Tree species diversity and land surface phenology in Zambia

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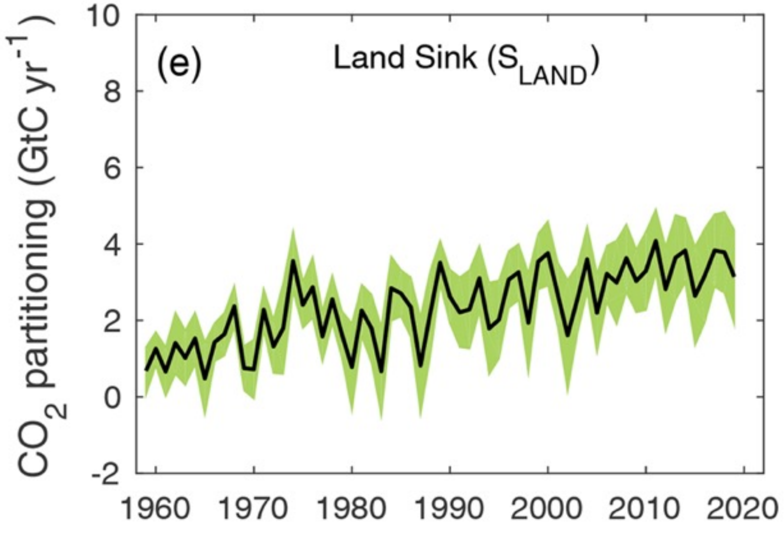
Motivations and approach

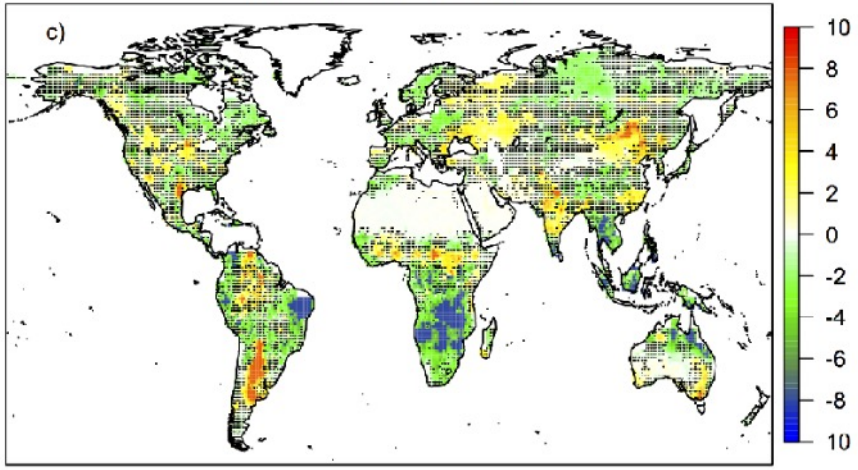
Big questions:

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

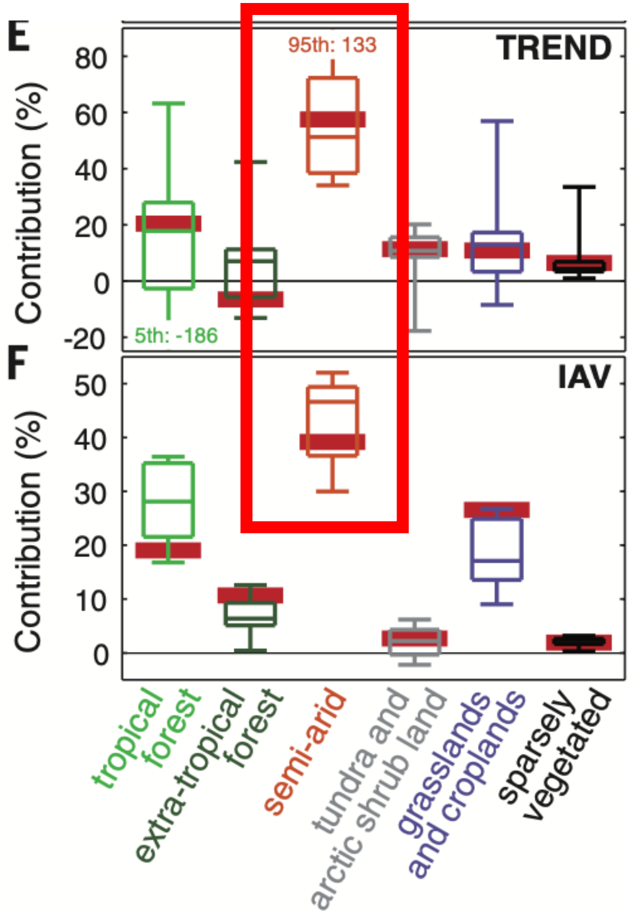
Models: increasing terrestrial carbon sink



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

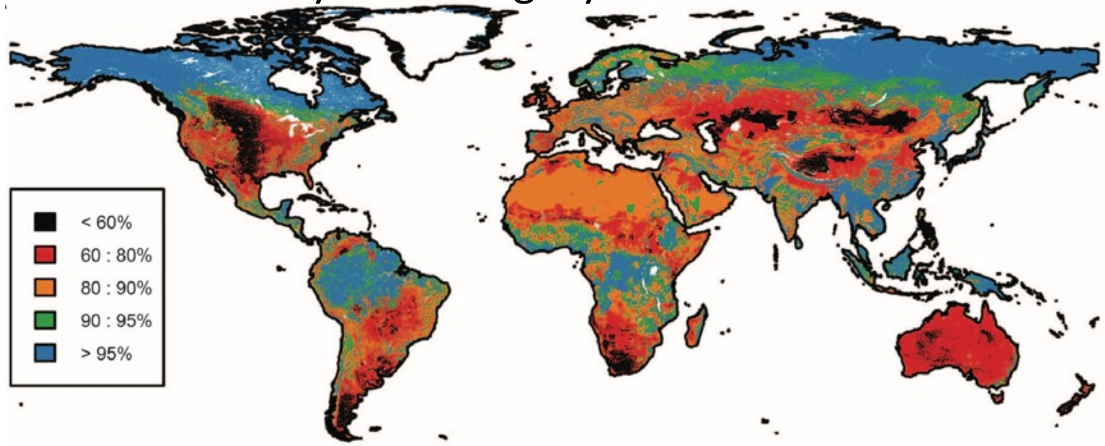
Big questions:

