Influence of different scales of forest structural complexity on ecosystem stability

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CLIMB-FOREST

Funded by the European Union

Motivation

The influence of **forest structure** on **stabilizing ecosystem functioning** against climate extremes across large spatial scales remains poorly understood. Existing studies are often regionally limited or focus on single functional properties, making it difficult to separate structural from climatic effects. This study addresses this gap by systematically analyzing how forest structural attributes shape both the **magnitude and interannual variability (IAV)** of key **ecosystem functional properties (EFP**) across temperate and boreal forests.

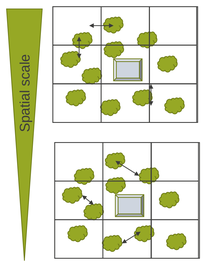
Objectives

1. Assess **if** forest **structure** has an influence on **mean** and **IAV** of EFP
2. Assess **which** structural variables are important **drivers** of mean and IAV of EFP
3. Assess **how** forest structure **affects** mean and IAV of EFP

Methods

Sites

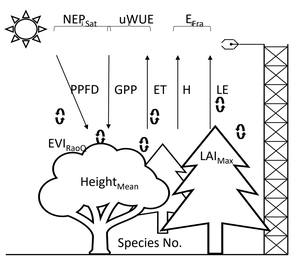
Structure



- Rao's Q of enhanced vegetation index (EVI_{RaoQ})
  - Satellite based
  - Structural difference between pixels
  - Expressed as index of variance (Rao's Q)
- Maximum leaf area index (LAI_{Max})
- Mean canopy height ($Height_{Mean}$)
- Number of dominant species (Species No.)
  - Inventory based
  - Structural difference on tree and leaf level
  - Expressed as average within footprint

Fig. 1: Forest structure variables describing differing scales of spatial heterogeneity. Satellite indices describe structural difference between pixels (large spatial scale) and inventory variables describe difference on tree level (small spatial scale).

Eddy covariance data from ICOS, Fluxnet and AmeriFlux



Ecosystem Functional Properties: photosynthetic capacity (NEP_{sat}), underlying water use efficiency (uWUE), evaporative fraction (E_{Fra})

Fluxes: photosynthetic photon flux density (PPFD), gross primary production (GPP), evapotranspiration (ET), sensible and latent heat (H and LE)

Statistics – Generalized Additive Models (GAM)

IF	**Null Model:** GAM with spatial term	**Full Model:** GAM with spatial term and structural predictors	**Importance metric:** Δdeviance explained ΔAIC
Which	**Null Model:** GAM with spatial term and all structural predictors	**Full Model:** GAM with spatial term and drop-one structural predictors	**Importance metric:** ΔRMSE

Results

1. If?

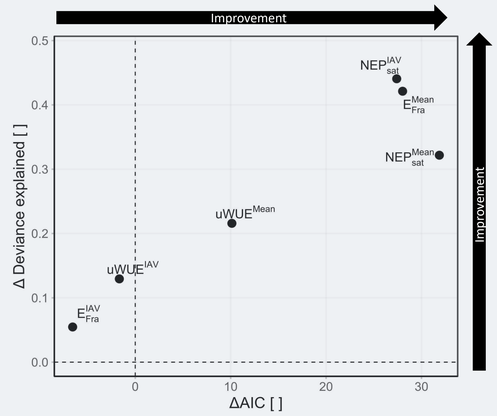


Fig. 2: Difference in deviance explained and AIC between a null model including only a spatial term and a full model with additional structural predictors. Positive values indicate model improvement.

