Combining isotopic and sap flux data to estimate GPP: an alternative ecophysiological approach to eddy-covariance based data

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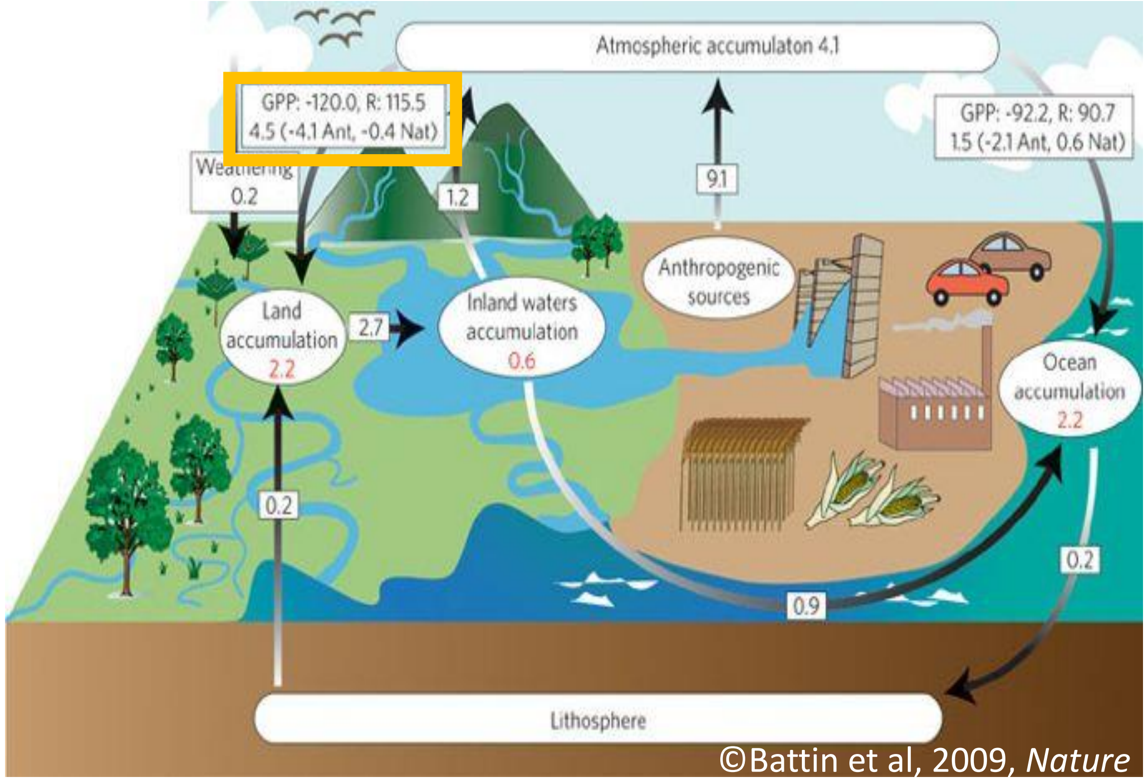
GPP, the biggest C flux

The gross primary production is the main terrestrial C flux ➔ forests play a important role to capture C via photosynthesis and influence other processes like plant growth, respiration,…

With global change, the boreal forest is predicted to increase its surface by 30 to 40% ➔ it is crucial to estimate GPP of boreal forests



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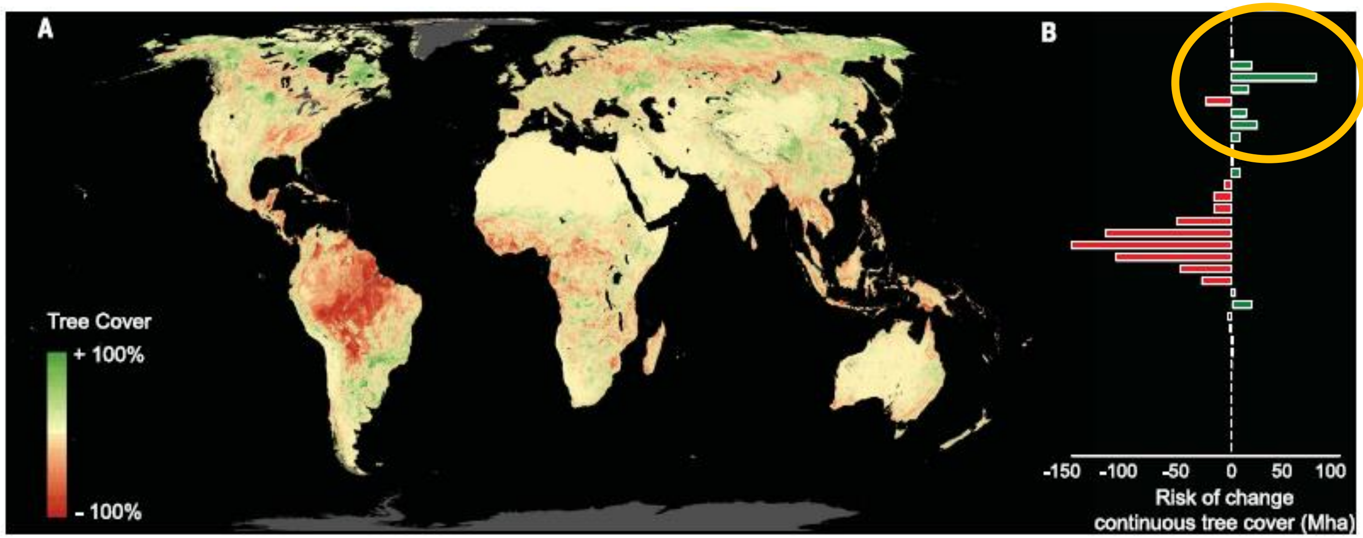

Fig. 3. Risk assessment of future changes in potential tree cover. (**A**) Illustration of expected losses in potential tree cover by 2050, under the "business as usual" climate change scenario (RCP 8.5), from the average of three Earth system models commonly used in ecology (cesm1cam5, cesm1bgc, and mohchadgem2es). (**B**) Quantitative numbers of potential gain and loss are illustrated by bins of 5° along a latitudinal gradient.