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

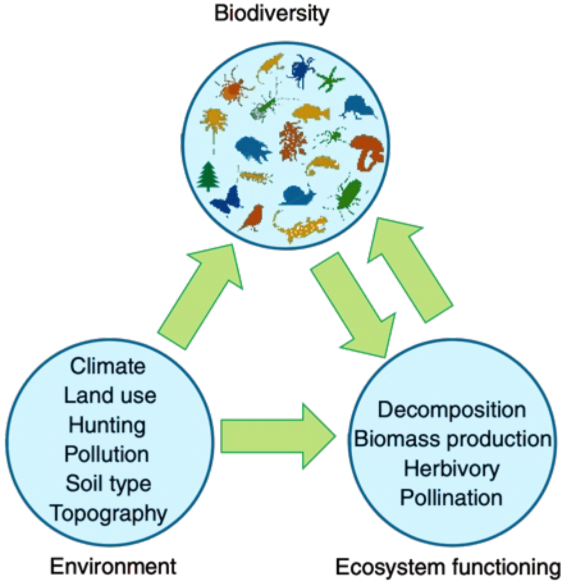
2. How do biodiversity and environment jointly affect ecosystem function?

Ecosystem integrity is under threat

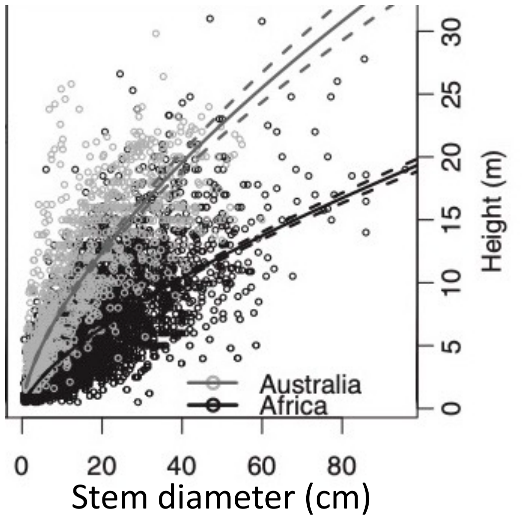
Ecosystem integrity (%)



Complex biodiversity-function feedbacks



Biogeographic mediation of structure and function



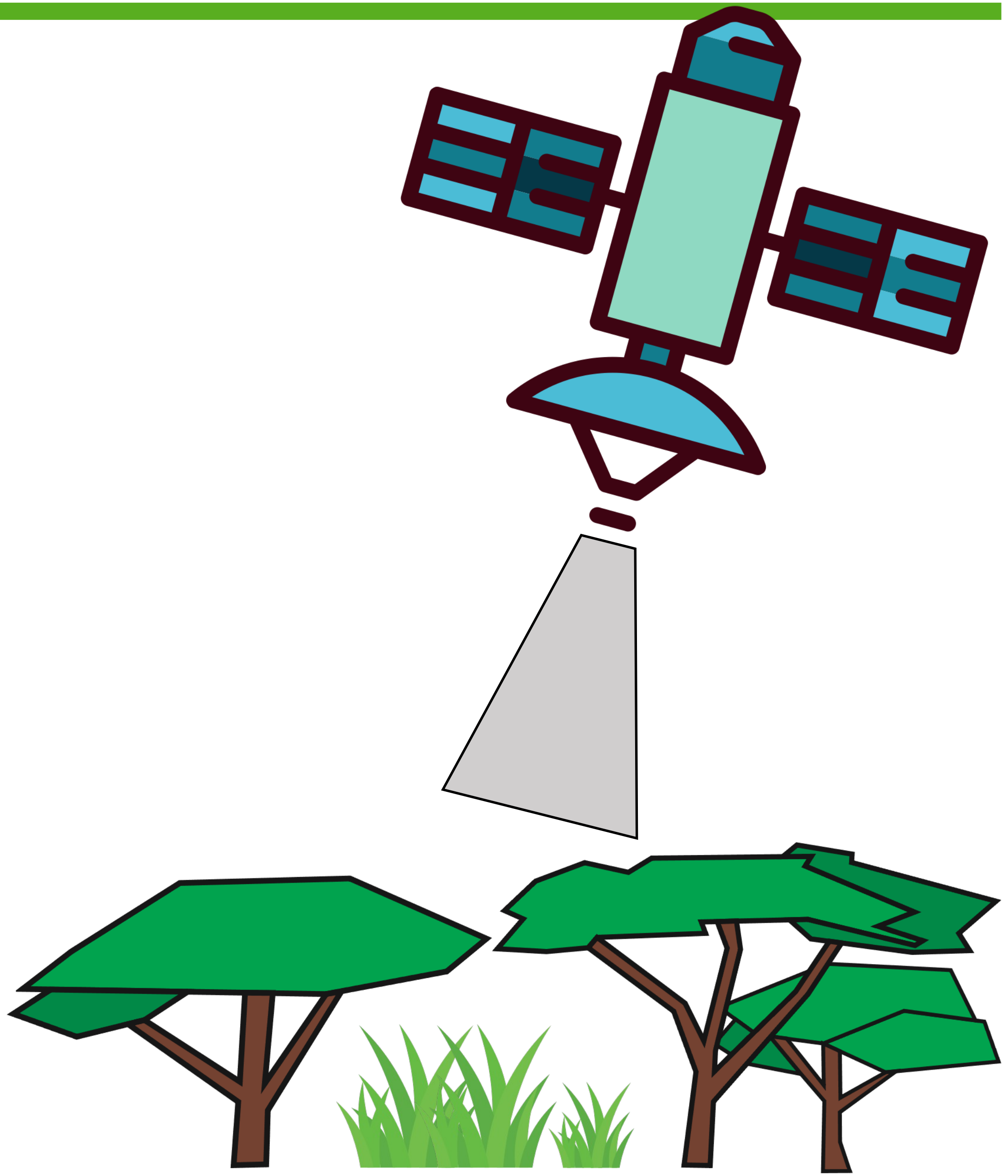
Newbold et al. (2016), van der Plas (2019), Moncreiff et al. (2014)

Background: Land surface phenology

Foliage – primary interface between vegetation, the atmosphere, and incoming solar radiation.

Leaf phenology – seasonal cycles of foliage display. Regulates carbon, water and energy fluxes.

Land surface phenology – remotely-sensed ecosystem-level phenological behaviour, normally measured from satellites.



Previous studies: **environmental drivers** of land surface phenology, e.g. photoperiod, precipitation, temperature (Adole et al. 2019, Guan et al. 2014, Ryan et al. 2017).

