European Commission

Assessing the relationship between European forest structural diversity and resilience in a warming climate

Mark Pickering, Agata Elia, Marco Girardello, Gonzalo Oton, Matteo Piccardo, Samuele Capobianco, Giovanni Forzieri, Mirco Migliavacca, Alessandro Cescatti

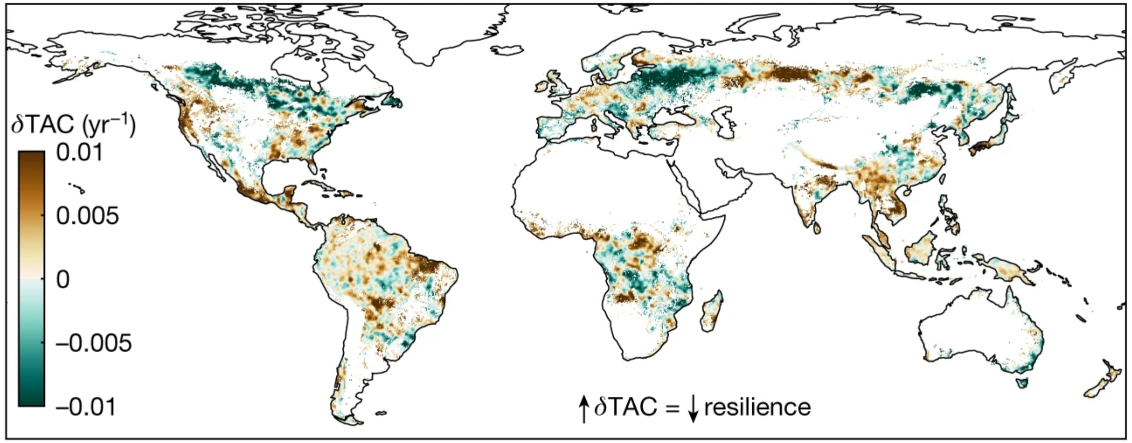
European Commission Joint Research Centre, Ispra, Italy

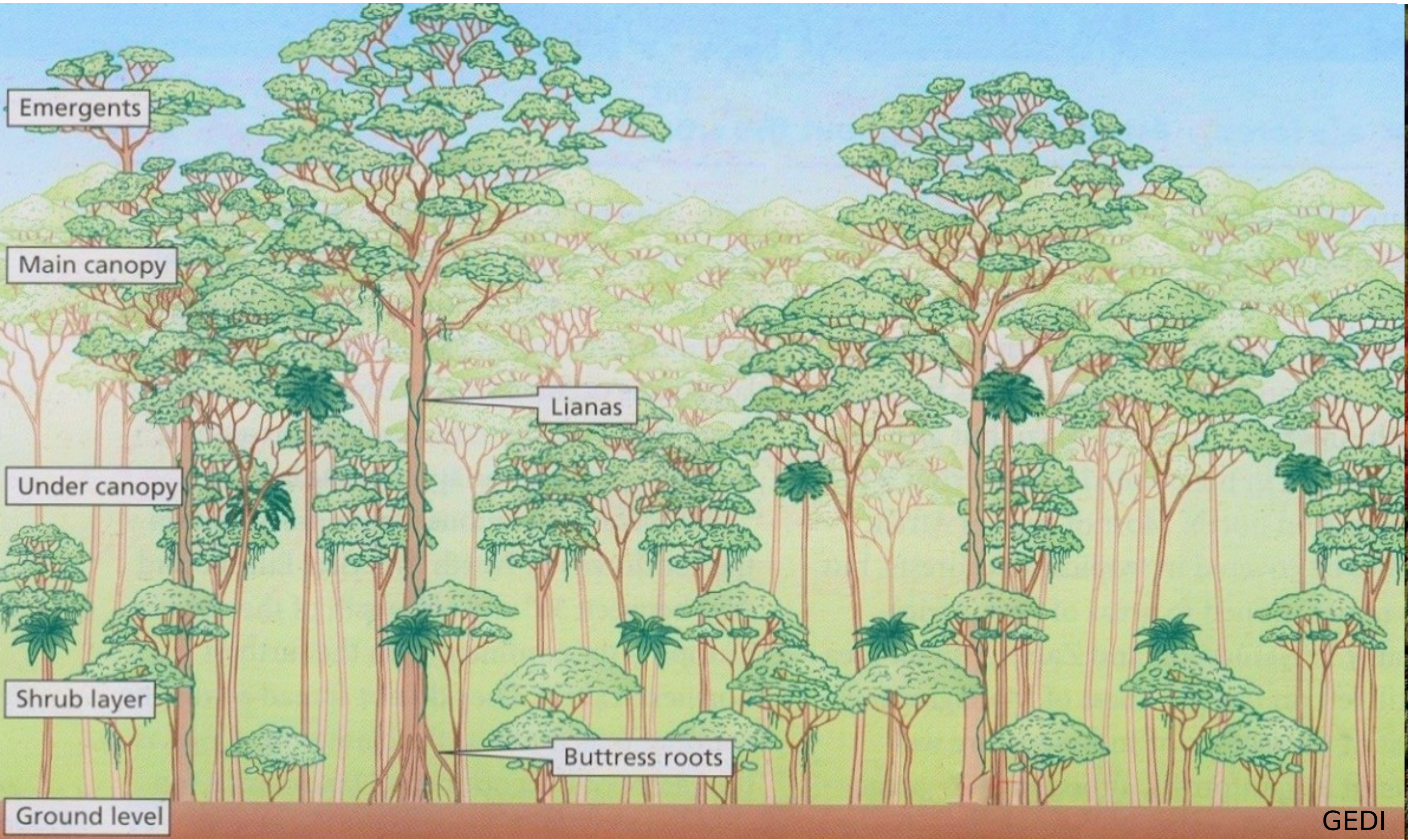
Joint Research Centre

Why?

- We are observing declines in vegetation resilience under climate change
- What makes forests resilient? What can we do?

Forzieri G. et al 2022





GEDI

Simon Fraser University

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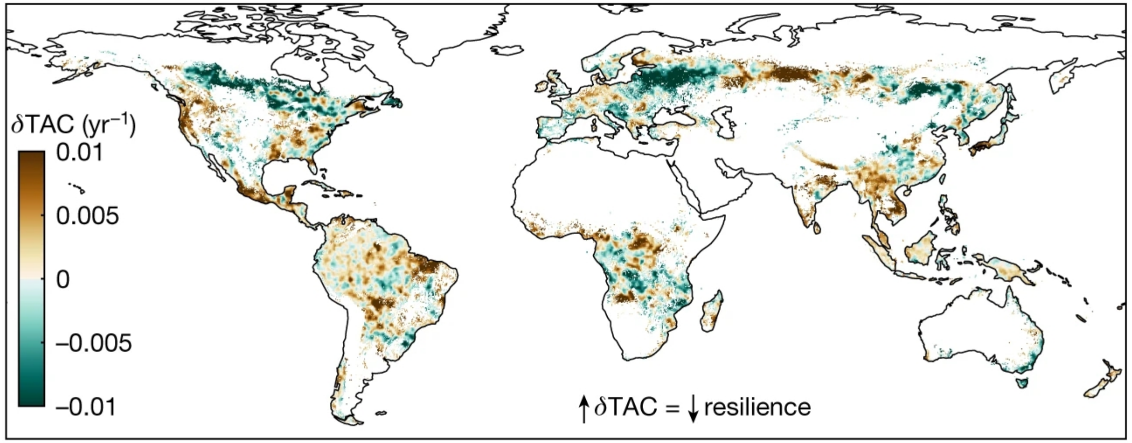
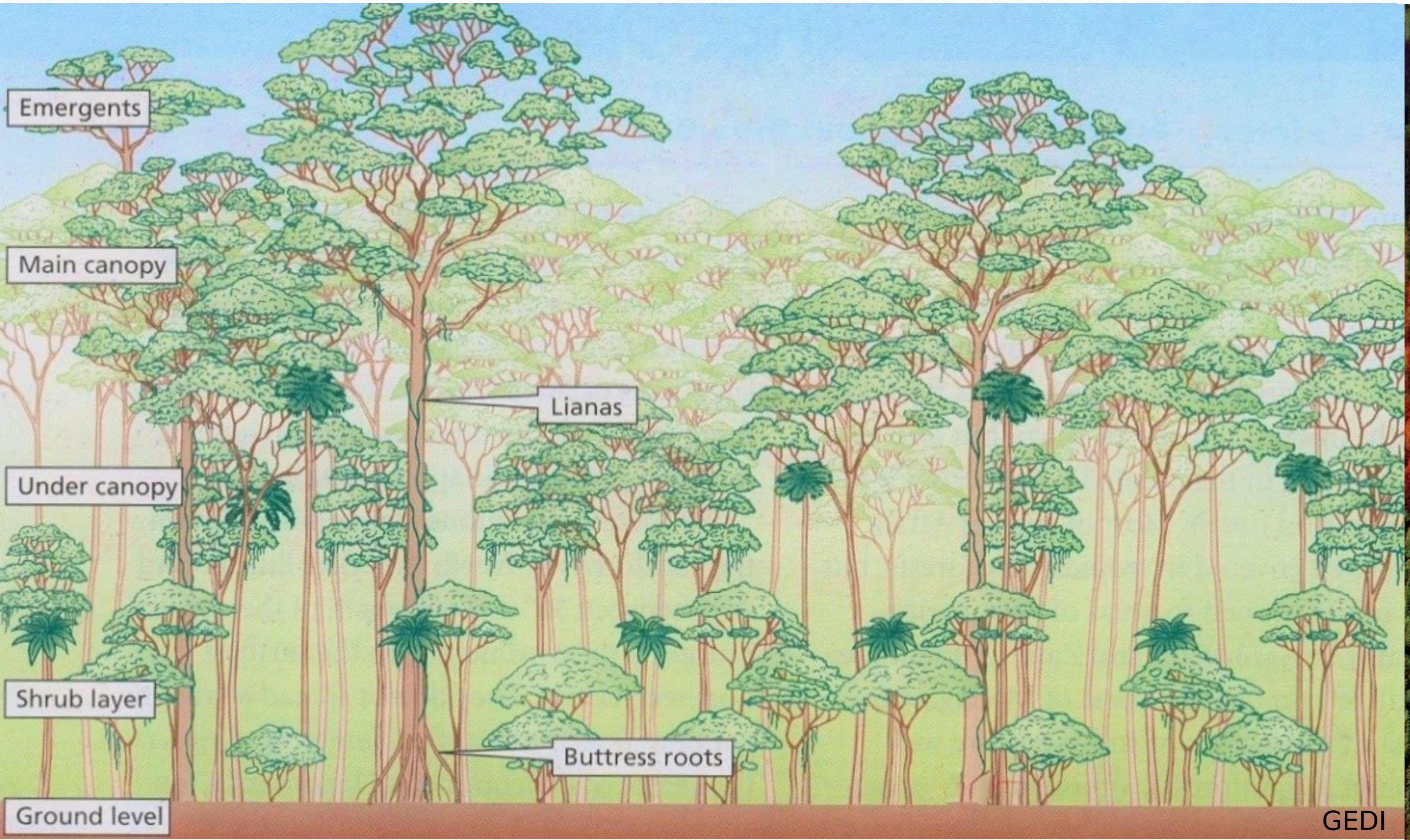