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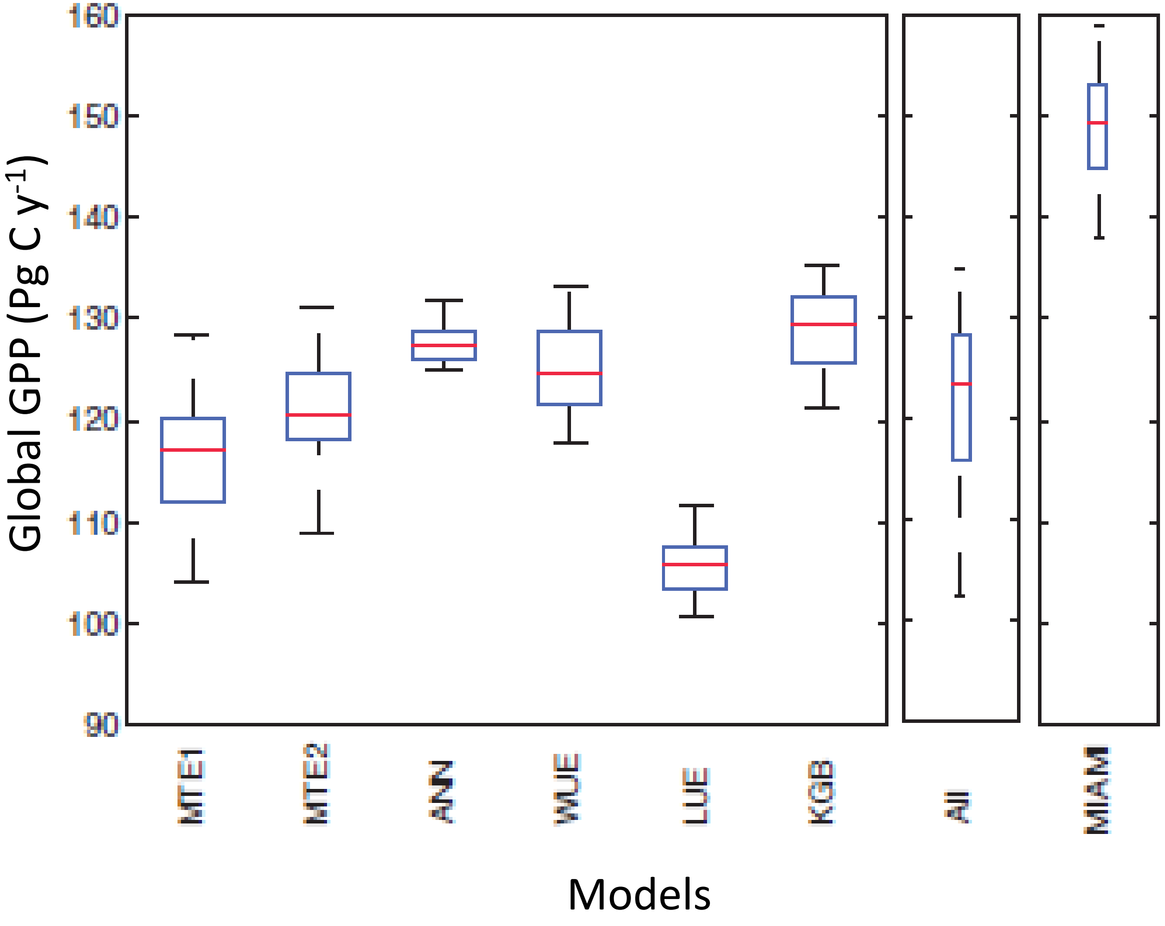
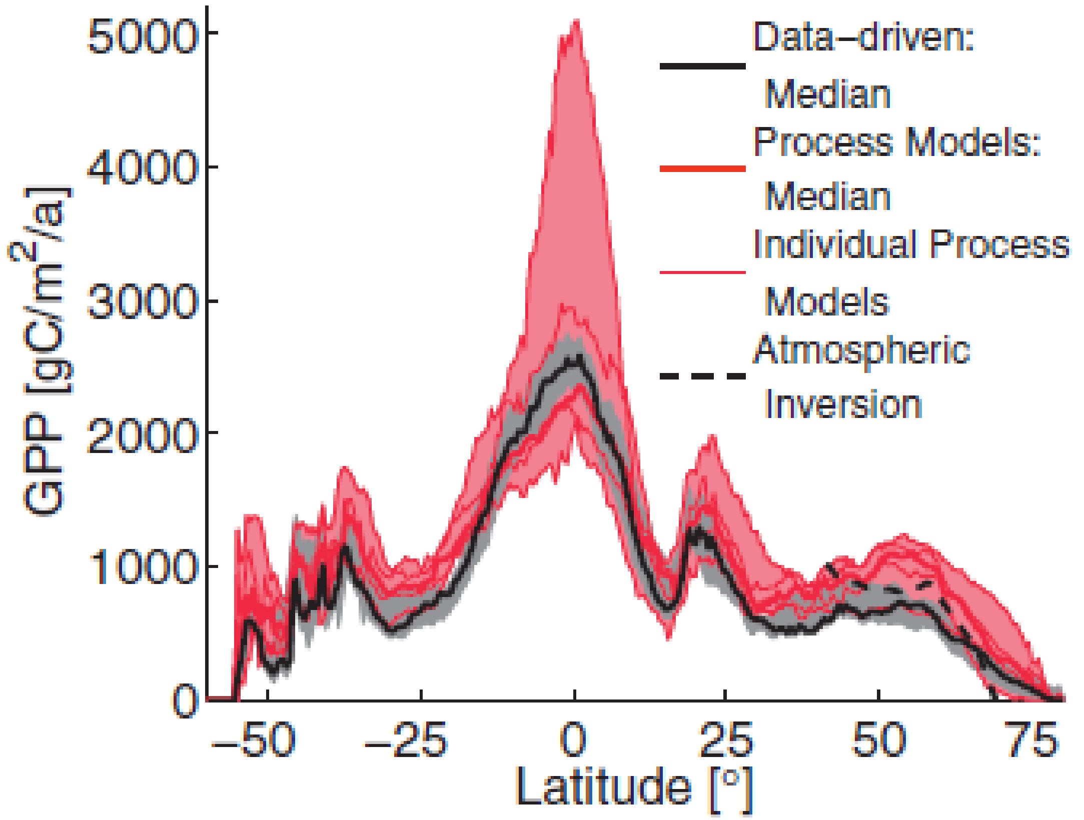
There are still some uncertaincies in GPP estimates





