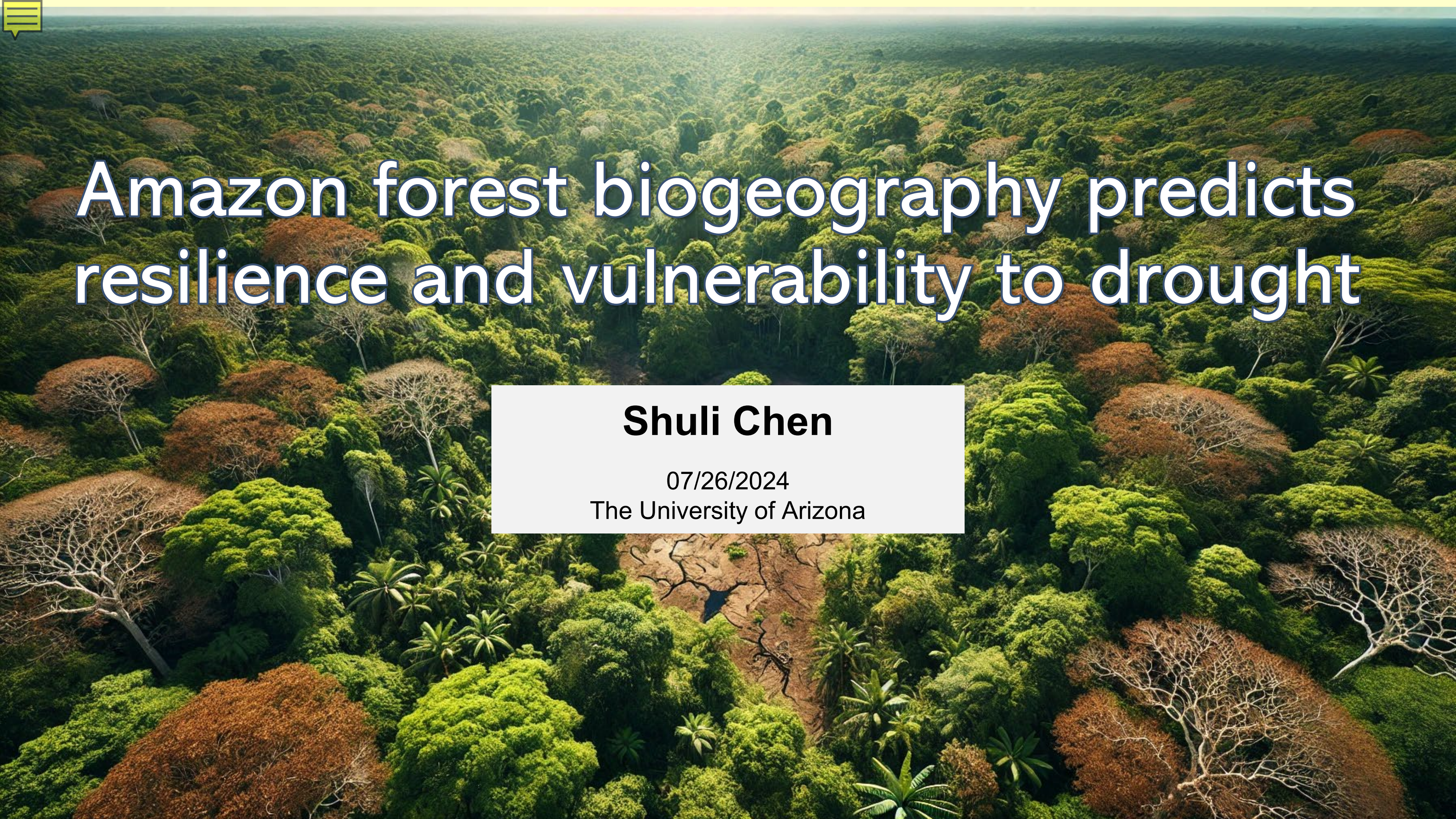
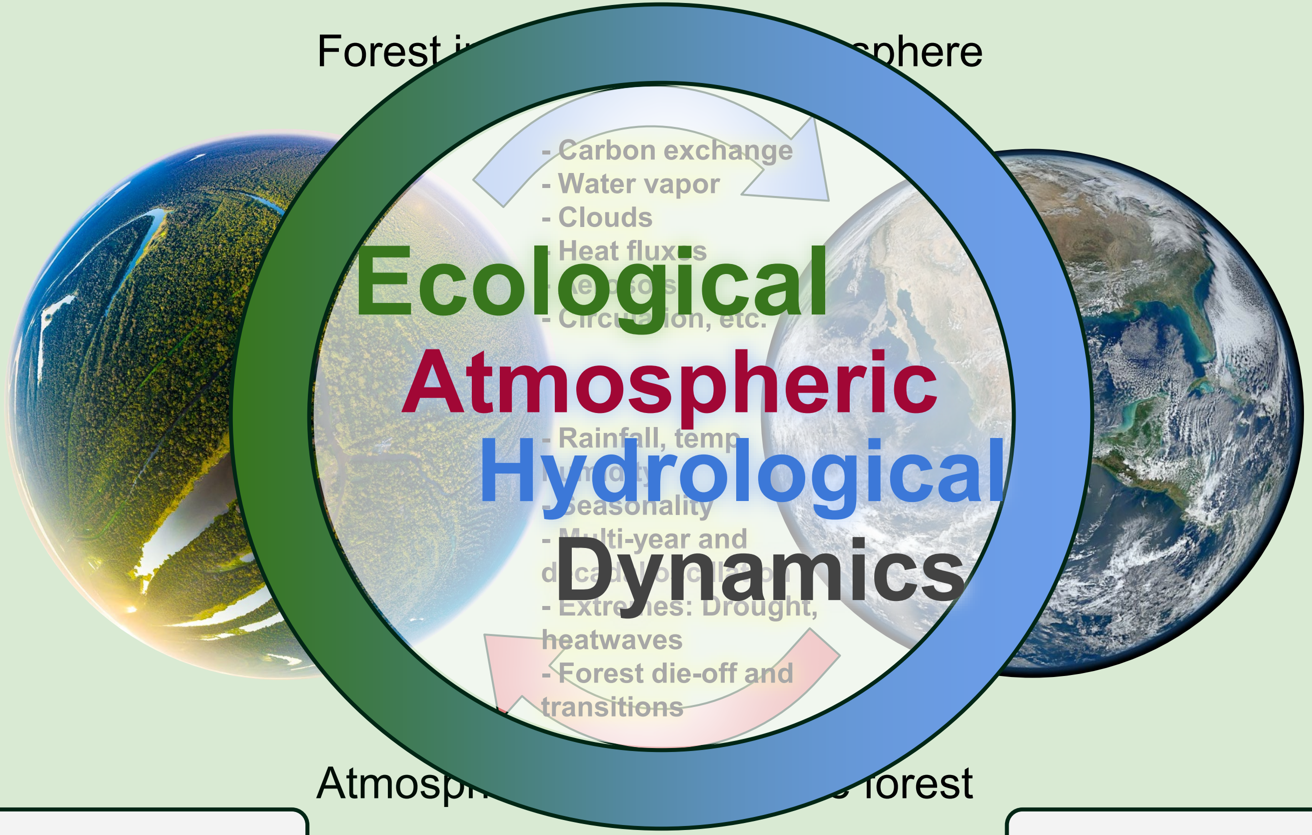