GEDI

nature

Emerging signals of declining forest resilience under climate change

Giovanni Forzieri, Vasilis Dakos, Nate G. McDowell, Alkama Ramdane & Alessandro Cescatti

ARTICLES
https://doi.org/10.1038/s41558-019-0583-9
nature climate change

Reduced resilience as an early warning signal of forest mortality

Yanlan Liu[1], Mukesh Kumar[1,2*], Gabriel G. Katul[1,3] and Amilcare Porporato[4,5]

nature climate change
ARTICLES
https://doi.org/10.1038/s41558-022-01287-8
Check for updates
OPEN

Pronounced loss of Amazon rainforest resilience since the early 2000s

Chris A. Boulton[1], Timothy M. Lenton[1] and Niklas Boers[1,2,3]

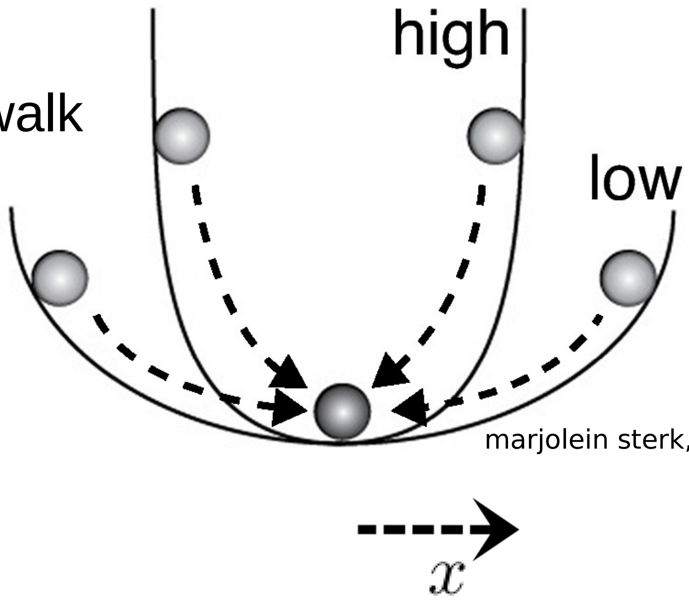
Resilience

- Engineering resilience: Restoration rate (λ) at which a system returns to equilibrium

$$\frac{dx}{dt} = \lambda x + \sigma \frac{d\epsilon}{dt} \quad ; \quad x(t) = x_0 e^{\lambda t} + \sigma\epsilon$$

$$x(t_{n+1}) = \alpha x(t_n) + \sigma\epsilon(t_n) + c \quad ; \quad \alpha = e^{\lambda} = AC$$

- With autocorrelation AC, variance V[x] and stochastic term σε
- Defines Ornstein-Uhlenbeck process: mean-reverting random walk



marjolein sterk, 2017

Metrics relating to system memory

$$\text{Rest. Rate AC1} = |\ln(\alpha)|$$

Metric relating to system stability

$$\text{Rest. Rate Variance} = \left|\frac{1}{2}\ln\left(1 - \frac{\sigma^2}{V[x]}\right)\right|$$

Rates often defined as negative (restoring equilibria) in literature
Here we consider the absolute value such that ↑ Rate = ↑ Resilience
As rates approach zero we see slowness in the system (CSD)

Smith, Taylor and Boers, Niklas, 2023 ; Scheffer, Marten et al. 2009

Vegetation data

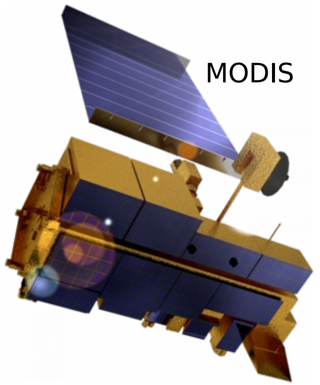
- Resilience in proxy for forest productivity

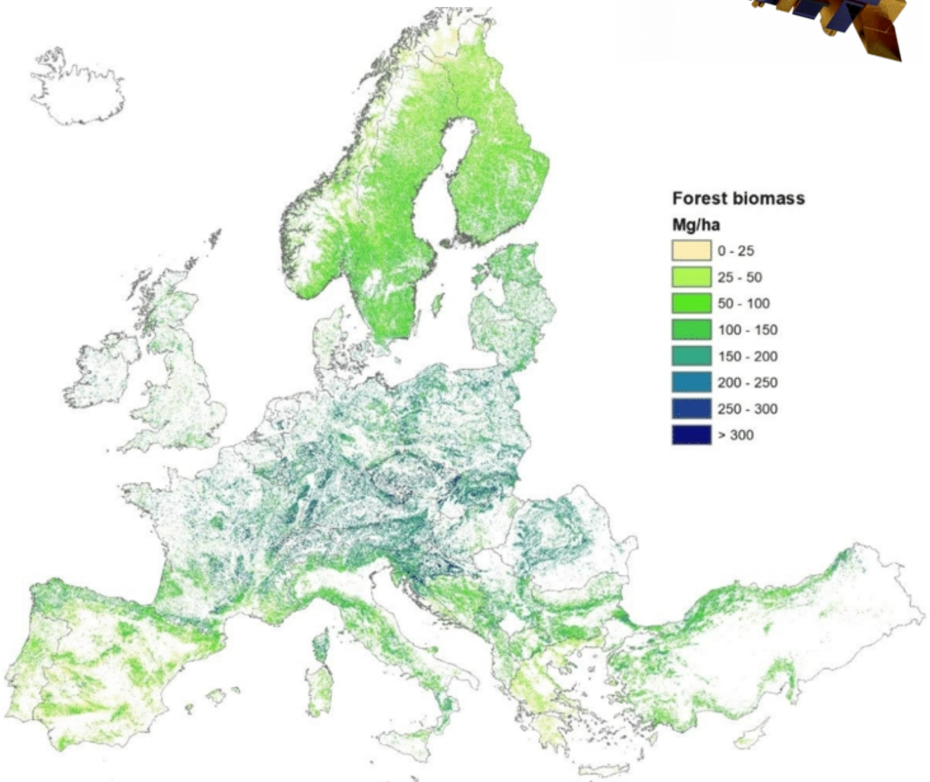
$$\mathrm{kNDVI} = tanh\left(\frac{NDVI^3}{|NDVI|}\right)$$

Camps-Valls et al., 2021

- Take forest masked pixels (500m) removing loss/change
- Remove the dominant seasonal cycle
- Filter (clouds) outlier points
- Correct the long term trend (CO_2 fert, GW, etc)
- Aggregate to 5km

