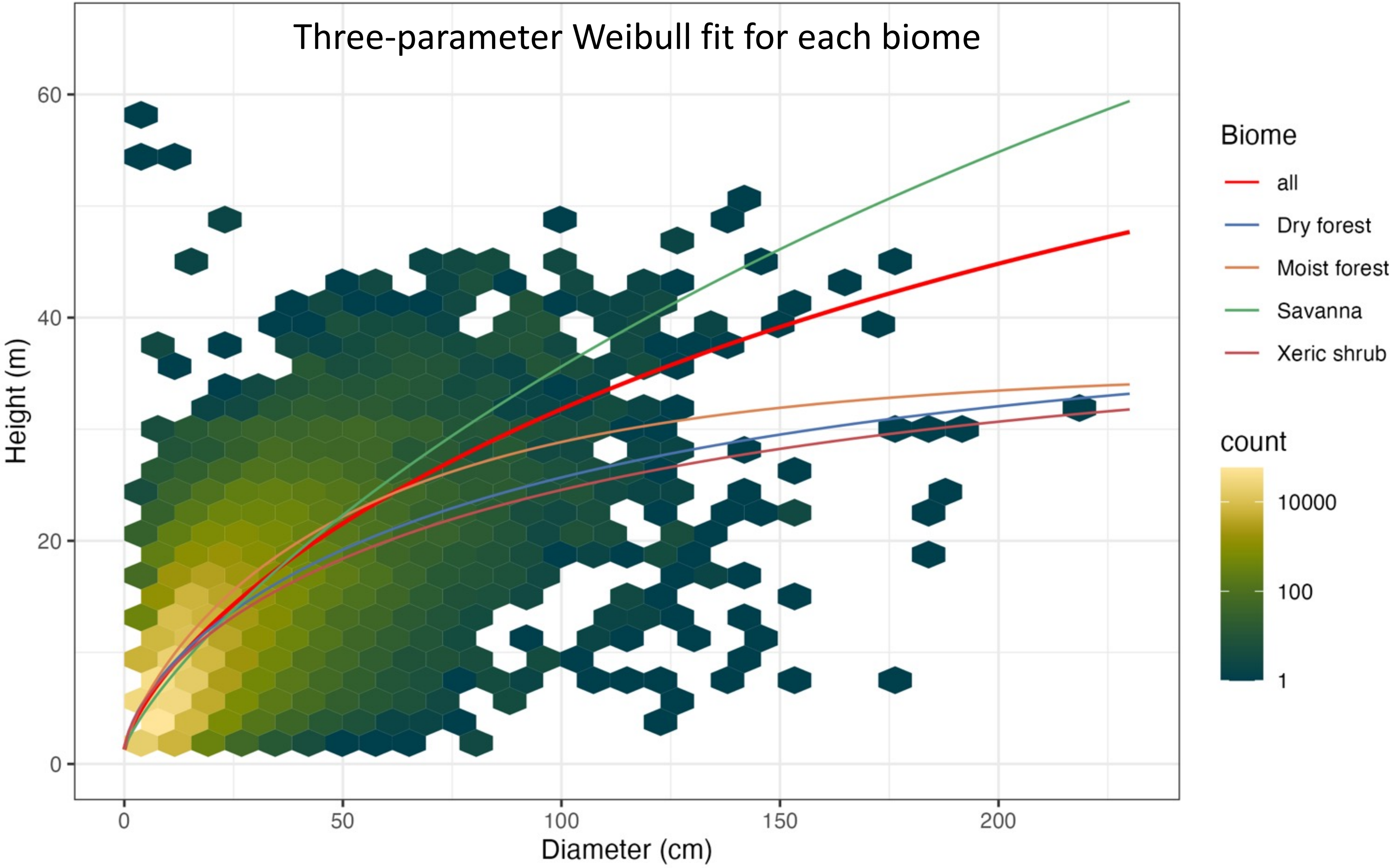
$$\ln(H) = 0.893 - E + 0.760\ln(D) - 0.0340[\ln(D)]^2$$



Estimating height: Is Chave's method appropriate?

