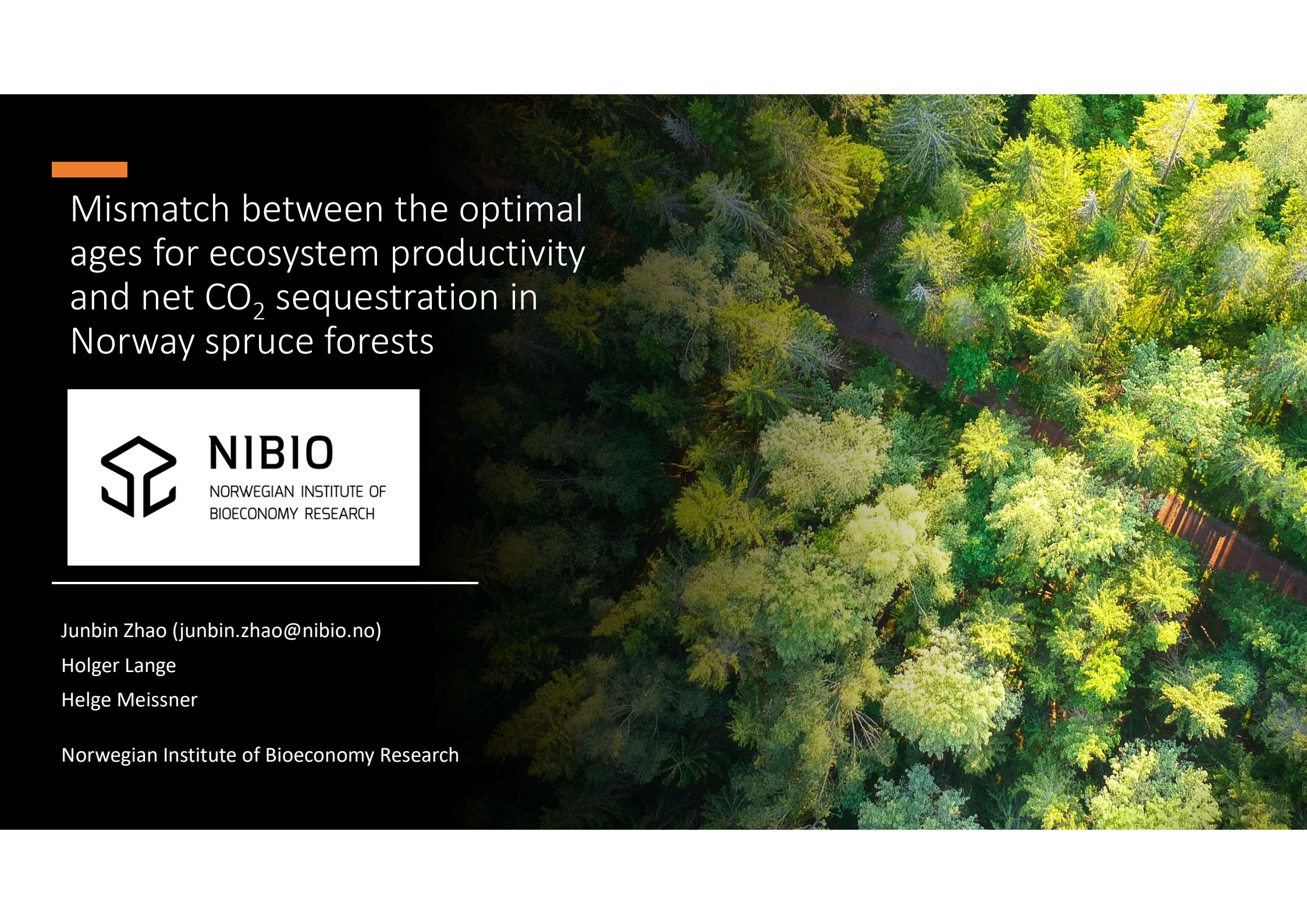


An aerial photograph of a dense forest, likely Norway spruce, with a narrow path or stream visible through the trees. The trees show varying shades of green and yellow, suggesting different stages of growth or seasonal changes.