Background: Pre-rain green-up

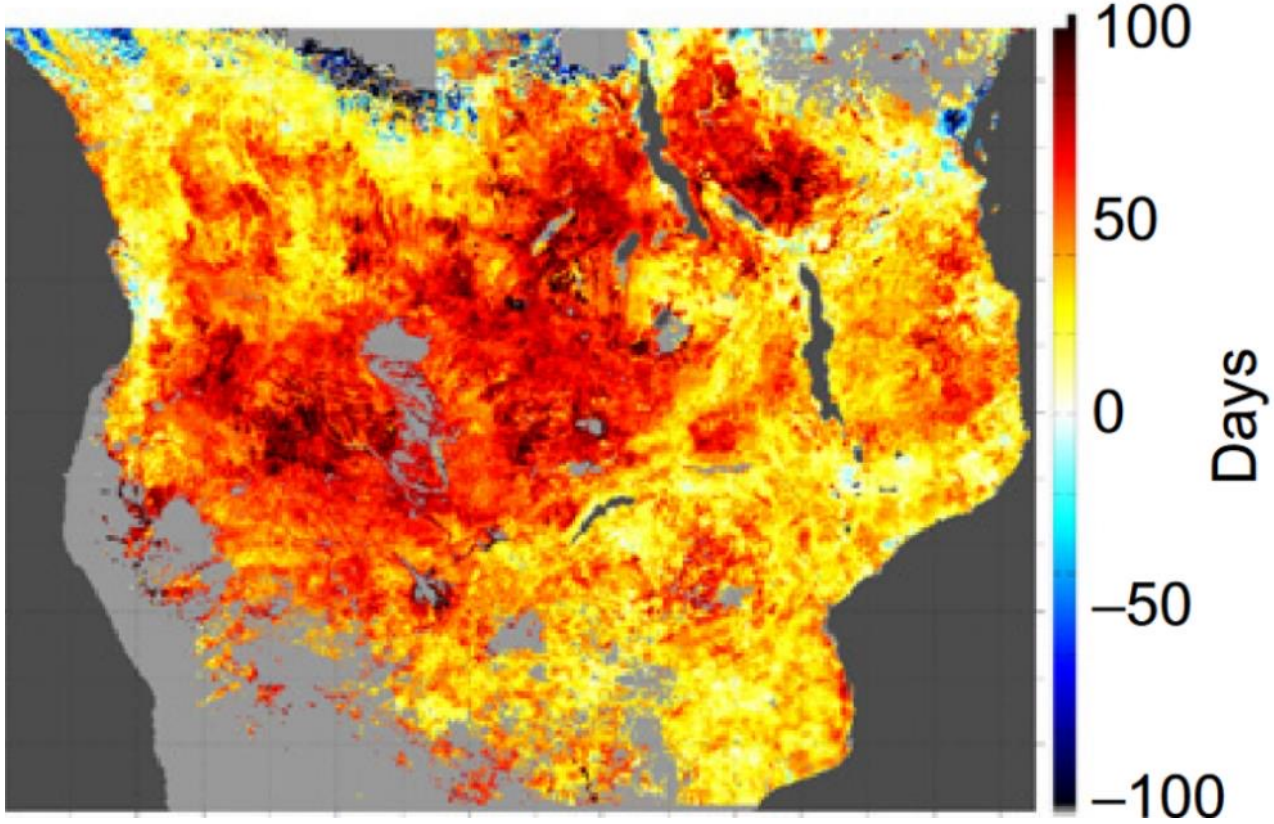
Across southern African woodlands, many trees produce foliage in advance of seasonal rains (Ryan et al. 2017).

Pre-rain green-up is high risk, requires heavy investment in hydraulic architecture, but may provide competitive benefits.

Ground observations show **Detarioideae** species (subfamily of Fabaceae, e.g. *Julbernardia*, *Brachystegia*) commonly do pre-rain green-up.

Species vary in their phenological behaviour.

Extent of pre-rain green-up across southern Africa



(Ryan et al. 2017)

Questions and predictions

Q: What are the biotic controls on land surface phenology in tropical seasonally dry deciduous woodlands?

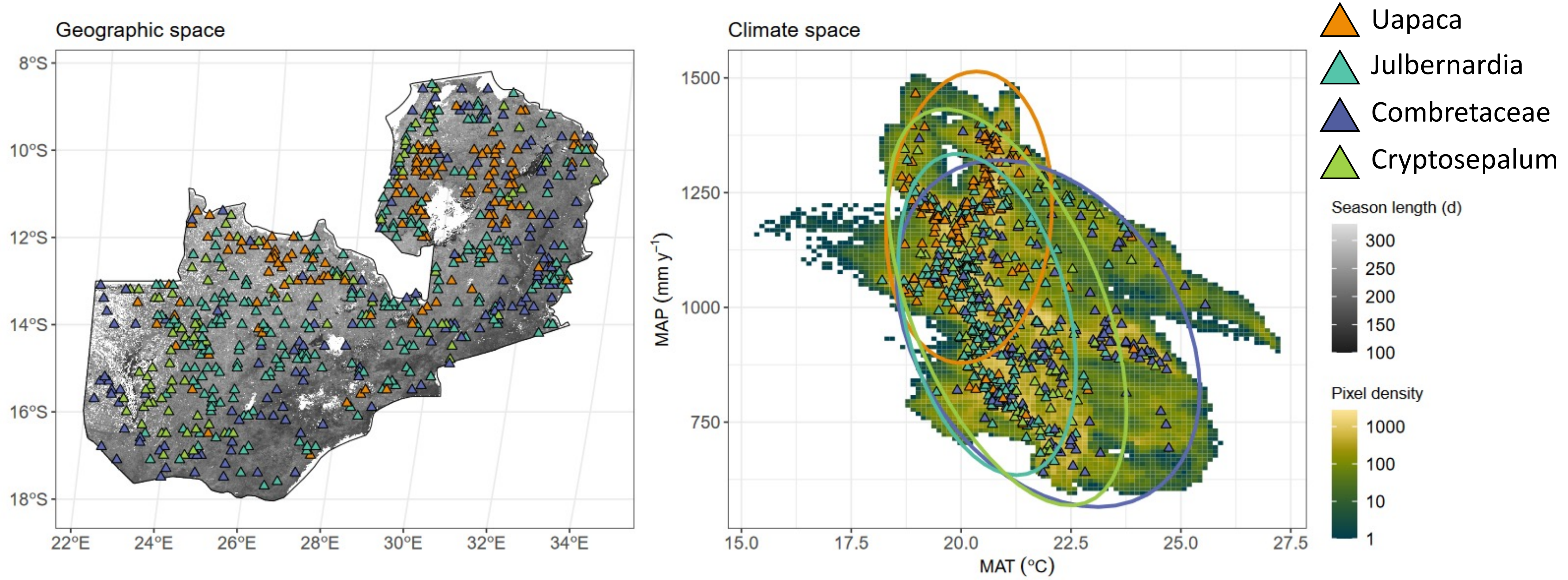
H_1: **Species diversity** will **promote longer growing seasons** through niche complementarity.