Amazon forest biogeography predicts resilience and vulnerability to drought

Shuli Chen

07/26/2024
The University of Arizona

How important are forests for climate change? **Forest - climate interactions**



Forests

The Atmosphere

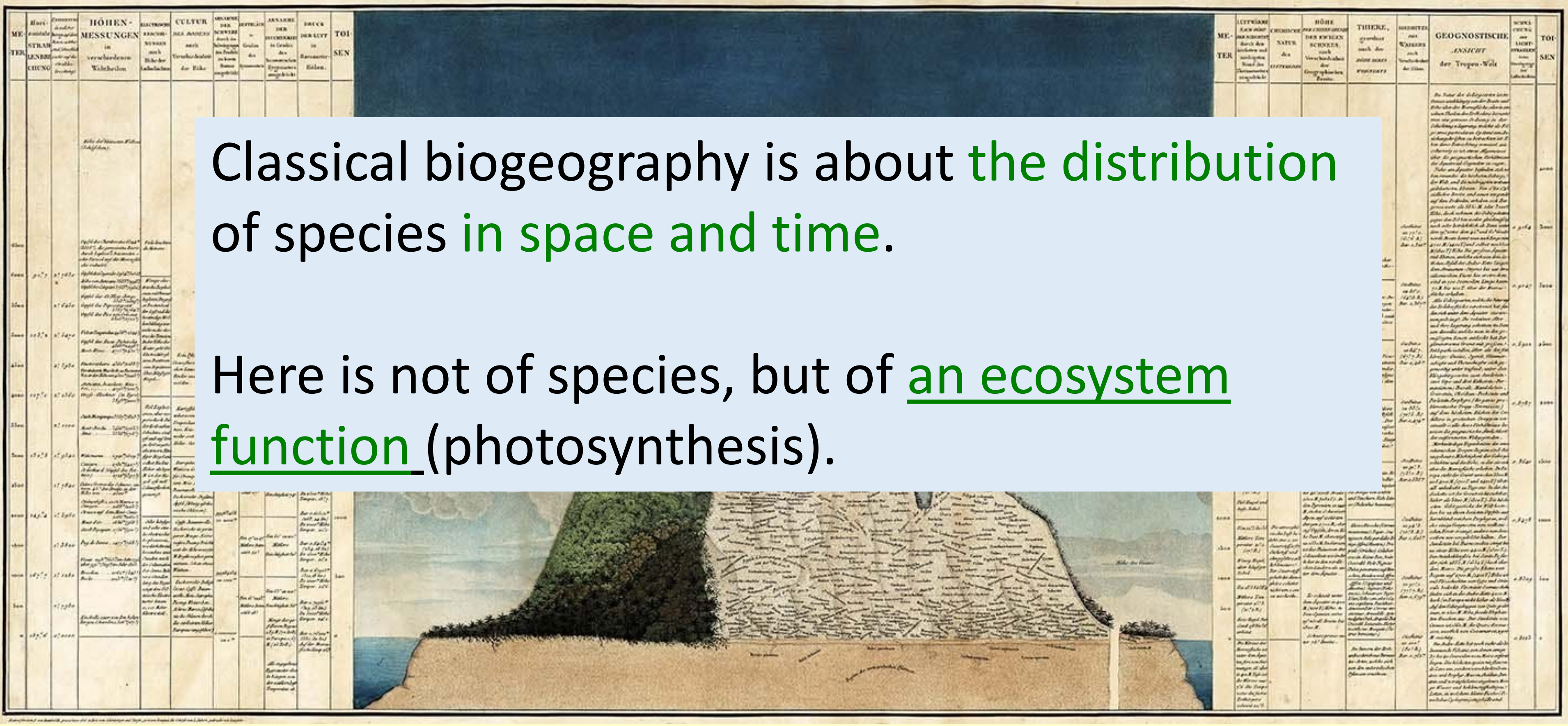
Left photo credit @ Enrico Pescantini

Right photo credit @ NASA The Blue Marble 2012

Key area to study photosynthesis: **tropical forests**

That is where photosynthesis is both important, and uncertain

<u>Biogeography</u>: a key early example of the science of scaling in biology



Classical biogeography is about the distribution of species in space and time.

Here is not of species, but of <u>an ecosystem function</u> (photosynthesis).

Humboldt's legacy. *Nat Ecol Evol* **3**, 1265–1266 (2019).

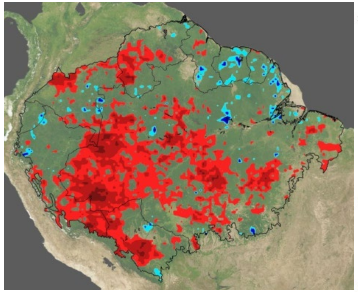
Alexander von Humboldt's view of Mount Chimborazo, Ecuado

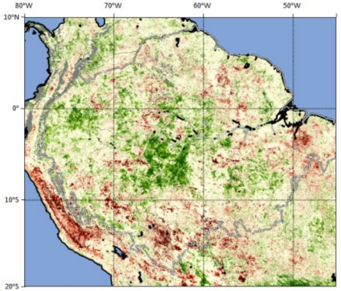
Previous results (2005 drought)

26 OCTOBER 2007 VOL 318 SCIENCE

Amazon Forests Green-Up During 2005 Drought (2007)

Scott R. Saleska,[1]*† Kamel Didan,[2]* Alfredo R. Huete,[2] Humberto R. da Rocha[3]





Drought extent, red=dry

Forest Response, green=↑EVI

REMOTE SENSING

“intact Amazon forests may be more resilient than most ecosystem models assume, at least in response to short-term climate anomalies.”

RAINFOR plots

6 MARCH 2009 VOL 323 SCIENCE

REPORTS

Drought Sensitivity of the Amazon Rainforest (2009)

Oliver L. Phillips,[1*] Luiz E. O. C. Aragão,[2] Simon L. Lewis,[1] Joshua B. Fisher,[2] Jon Lloyd,[1] Gabriela López-González,[1] Yadvinder Malhi,[2] Abel Monteagudo,[3] Julie Peacock,[1] Carlos A. Quesada,[1,4] Geertje van der Heijden,[1] Samuel Almeida,[5] Iêda Amaral,[4,6] Luzmila Arroyo,[7,8] Gerardo Aymard,[9] Tim R. Baker,[1] Olaf Bánki,[10] Lilian Blanc,[11] Damien Bonal,[12] Paulo Brando,[13,14] Jerome Chave,[15] Átila Cristina Alves de Oliveira,[4] Nallaret Dávila Cardozo,[16] Claudia I. Czimczik,[17] Ted R. Feldpausch,[1] Maria Aparecida Freitas,[5] Emanuel Gloor,[1] Niro Higuchi,[18] Eliana Jiménez,[19] Gareth Lloyd,[20] Patrick Meir,[21] Casimiro Mendoza,[22] Alexandra Morel,[2] David A. Neill,[8,23] Daniel Nepstad,[24,25] Sandra Patiño,[1,11] Maria Cristina Peñuela,[19] Adriana Prieto,[26] Fredy Ramírez,[16] Michael Schwarz,[1,27] Javier Silva,[2] Marcos Silveira,[28] Anne Sota Thomas,[29] Hans ter Steege,[30] Juliana Stropp,[30] Rodolfo Vásquez,[3] Przemyslaw Zelazowski,[2] Esteban Alvarez Dávila,[31] Sandy Andelman,[6] Ana Andrade,[4] Kuo-Jung Chao,[1] Terry Erwin,[32] Anthony Di Fiore,[33] Eurídice Honorio C.,[34] Helen Keeling,[1] Tim J. Killeen,[7] William F. Laurance,[4,35] Antonio Peña Cruz,[3] Nigel C. A. Pitman,[36] Percy Núñez Vargas,[37] Hirma Ramírez-Angulo,[38] Agustín Rudas,[39] Rafael Salamão,[5] Natalino Silva,[40] John Terborgh,[41] Armando Torres-Lezama[38]

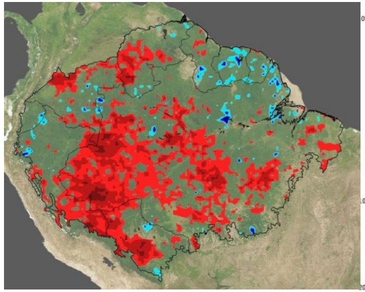
→ Reported increase in tree mortality during the period that included the 2005 drought.

"Amazon forests therefore appear vulnerable to increasing moisture stress, with the potential for large carbon losses to exert feedback on climate change."

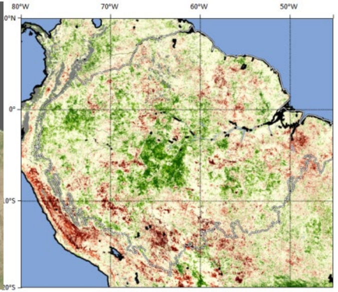
26 OCTOBER 2007 VOL 318 SCIENCE

Amazon Forests Green-Up During 2005 Drought (2007)

Scott R. Saleska,[1*†] Kamel Didan,[2*] Alfredo R. Huete,[2] Humberto R. da Rocha[3]



