Understanding climate change impacts on tropical forests across scales

Patrick Meir, ACL da Costa, Lion Martius, Kristian Bodolai, Rachel Selman, Vanessa Rodrigues, Pablo Sanchez-Martinez

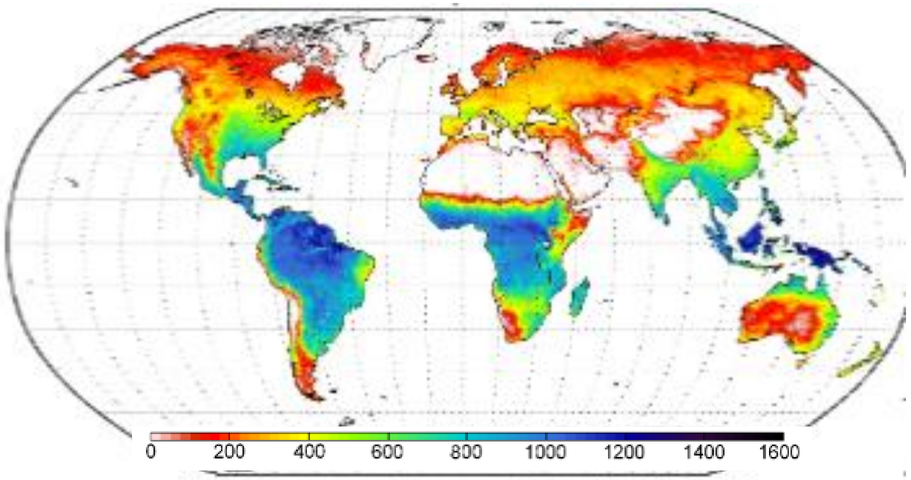
MUSEU GOELDI

Space Intelligence

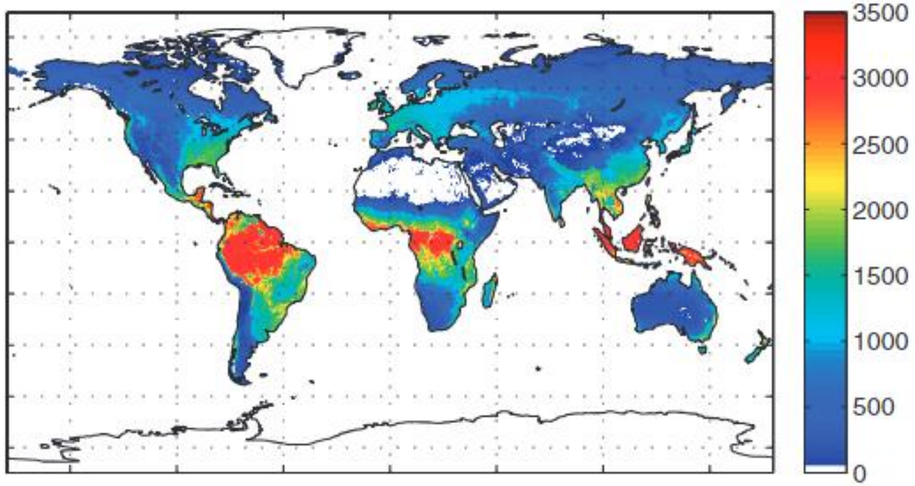
THE UNIVERSITY of EDINBURGH

Global carbon and water cycles

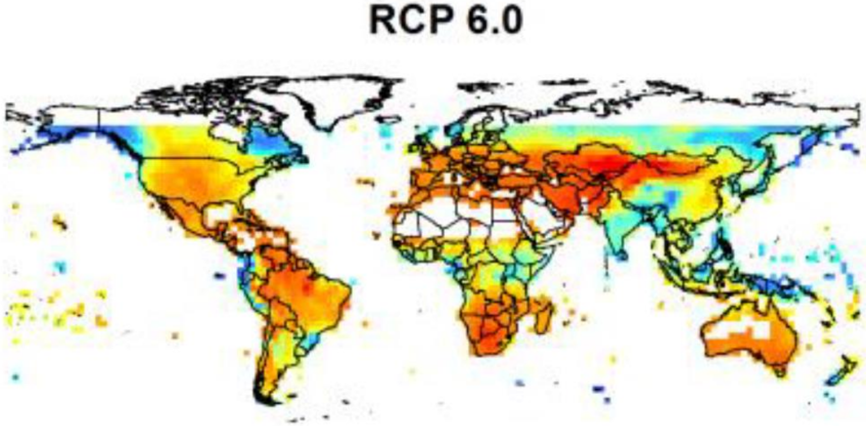
Transpiration (mm yr^{-1})



Gross primary productivity (gC m^{-2} yr^{-1})



Drought index (SPEI)



Miralles et al (2011) Hydrol. Earth Syst. Sci.

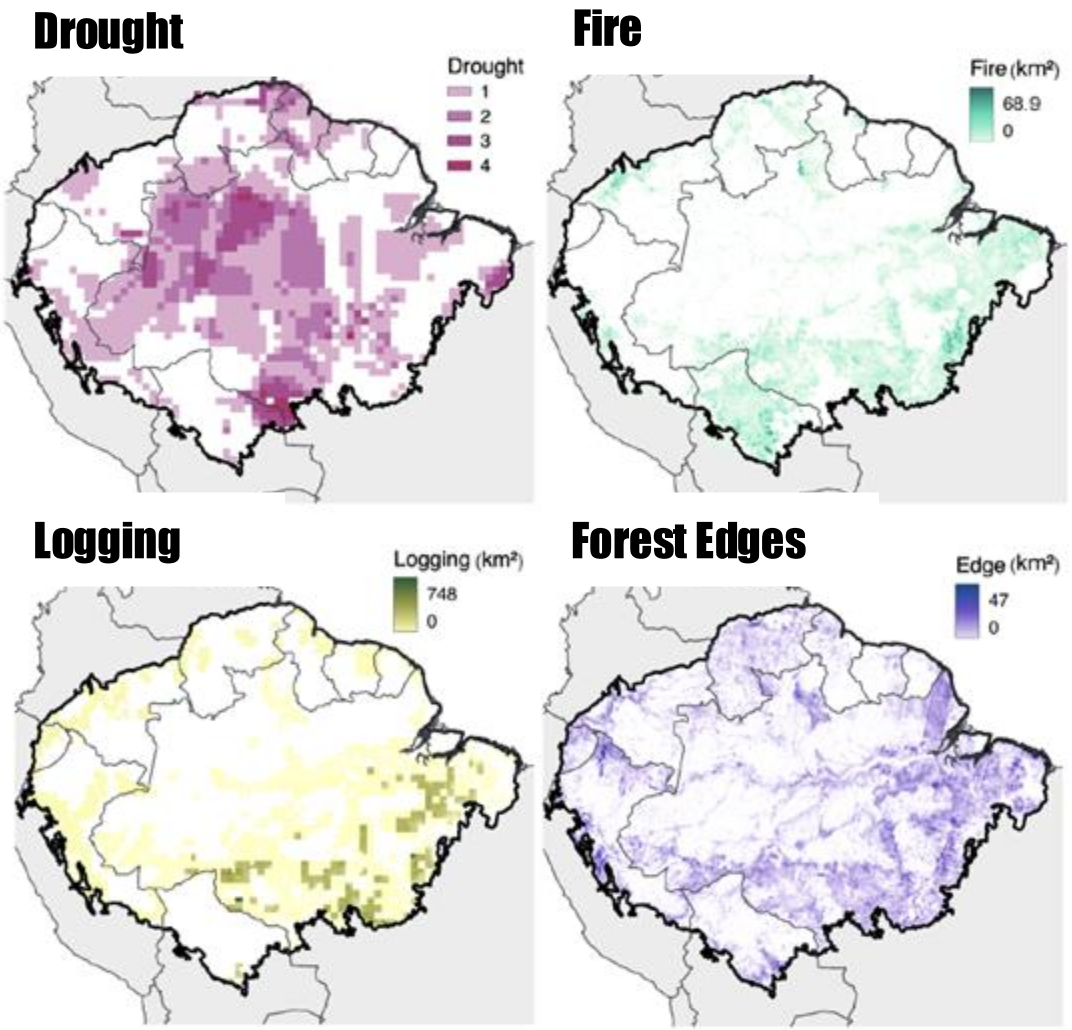
Beer et al (2010) Science

Vicente Serrano 2019, Earth Sci Rev

Why is the Amazon important?
Climate, carbon, diversity, economy

- Vast area: 23 x size of UK
- 25% global land biomass & land carbon sink
- 15% global freshwater flux to oceans
- 10-15% global biodiversity
- Home to millions, ethnic & biocultural diversity
- Transports 33% of water to S. America's grain belt
- Forest loss >$250billion
- Potential model for elsewhere

Change



Increasing pressures with future warming, drying and disturbance

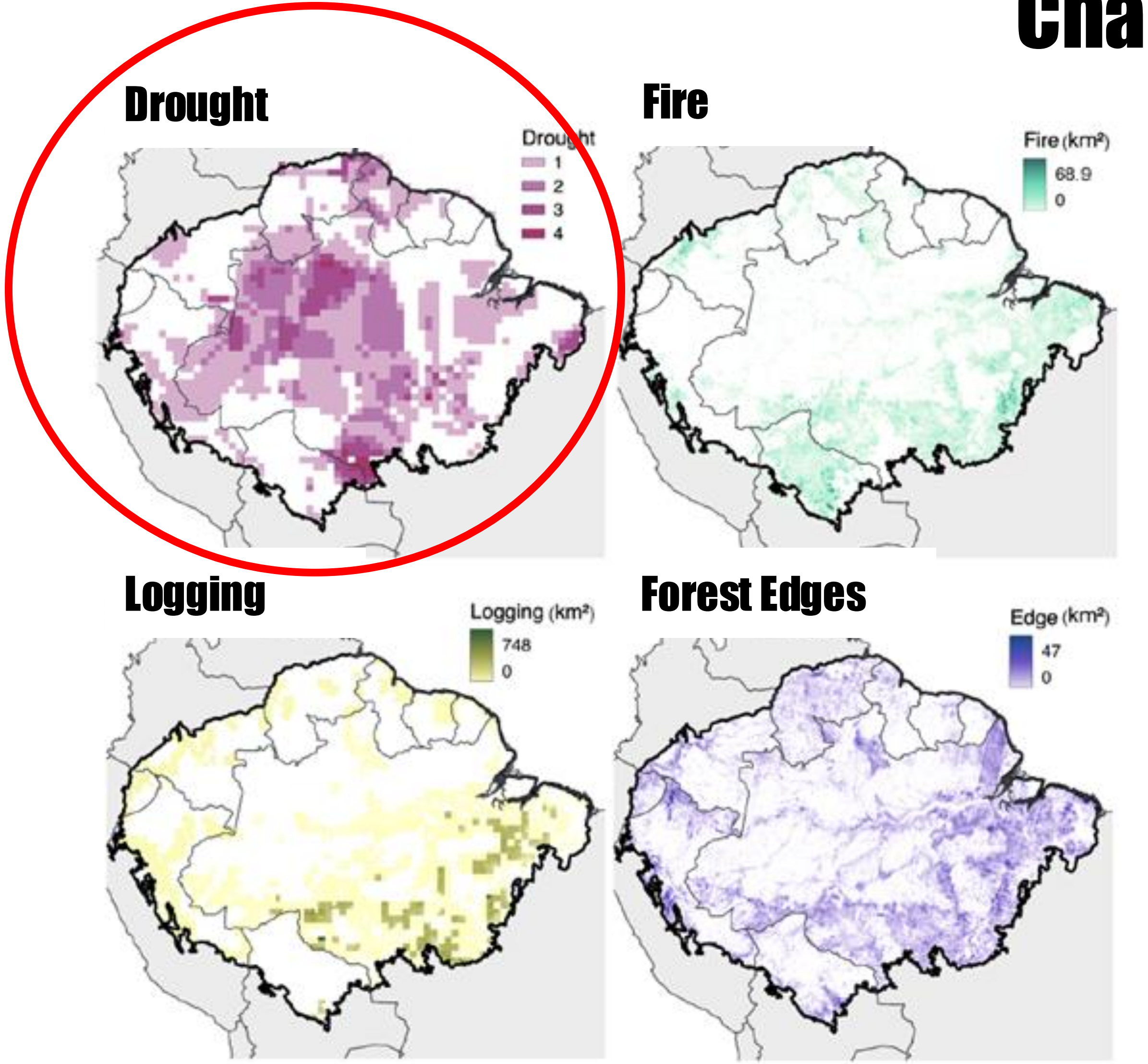
20% Deforestation of Brazilian Amazon

38% of remaining forests are degraded

<u>Combined</u> impact of climate change & disturbance?