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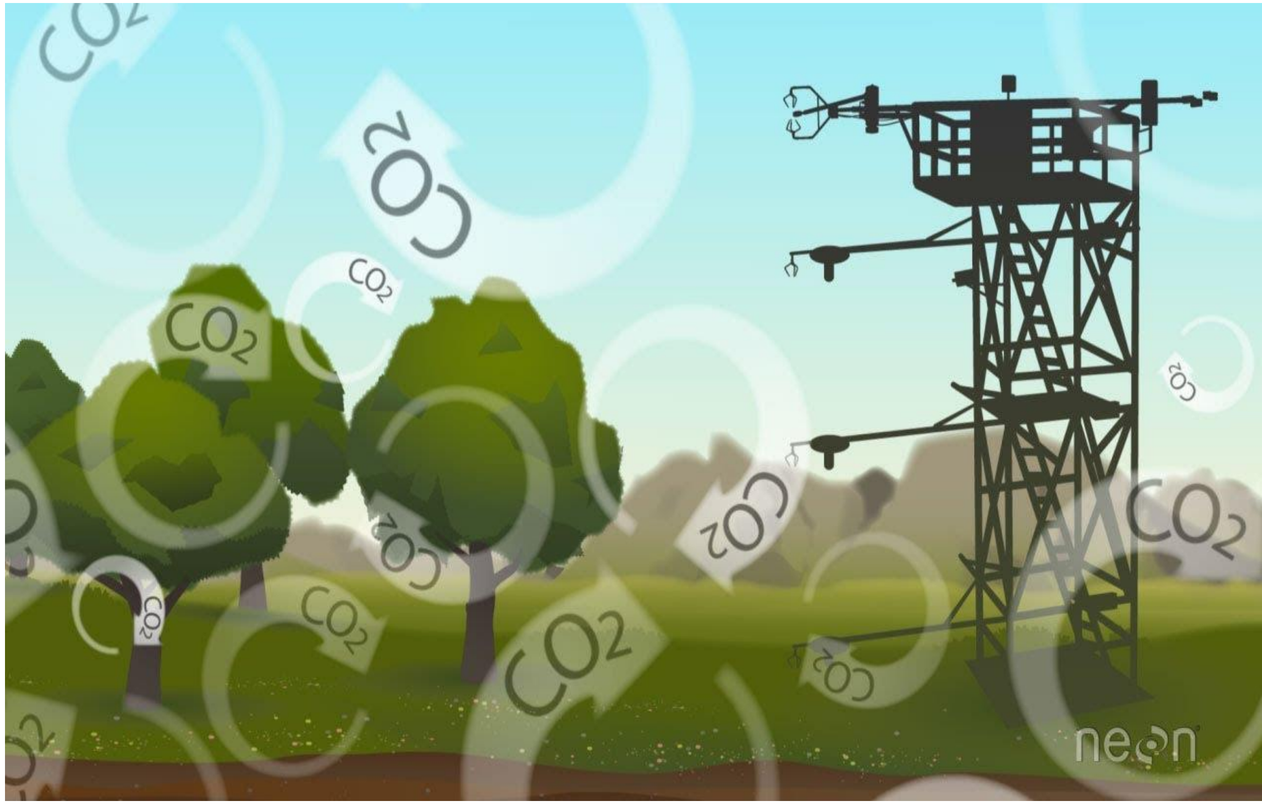
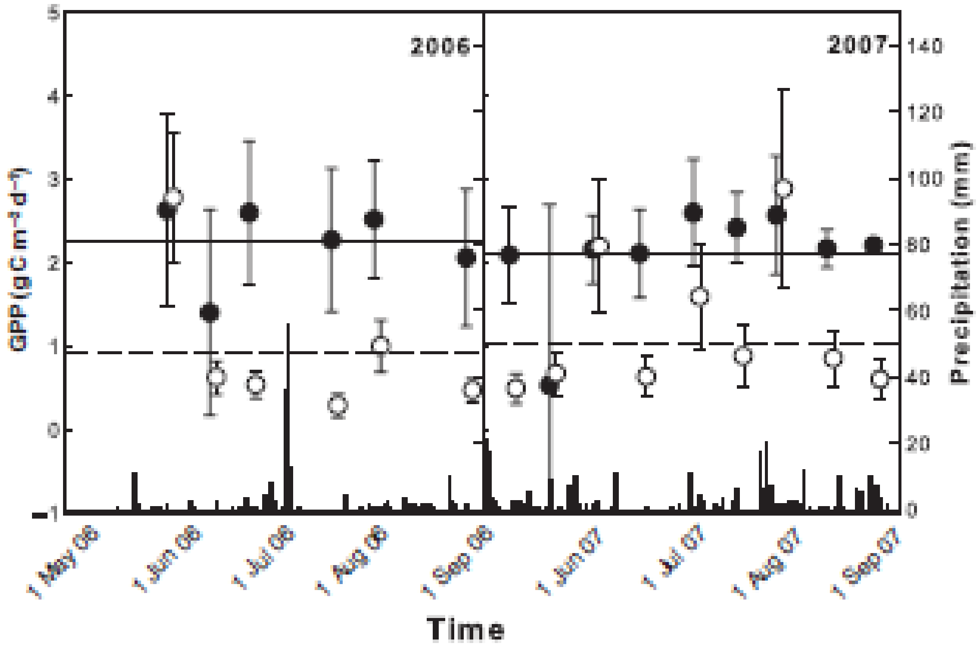
Eddy-Covariance (EC), the ”standard” to modelize GPP