Drought extent, red=dry



Forest Response, green=↑EVI

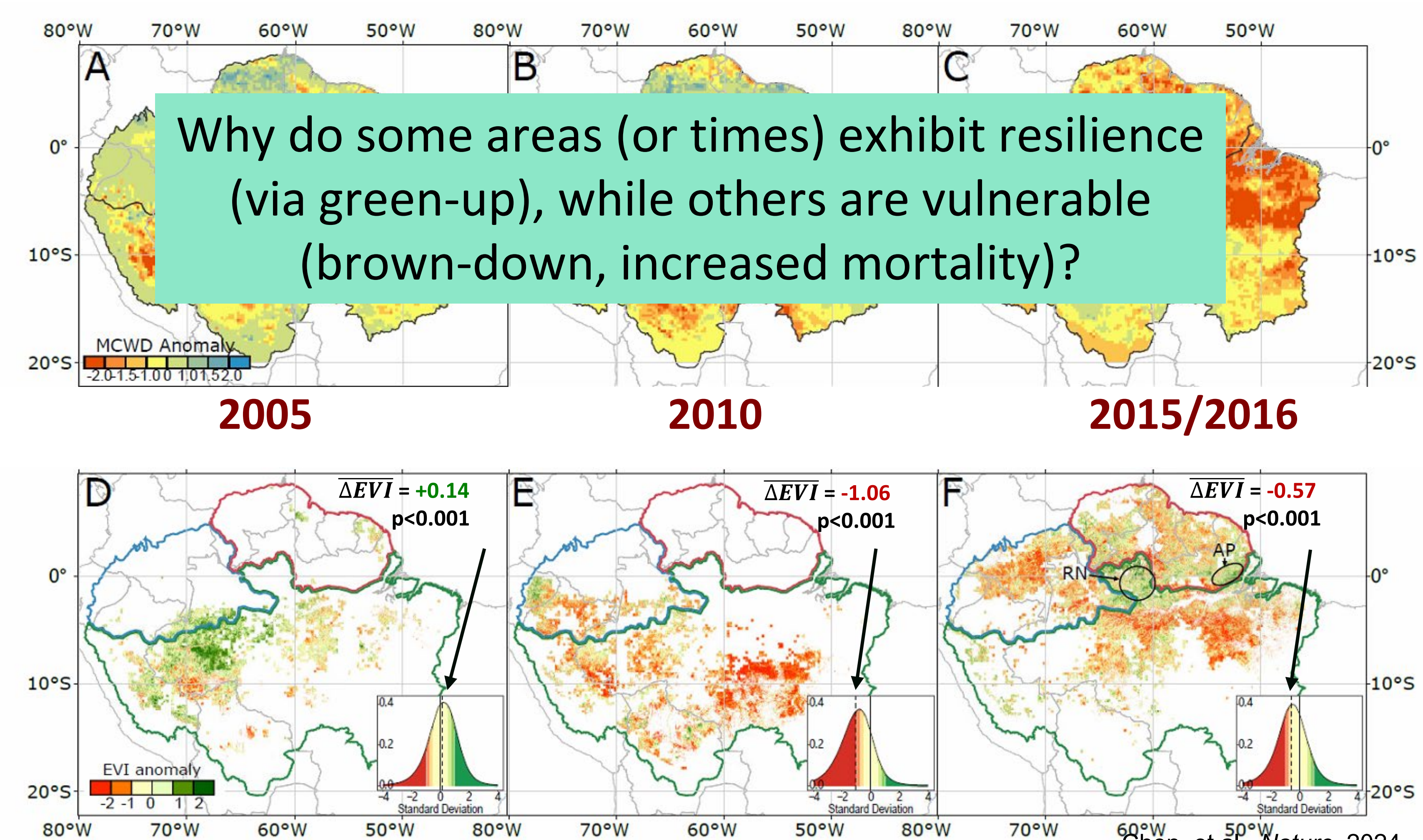
REMOTE SENSING

"intact Amazon forests may be more resilient than most ecosystem models assume, at least in response to short-term climate anomalies."

Can we reconcile these observations?

Drought (Browning)

Drought Response (Positive - Greening)



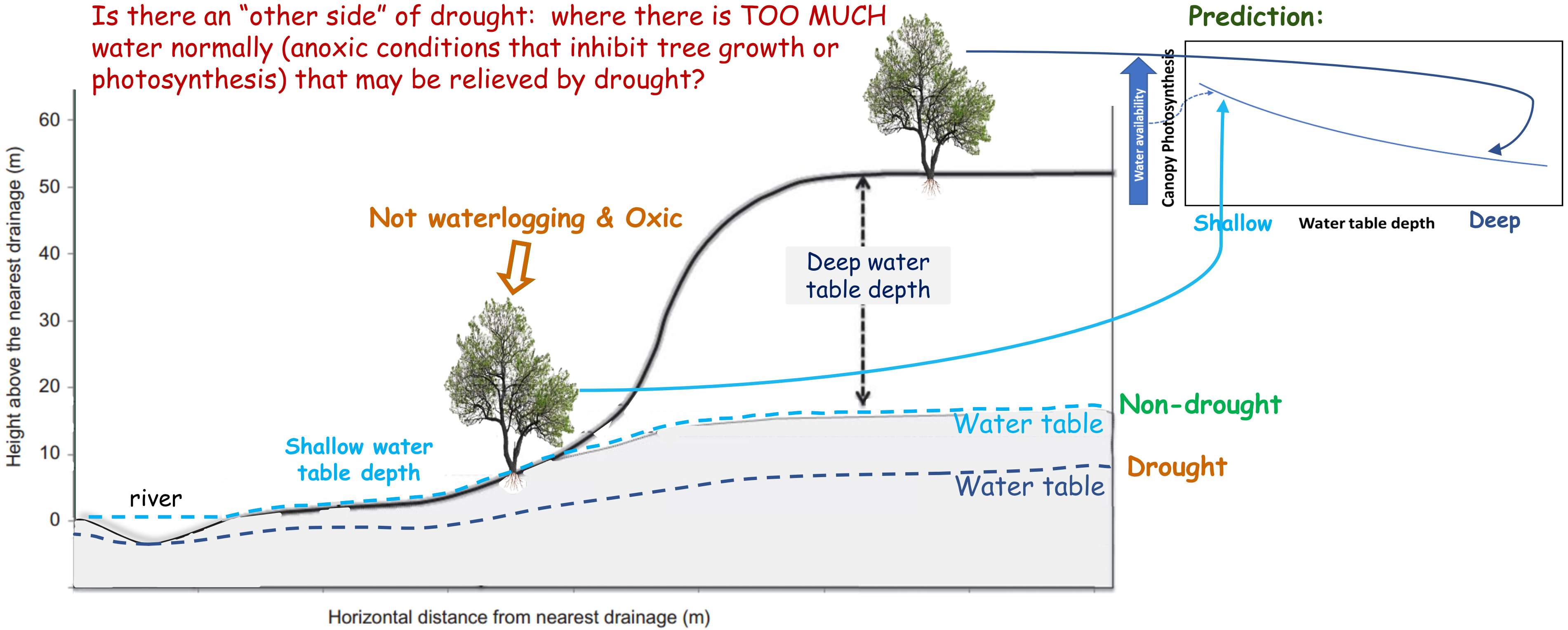
Why do some areas (or times) exhibit resilience (via green-up), while others are vulnerable (brown-down, increased mortality)?

Chen, et al., *Nature*, 2024.

What are the mechanisms that drive forest photosynthetic response to drought?

Local hydrological gradients: Water table depth (WTD): The accessibility of water to trees.

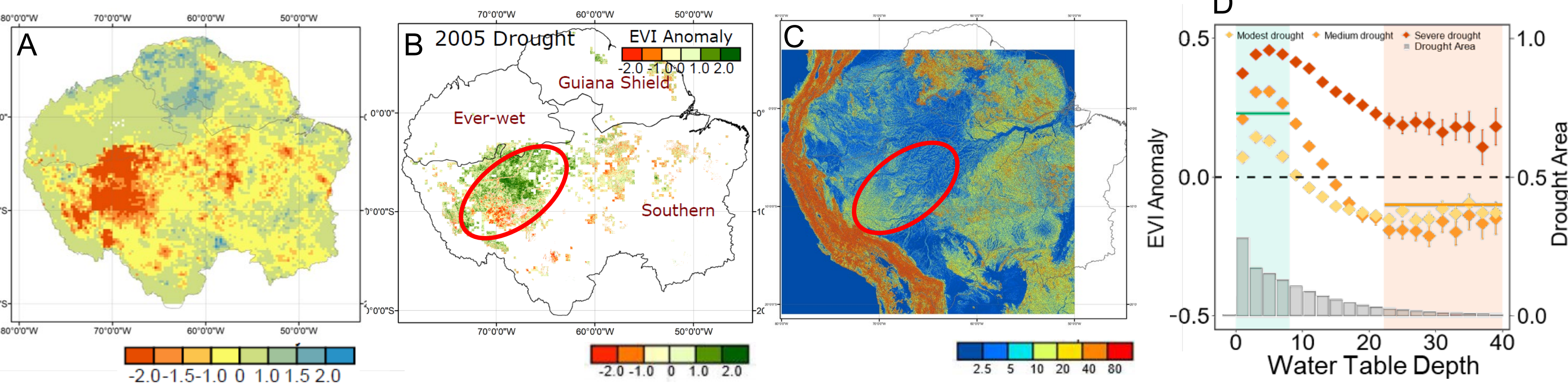
Is there an "other side" of drought: where there is TOO MUCH water normally (anoxic conditions that inhibit tree growth or photosynthesis) that may be relieved by drought?



The ecological hypothesis is proposed by Costa et al (2022), Sousa et al (2020) and Esteban et al (2020. Figure from Schietti et al., 2014.

2005 drought

Drought Region | EVI response to drought | Water Table Depth

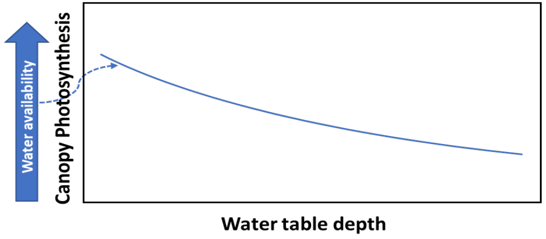


Drought Region: MCWD < mean(MCWD)-SD

Maximum Cumulative Water Deficit (MCWD):an index to address drought stress (balance between precipitation and evaporation).