Mismatch between the optimal ages for ecosystem productivity and net CO₂ sequestration in Norway spruce forests



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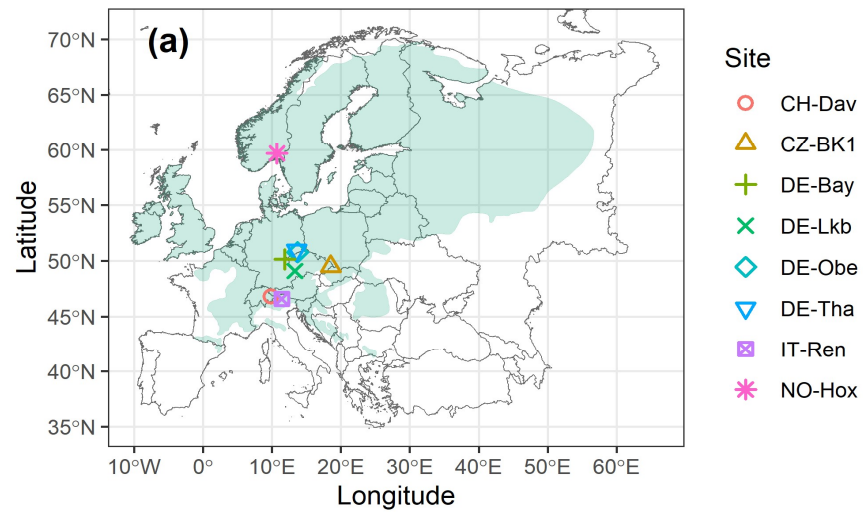
Background and data

- The forest age at the **peak of Net Ecosystem Exchange (NEE)** is usually believed to be concurrent with that of the **peak of primary production** (gross primary production, **GPP**)
- Norway spruce (*Picea abies* L.) is the most prevalent species that widely dominates conifer forests throughout Europe.
- We investigated NEE of Norway spruce forests using eddy-covariance (EC)-based observations from 8 sites dominated by Norway spruce with a very wide range of ages.

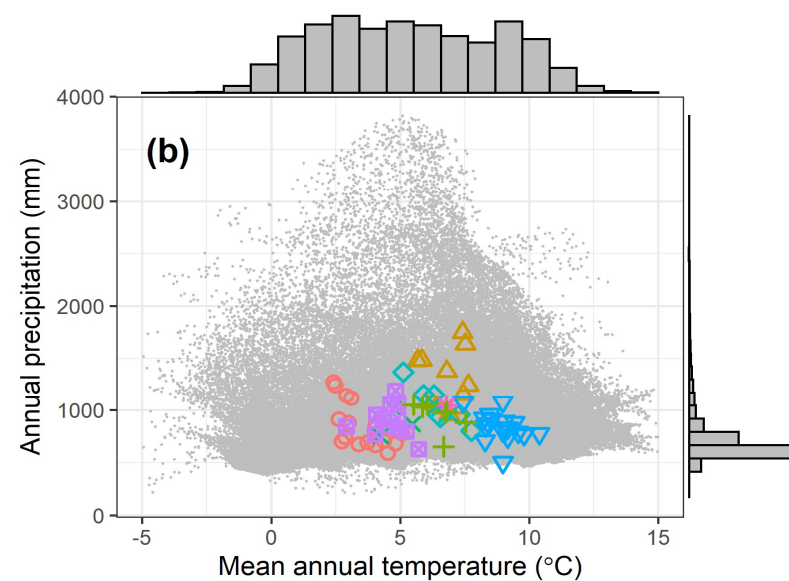
Research questions

- 1) At what stand age do Norway spruce forests show peaks of NEE?
Does this age match the optimal age for GPP?
- 2) At what age are they more prone to be a CO₂ source?
- 3) How does the NEE of different age groups respond to a projected future climate?