H_2: **Detarioideae abundance**, slow growing with robust leaves, dense wood, and deep roots, will be associated with **earlier pre-rain green-up.**

H_3: **Stands with larger trees** will **green-up earlier** with respect to seasonal rainfall.

Zambian Integrated Land Use Assessment II

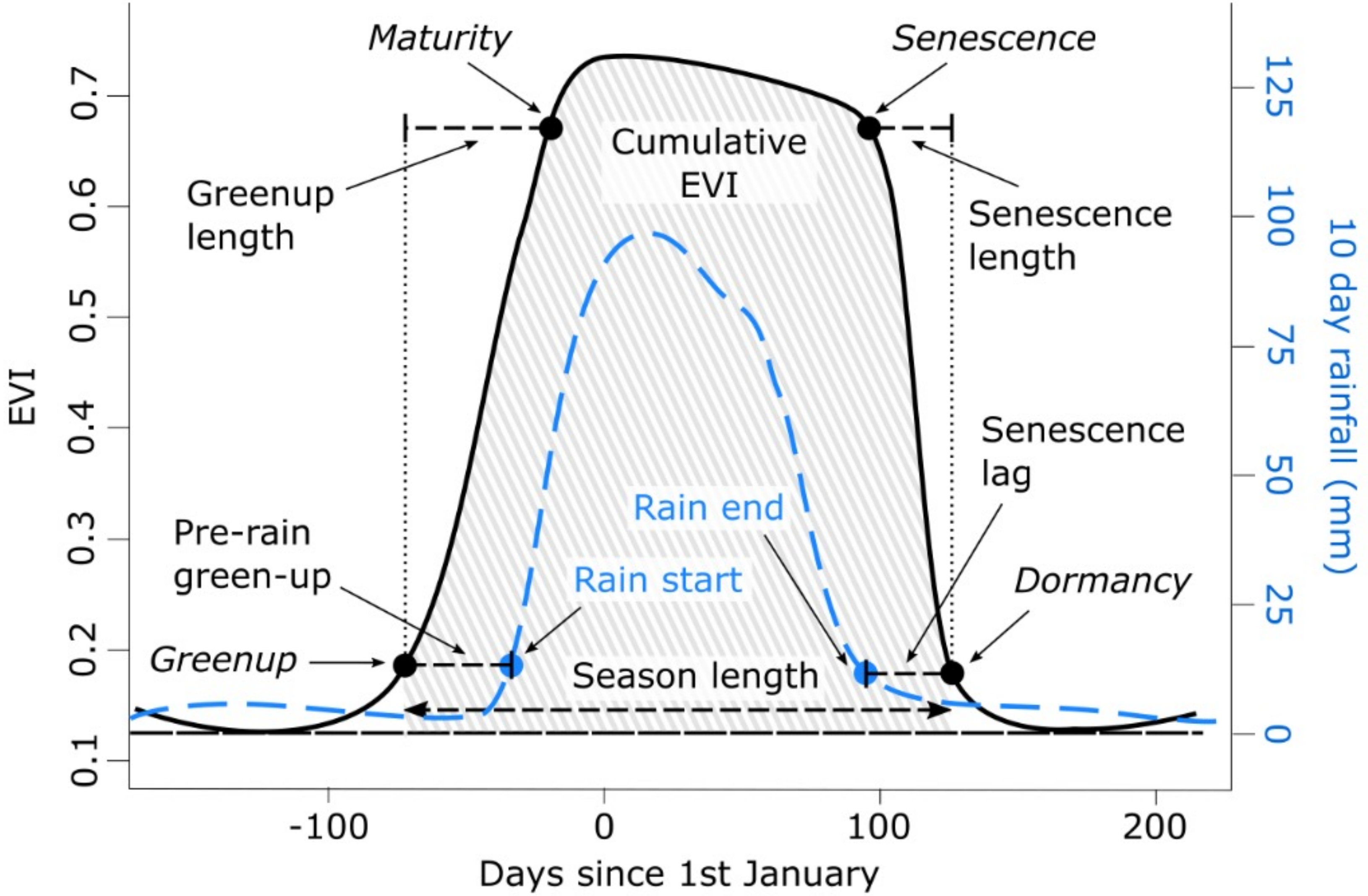
- 619 clusters of four 20x50 m vegetation plots
- Tree species composition, stem diameter (>10 cm DBH)
- Collected in 2014



Mukosha & Siampale 2009; Fayolle et al. 2014

Phenological metrics – MODIS + GPM

- Hydrological year bounded by 14 day period with lowest rainfall per year.
- Rainy season onset: first 10+20 days with >20+20 mm total rainfall.
- Rainy season end: first period with <4 days per 30 days with >0.5 mm rainfall.
- Phenological metrics from MODIS MCD12Q2 v6.1 (2-band EVI), from 2001-2019
- Pre-rain green-up: days between rainy season onset and green-up onset.