EVI: A remote sensing index for photosynthetic capacity

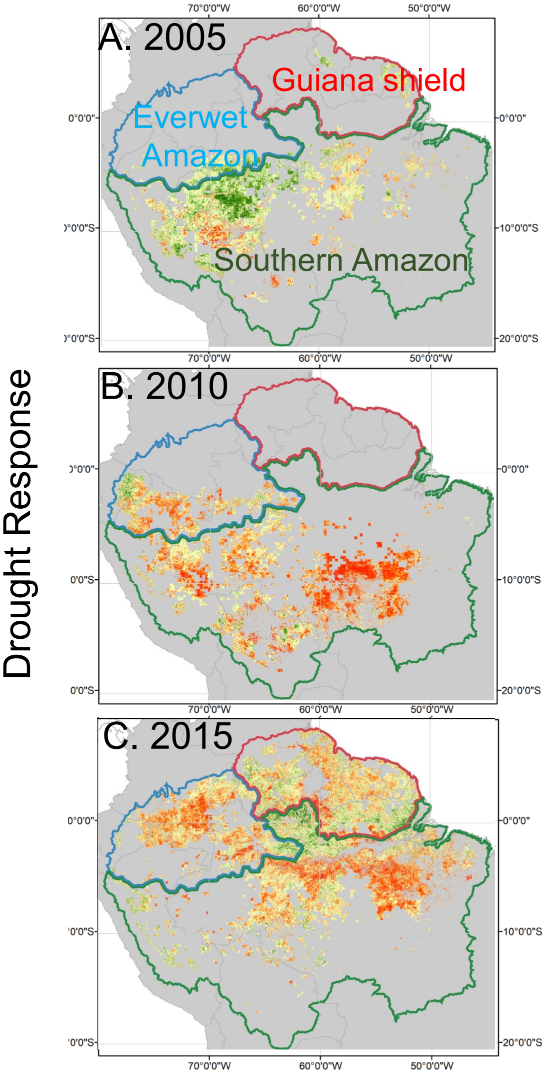
Prediction:

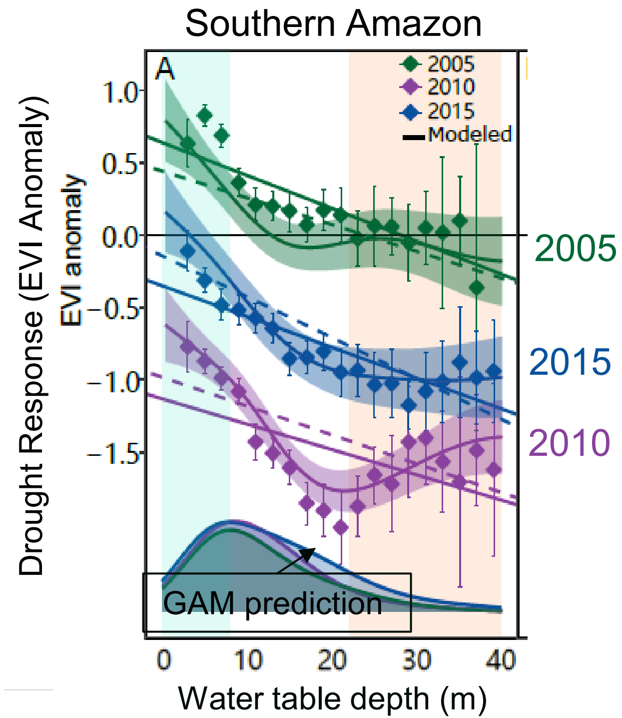


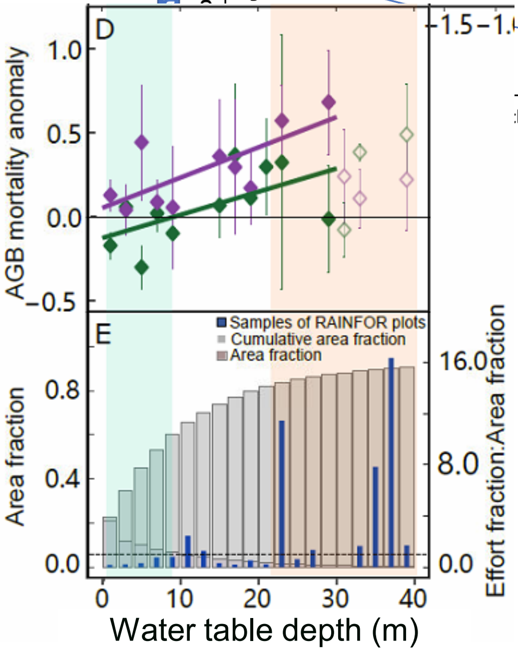
Note: Water table depth represented as the height above the nearest drainage

Sousa et al., 2020.; Chen, et al., *Nature*, 2024.

Consistent with plot mortality







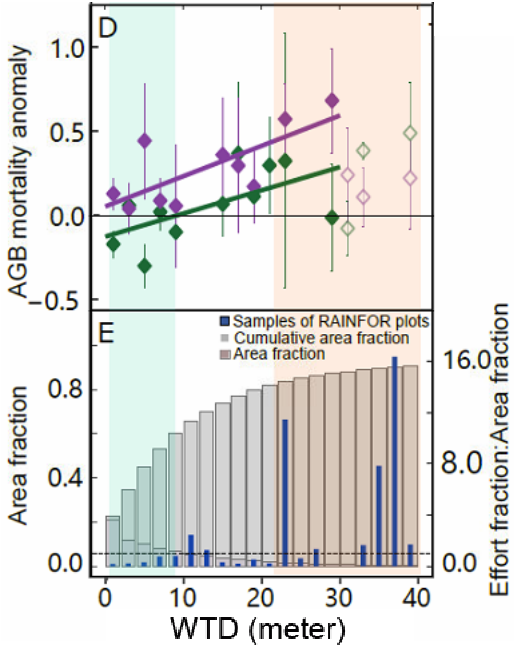
Model: ΔEVI ~ ΔPAR+ ΔVPD+ ΔP+ ΔMCWD+ Drought Length + HAND + All pairwise interactions.

Consistent decreasing patterns dependence on WTD with variability in mean drought responses were observed in Southern Amazon;

Chen, et al., *Nature*, 2024

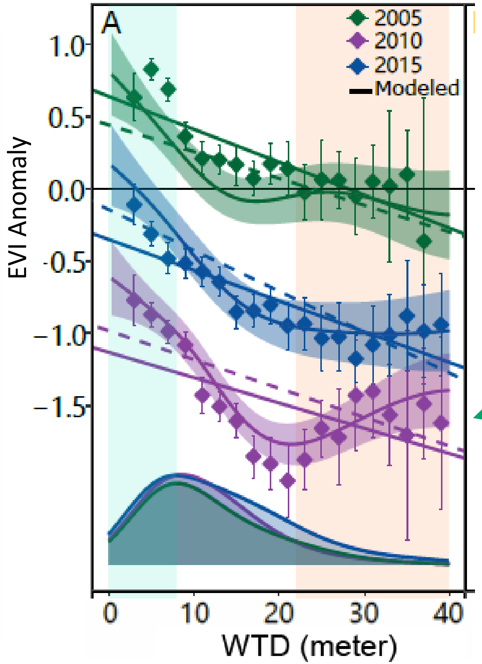
H1 – "Other side of drought": all three droughts, Southern Amazon only

Consistent with plot mortality



Brienen et al 2015

Consistent support of "other side of drought" (negative slope) across droughts



But why are drought responses so different?

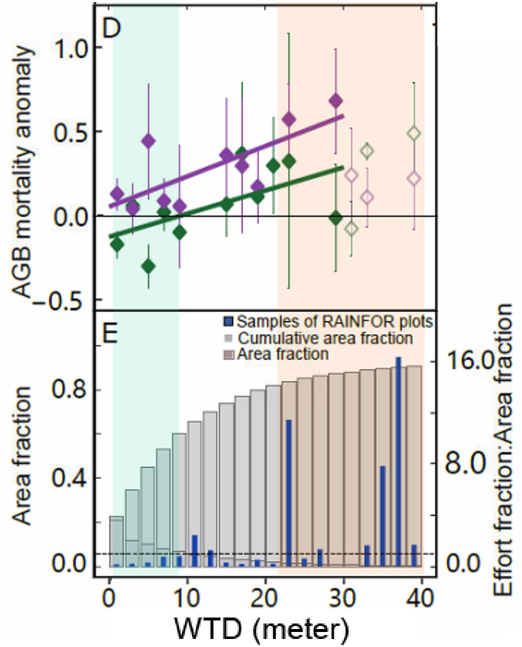
Shuli Chen et al, Nature, 2024

Shaded area = Statistical General Additive Model (GAM) prediction

Model: ΔEVI ~ ΔPAR+ ΔVPD+ ΔP+ ΔMCWD+ Drought Length + HAND + All pairwise interactions