Lapola incl. Amazon-SOS team, *Science*, 2023
Flores et al. 2024 Nature
Brando et al. 2025 Ann Rev Ecol Syst

Change



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Forest – climate interactions: Drought

1998, 2005, 2010, 2015/16, 2023/24

⇨ Increasing frequency; predicted further increase with warming, land use

Forest function? (reduced tree growth, increased mortality)

Carbon? Water? Species?

Land surface model prediction limited by data.

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ESECAFLOR
CAXIUANÃ - PA

Brazil – UK, 25+ yrs

Intl collaboration
EU, USA, Australia

Plot networks
Large scale

AFEX

AMAZONFACE

Seca Limite

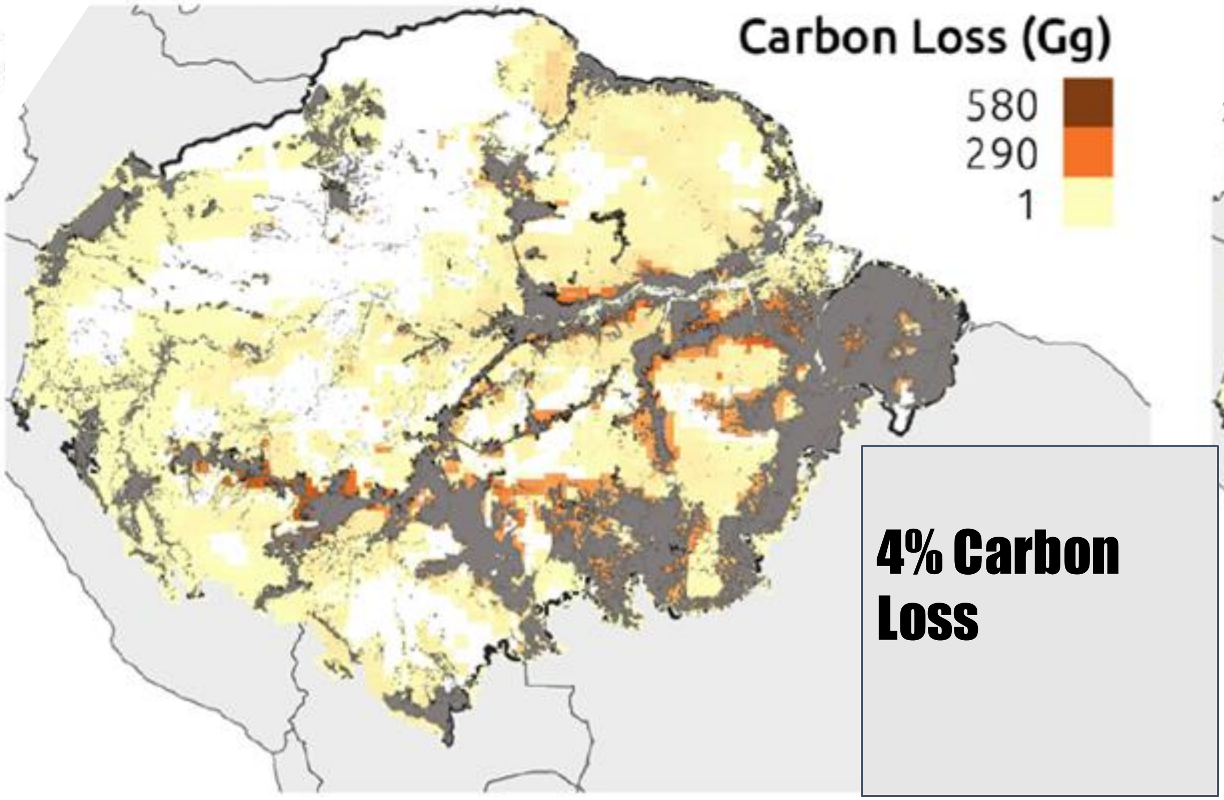
ESECAFLOR
CAXIUANÃ - PA

SWELTR
SOIL WARMING EXPERIMENT
IN LOWLAND TROPICAL RAINFOREST

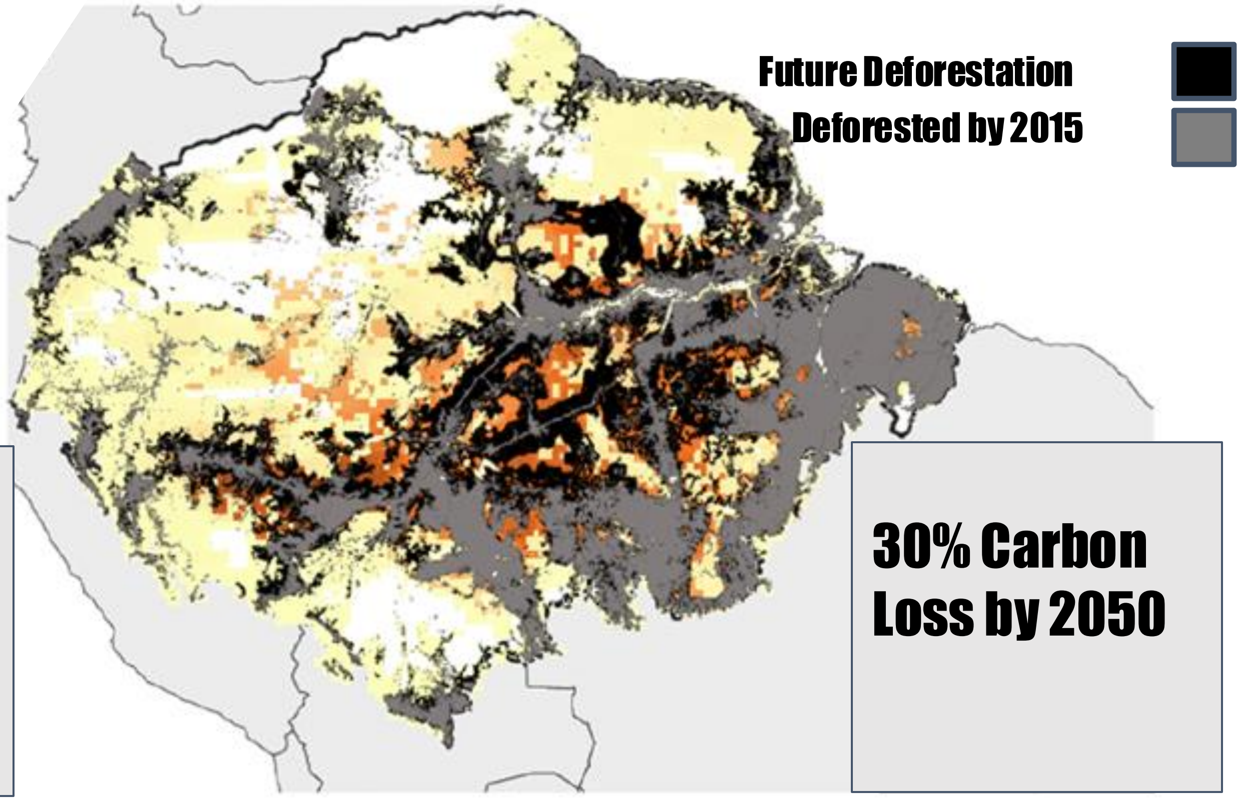
Field experiments
Test process
Change model?

Policy + Discovery Science

<u>Governance (Climate + Deforestation)</u>



<u>No Governance</u>



Is there a combination of pressures that might lead to a so-called 'tipping point', with large scale forest dieback?

Lapola incl. Amazon-SOS team, *Science*, 2023
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Brando et al. 2025 Ann Rev Ecol Syst



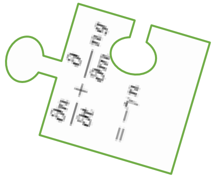

Amazon – SOS

A Safe Operating Space for Amazonian Forests

[NERC Large Grant, 2024-2029]

Lead UK : Exeter (Sitch), Edinburgh (Meir), Lancaster (Barlow), Leeds (Gloor), WCMC (Kapos)
Lead Brazil: USP (Domingues), INPE (Aragão, Aguiar), UNICAMP (Oliveira), UNIMAT (Marimon), EMBRAPA (Ferreira)

Multiple aspects, community effort



✓ Field experiments: mortality/ recovery from drought

✓ Forest plot networks: intact and human-modified forest

✓ Remote-sensing: mortality, drought and fire risk

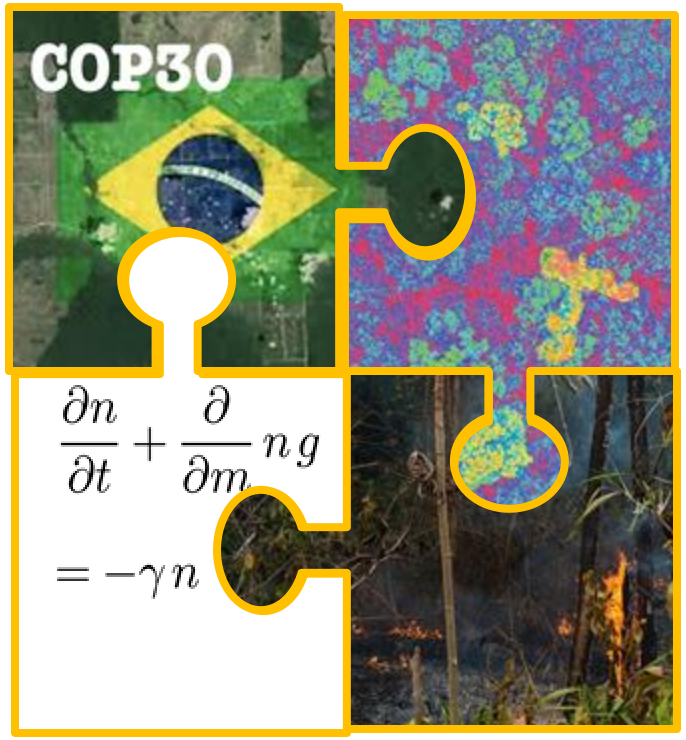
✓ Modelling: climate stress & demography UK Earth system model

✓ Science-policy process to deliver impact, local - international.