Tadross et al. 2005; February & Higgins 2006, Friedl et al. 2022

Linear mixed effects models

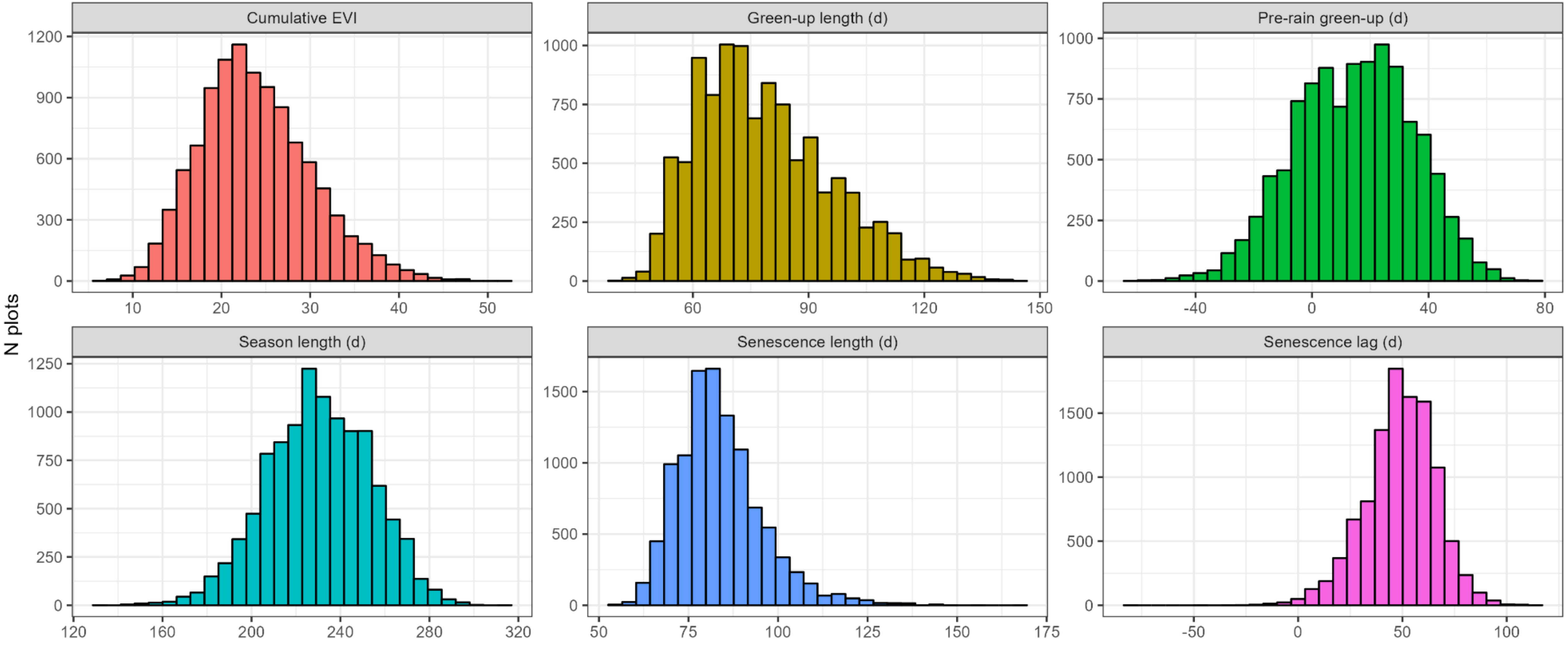
Phenological metric response		Biotic predictors	Abiotic predictors
Cumulative EVI			
Season length		Shannon diversity index [H’] +	<u>Temperature [degree days]</u> +
Green-up length	~	Quadratic mean stem diameter +	<u>Cumulative rainfall</u> +
Pre-rain green-up		Detarioid abundance +	(1|site)
Senescence length			
Senescence lag			

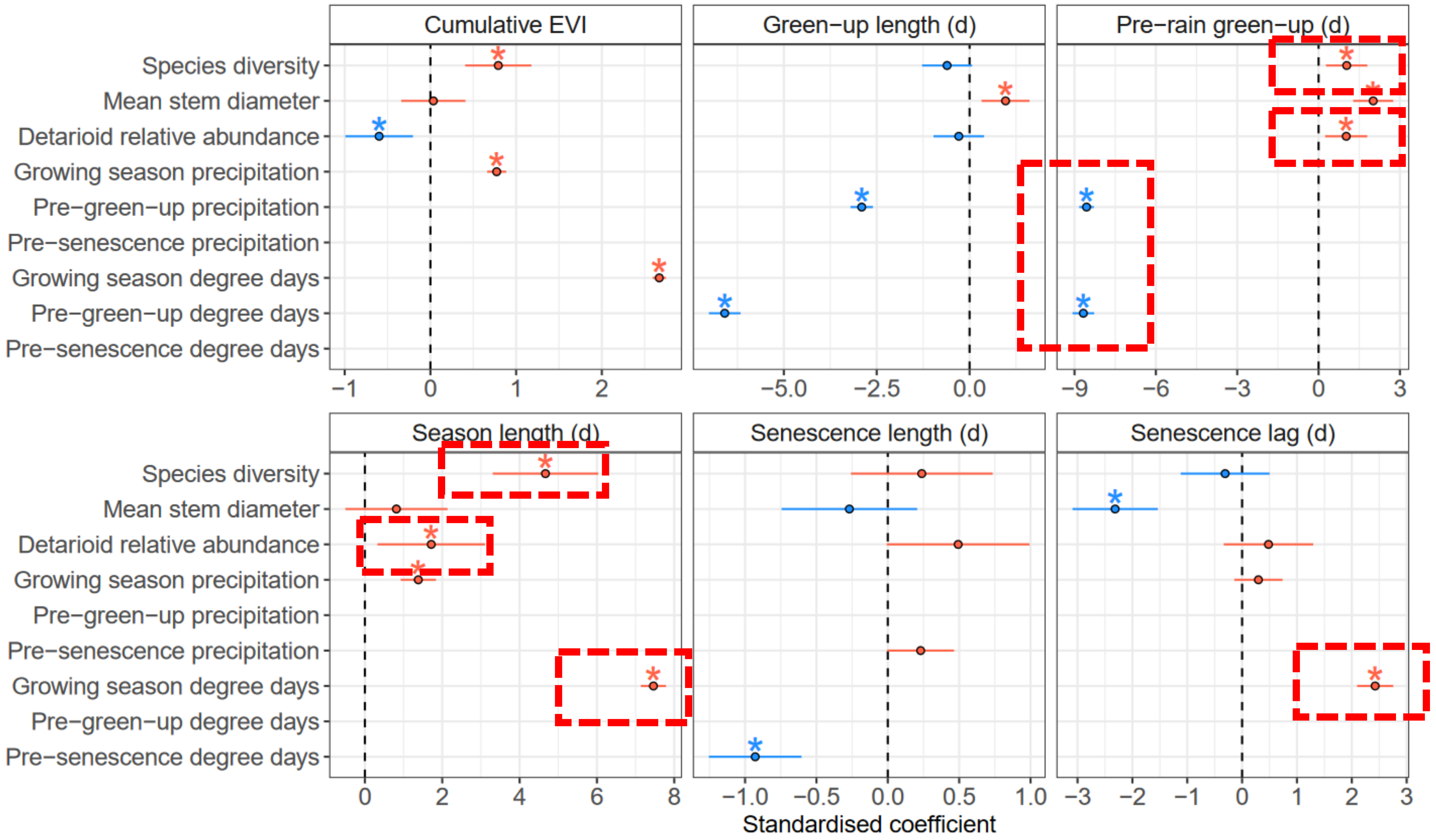
Phenological metrics - per year, per site

498/619 plots exhibit pre-rain green-up.