H1 – “Other side of drought”: all three droughts, Southern Amazon only

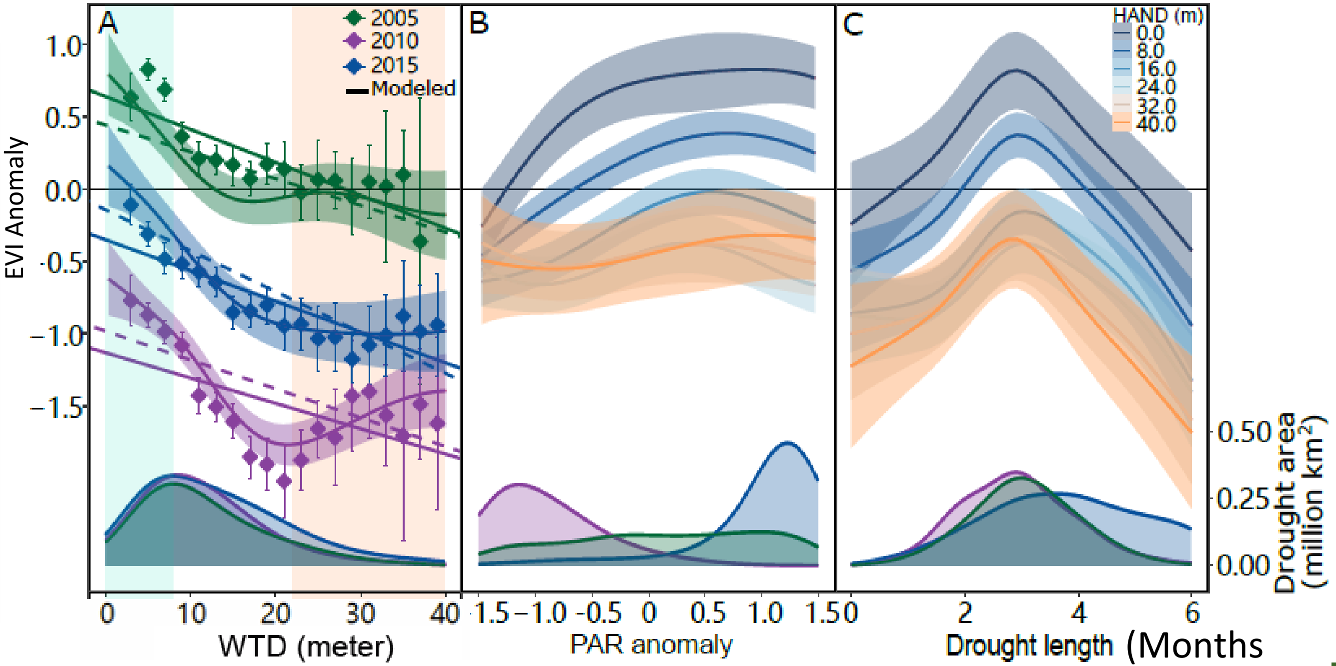
Consistent with plot mortality



Consistent support of “other side of drought” (negative slope) across droughts

1: excess PAR/HAND interaction

2: drought duration / WTD interaction

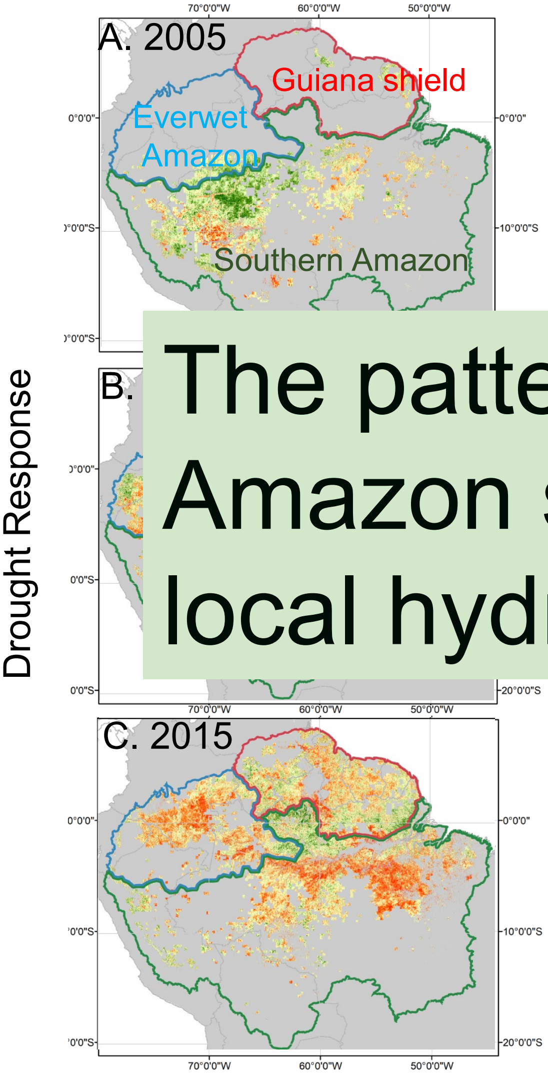


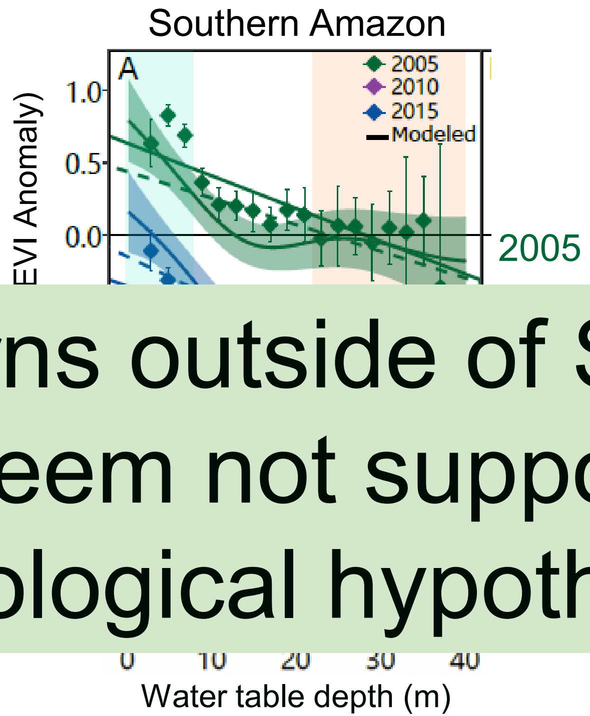
Brienen et al 2015

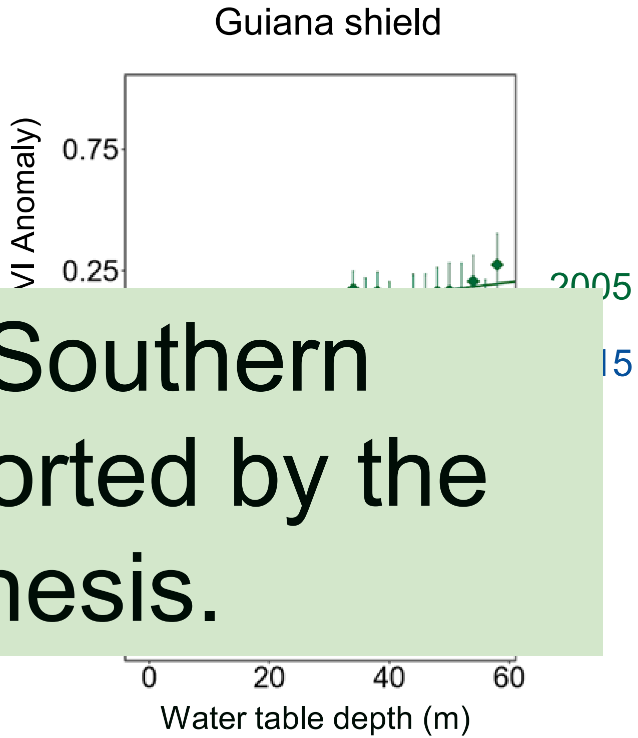
Shuli Chen et al, Nature, 2024

Shaded area = Statistical General Additive Model (GAM) prediction

Model: $\Delta EVI \sim \Delta PAR + \Delta VPD + \Delta P + \Delta MCWD +$ Drought Length + **HAND + All pairwise interactions**







The patterns outside of Southern Amazon seem not supported by the local hydrological hypothesis.

Drought responses were driven by local hydrological gradients in Southern Amazon;
But the trend is very different from regions outside of Southern Amazon.

Chen, et al., *Nature*, 2024.