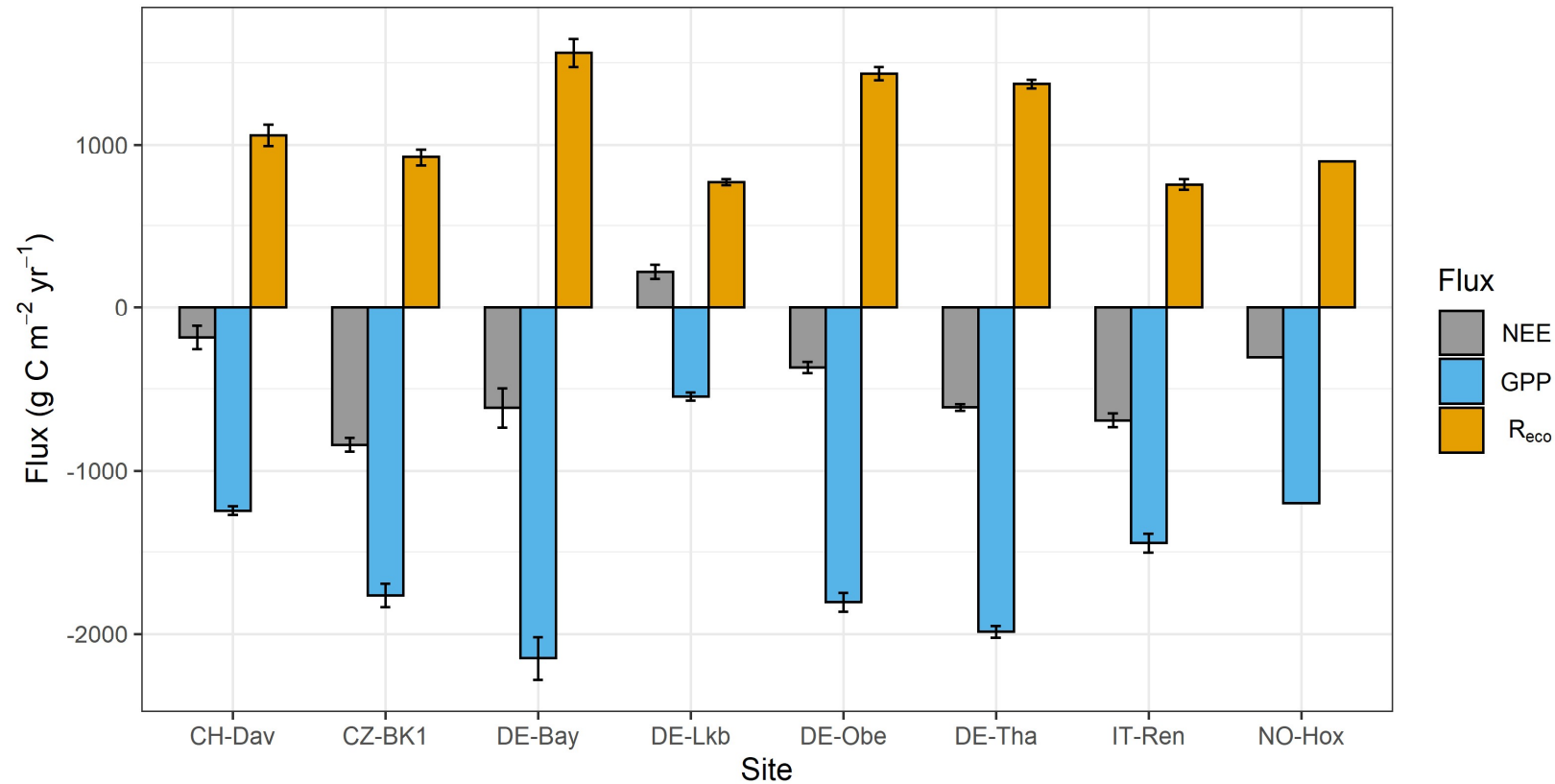
Study sites



Site name	Country	Code	Stand age (yr)
Davos	Switzerland	CH-Dav	240-257
Bily Kriz forest	Czech Republic	CZ-BK1	23-33
Lackenberg	Germany	DE-Lkb	2-3
Oberbärenburg	Germany	DE-Obe	54-60
Tharandt	Germany	DE-Tha	111-128
Renon	Italy	IT-Ren	180-194
Weidenbrunnen	Germany	DE-Bay	49-61
Hoxmark	Norway	NO-Hox	8