- Result: pixelwise time series of kNDVI perturbations from seasonal average





Avitabile, V, JRC, Forest Biomass Europe, 2020

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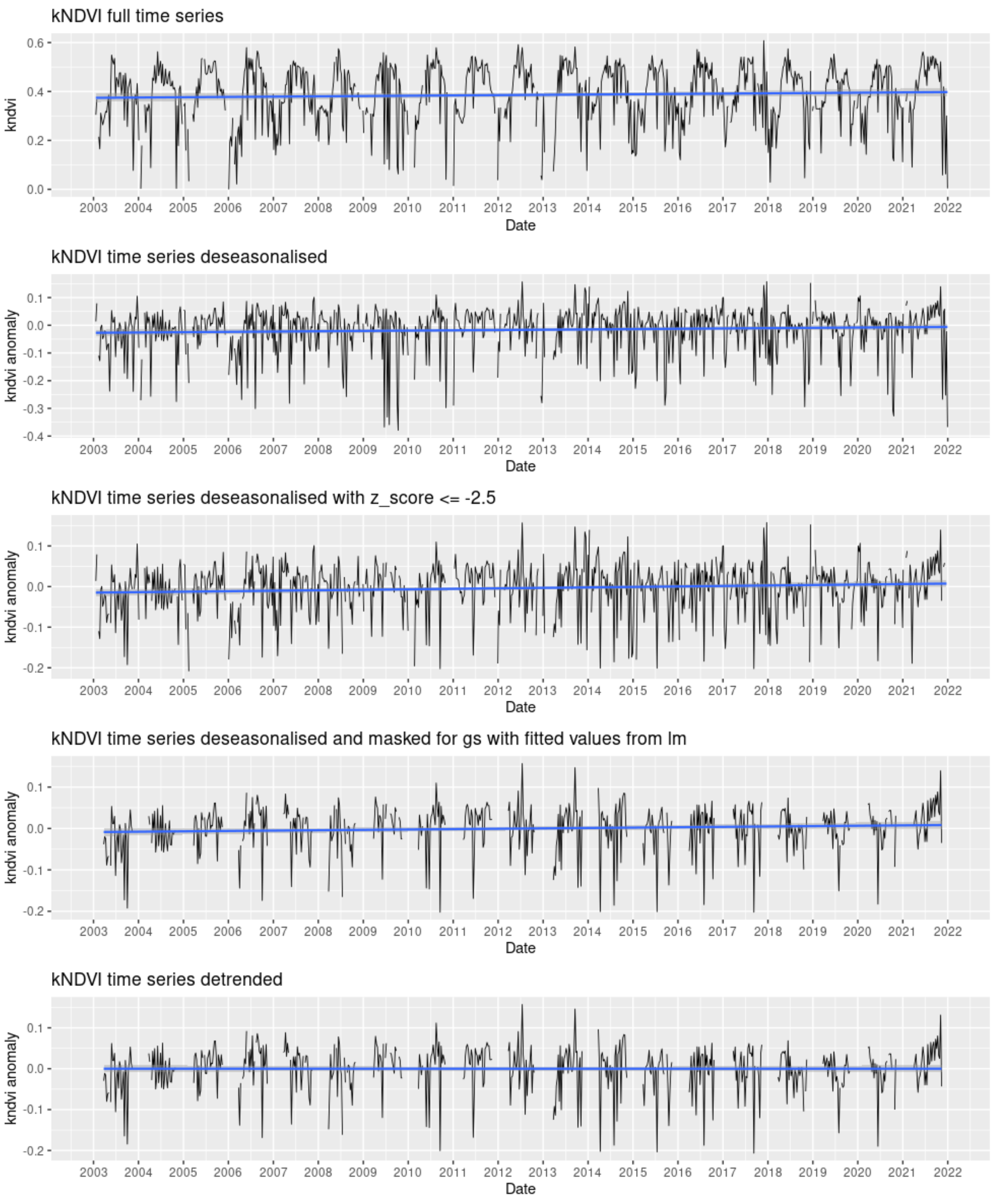

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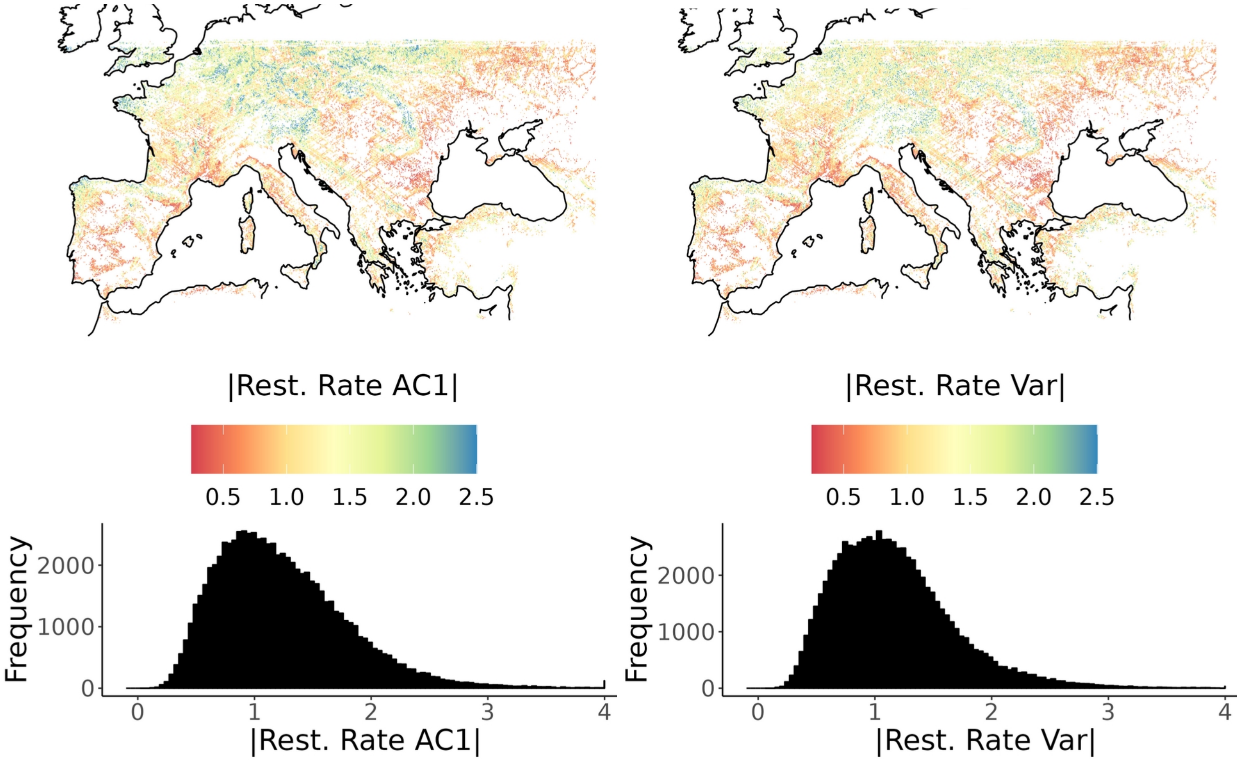


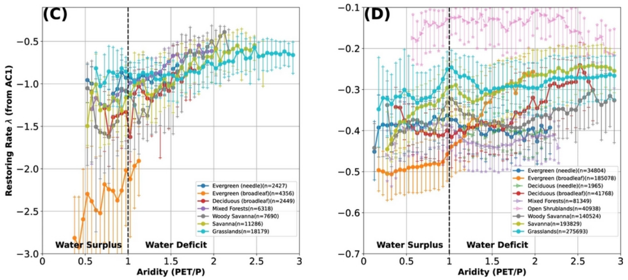
more positive (blue) = lower autocorrelation/variance

But, we can’t compare the ‘resilience’ of spatial pixels yet!

What determines TAC & Variance

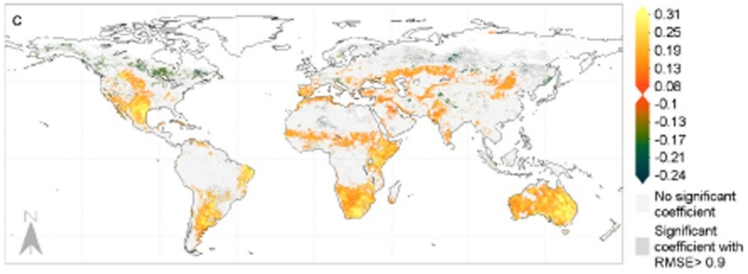
- Aridity dominates
- Short and long term climate factors & variability
- Forest density, soil quality, etc