GPP from sap flux and isotopic measurments

Fig. 8 Left y-axis: a comparison of gross primary productivity (GPP) modeled using $\delta^{13}C$ and transpiration (E) (open circles), and GPP modeled from the simplified photosynthesis and evapotranspiration model (SIPNET; closed circles) for 2006 and 2007. Error bars represent 95% confidence intervals generated by Monte Carlo analysis. Dashed horizontal lines, mean annual GPP modeled using $\delta^{13}C$ and E; solid horizontal lines, mean annual GPP modeled using SIPNET. Right y-axis: daily precipitation for 2006 and 2007.



©Hu et al, 2010, *New Phytologist*

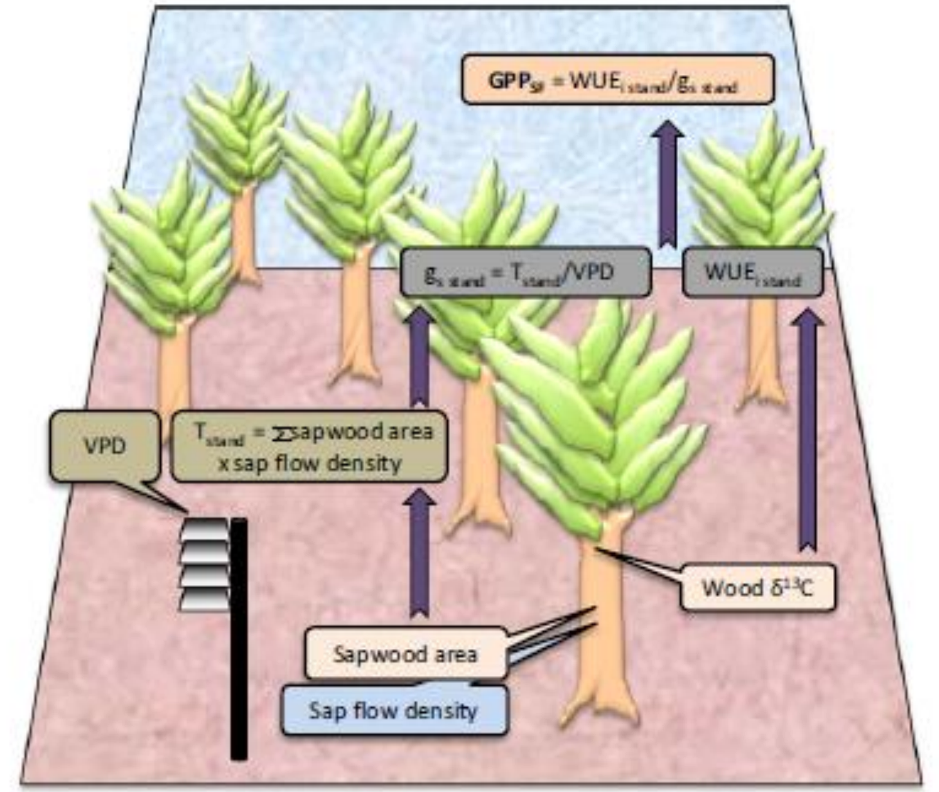


Fig. 1 Summary of measured and calculated variables (callouts and boxes, respectively) and equations used in the estimation of forest gross primary productivity (GPP) using the sap-flow method and the eddy covariance method (GPP_{SF} and GPP_{EC}, respectively). Tree measurements are described for one individual but need to be replicated in multiple trees. *T*, transpiration; VPD, vapor pressure deficit; g_s, stomatal conductance; WUE_i, intrinsic water-use efficiency. The background image shows a *Pinus halepensis* plot in Yatir forest.