Stakeholders integral

Brazil-UK co-leadership

Multiple aspects, community effort



- ✓ Field experiments: mortality/ recovery from drought
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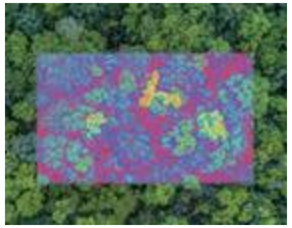
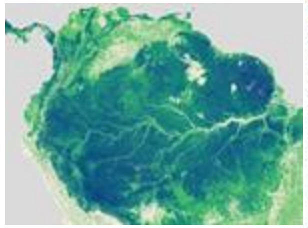
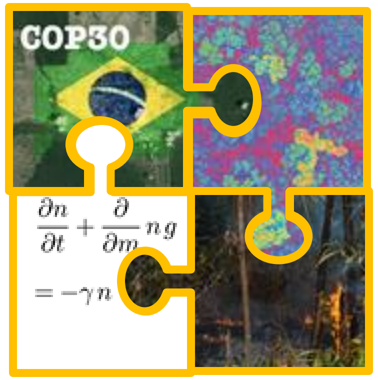




Amazon – SOS



- Risk of collapse or recovery?
- Time scales of forest loss?
- What are the thresholds?
- Policy needs?

New analysis across scales – experiment + region

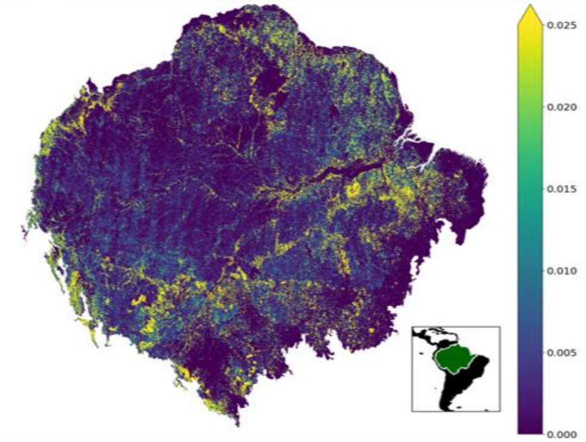
ESECAFLOR
Soil moisture reduction
Growth, mortality, water stress

Scale?
Natural climate?

Pablo Sanchez-Martinez

Lion Martius

Kristian Bodolai



Amazon SOS
Remote sensing of mortality
Climate variability

New data exploration
Tree to region

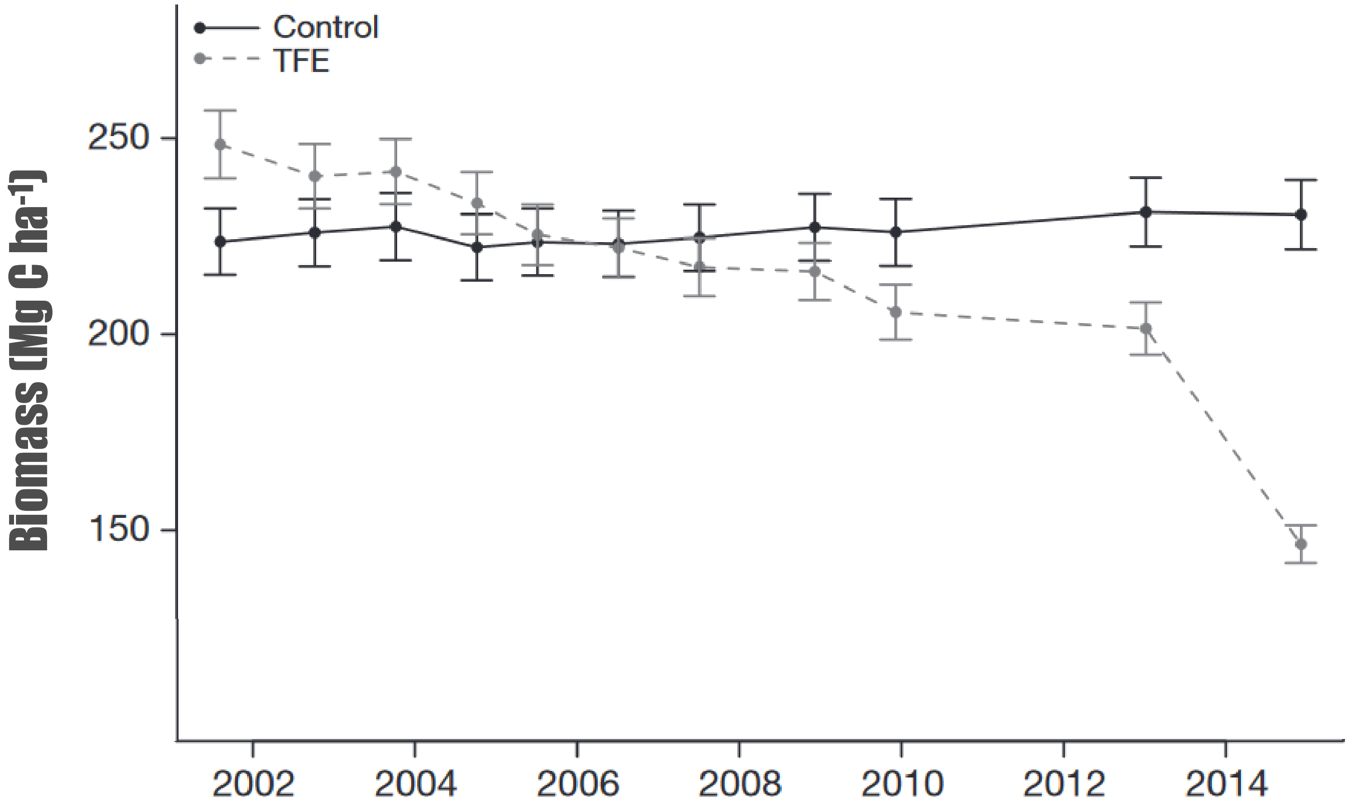
Esecaflor project in Floresta Nacional de Caxiuanã (Br)

Da Costa et al. (2010); Meir et al. (2018)