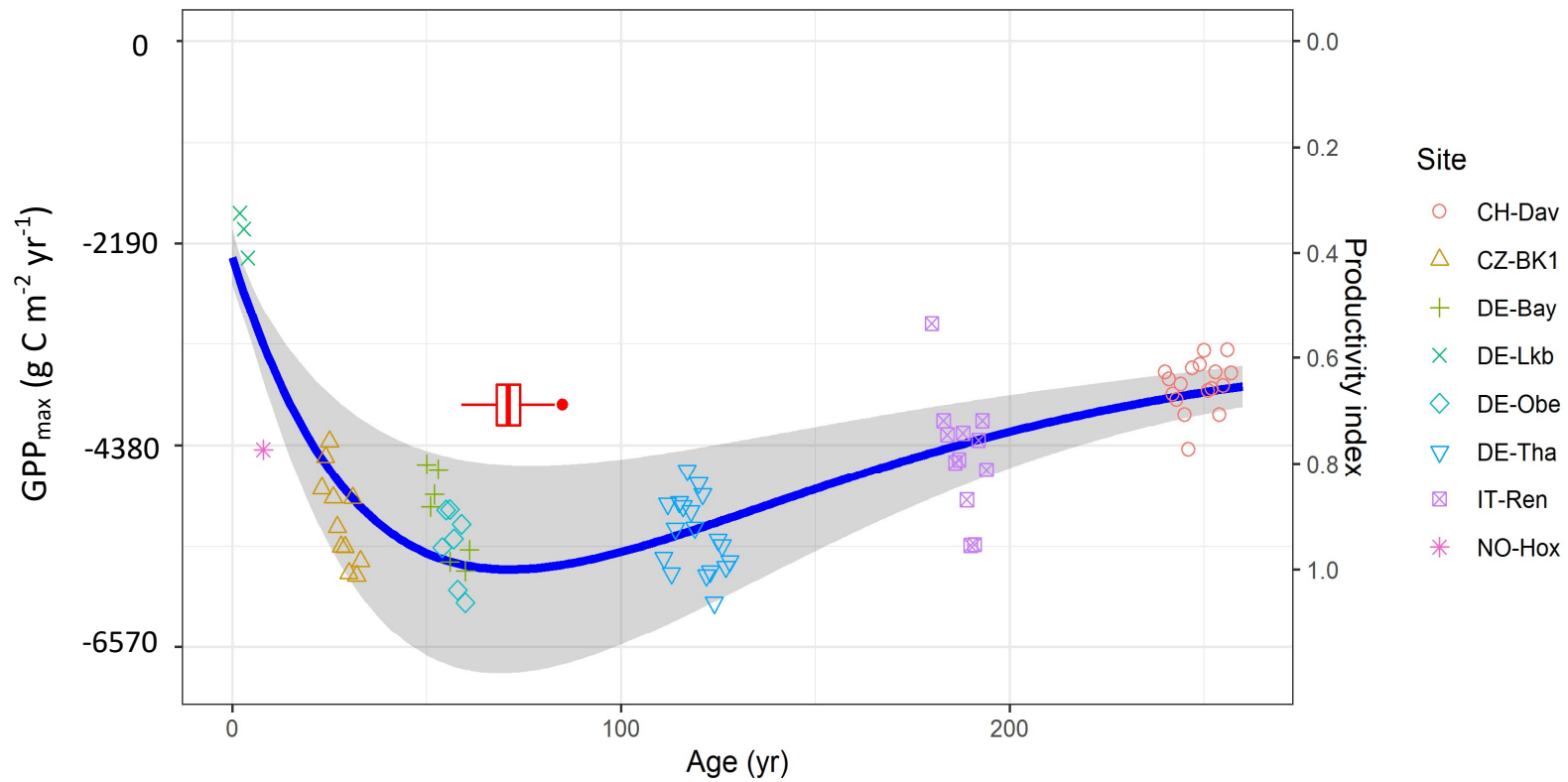
Green area in (a) and grey dot clouds in (b): areas where Norway spruce distributed