©Klein et al, 2016, *New Phytologist*

- Some studies modelled GPP with transpiration and $\delta^{13}C$ in different issues (sugar needles for Hu et al 2010 and wood material for Klein et al 2016)
- However, we need to have data which integrates the whole plant C assimilation and to consider an accurate mesophyll conductance, g_m, when we estimate the intrinsic water use efficiency, WUE_i (Seibt et al, 2008; Wingate et al, 2007)

Objective

Estimate GPP at stand scale using an ecophysiology-based method (sap flux/isotopic), which:

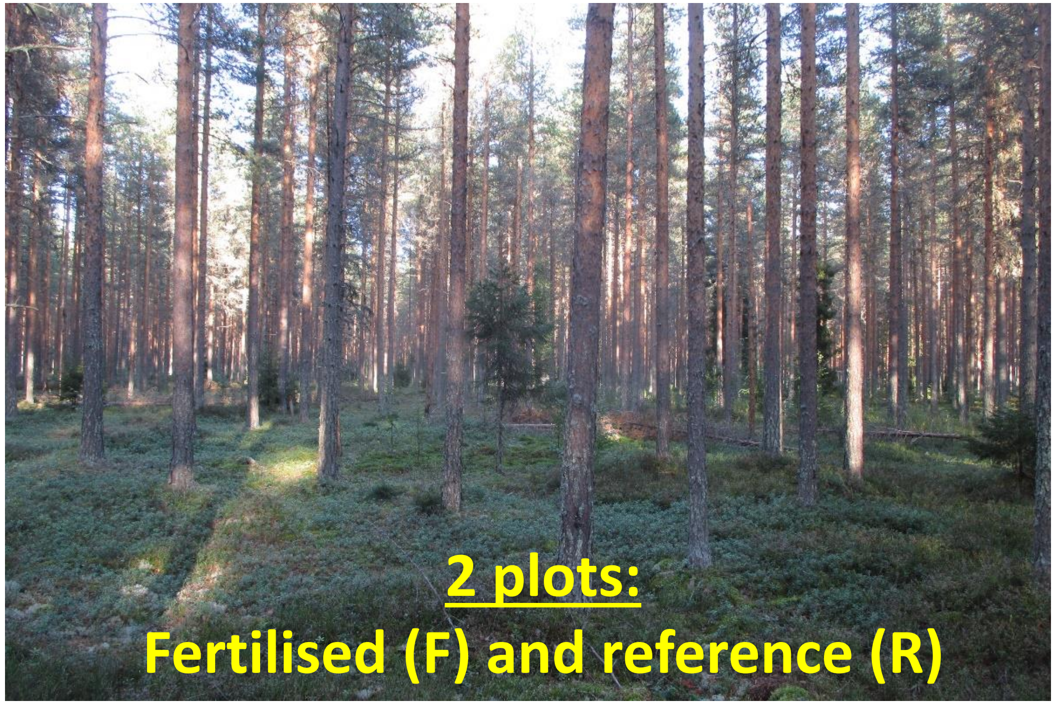
- Is independent from EC
- Account for g_m consideration
- Use species functional traits as variables
- Is able to partition the stand GPP into the tree species of the community

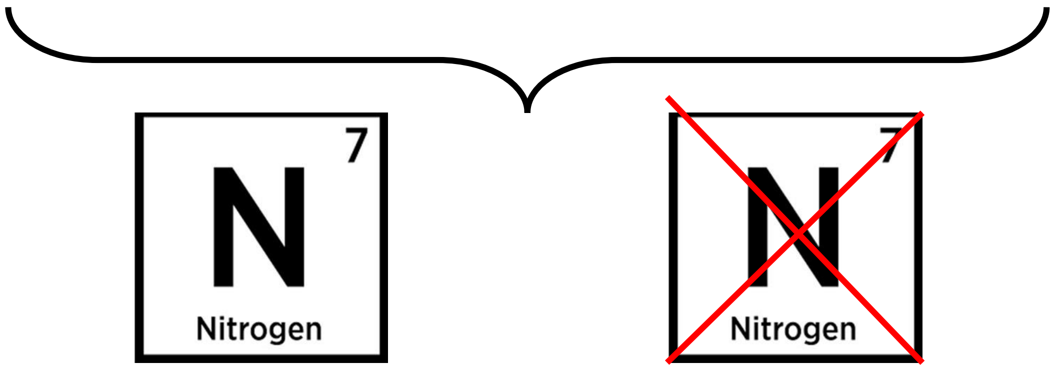
→ We compare the sap flux/isotopic method with PRELES, a semi empirical EC-based nodel.

Study site

Rosinedal, near Vindeln (64°10’ N, 19°45’ E)

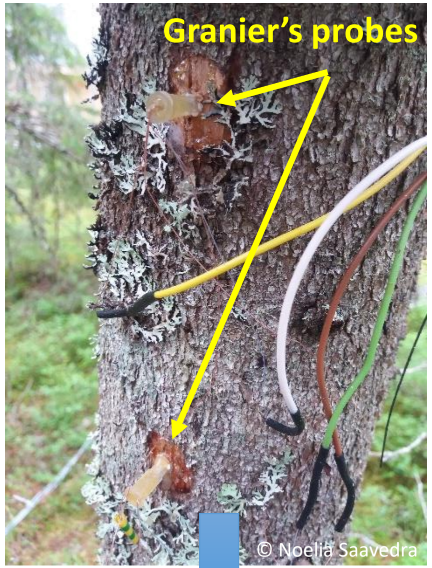
Scots pine (*Pinus sylvestris*) monoculture