Experimental setting

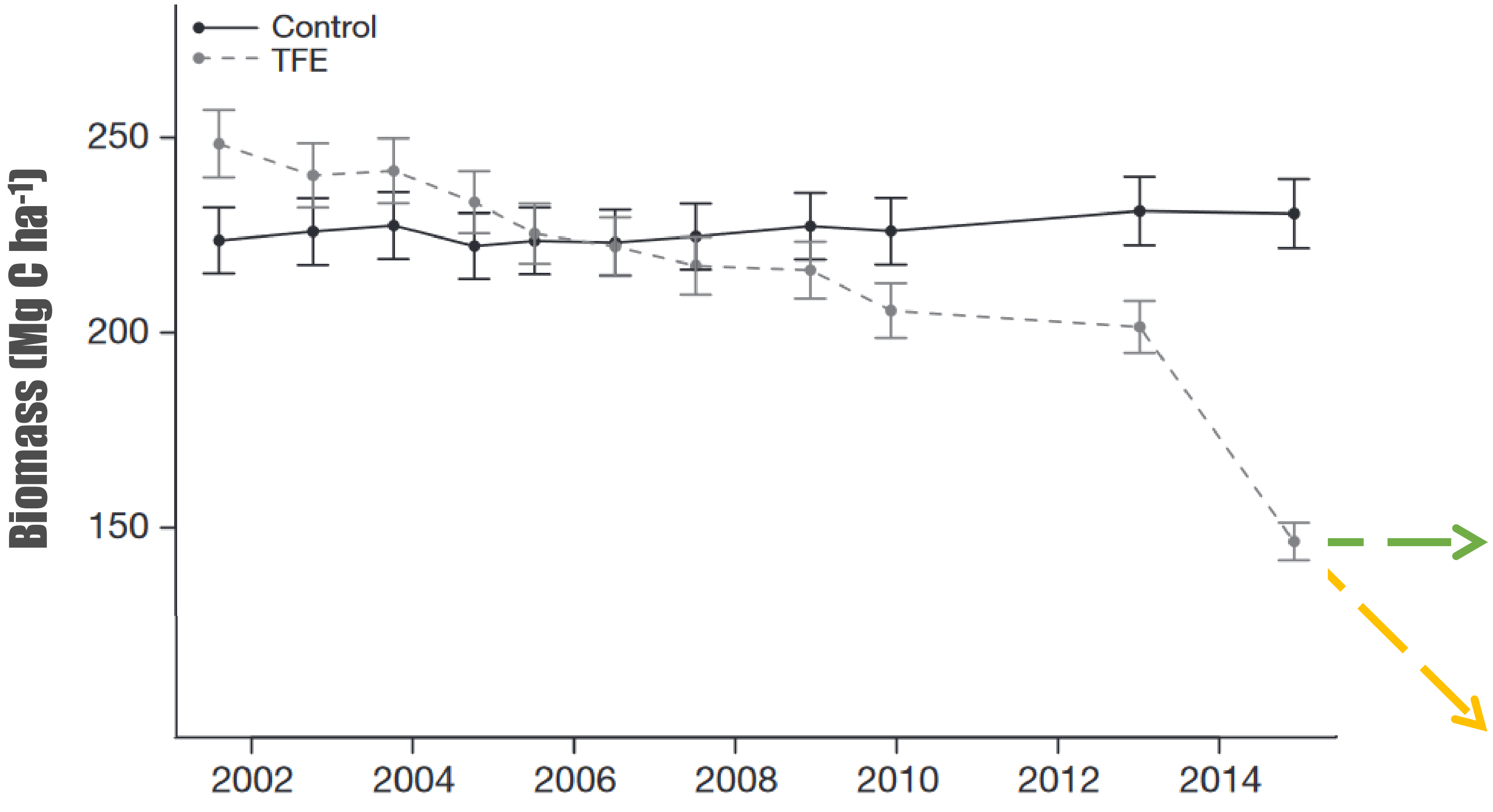
Experimental setting

Previous studies showed biomass decrease in the droughted forest



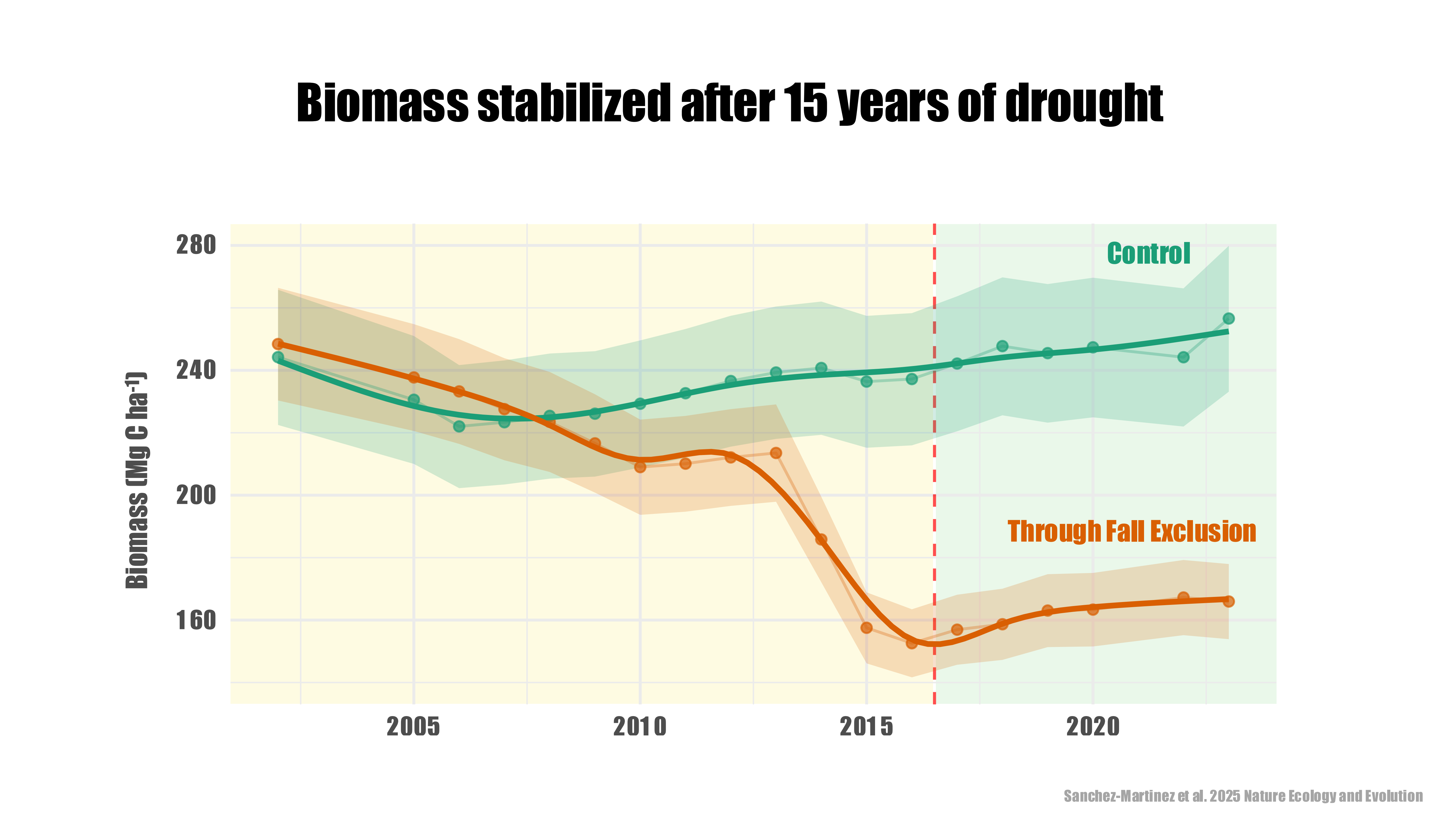
Rowland et al. 2015 Nature

Previous studies showed biomass decrease in the drought plot

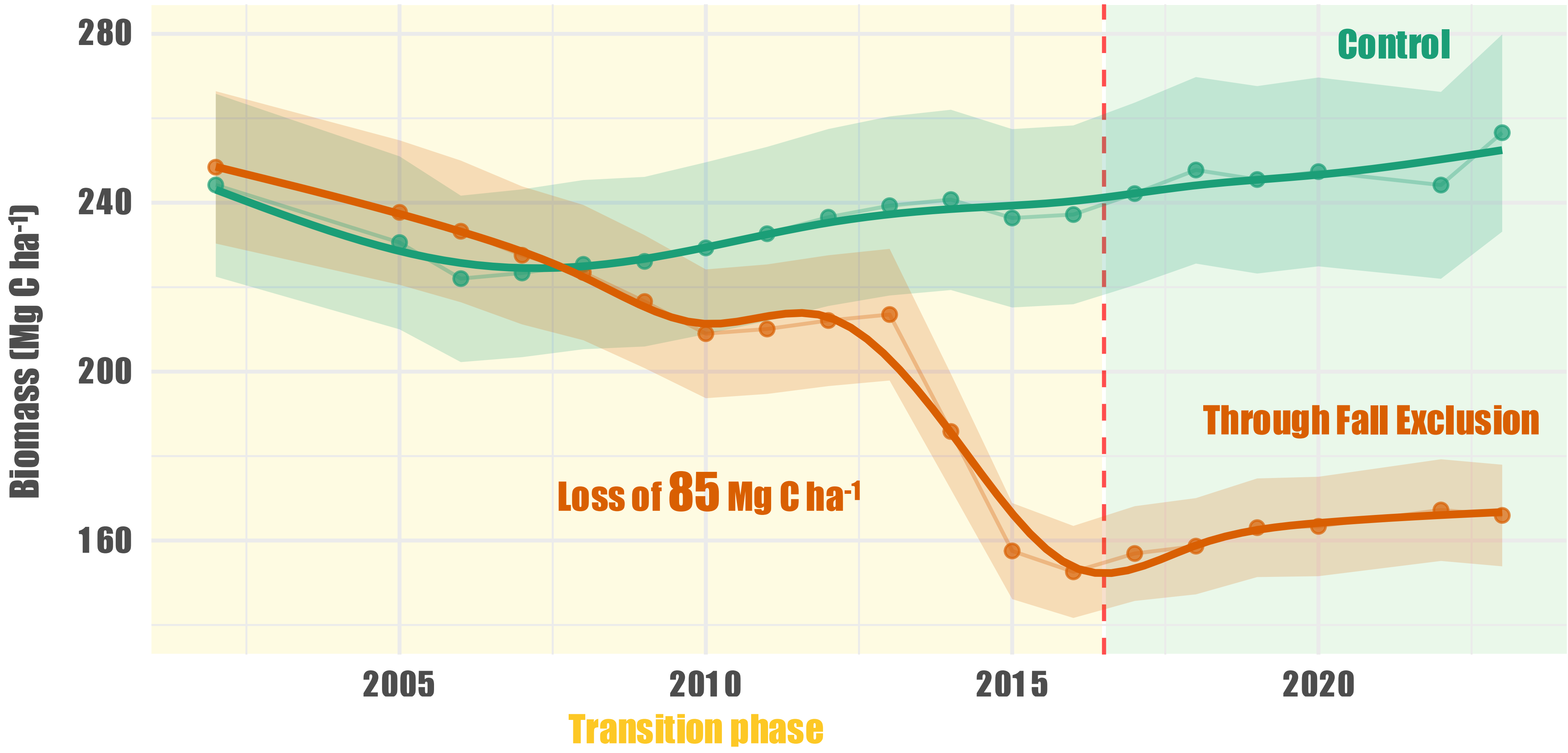


Collapse or stabilization after long-term drought?

Rowland et al. 2015 Nature


Biomass stabilized after 15 years of drought
Control
Through Fall Exclusion
Biomass (Mg C ha-1)
280
240
200
160
2005
2010
2015
2020
Sanchez-Martinez et al. 2025 Nature Ecology and Evolution

Biomass stabilized after 15 years of drought



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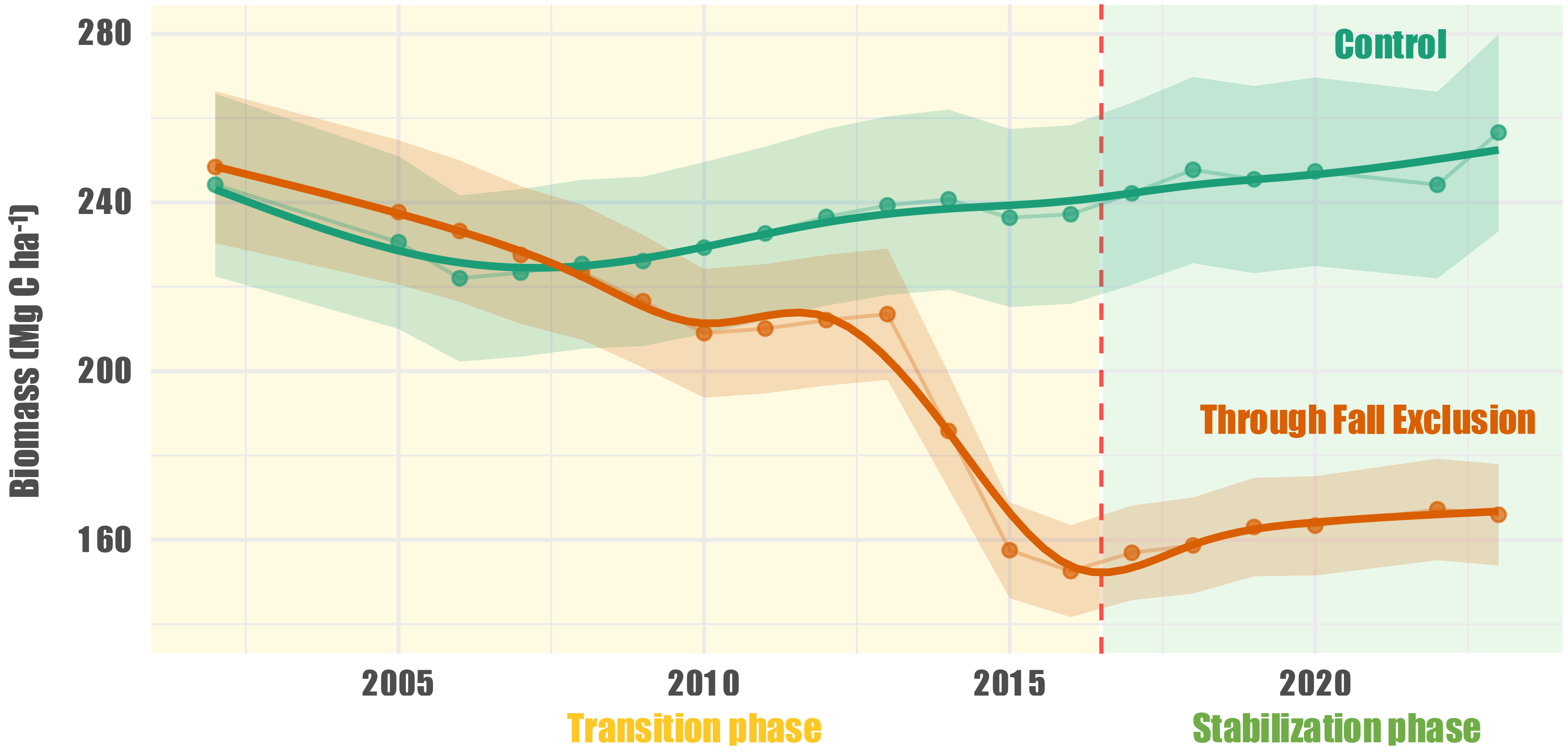