VOD + NDVI Rest. Rate with aridity



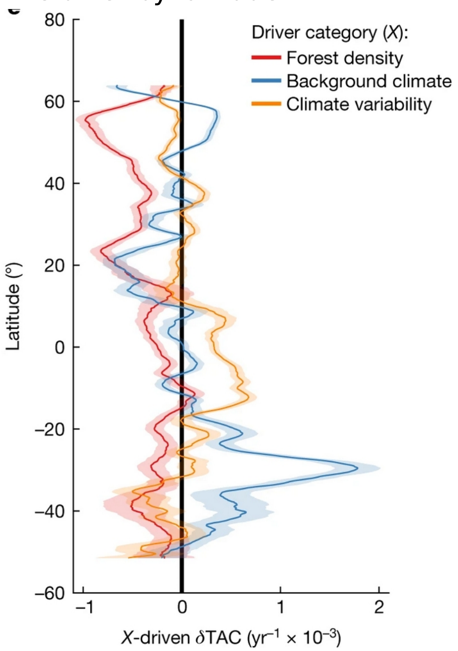
Smith, T and Boers, N 2023

Vegetation resistance against drought

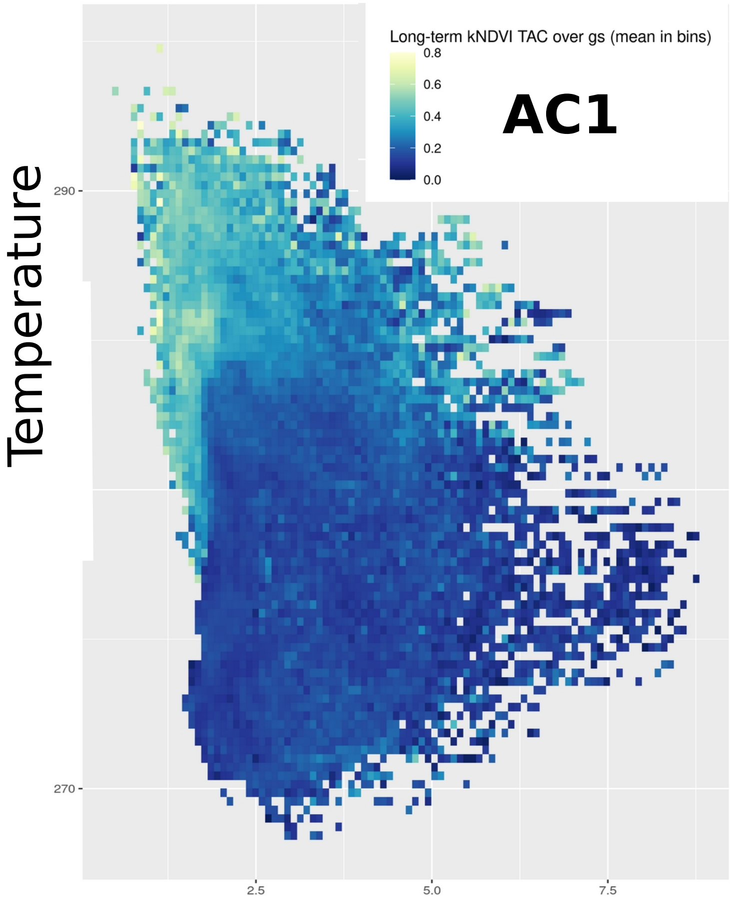


Keersmaecker et al. 2015

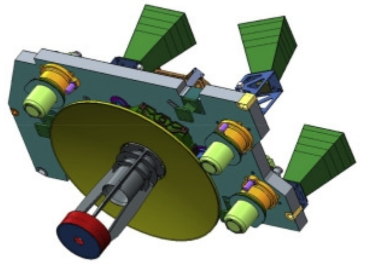
TAC diver by latitude



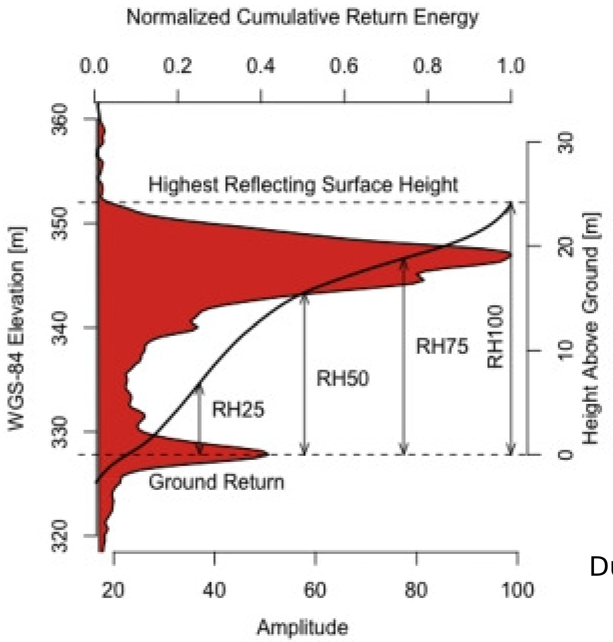
Forzieri G. et al 2022

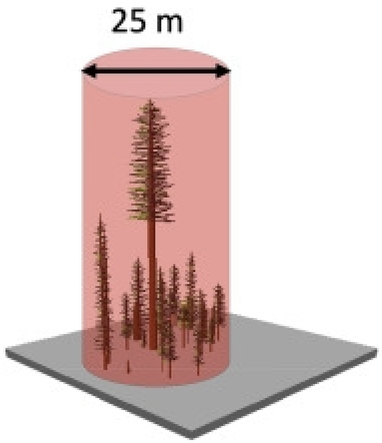


Vegetation Structure



- GEDI maps forest Lidar waveform from ISS
- Gives us relative canopy heights (RH) and forest canopy cover

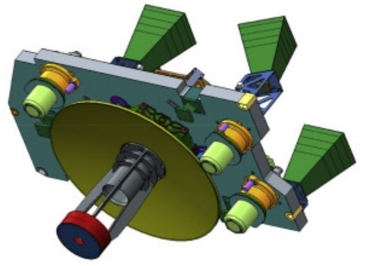




Dubayah, R., (2020)

Structural Diversity

GEDI



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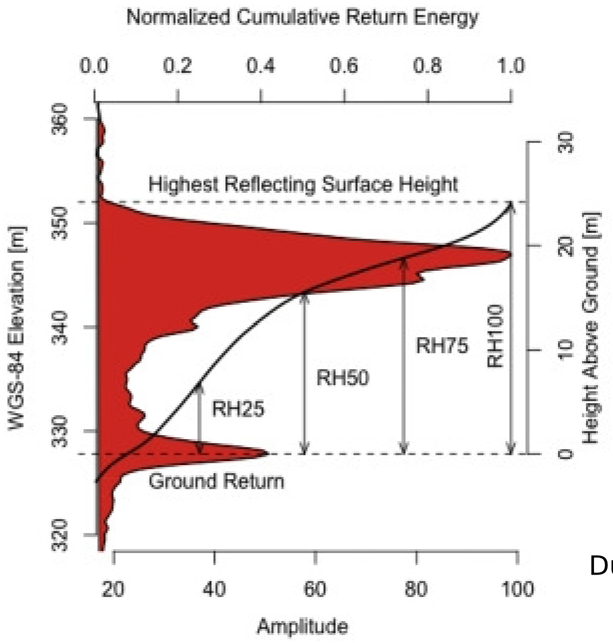

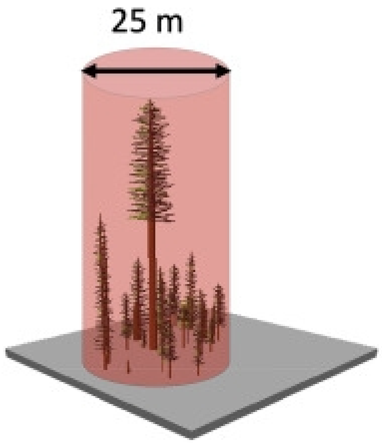

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Horizontal

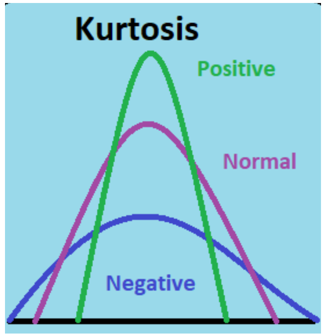
$$\text{S.D. in RH98} = \sqrt{\frac{1}{N}\sum_{i=1}^{N}\left(RH98_i - \mu(RH98) \right)^2}$$

Higher S.D. = More diversity in canopy height

Horizontal & Vertical

$$\text{Shannon Entropy} = -\sum p_i \, log(p_i)$$
$$\{RH50, RH75, RH98, CC\}$$

Higher Entropy = More diversity in canopy structure



Vertical

$$\text{Excess kurtosis} = \frac{E[(X-\mu(X))^4]}{(E[(X-\mu(X))^2])^2} - 3$$

More negative = More diversity in vertical structure

See future dataset paper: “A dataset on the diversity of canopy structure of European Forests”
Marco Girardello, Gonzalo Oton, Matteo Piccardo, Mirco Migliavacca, Alessandro Cescatti

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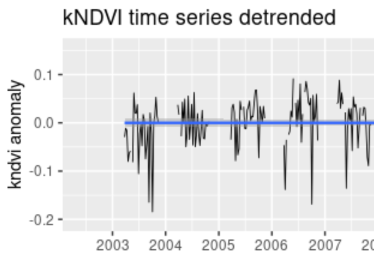
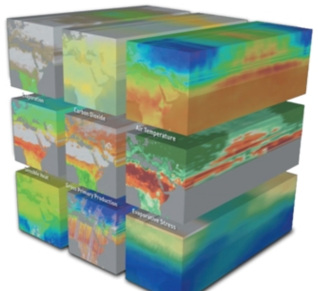
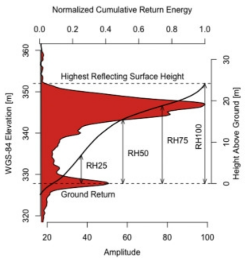
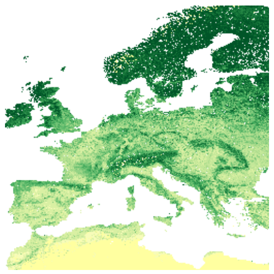
Modelling Framework





Copernicus





OpenLandMap

Time series

Vegetation
KNDVI

MODIS
8-day time series at 500m (2003-2021)

Climate
Temperature
Precipitation
VPD
Solar Radiation

ERA5
8-day time series at 10km (2003-2021)

Long-term/static stats:
- TAC (anomalies)
- Climate variability (CV)
- Background climate (μ)

Static

Structural Diversity
S.D.(RH98)
Shannon Entropy
Excess Kurtosis

GEDI
Single snapshot at 30m (2019-2022)

Other
Topo Diversity
Soil Carbon
Forest Cover

Single snapshot 25m
Single snapshot at 250m
Single snapshot at 30m (2000-2021)

RANDOM FOREST

Restoration Rate =
kNDVI (μ) +
climate (TAC CV μ) +
1 Diversity metric +
FC + SC + Topo div

Outputs:
Feature importance ranking, partial dependence, etc

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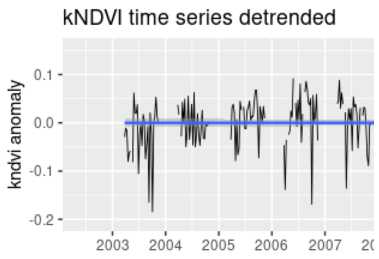
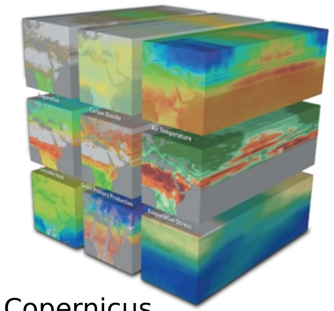
Modelling Framework





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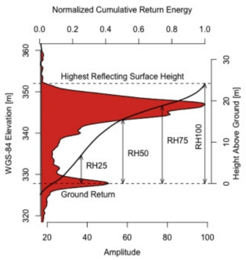