Season length is highly variable (133-315 days).

Senescence date highly variable across sites. On average, senescence occurs after seasonal rains decline.





Cumulative EVI
Green−up length (d)
Pre−rain green−up (d)
Species diversity
Mean stem diameter
Detarioid relative abundance
Growing season precipitation
Pre−green−up precipitation
Pre−senescence precipitation
Growing season degree days
Pre−green−up degree days
Pre−senescence degree days
−1
0
1
2
−5.0
−2.5
0.0
−9
−6
−3
0
3
Season length (d)
Senescence length (d)
Senescence lag (d)
0
2
4
6
8
−1.0
−0.5
0.0
0.5
1.0
−3
−2
−1
0
1
2
3
Standardised coefficient

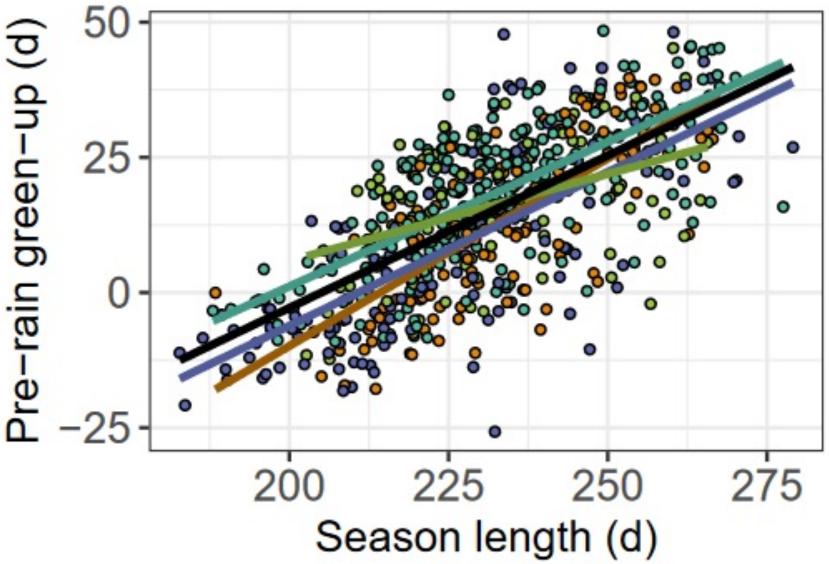
Senescence metrics are poorly explained

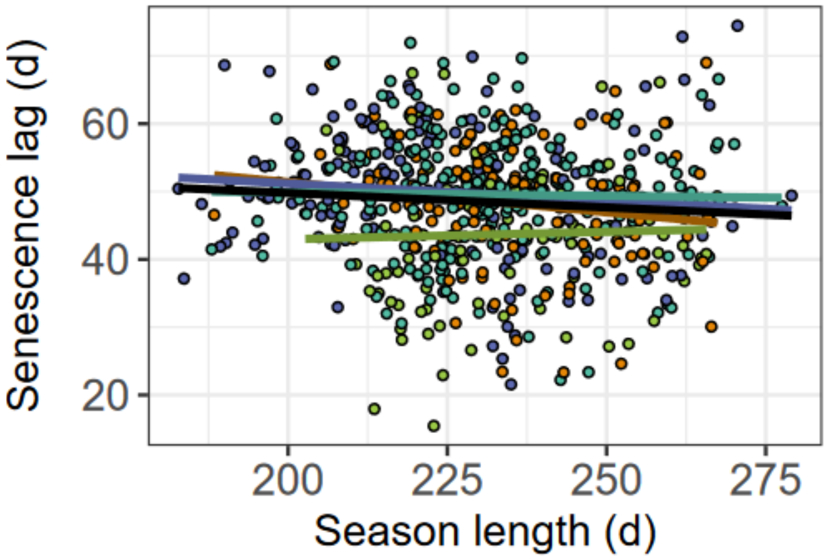
Variation among sites, but explanatory power of models is poor ($R^2c = 0.3$)

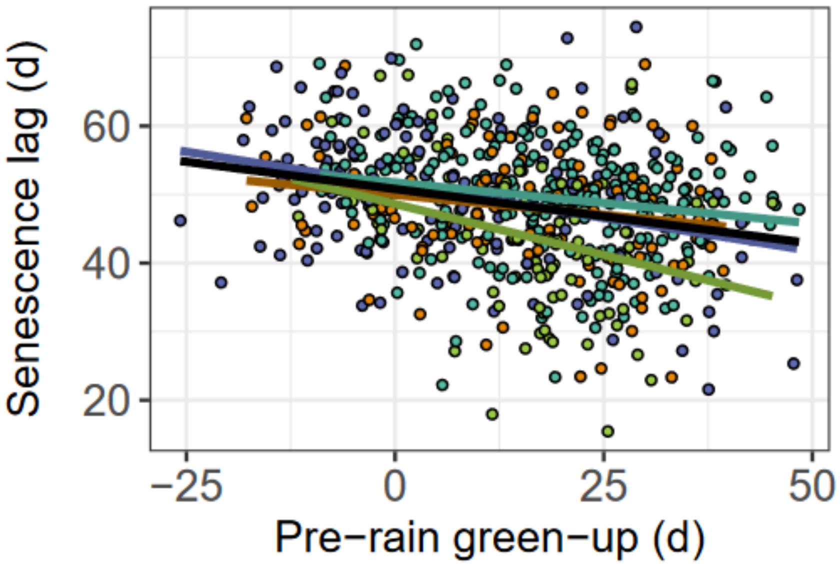
Senescence driven by grass, short-term oscillations in green-ness?

Plots with larger trees keep leaves later.

Hotter days associated with earlier leaf drop.







Implications

Niche complementarity effect (i.e. true diversity effect) – species diversity lengthens growing seasons.

Keystone species effect (i.e. mass-ratio effect) – Detarioideae abundance associated with longer growing seasons and earlier pre-rain green-up, separate from tree size and species diversity effect.

Will risky pre-rain green-up behaviour lead to **decline of pre-rain green-up species** under climate change?