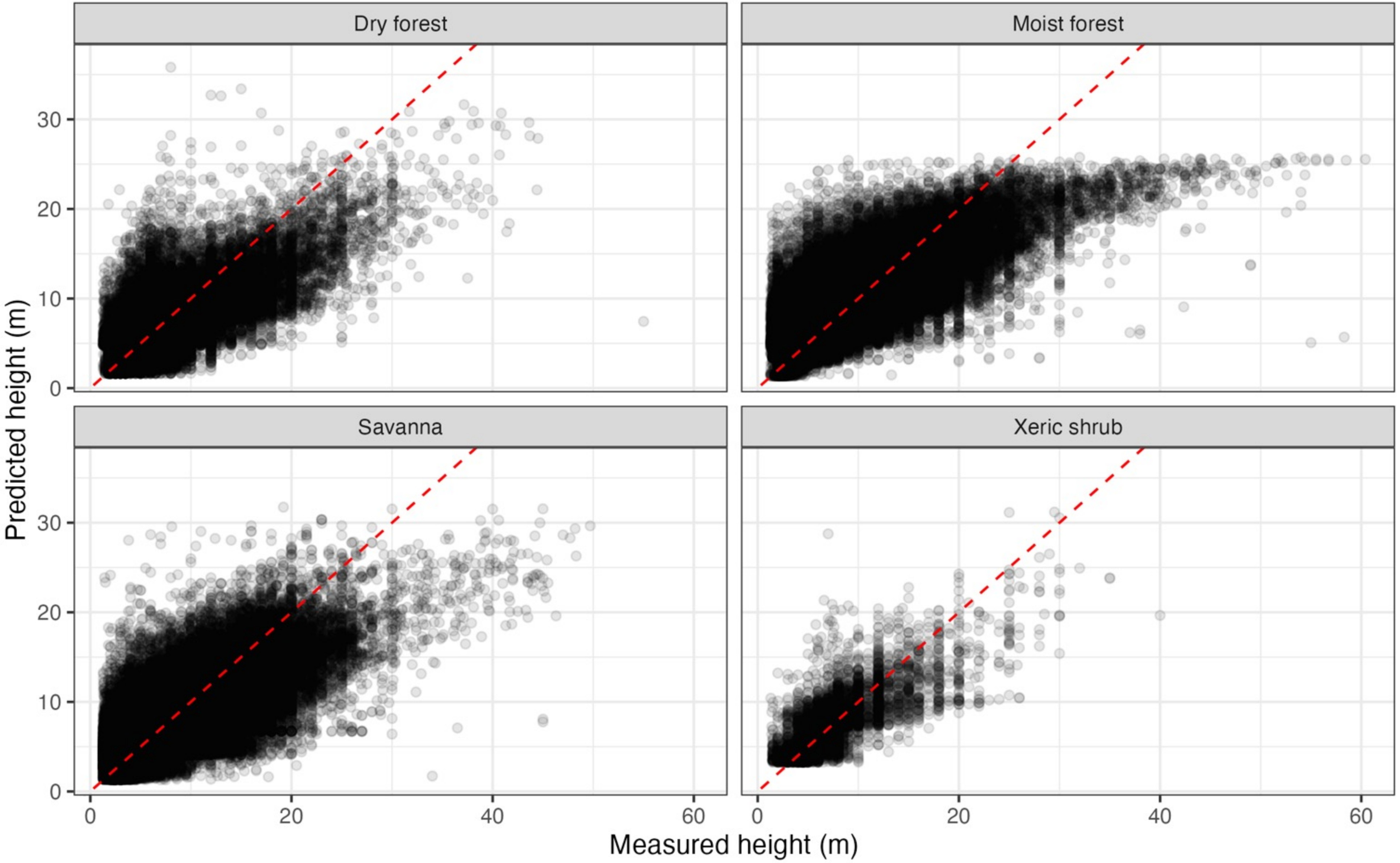


Estimating height: Is Chave's method appropriate?



Feldpausch et al. (2012)

Estimating height: Is Chave's method appropriate?



Carbon dynamics in the dry tropics: next steps

- Explore species- and phylogenetic-specific vital rate responses to environmental change.
- Explore population dynamics using structured population models to predict shifts in vegetation structure.
- Where is biomass increasing and decreasing across the dry tropics?

Summary

- Global environmental change is causing shifts in dry tropics vegetation structure and carbon dynamics.
- Dry tropical vegetation is globally important to the terrestrial carbon cycle.
- In African woodlands, tree species diversity plays a major role in determining biomass and productivity.
- Across the dry tropics, woody biomass responds to disturbance, climate, soil.
- Vital rates (dynamics) are more tricky to explain, but recruitment generally greater than mortality.
- Estimating woody biomass is not straightforward, and methods can introduce bias.

Acknowledgements and contact

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SEOSAW website: https://seosaw.github.io
SECO website: https://blogs.ed.ac.uk/seco-project

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