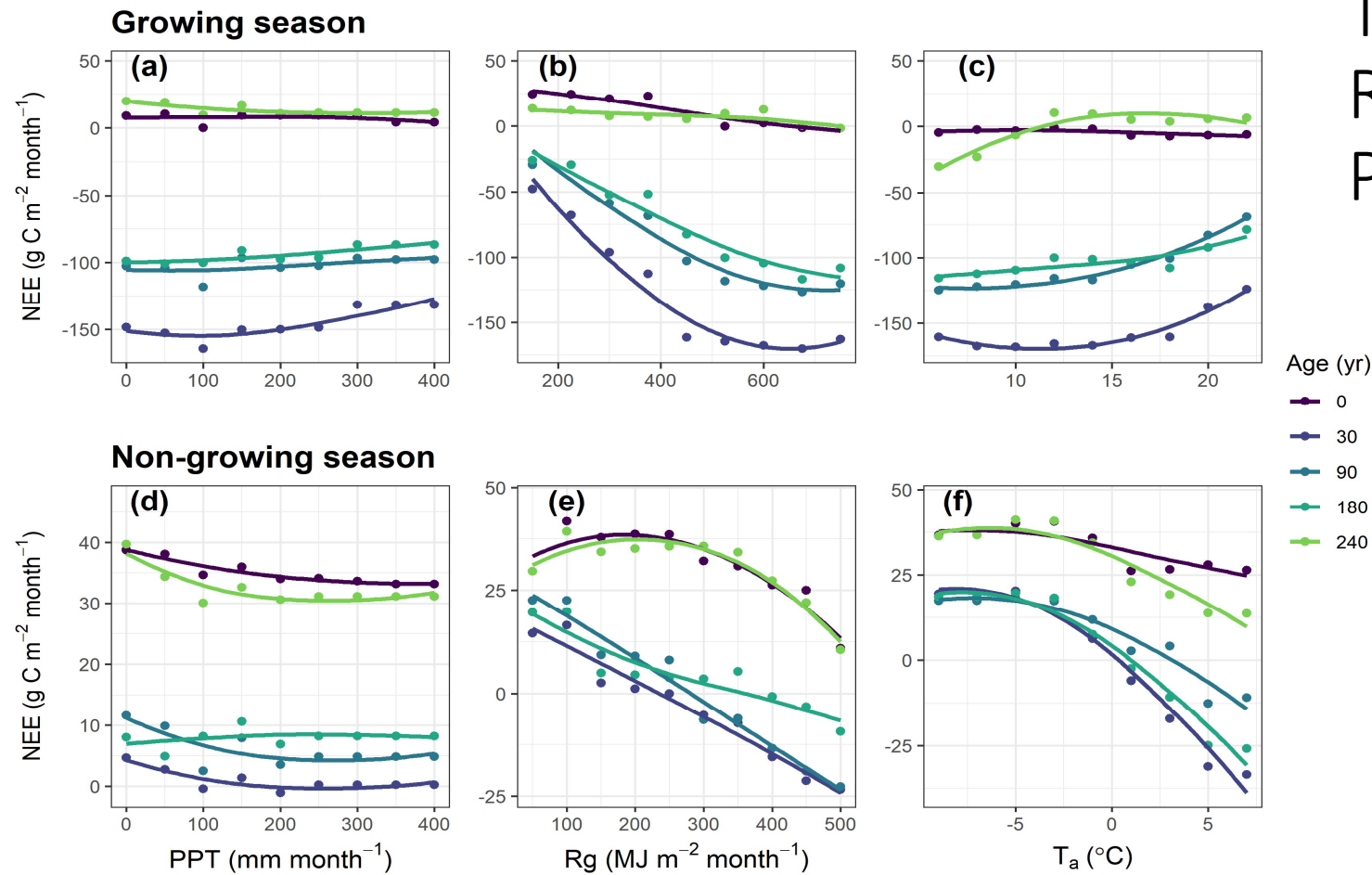
NEE: net ecosystem CO₂ exchange (negative values indicate carbon uptake), measured using eddy covariance
R_{eco}: ecosystem respiration, computed using the night-time-based algorithm from Reichstein et al. 2005
GPP: gross primary production, $GPP = R_{eco} + NEE$

$$GPP_{max} = a \cdot \left(1 + \frac{b \cdot Age - 1}{e^{c \cdot Age}}\right) + d$$