2. What are the mechanisms that drive forest photosynthetic response to climate?

Hypotheses: geographically distributed mechanisms of drought response

- 1. Different hydrological Environments:
- 2. Different edaphic environments:
- 3. Different ability of trees to tolerate drought:

Other side of Drou... Hypothesis: shallow... forests better acc... better drought per... et al. 2022)

Proximity of water to trees

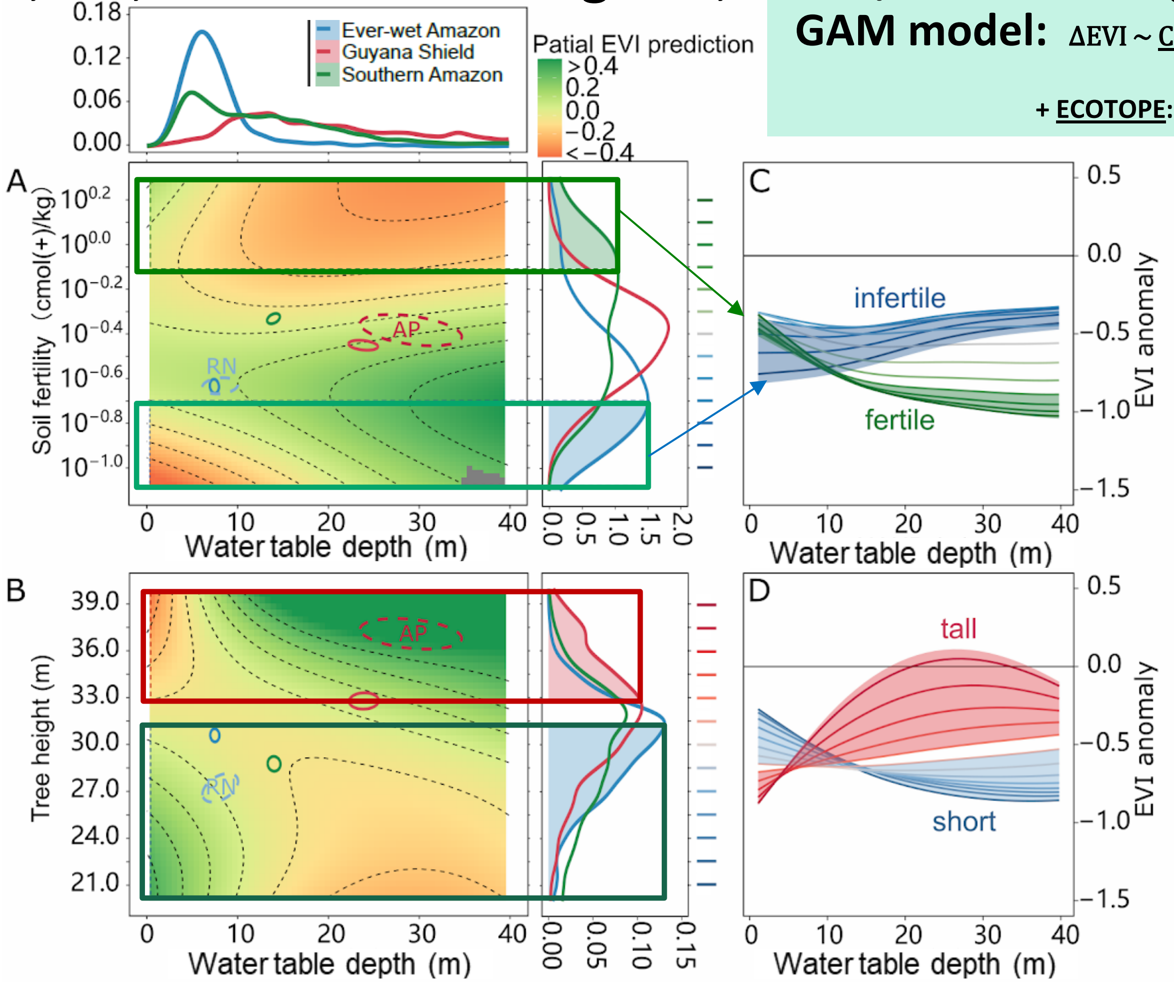
"Edaphic/soil fertility" hypothesis: fertile forests, where growth/turnover is high, invest less in drought resistance... quickly following rare dro... drought performance (Oliveira et al 2021)

Soil fertility

"rooting depth/traits" hypothesis: forests dominated by avoidance traits (tall trees with deep roots) or tolerance (embolism resistance, wood density) → better drought pe... (Chitra-Tarak et al 2021; McDowell et al 2008; ter Steege et...

Proximity of trees to water

H1, H2, H3 –all three regions, 2015/2016 drought only



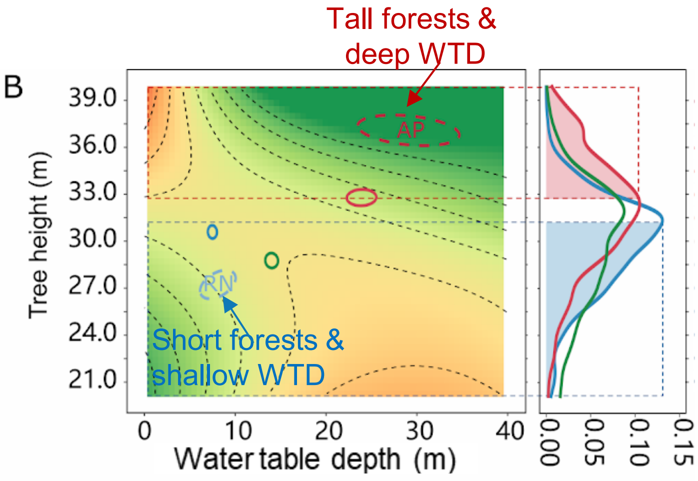
GAM model: $\Delta EVI \sim$ <u>CLIMATE</u>: $\Delta PAR + \Delta VPD + \Delta P + \Delta MCWD$ + Drought Length + <u>ECOTOPE</u>: + WTD + SoilFertility + TreeHeight

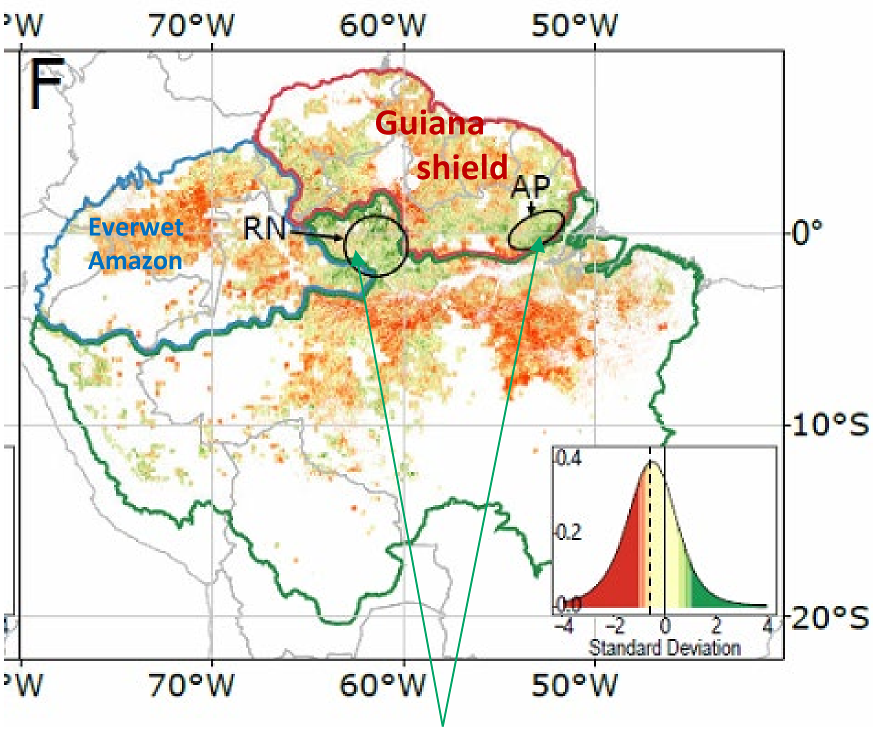
Ecotopes are important in structuring biogeography of forest drought response:

1. **ecotope GAM Models more predictive**
   - <u>R2 = 0.25</u> (climate only)
   - <u>R2 = 0.37</u>(Climate+ecotope)
2. **GAM model reveals different greenup/browndown mechanisms in different ecotopes**