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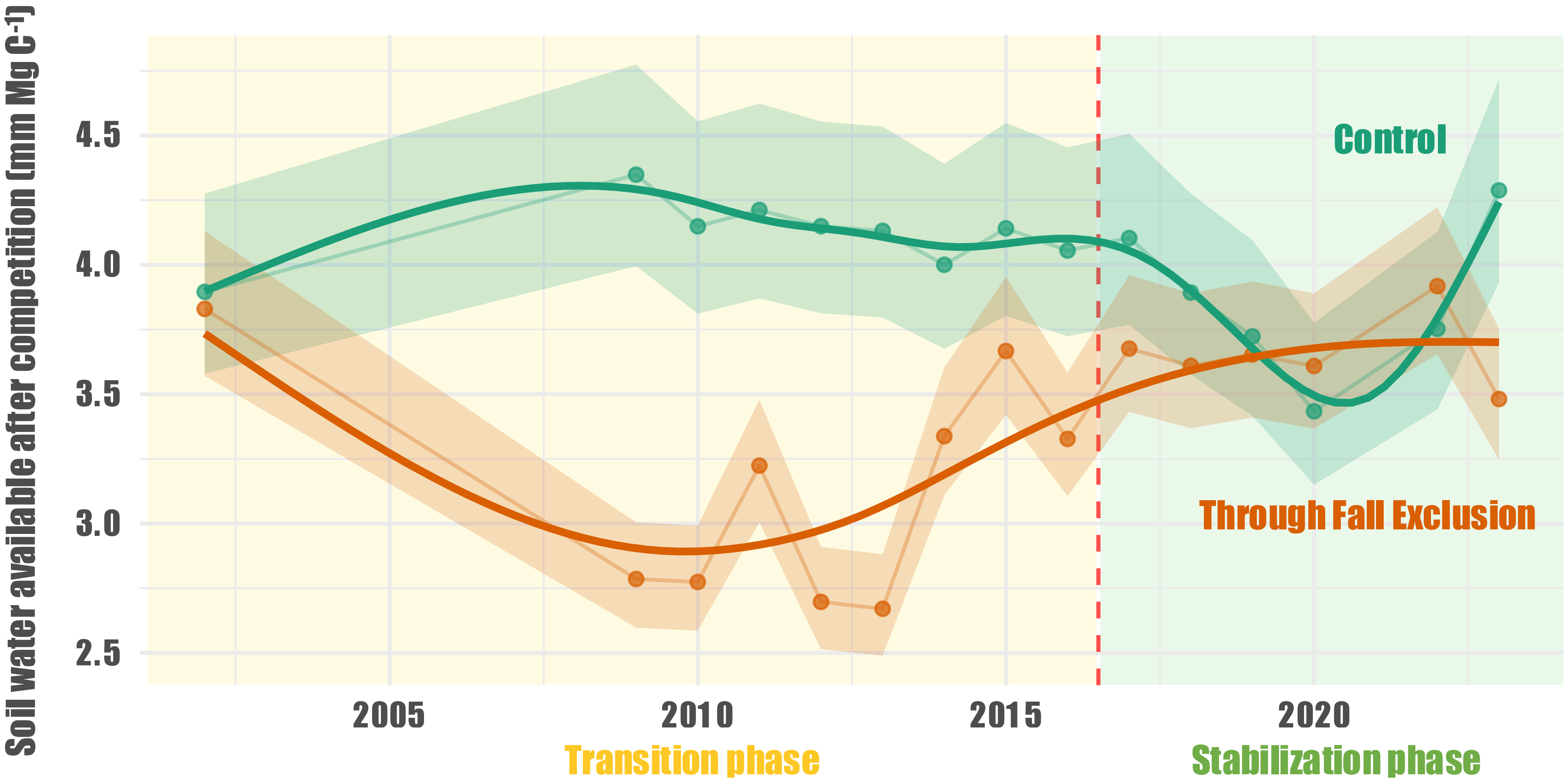
Increase of biomass-relative soil water content



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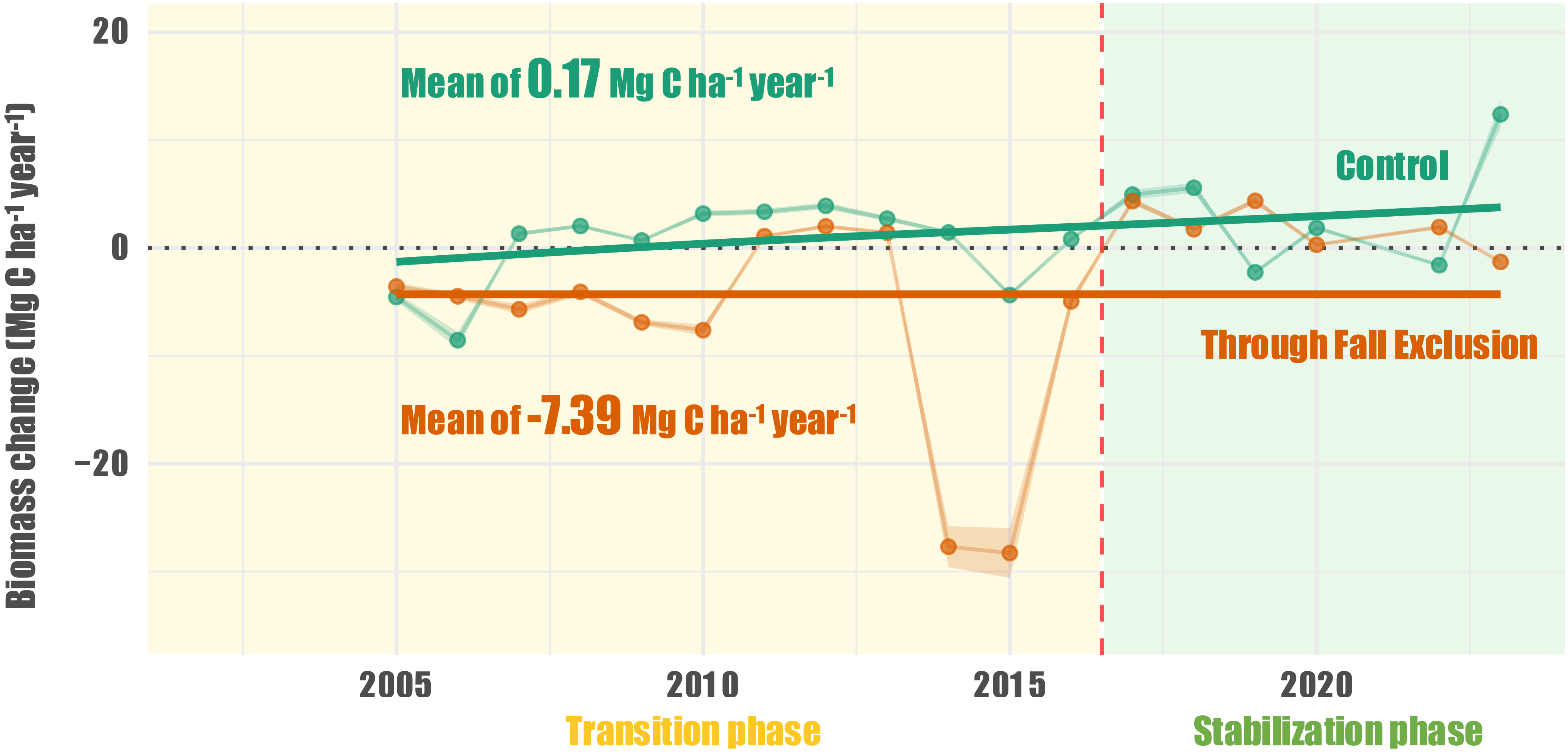
Wood productivity stabilized



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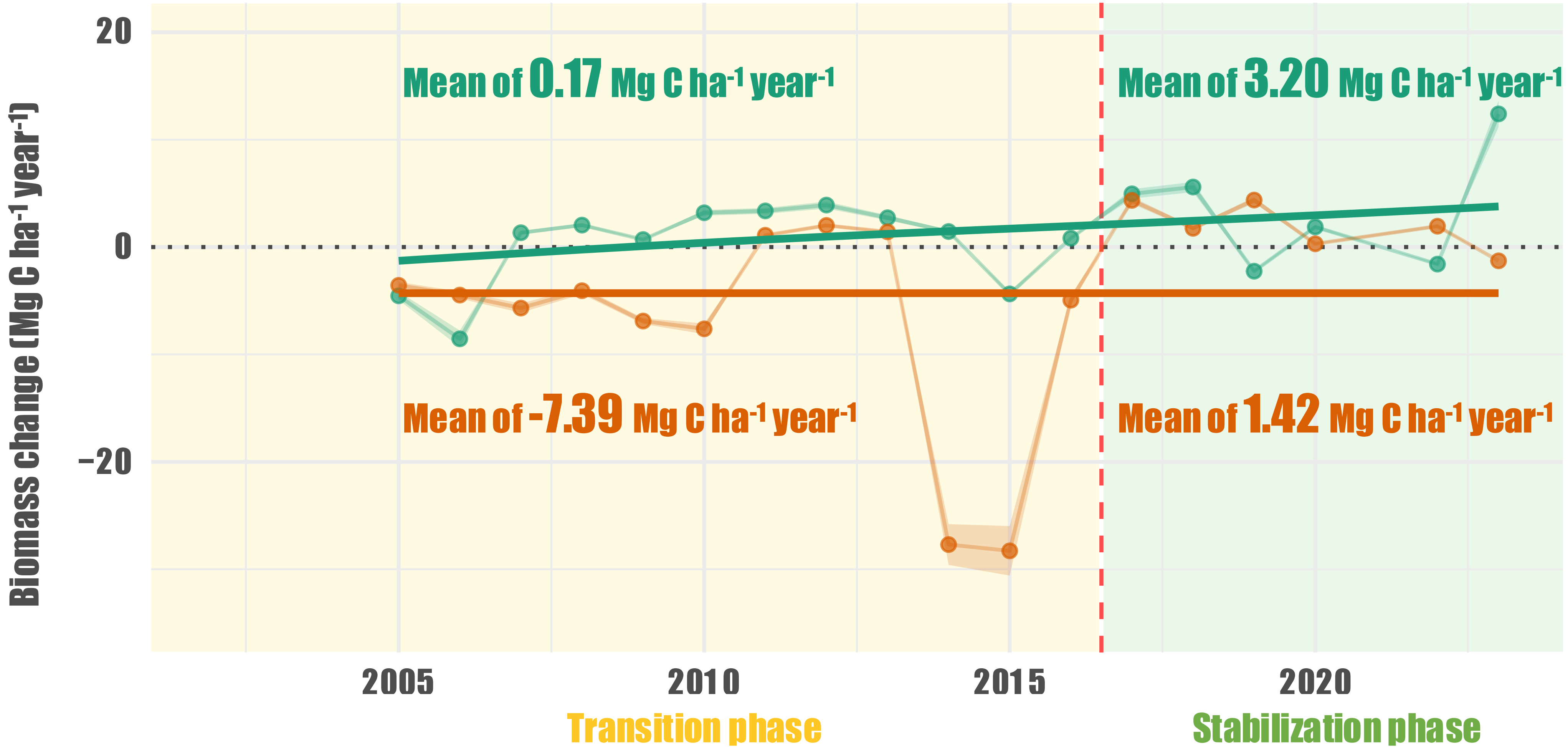

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Do trees show signs of current hydraulic stress?