$$Productivity\ Index\ (Age) = \frac{|GPP_{max}(Age)|}{\max(|GPP_{max}|)}$$

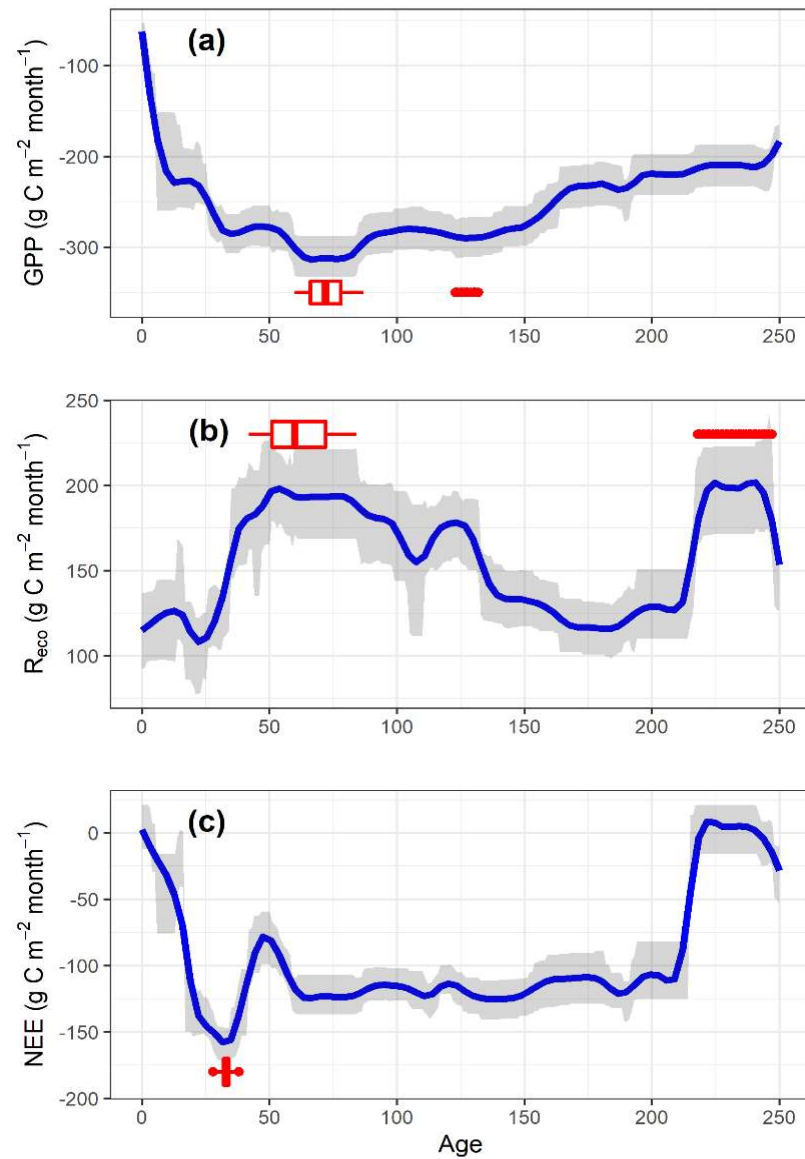


NEE vs environmental factors and age



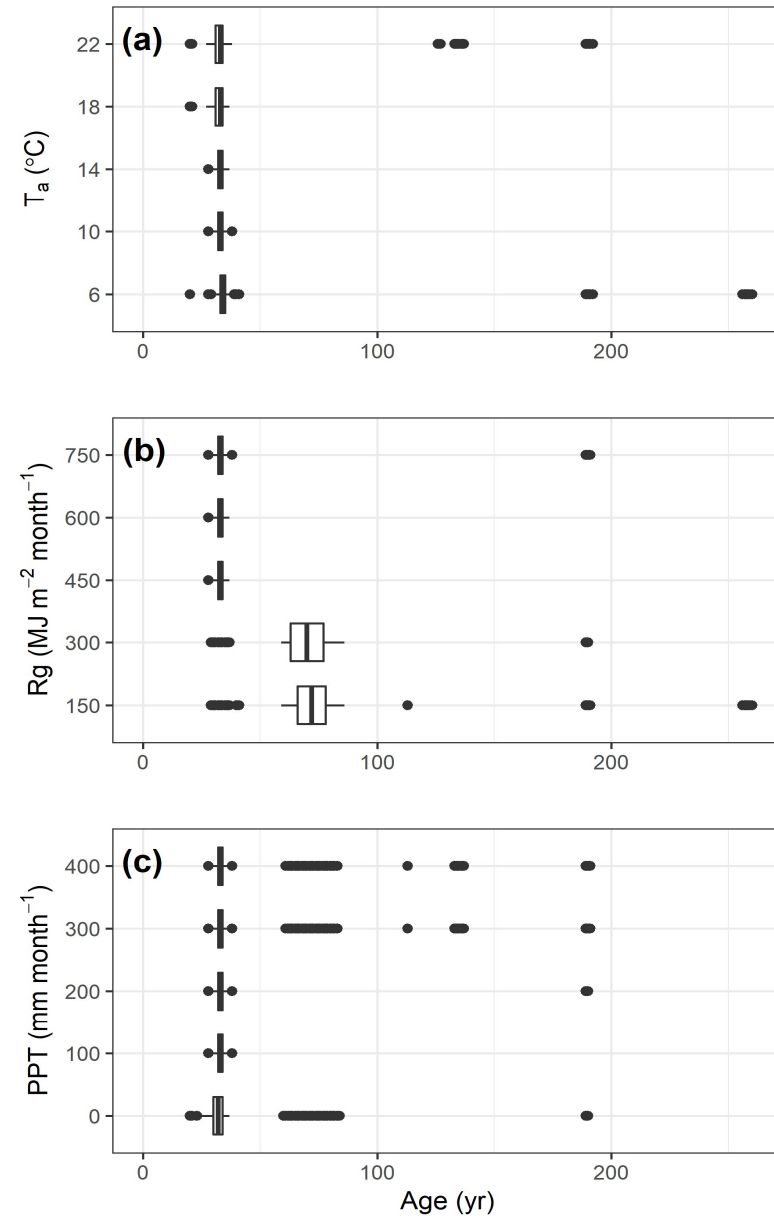
Ta: air temperature
Rg: global radiation
PPT: precipitation