The "sap flux/isotopic" approach

From sap flux measurement, transpiration is calculated to estimate canopy conductance



g_{canopy}

Tor-ngern et al, 2017, *Ecological Application*

$$g_{canopy} = \frac{Transpiration}{VPD}$$

+

A small disc of phloem is collected in the trunk and analyze to determine $\delta^{13}C$ and then to infer intrinsic water use efficiency (WUE_i). Sampling took place during the growing season

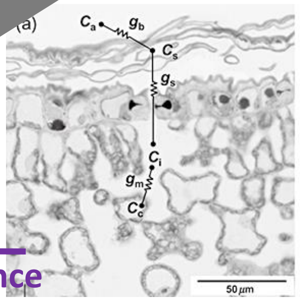
×

$$WUE_i = f(\frac{g_{canopy}}{g_m}, \Delta C)$$

Seibt et al, 2008, *Oecologia*

Mesophyll conductance

Gross Primary Production ($GPP_{iso/SF}$)



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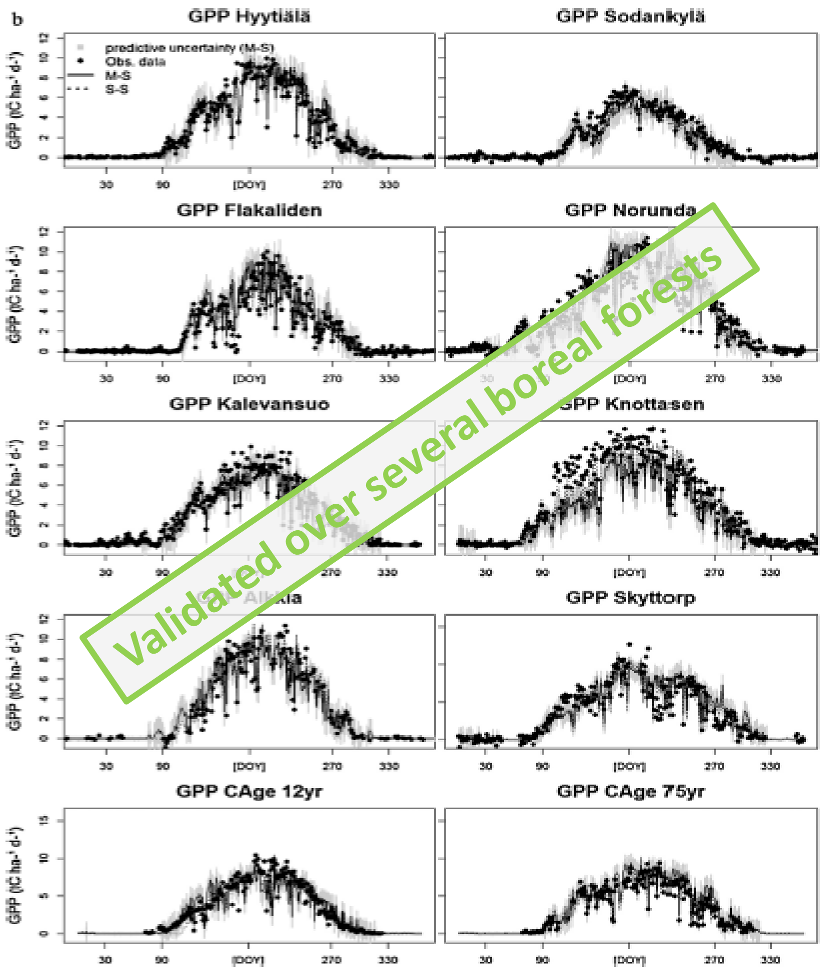
g_m values were measured in our experimental site, for more details see Stangl et al, 2019, *Photosynthesis Research*

PRELES model

- PRELES = PREdict Light-use efficiency, Evapotranspiration and Soil water (Peltoniemi et al, 2015)
- Run with few environmental data (precipitations, PAR, VPD, temperature)
- Estimate GPP and ET