42 Monitored trees (21 per plot) 2023-2024

Sap flow → Transpiration

Stem and leaf water content → Tissue hydration

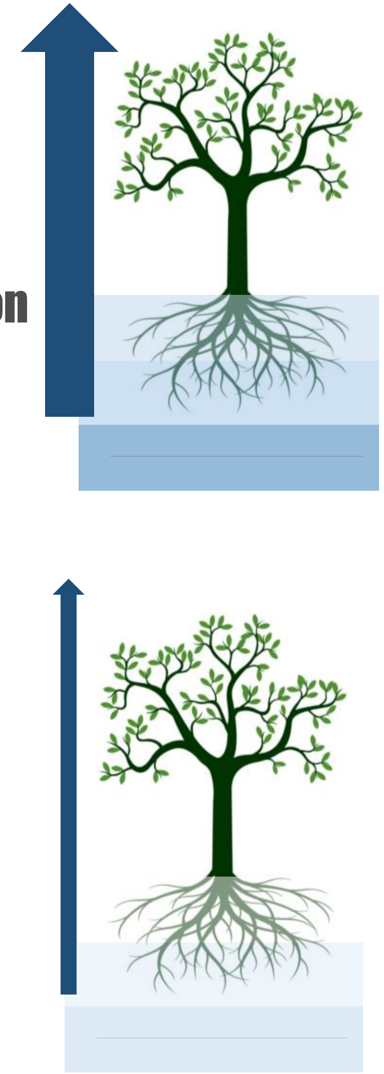
Large scale assessment 352 trees (176 per plot) at the peak of the dry and wet seasons

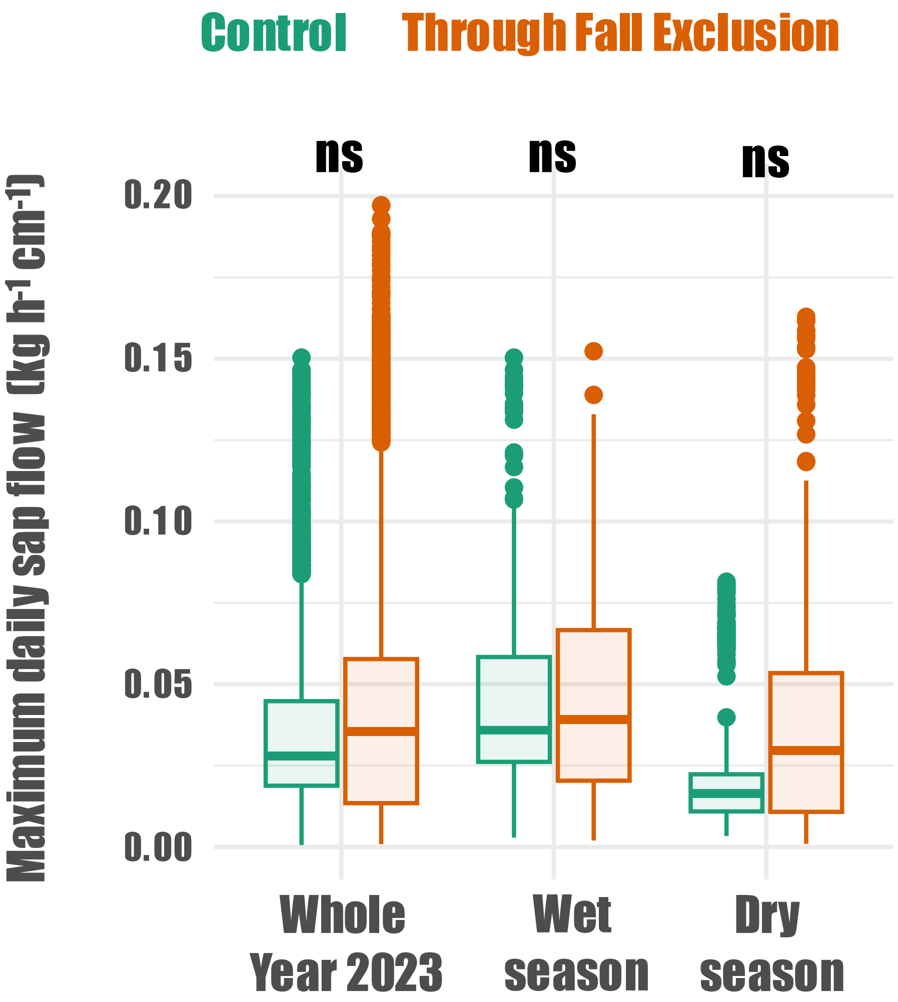
Leaf water potential → Hydraulic stress

No differences in transpiration

More transpiration

Less transpiration





EMS to measure sap flow

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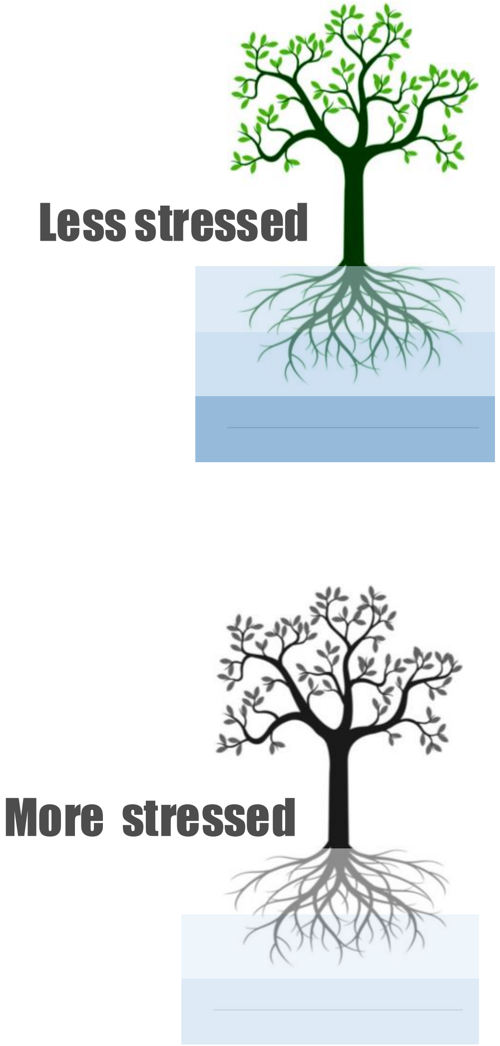
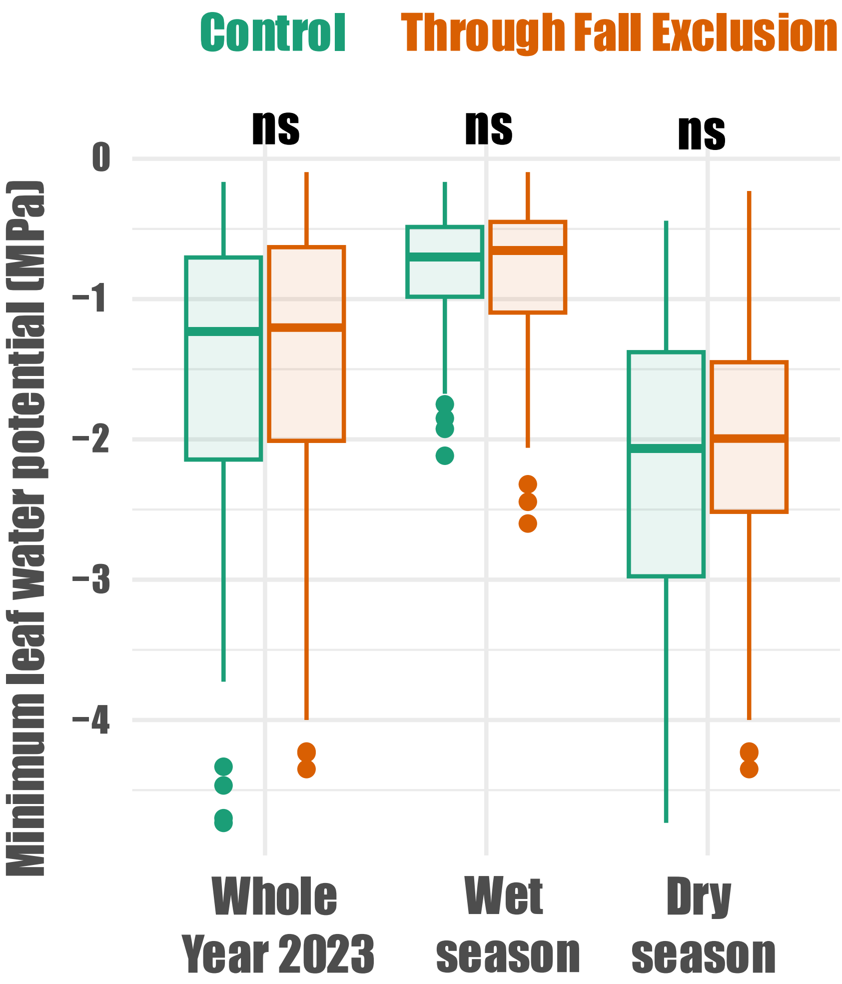
No differences in maximum hydraulic stress





Lion Martius and Vanessa Negrão-Rodrigues + pressure chamber system to measure leaf WP