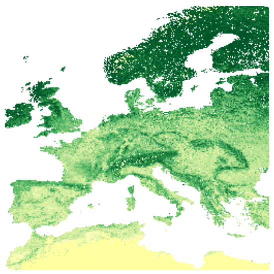

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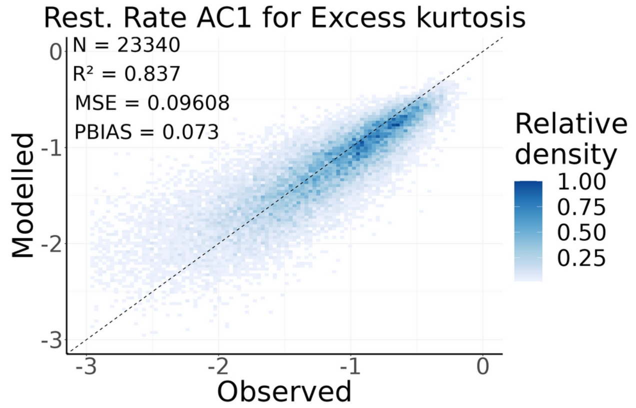

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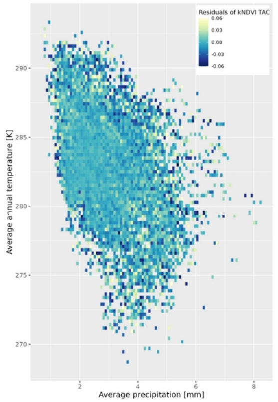

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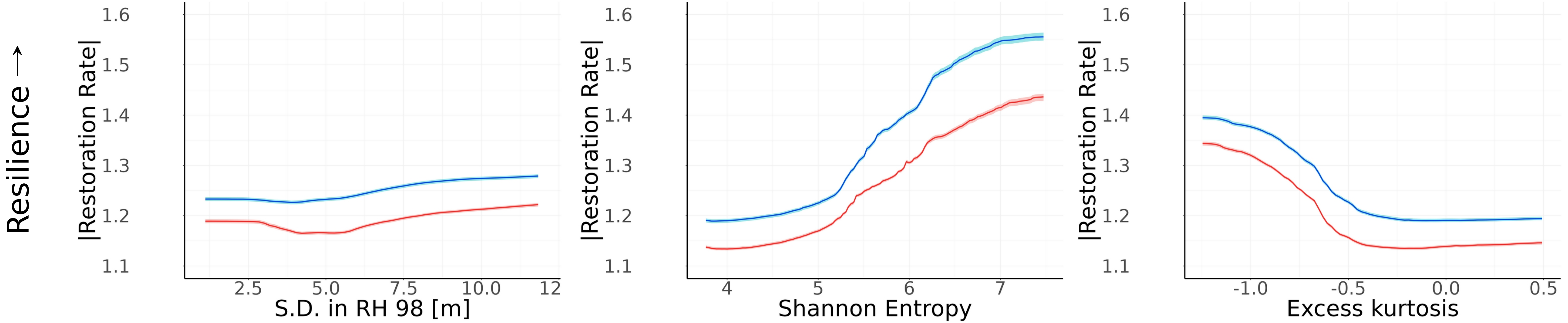
Diversity-Resilience relationship

- Controlling for all the model variables except diversity – what is the effect on resilience?
- Europe-wide relationship between the different diversity and resilience metrics



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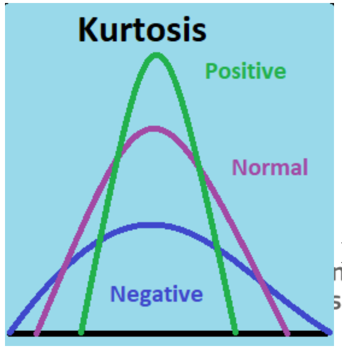
$$\text{Rest. Rate AC1} = |\ln(\alpha)|$$

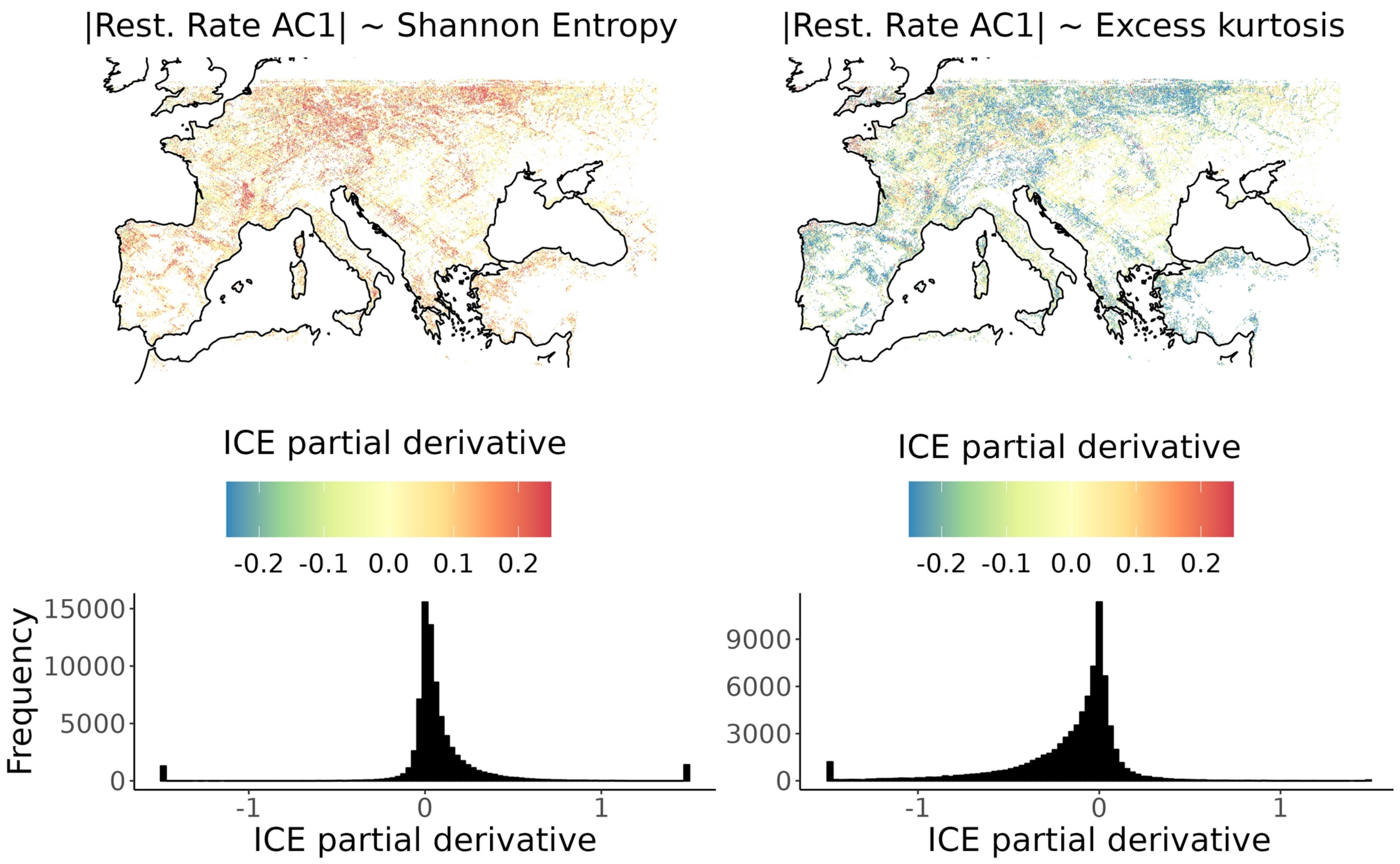
Resilience metric

- Rest. Rate Variance
- Rest. Rate AC1



Diversity-Resilience relationship (local)

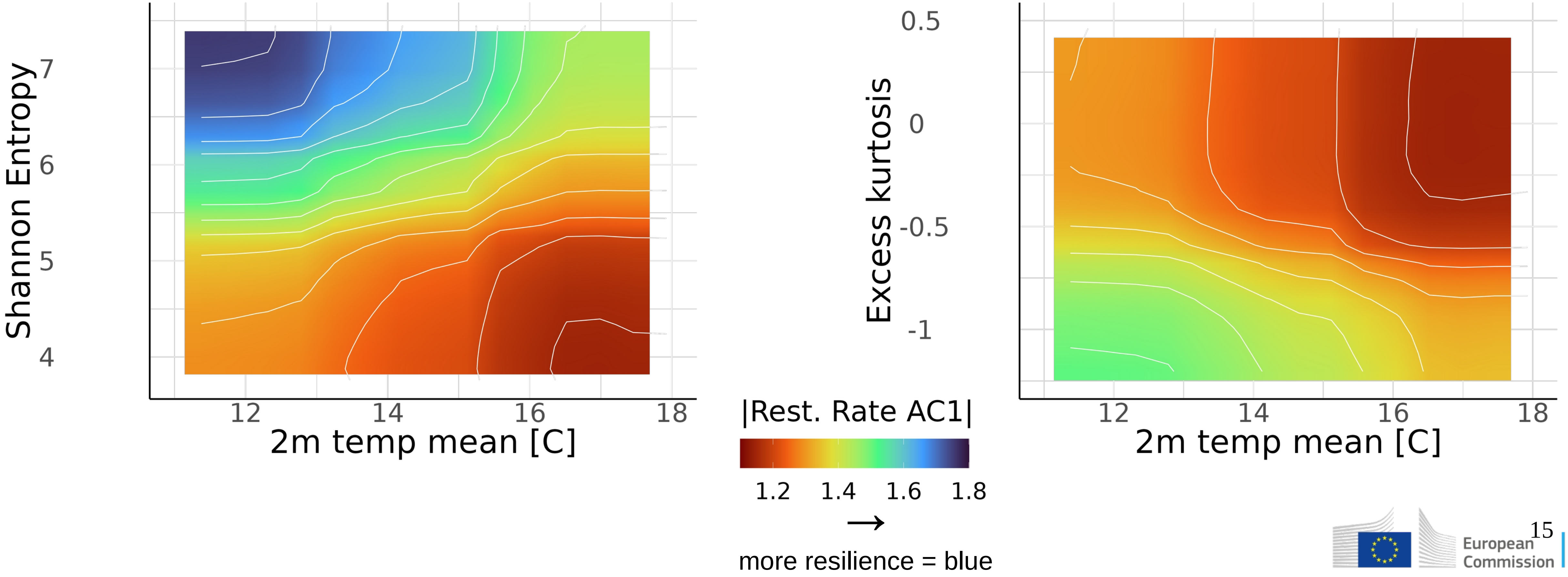
- Individual conditional expectation ICE figures
- Control each variable at the local pixel level value and allow the diversity metric to vary
- Gives the local level relationship direction and strength
- As we increase diversity, resilience metric increases



Diversity-Resilience-Temperature relationship

What is the relationship as a function of temperature?