Biodiversity loss could reduce productivity and ecosystem resilience.

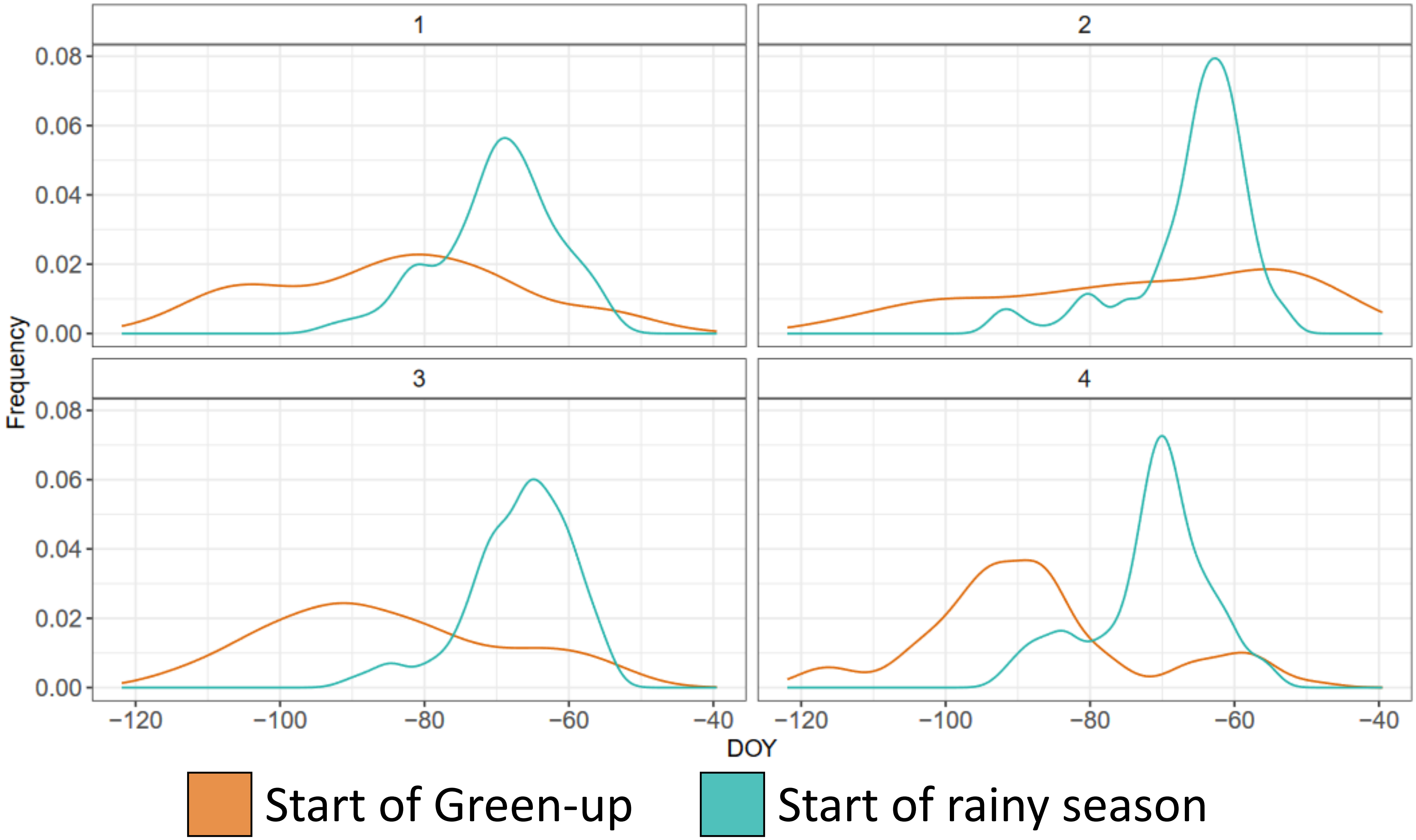
Wrapping up: future work

At the individual-scale, how does tree size, species identity and **evolutionary history** affect patterns of foliage display?

Land surface phenology mixes the tree and grass canopy signal. **How do the phenological signals of trees and grasses differ?**

See **PhenoChange project** (Kyle Dexter, Patricia Morellato et al.). Using repeat photography from camera traps to characterize individual tree and grass leaf phenology across southern Africa and Brazil.