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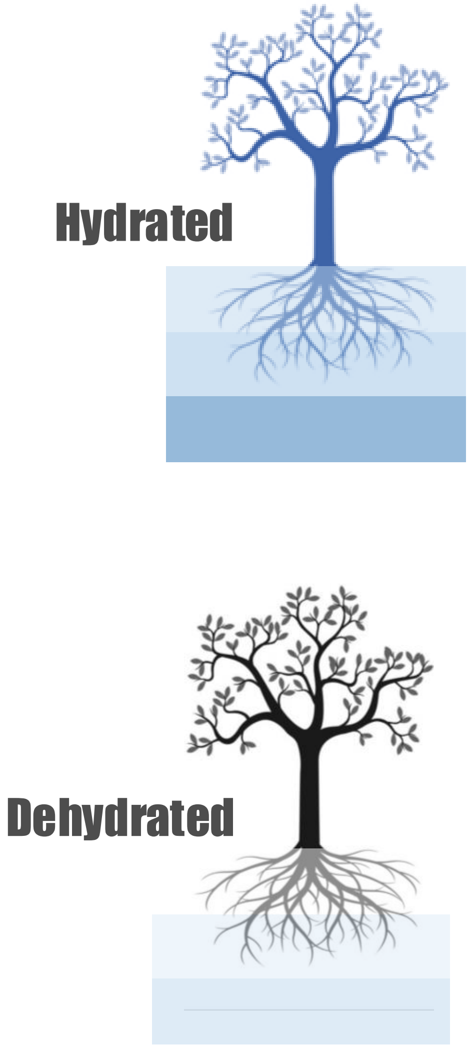
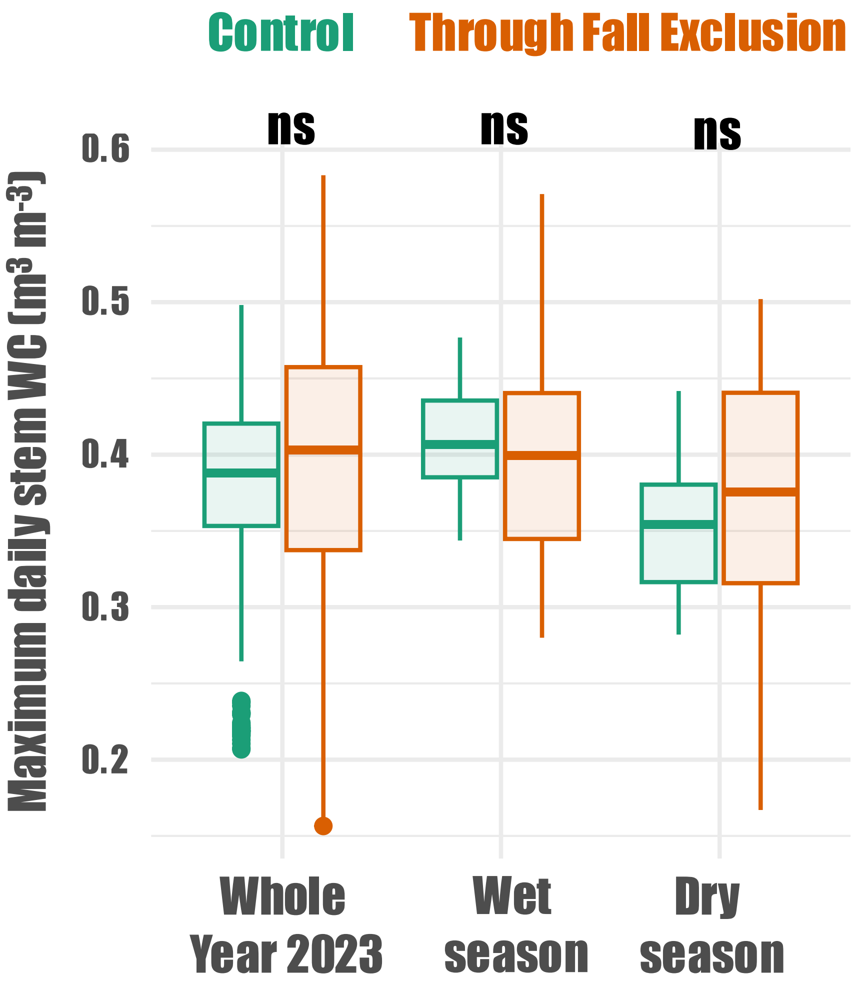
No differences in tissue hydration





Scary spider + Teros 12 sensor to measure water content

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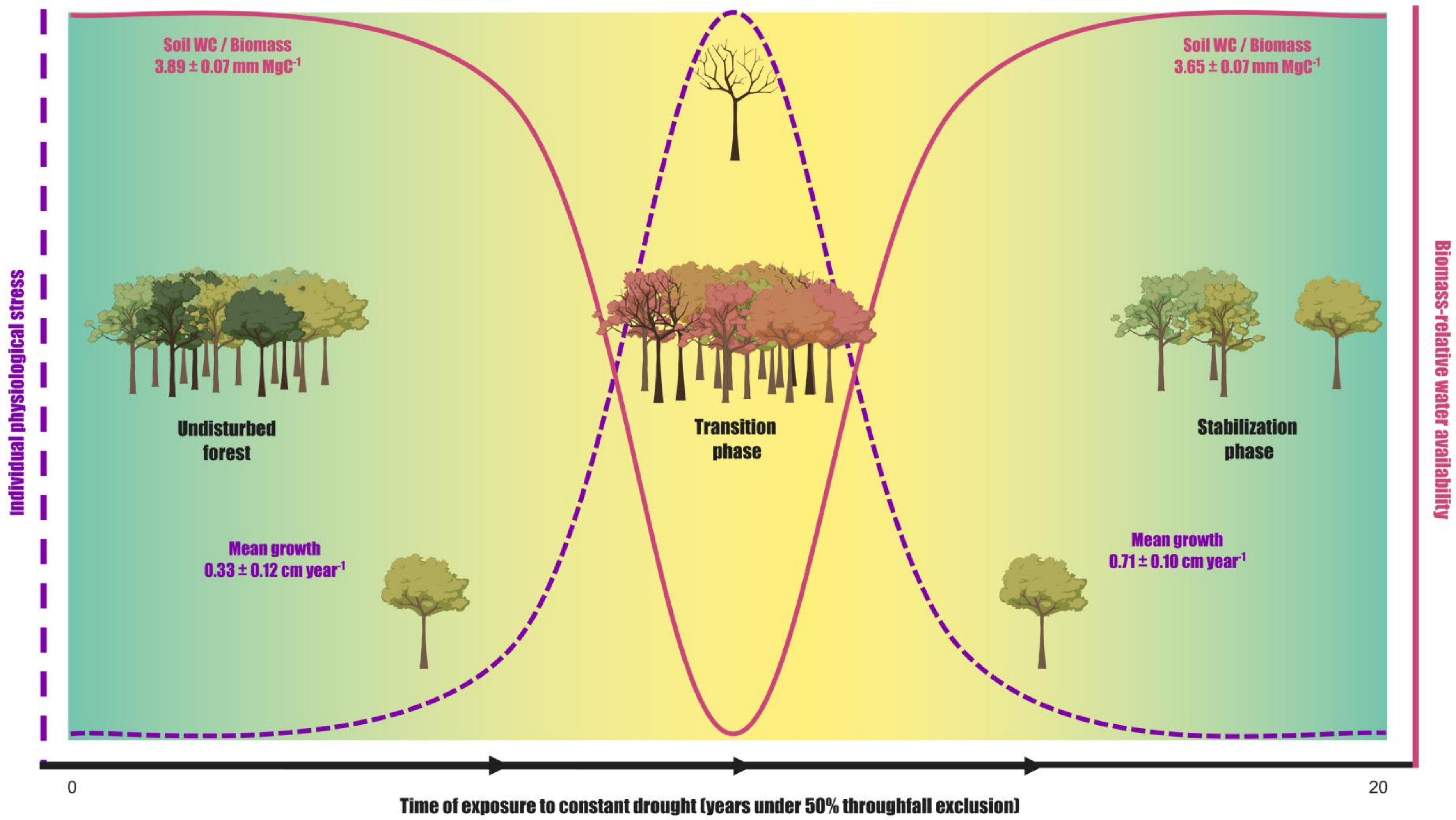
Eco-hydrological stability under drought



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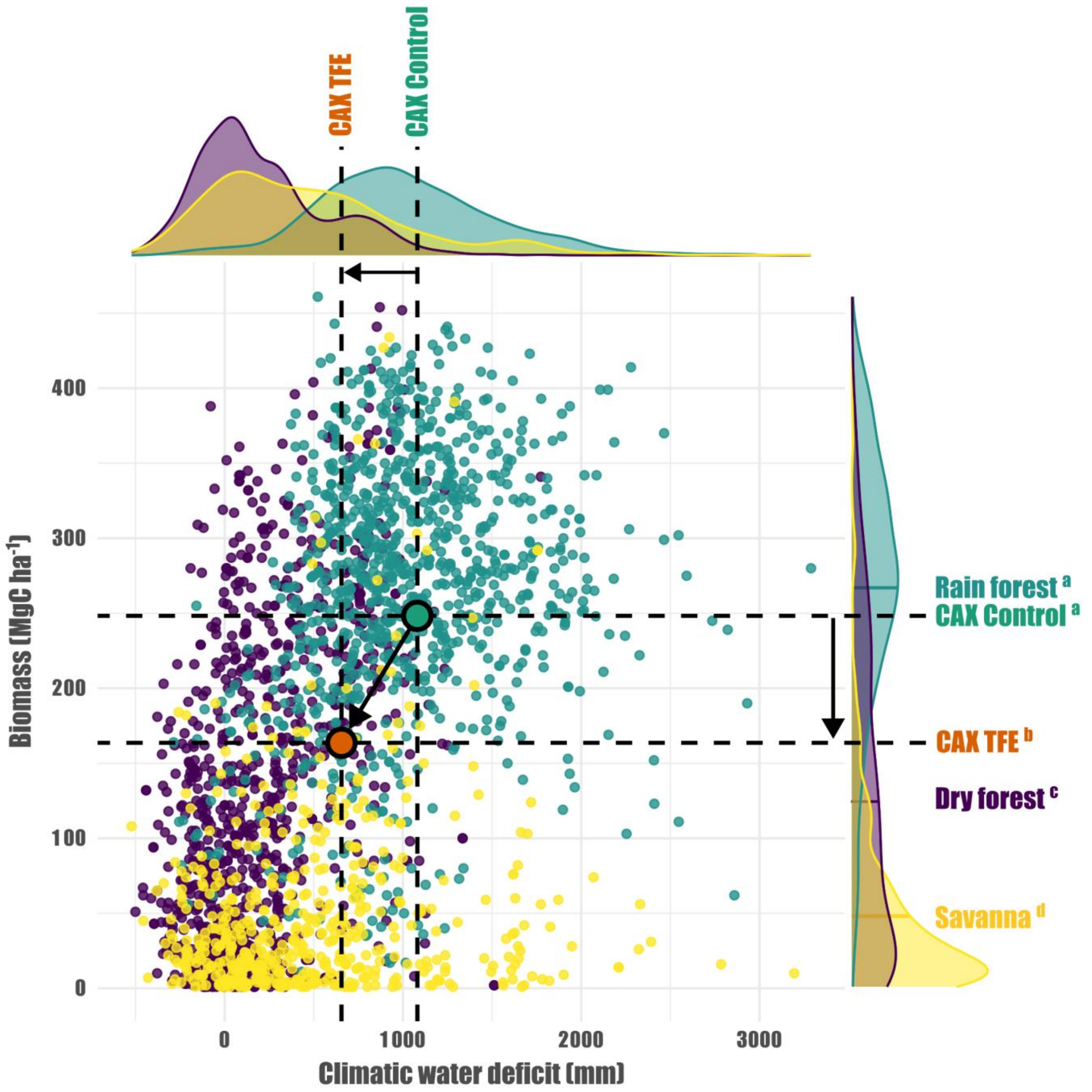
New drought-adjusted forest has higher biomass than dry forests and savannas