As temperatures rise, resilience declines – unless diversity also increases



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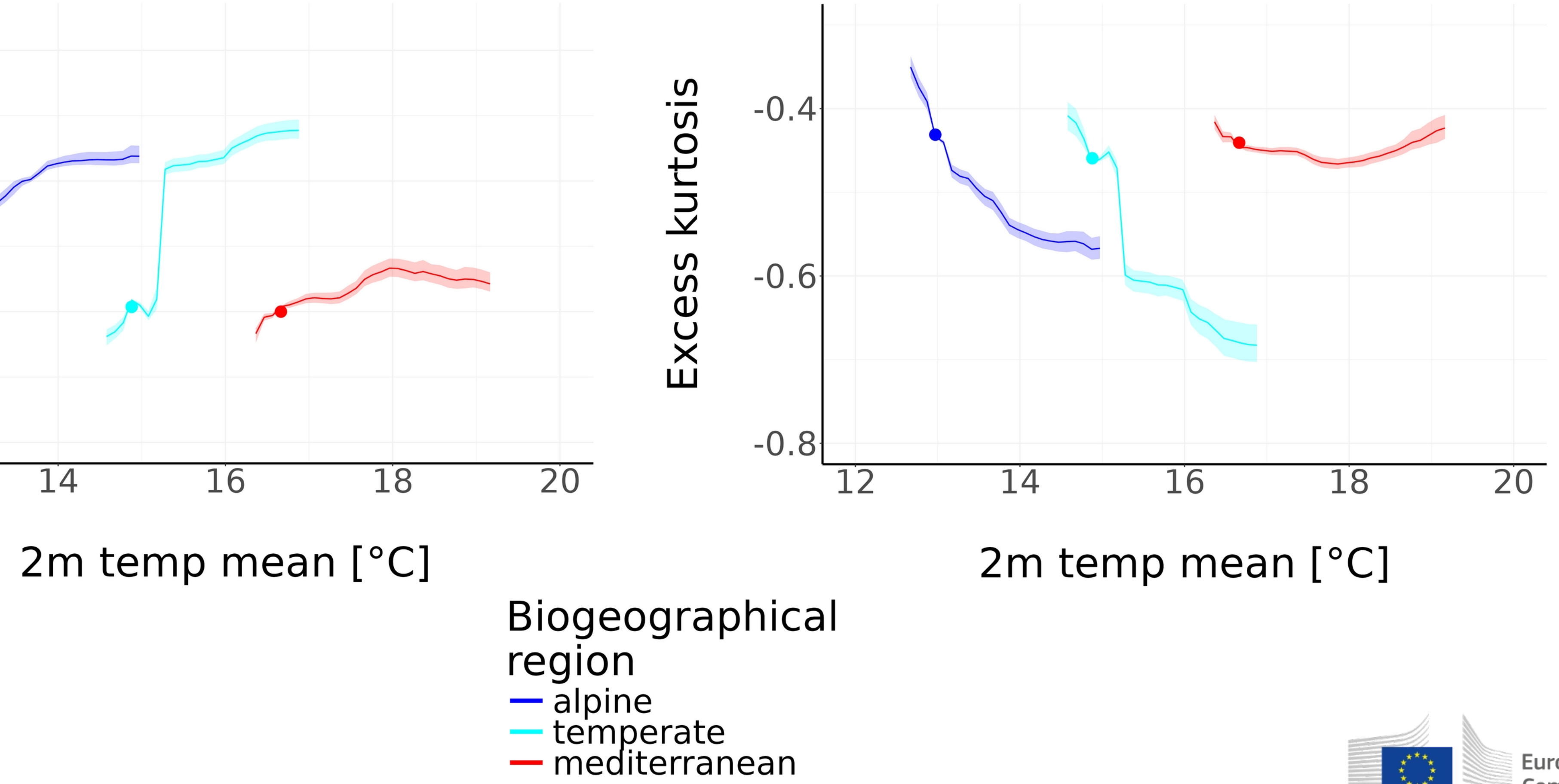
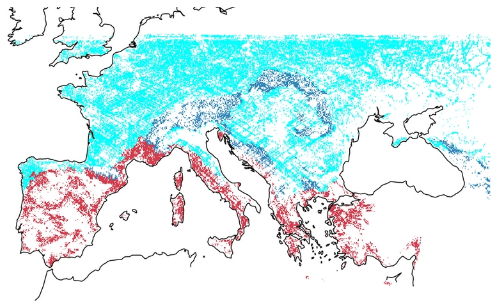
Can diversity offset resilience decline?

Isolines of constant resilience (current mean for that BGR)

As temperatures rise, resilience declines – unless diversity also increases





Summary

- There is a relationship between forest structural diversity and forest resilience: more structurally diverse forests are more resilient.
- Canopy complexity is more important than diversity in forest height
- In the near-term, increases in forest structural diversity may compensate for the resilience loss associated with warming temperatures
- This is particularly true for Mediterranean species which may be more adapted to aridity

Questions?

End

Structural Diversity

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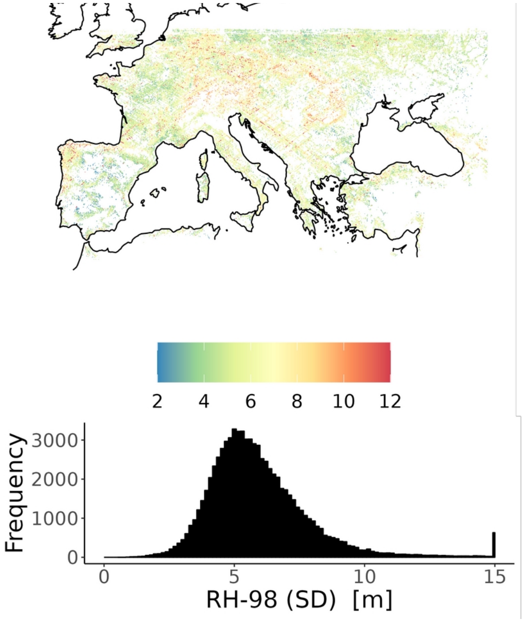
- Several metrics of structural diversity computed across 5km pixel:



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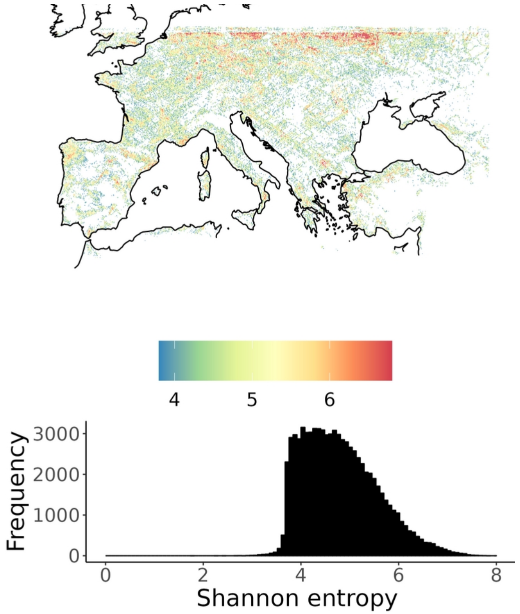