- Improved GAM performance for **all mean** responses
- NEP_{sat}^{IAV} substantially **improved** by forest structure
- **No** meaningful **improvement** for other **IAV** responses
- NEP_{sat} was the **only EFP** for which adding structural variables meaningfully **improved** models for both **mean and IAV**

2. Which?

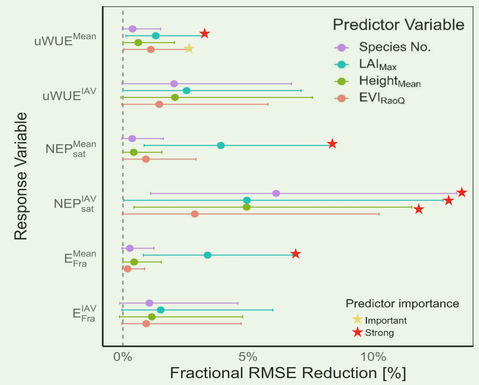


Fig. 3: Fractional RMSE reduction by structural predictors. Positive values mean model improvement if predictor is included. Stars indicate predictors meeting importance criteria ('Important' = consistent improvement across bootstraps of > 5% and 'Strong' = consistent improvement across bootstraps of > 10%).

- LAI_{Max} is the most consistent **'strong' predictor** across responses, and the strongest overall except for NEP_{sat}^{IAV}
- NEP_{sat}^{IAV} stands out among IAV responses, with the highest number of **'strong' predictors**
- Improvements are generally **stronger for IAV** responses, but accompanied by **higher uncertainty**

3. How?

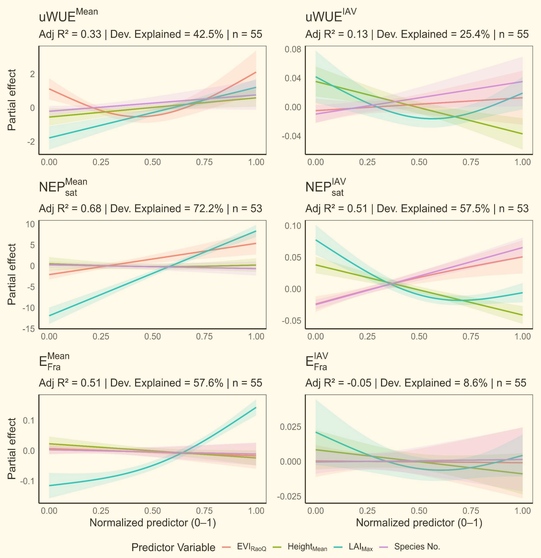


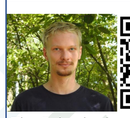
Fig. 4: Partial effects of structural predictors on mean and interannual variability (IAV) of photosynthetic capacity (NEP_{sat}) , underlying water use efficiency (uWUE) and evaporative fraction (E_{Fra}).

- **Positive** effect of LAI_{Max} on **mean** EFP and **negative** effect on their **IAV**
- **Species No.** and EVI_{RaoQ} have **positive** effect on **IAV** of NEP_{sat} → contrasting to other studies[1]
- $Height_{Mean}$ has **negative** effect on **IAV** of **uWUE** and NEP_{sat}

[1]: Musavi et al., 2017; doi: 10.1038/s41559-016-0048

Conclusion

- Structural variables explain **interannual variability** and **mean** of NEP_{sat} beyond spatial structure
- Structural variables explain **mean** of **water- related functional properties** beyond spatial structure, but **not** their **interannual variability**
- LAI_{Max} is the most **important predictor** across EFP, with **positive** effect on **mean** and **negative** effect on **interannual variability**
- **Biomass** (LAI_{Max} and $Height_{Mean}$) are **more important** for EFP stability than **spatial heterogeneity** (Species No. and EVI_{RaoQ})



Abstract

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Acknowledgements
This project is funded by the European Union under the Horizon Europe research and innovation program, grant agreement No. 101059888. The views and opinions expressed are those of the authors and do not necessarily reflect those of the European Union or the Research Executive Agency. Neither the European Union nor the Research Executive Agency can be held responsible for them. We would also like to thank all staff at the experimental sites, as well as ICOS, AmeriFlux and FLUXNET.

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