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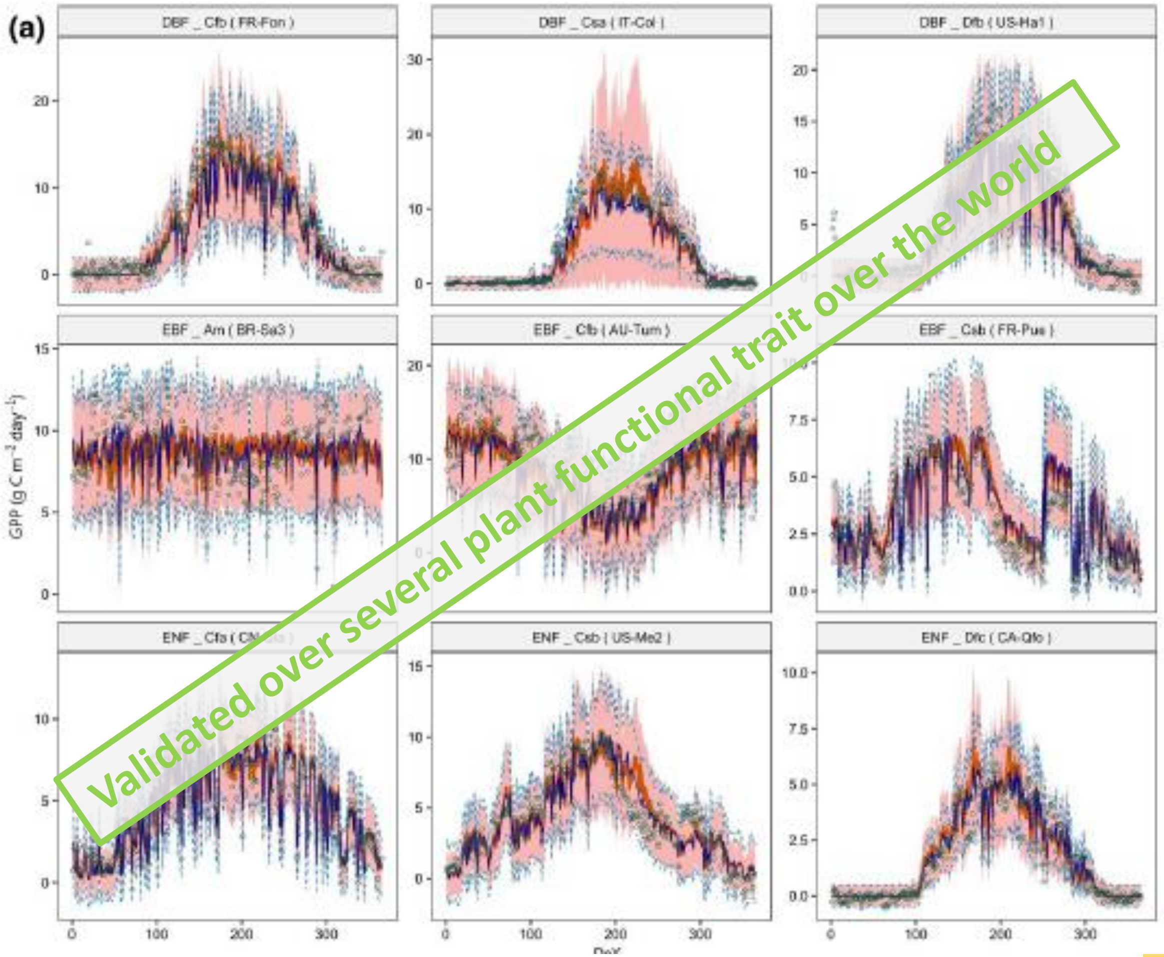

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GPP$_{iso/SF}$ "recipe"

- $E_{cdmax} = 1.812 \times \left(1 - e^{(-3.121 \times VPD_z)}\right)$ — ©Tor-ngern et al., 2017, *Ecological Applications*
- $E_{cd} = E_{cdmax} \times \left(1 - e^{(-18.342 \times REW)}\right)$ — ©Tor-ngern et al., 2017, *Ecological Applications*
- $g_{Sstand} = \dfrac{(E_{cd}/M_{H2O}) \times \frac{10^4}{r}}{\frac{VPD_Z}{P_{145}}}$ — ©Klein et al., 2016, *New Phytologist*
- $g_C = g_{Sstand} \times \text{prop.}\hat{\alpha}$

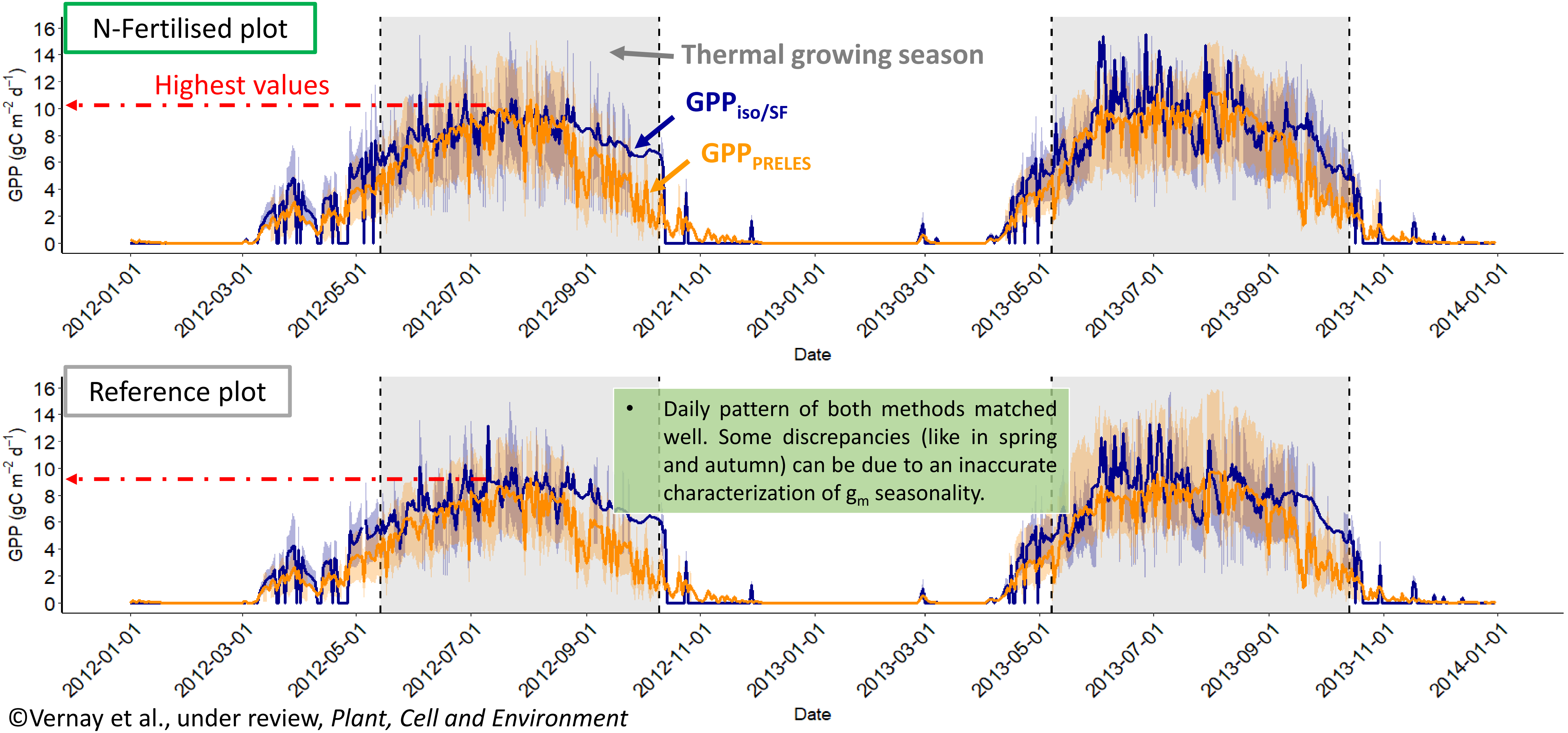
$\hat{\alpha}(S_t) = \max\{c_1 \times (St - S_0), 0\}$