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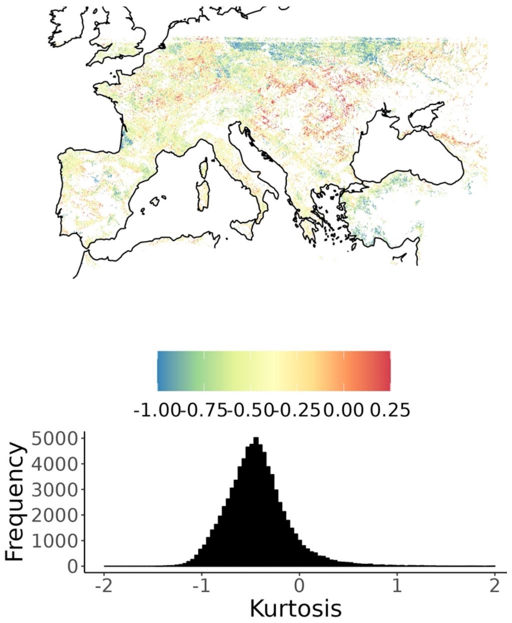
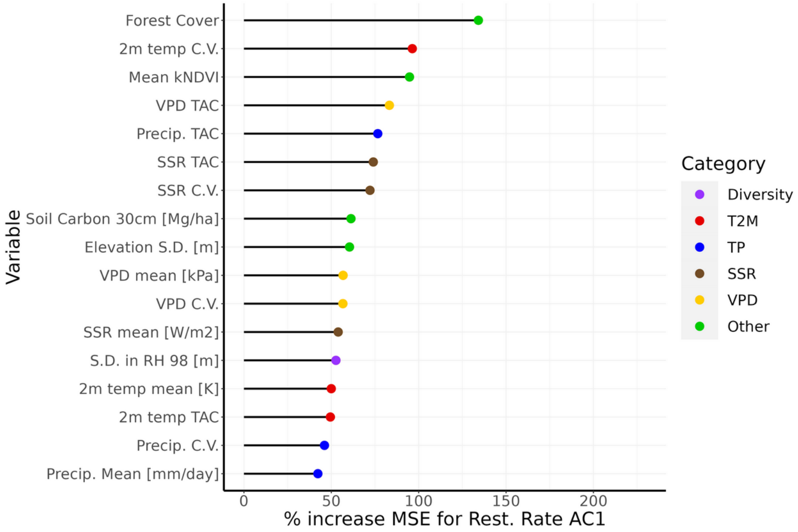
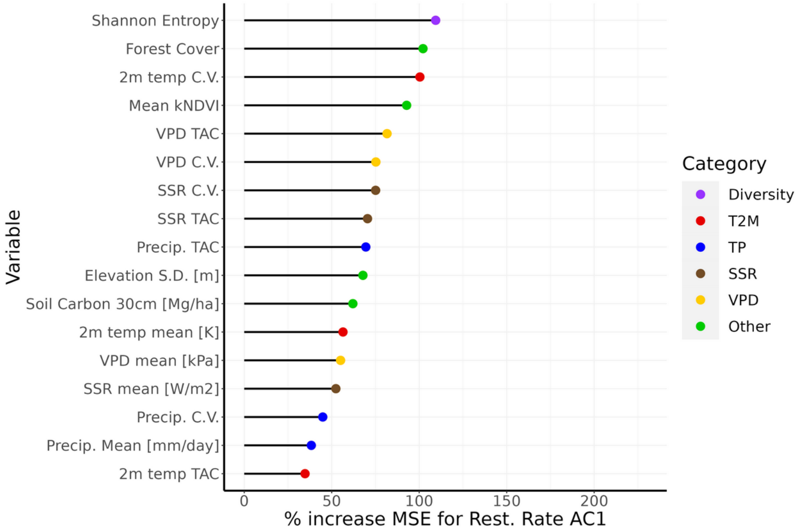
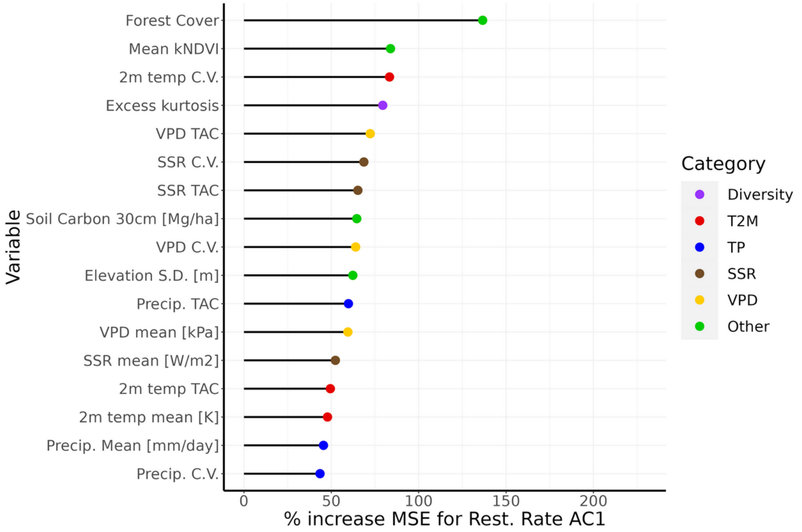


Feature Importance

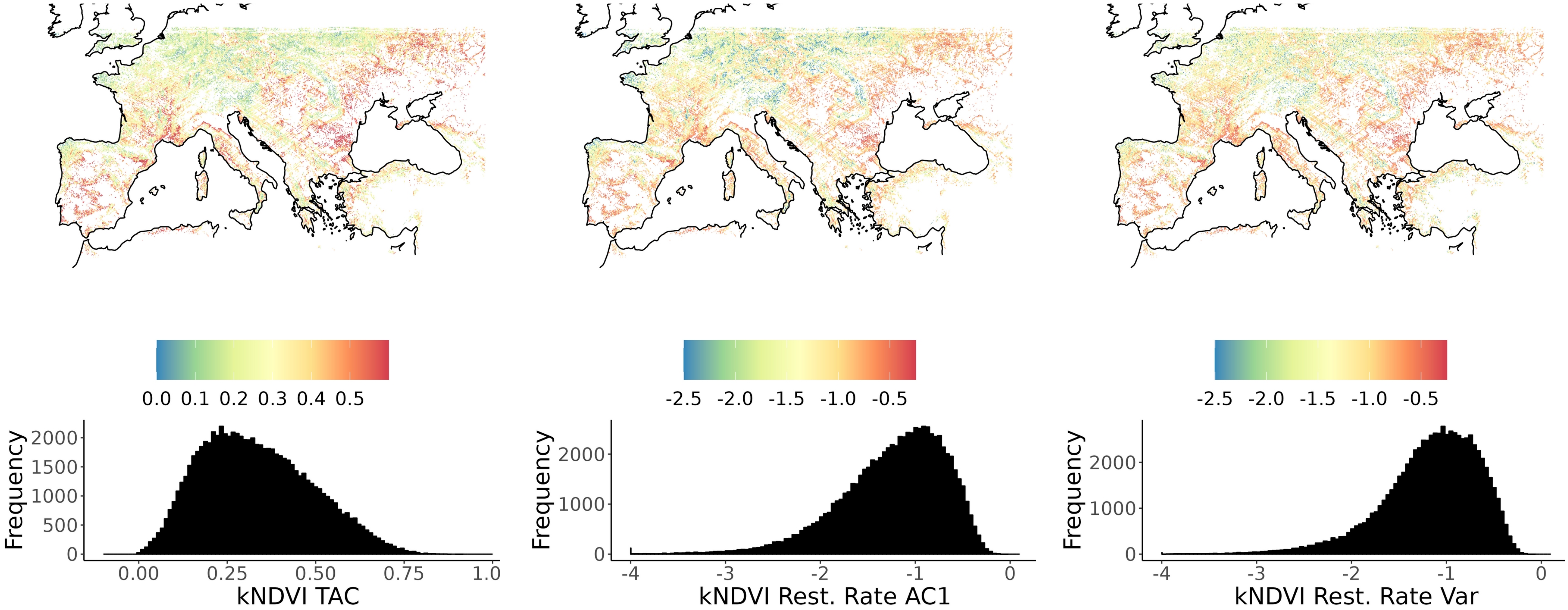
- Build separate models for each diversity metric
- Build separate models for each resilience metric
- Resulting model has high R^2 and low bias
- Different diversity metrics – differences in importance