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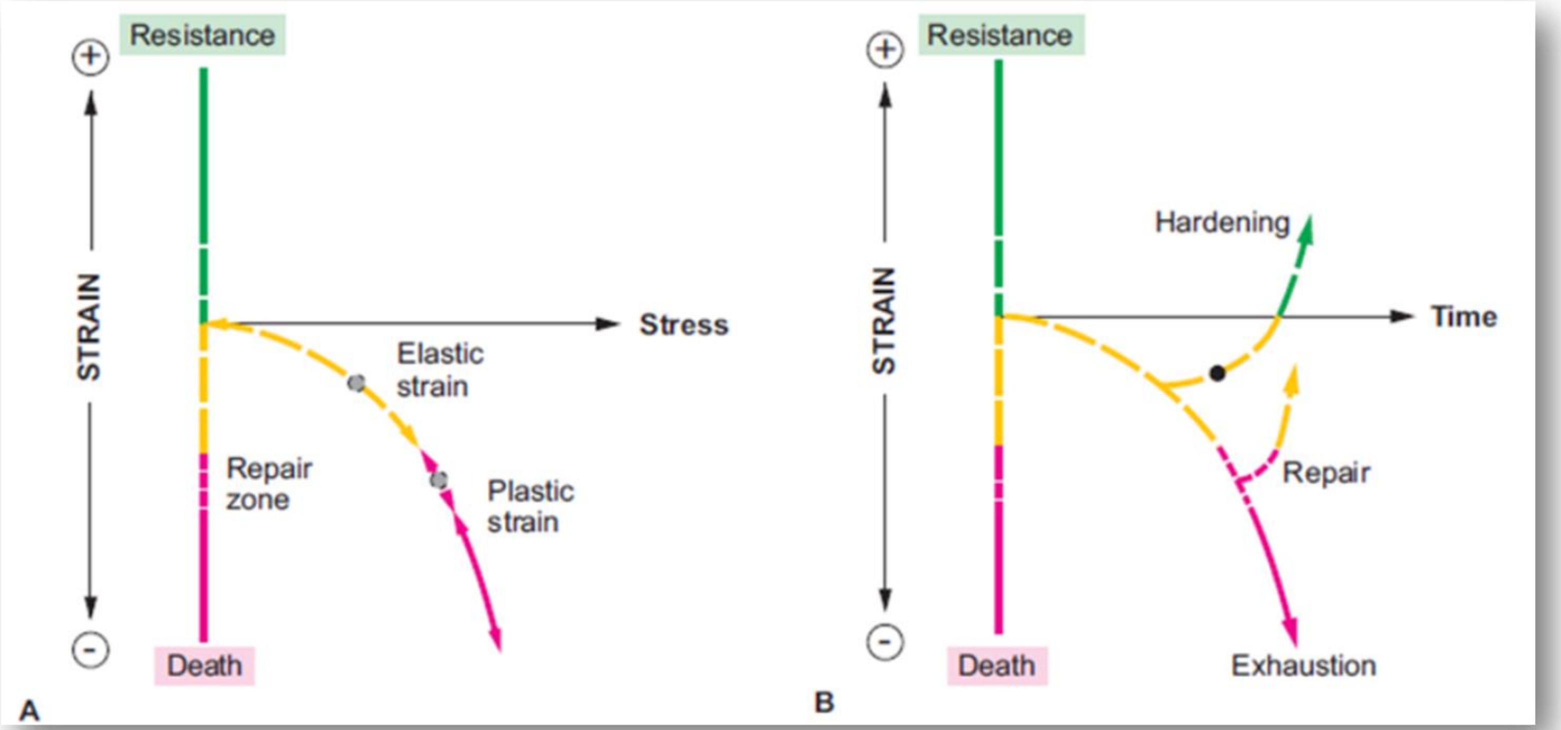
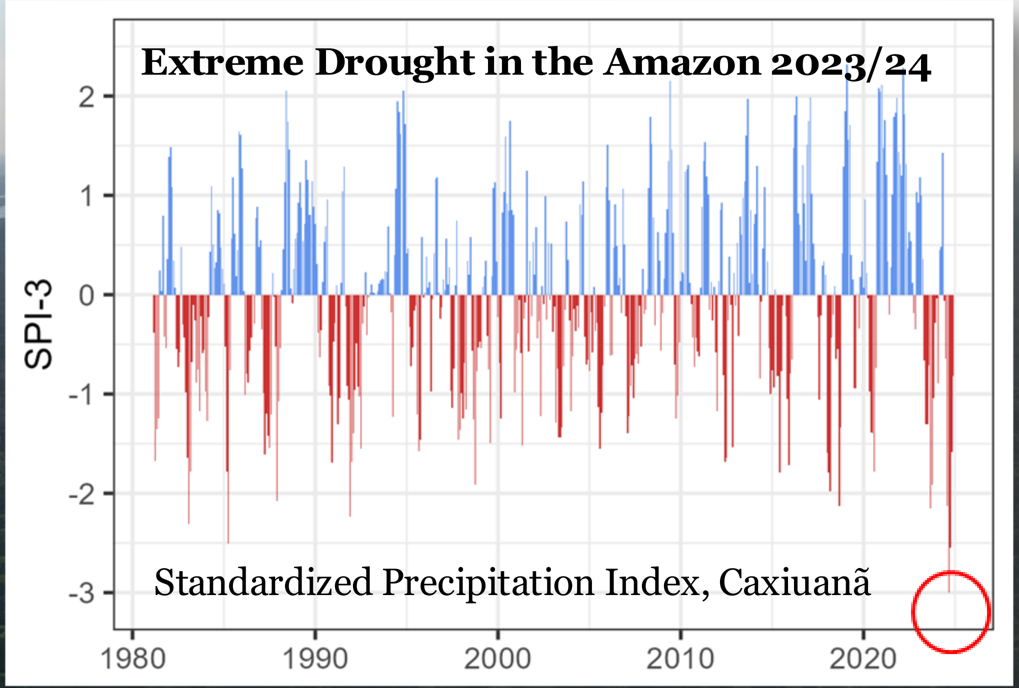
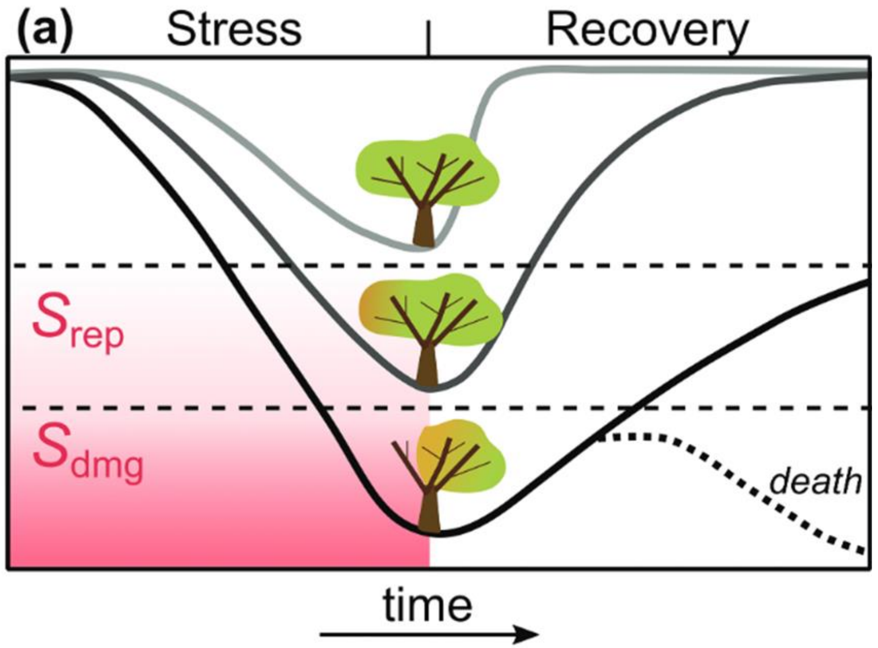
What about future extreme events?
Have trees 'learnt' from chronic soil drought exposure?



How do trees subjected to long-term drought respond to future extreme events?



Drought Resistance & Resilience
El Niño 2023/2024



- **Resistance (Rt):**
  the ability of a tree to limit the reduction in physiological performance during drought
- **Resilience (Rs):**
  […] to reach pre-drought physiological performance levels

Amazonian trees under long-term drought are more resilient to El Niño extreme

Modification of the canopy

Droughted trees have a smaller relative crowns

Smaller crown reduces:
- transpiration surface area
- sensitivity to evaporative demand
- plot & tree level adjustments → full recovery

Control trees

- 'shocked' by El Niño
- water losses high (large crown area, biomass)
- drought induced leaf loss → legacy effect

Structural Adjustments at the Ecosystem & Tree Level as a Path to Future Forest Resilience?

Martius et al. in prep.

Detecting tree mortality at scale using planet data

Standing dead

Broken

Uprooted

Detecting tree mortality at scale using new Planet data

Detect mortality using high resolution hyperspectral data from Planet

We used time series of satellite data to detect abrupt changes in “greeness” indexes such as EVI and NDVI

Remotely sensed mortality dataset for the whole Amazon basin

We created a first mortality dataset covering the whole Amazon Basin for the last five years

Understanding drought impacts on the Amazonian intact forests

Drivers of mortality

We are currently exploring potential drivers related to the occurrence of mortality, such as physiological vulnerability of species, canopy height and climate forcing

Taller forests show higher mortality signal

Forest canopy emerged as the most important variable explaining the incidence of mortality in intact forests of the Amazon Basin

Within forests, larger trees are more affected

We show how trees dying are taller compared to the surrounding area

These results match with our plot-level results showing how large tres are more vulnerable to drought, having strong impacts on carbon storage, biodiversity and microclimatic conditions, among others

Conclusions

Long-term - unique insights, utility

High mortality, then stabilisation, but biomass loss

Larger trees more affected by climate extremes

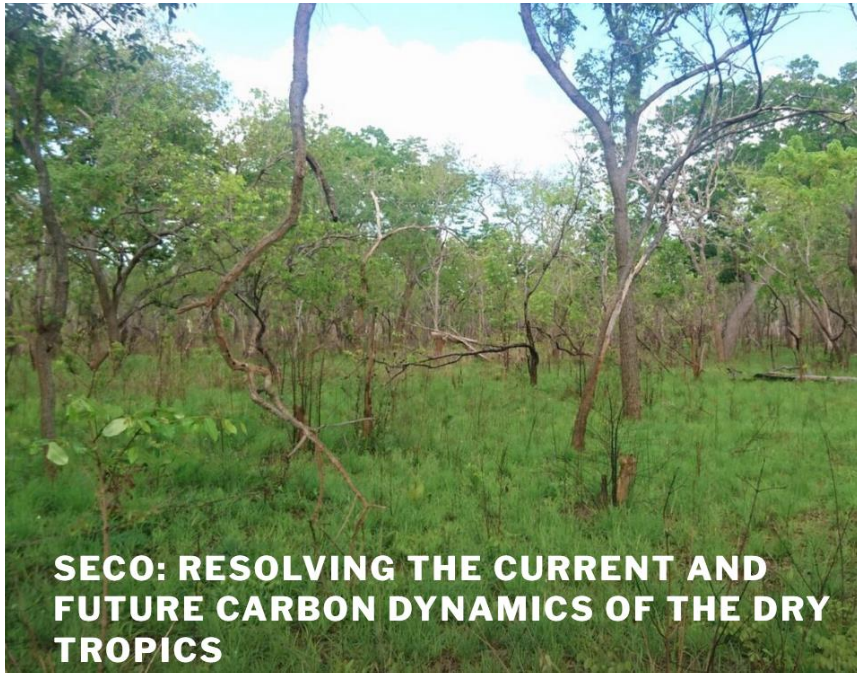
Remaining trees more resilient

Structural change - resilience (tree + ecosystem)

NEW capacity to detect mortality across region

Long-term, balanced, international collaboration

More tropical ecosystems and global change at Edinburgh
…drylands and savannas



<u>Edinburgh leadership</u>

Prof Caroline Lehmann
(RBGE and Geosciences)

Prof Casey Ryan
(Geosciences)

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