Possible peaks are shown using red boxplots

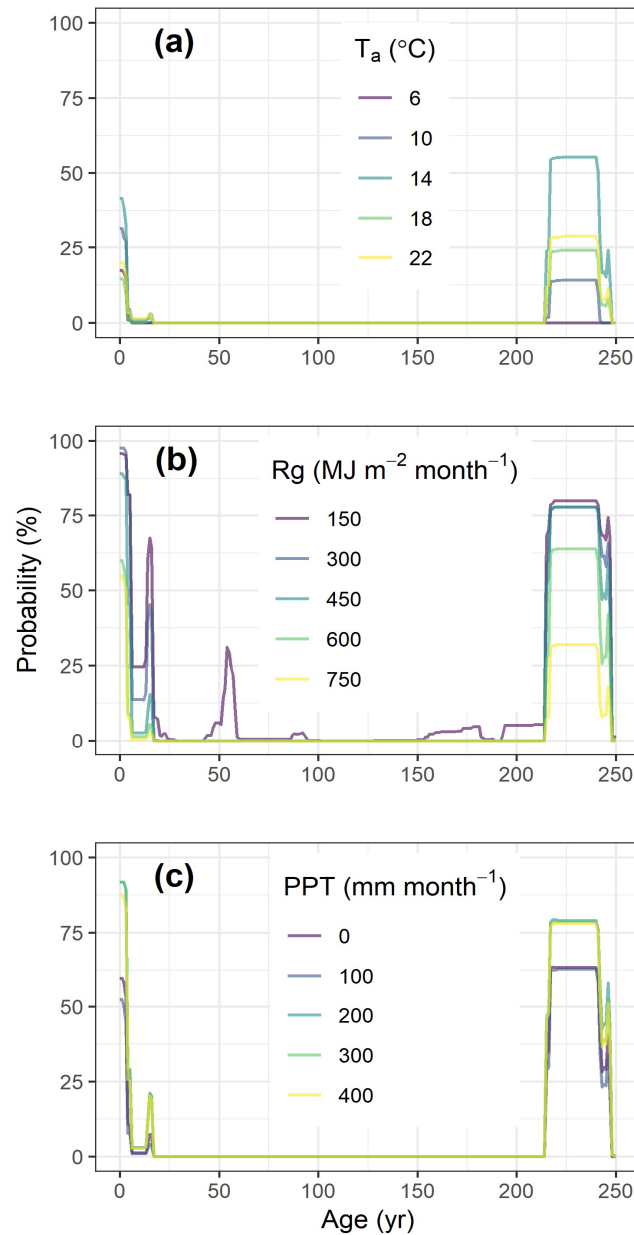


NEE peak age v.s. environmental factors

Ta: air temperature
Rg: global radiation
PPT: precipitation



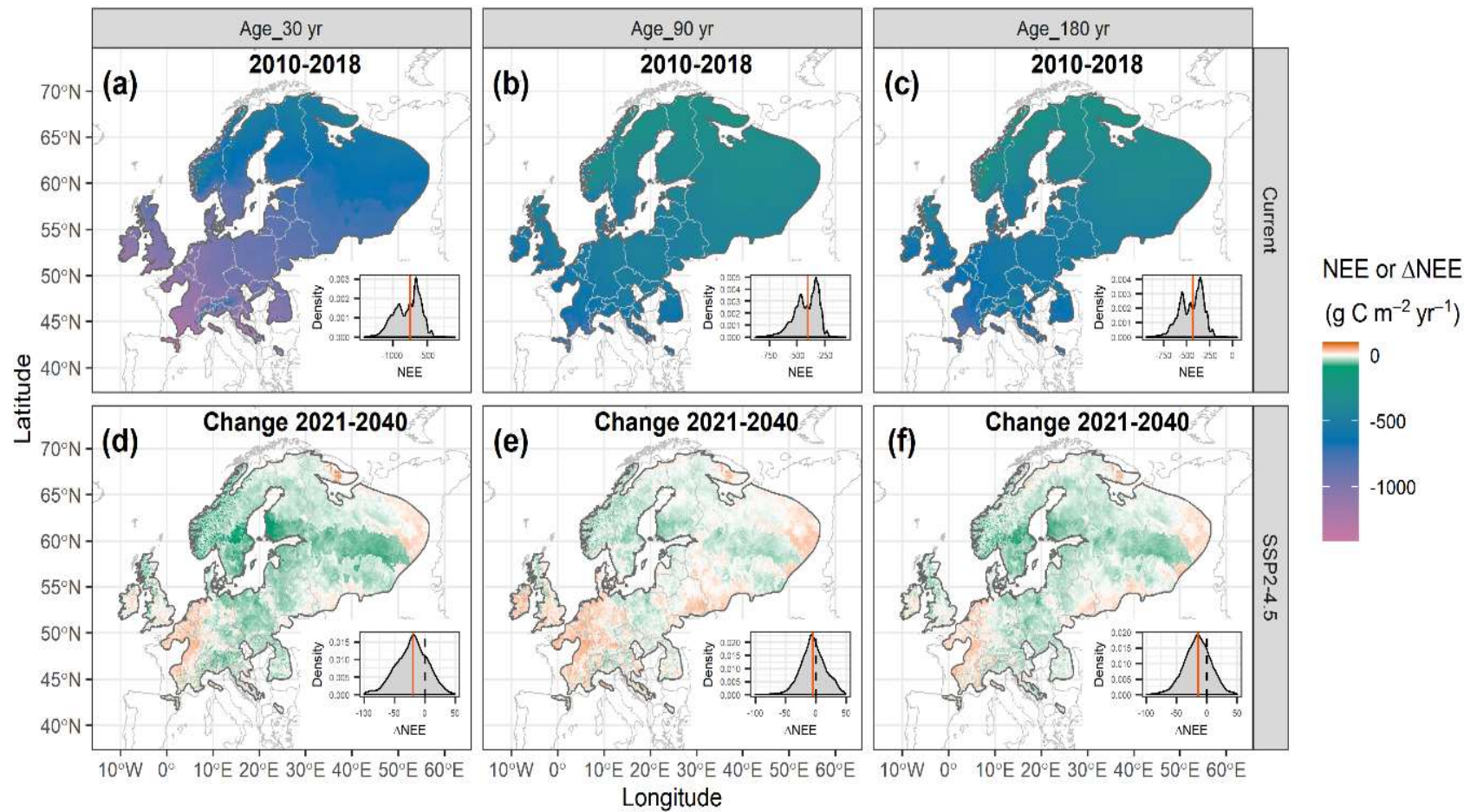
Probability of being a CO₂ source during the growing season under different environmental conditions



T_a : air temperature
 R_g : global radiation
PPT: precipitation

NEE of Norway spruce forest of different ages (a-c)

Possible NEE changes in 2021-2040 under the SSP2-4.5 projection (d-f)



Conclusion

- NEE peaked at ages of **30-40 yr**, which did not overlap with the peak of gross primary production (GPP) that appeared later at ages of **60-90 yr** (slide 8).
- Under the “middle-of-the-road” SSP2-4.5 climate projection, Norway spruce forest stands at a younger age (30 yr) tend to have a greater increase in net CO₂ uptake than mature (90 yr) and old stands (180 yr) in 2021-2040, especially in the high latitude areas (slide 11).
- Forest **productivity** and **CO₂ sequestration** should be considered separately in forest management practices to gain full benefits economically and environmentally.

Acknowledgement

The authors are grateful to Christoph Thomas and Wolfgang Babel in University of Bayreuth for providing the flux data from the site of DE-Bay.



The author, Junbin Zhao, is hosting a special issue on “**Greenhouse gas fluxes in forest ecosystems**” in the open-access journal *Frontiers in Forests and Global Changes*.

We welcome outstanding manuscripts in forms of **original research, method advances, opinions** and **reviews**.

Please visit the webpage for more information:

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