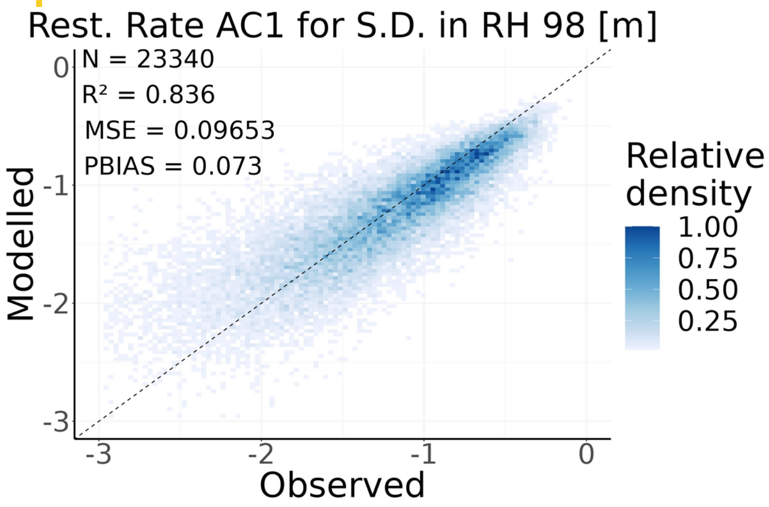


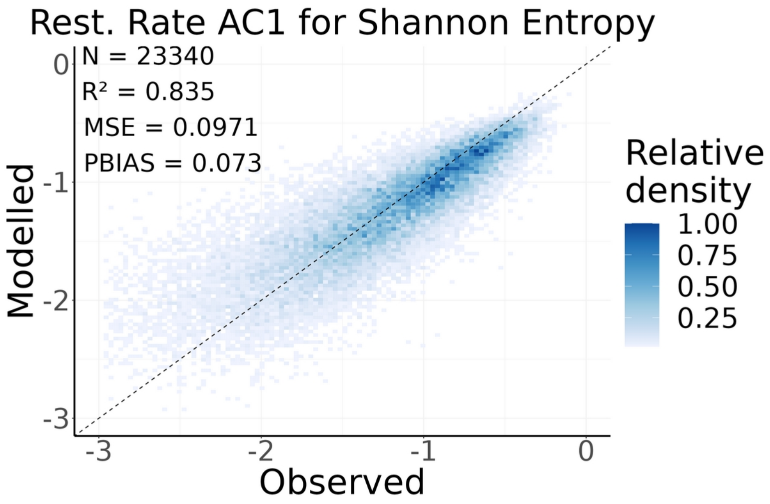


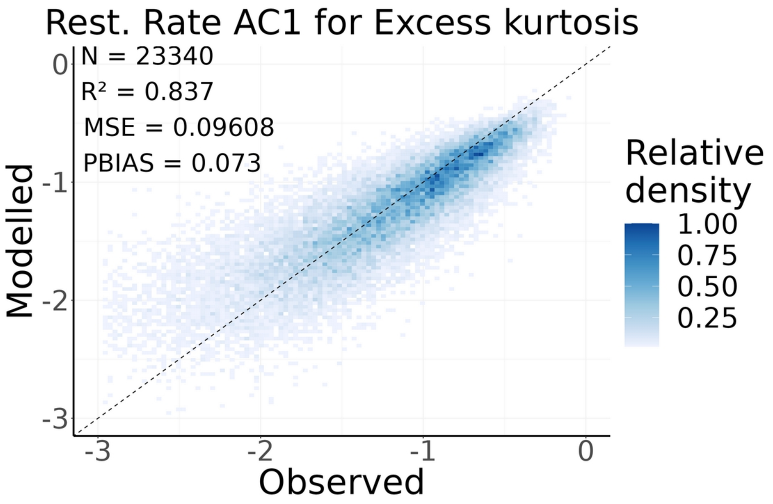
Vegetation resilience

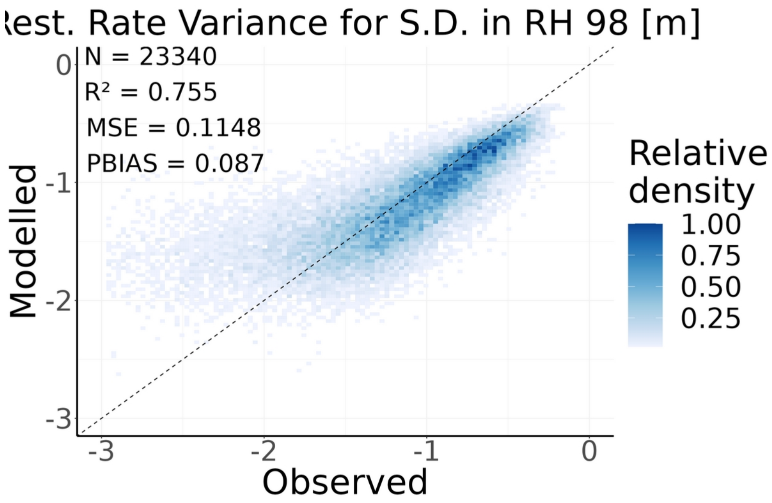


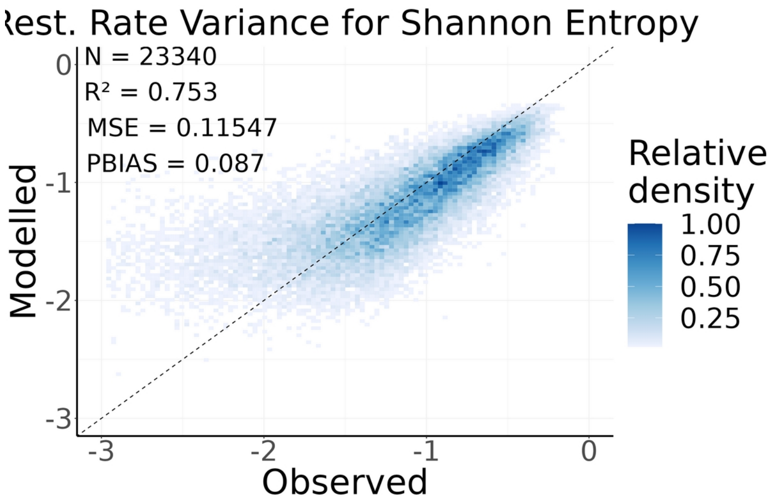
Model Performance

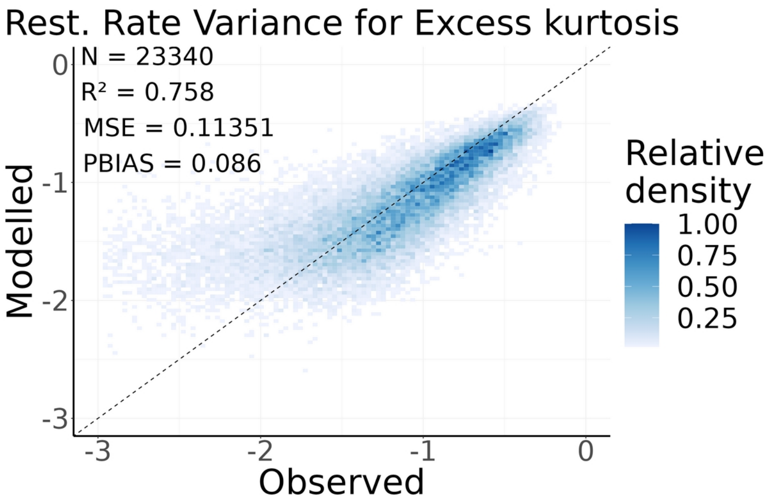




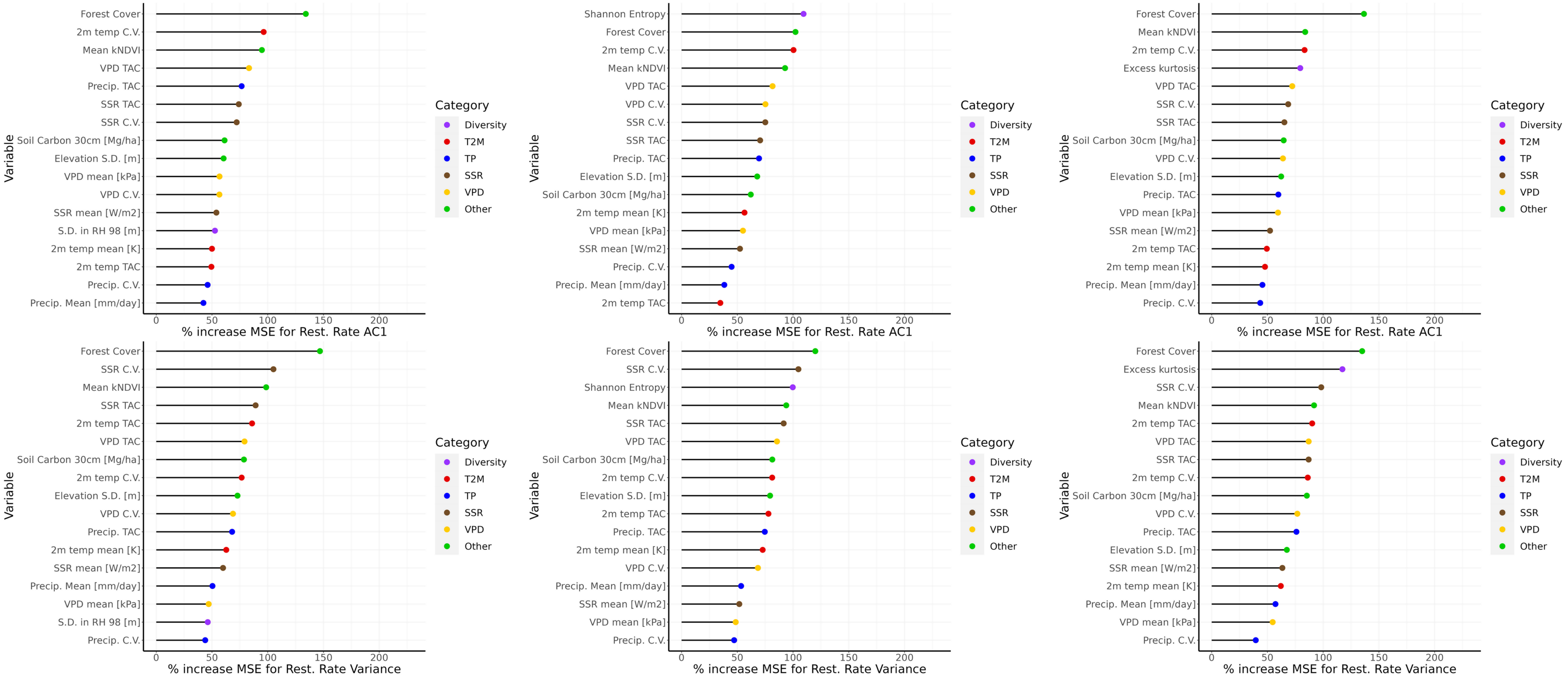




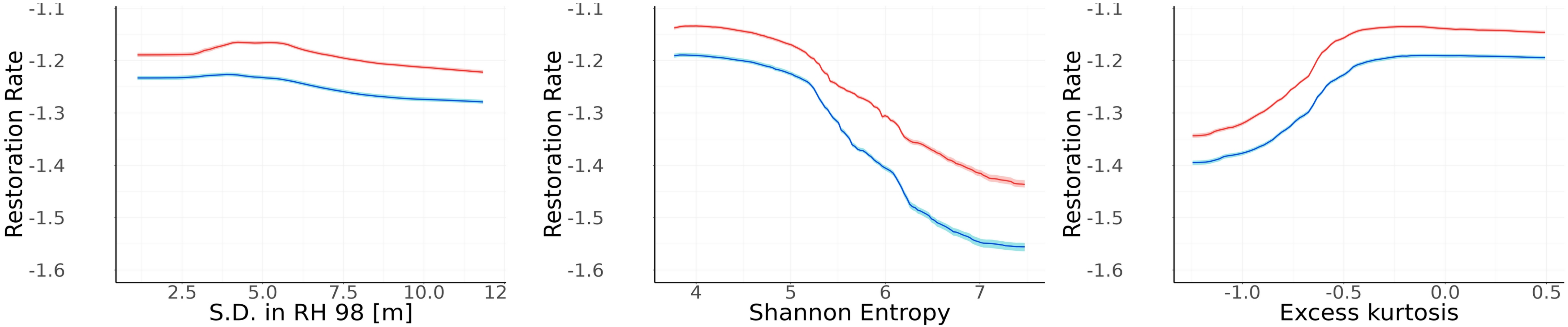




Variable Importance



Diversity-Resilience Relationship



Diversity-Resilience Relationship With Temperature