Chen, et al., *Nature*, 20

H1, H2, H3 –all three regions, 2015/2016 drought only



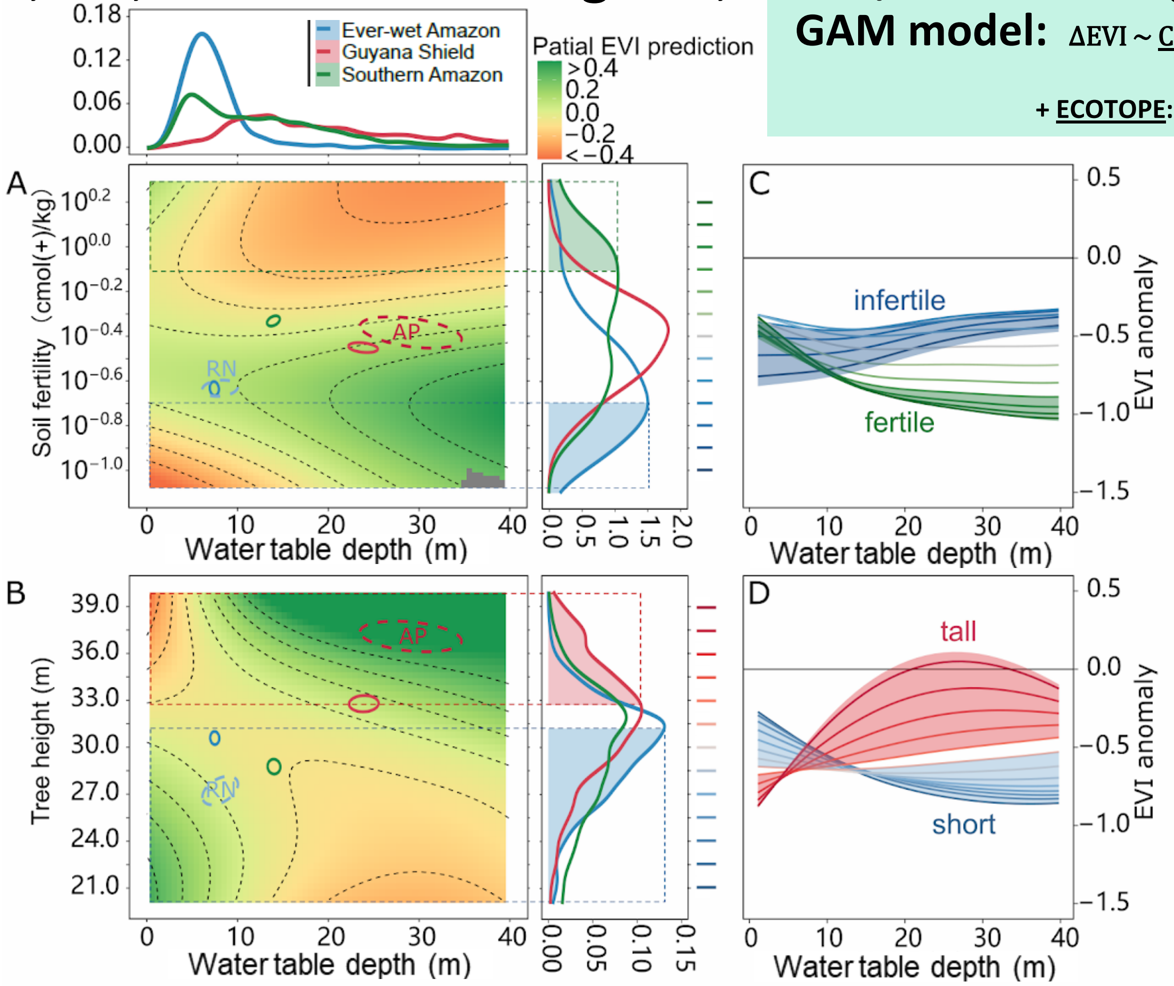


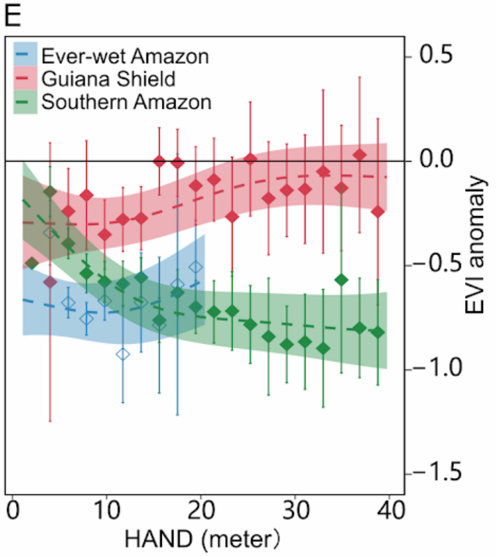
GAM model fit Reveals different greenup mechanisms in different forest ecotopes

Chen, et al., *Nature*, 2024.

H1, H2, H3 –all three regions, 2015/2016 drought only

GAM model: $\Delta EVI \sim$ <u>CLIMATE</u>: $\Delta PAR + \Delta VPD + \Delta P + \Delta MCWD$ + Drought Length + <u>ECOTOPE</u>: + WTD + SoilFertility + TreeHeight

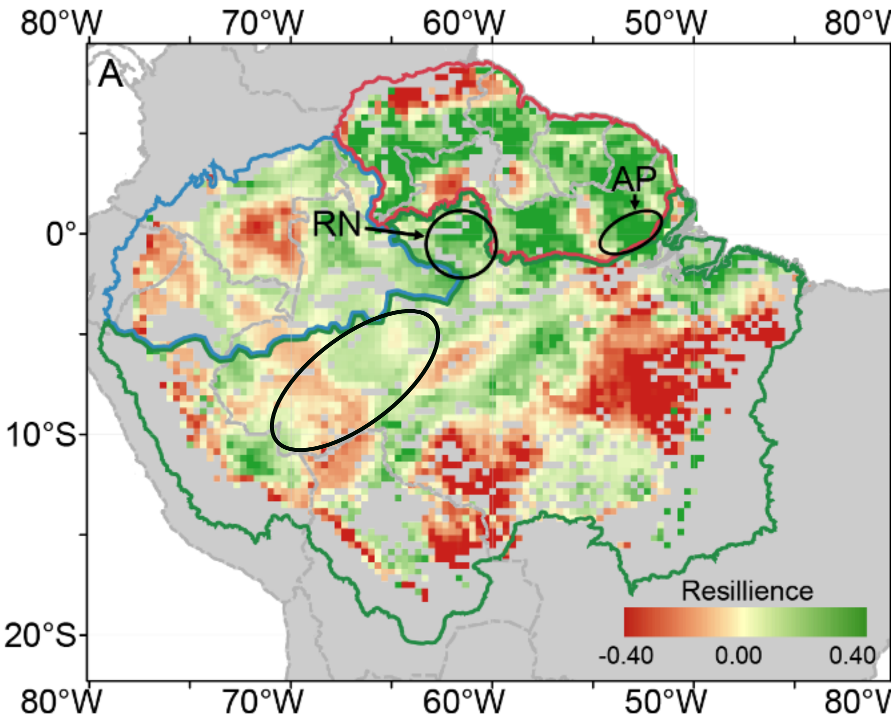




Distinct validated predictions for 3 Amazon regions reveal a **Biogeography of forest drought response**

Chen, et al., *Nature*, 2024.

A biogeography of Amazon forest resilience and vulnerability to drought

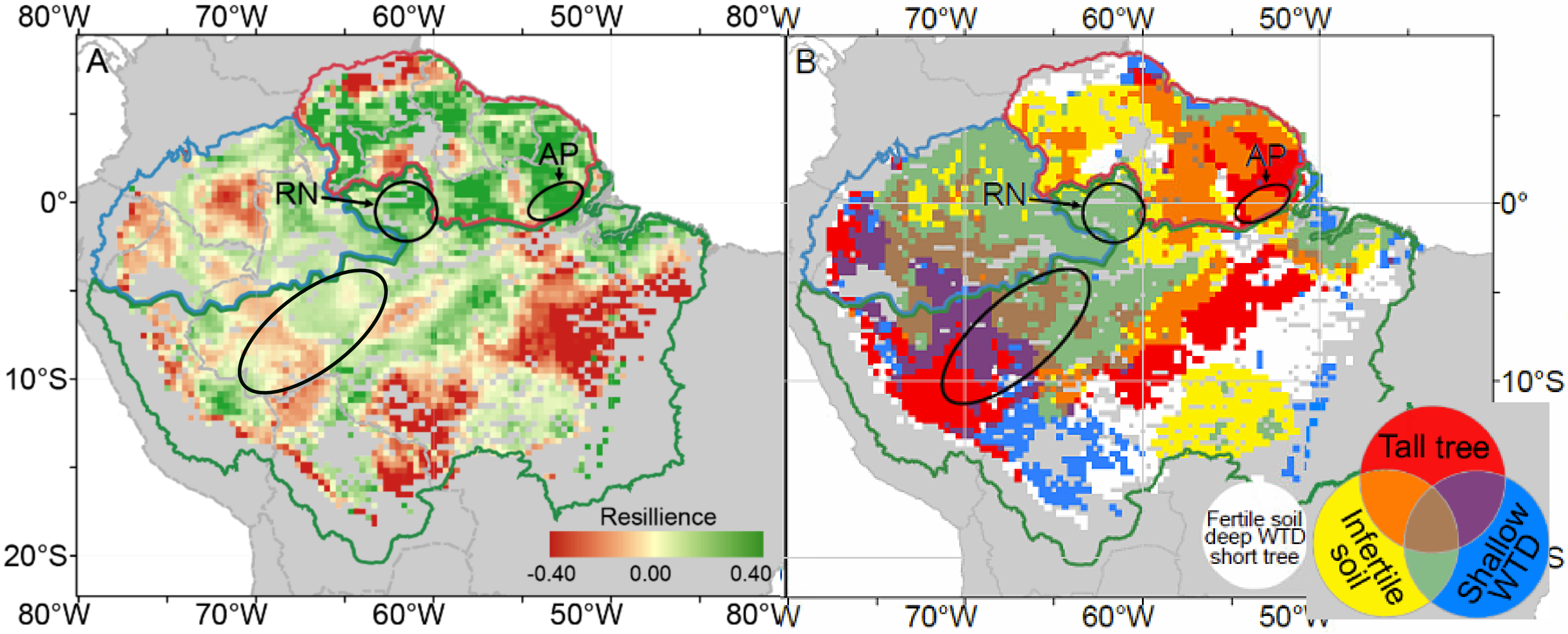


A. Map of GAM-predicted vulnerability (red) and resilience (green)

A biogeography of Amazon forest drought resilience and vulnerability: Regions relatively more resilient (green) or more vulnerable (red) to drought, based on standardized GAM drought response predictions from ecotope factors only (removing effects of climate variability by setting climate equal to its basin-wide average)

Chen, et al., *Nature*, 2024.