EXTRA: Temporal variation in rainy season and phenology



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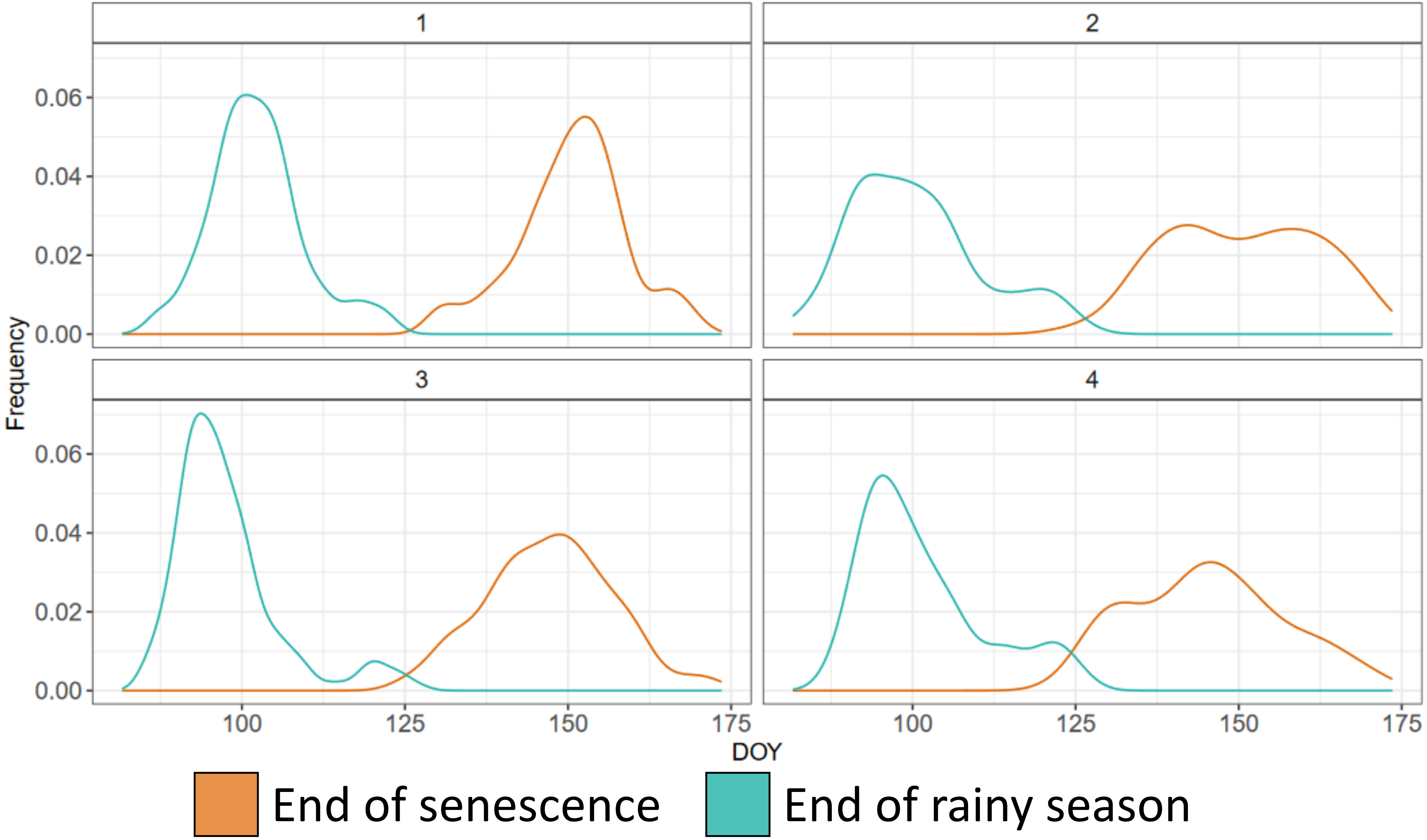
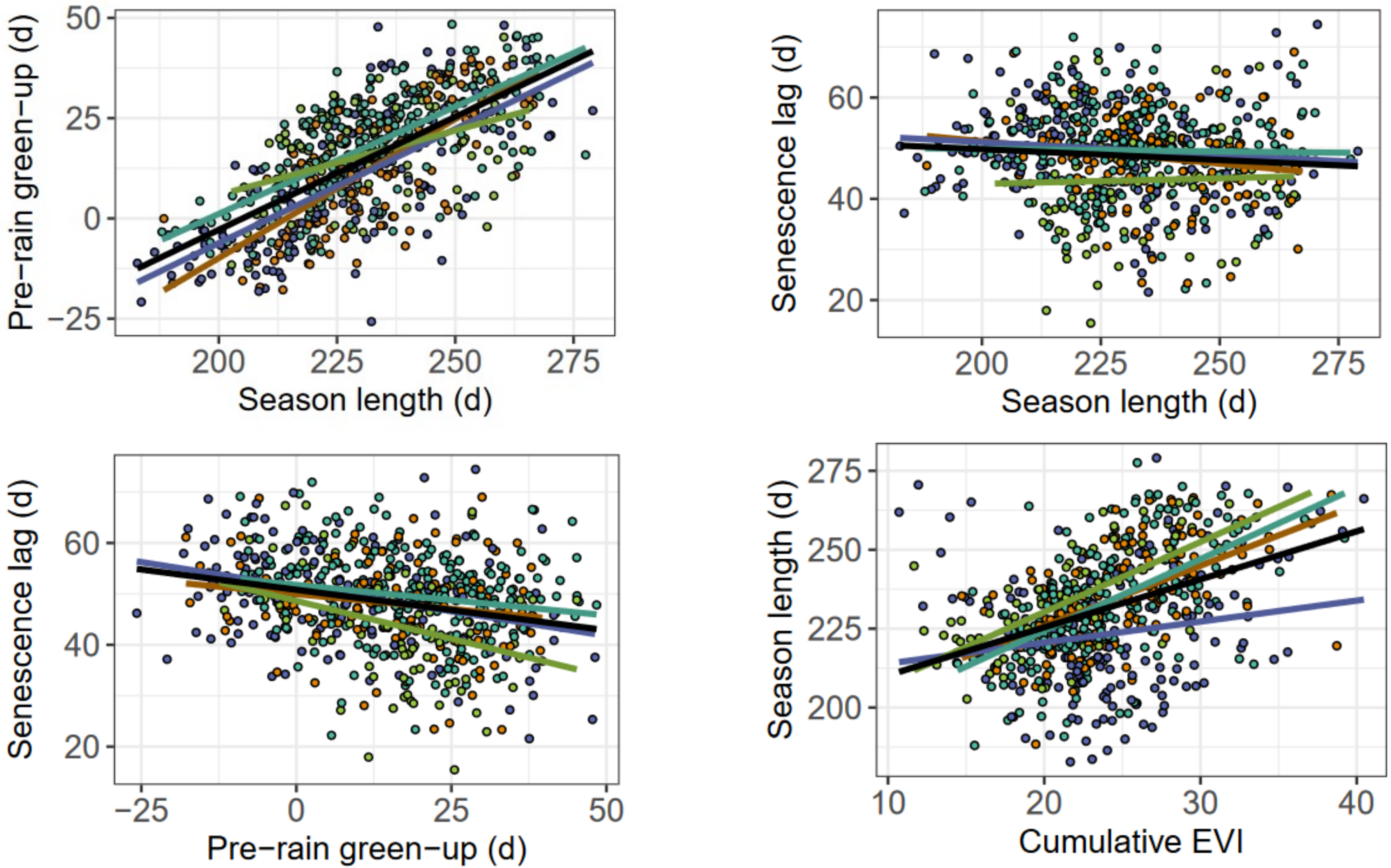


EXTRA: Pairwise comparisons of phenological metrics



EXTRA: Vegetation type indicator species

Vegetation type	N sites	Richness	Indicator species	Indicator value
Uapaca miombo	135	17(7)	*Brachystegia longifolia*	0.393
			Uapaca kirkiana	0.384
			Marquesia macroura	0.278
Combretaceae woodland	144	14(5)	*Combretum molle*	0.258
			Lannea discolor	0.229
			Combretum zeyheri	0.212
Julbernardia miombo	244	17(6)	*Julbernardia paniculata*	0.556
			Brachystegia boehmii	0.540
			Pseudolachnostylis maprouneifolia	0.227
Cryptosepalum miombo	96	14(6)	*Brachystegia spiciformis*	0.582
			Cryptosepalum exfoliatum	0.285
			Guibourtia coleosperma	0.282