A biogeography of Amazon forest resilience and vulnerability to drought

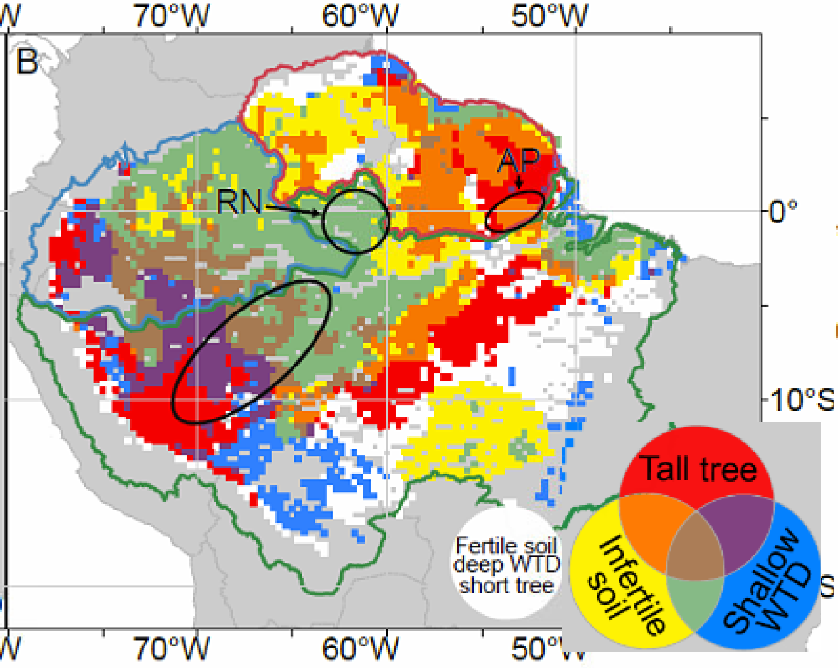


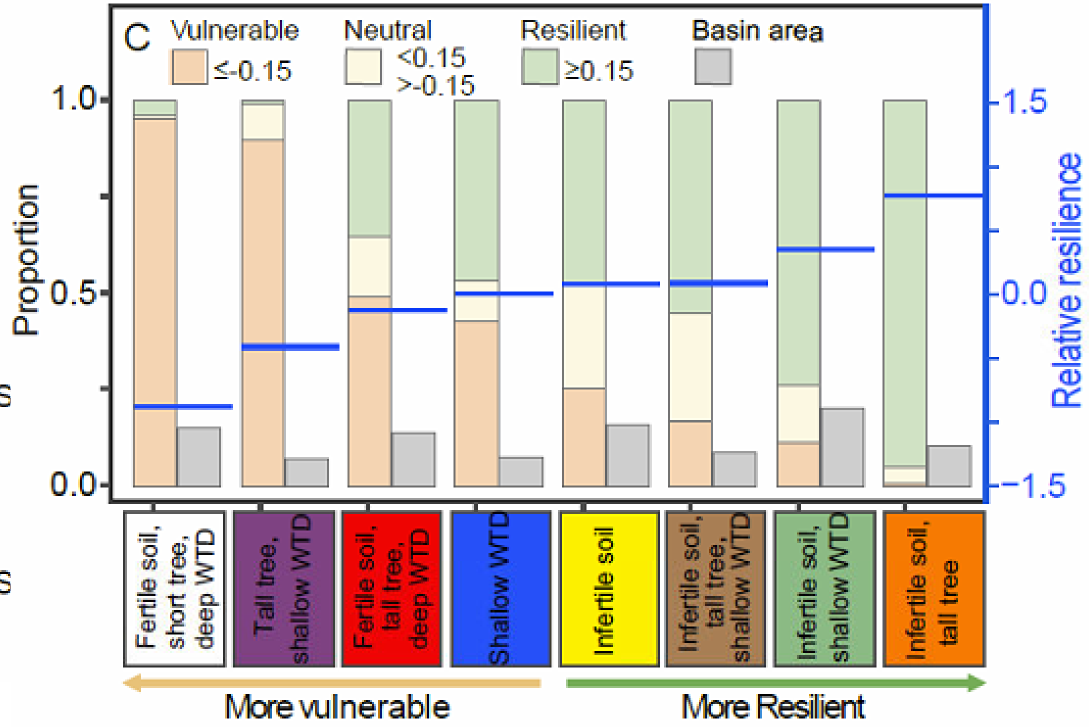
A. Map of GAM-predicted vulnerability (red) and resilience (green)

B. Distribution of Strategies/Ecotopes underlying resilience

Chen, et al., *Nature*, 2024.

A biogeography of Amazon forest resilience and vulnerability to drought



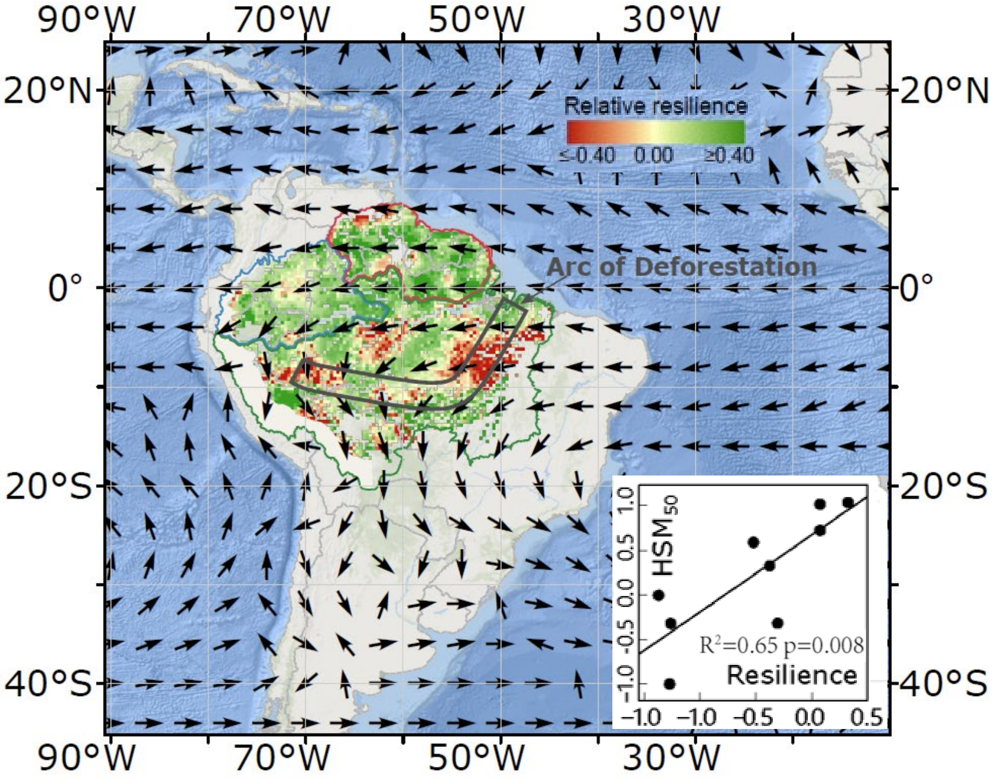


The most resilient forest types were those with in low soil fertility, either in combination with shallow water tables, or with tall deep-rooted forests.

Chen, et al., *Nature*, 2024.

3. Can we predict forest photosynthetic resilience to drought?

--A biogeography of Amazon forest resilience and vulnerability to drought



The most vulnerable forest are predominantly situated under prevailing winds that bring moist Amazonian air to the south, with high risk to maintaining the evapotranspiration that feeds the "atmospheric rivers" to sustain South America's breadbasket in the agricultural regions.

Chen, et al., *Nature*, 2024.

Summary, scaling to the basin via remote sensing

1. Hydraulic environments structure basin-scale drought response: → shallow water table forests persist (or increase) their function during drought, a contrast to deep water table forests.

2. BUT: ecotopes (including fertility, and tree height) matter! Three forest ecotopes show that **water table depth sensitivity**:
   1. … depended on fertility: *fertile areas* (e.g. S. Amazon) support fast-growing but drought-vulnerable trees; these were most strongly protected by shallow WTD; *lower-fertility areas* (in Guiana shield and everwet NW Amazon): less affected by WTD or showed opposite response
   2. … depended on tree-height: tallest/deepest rooted trees enabled green-up (resilience) even in regions (like the Guiana shield) with deeper water tables

What did I learn during this process?

1. What is your motivation? Curiosity or tasks?
2. How important is the topic? There is always more to do! --- To determine your goal is to reveal the unknowns.
3. Don't be discouraged if the results are unexpected.
4. Think broadly and analyze in-depth.
5. Writing is super important!
6. There is always room for improvement

What did I learn during this process?

Stay resilient & insistent!