$\text{prop.}\hat{\alpha} = \dfrac{\hat{\alpha}(St)}{\widehat{\alpha_{max}}}$

©Mäkelä et al., 2004, *New Phytologist*

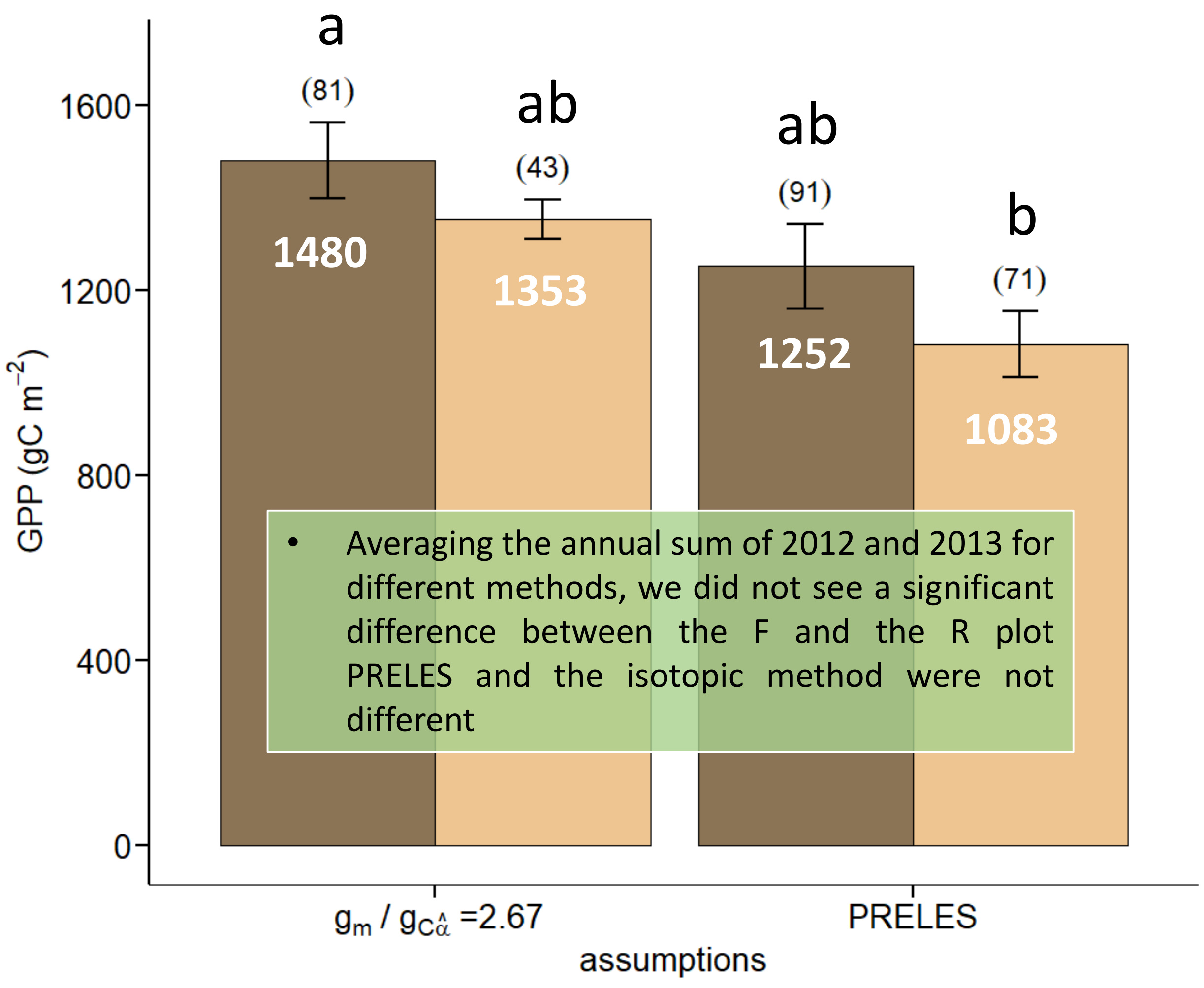
- $WUE_{istand} = \dfrac{C_a}{r} \times \left[\dfrac{b - \Delta C - f \times (\frac{\Gamma^*}{C_a})}{b - a_a + (b - a_i) \times \frac{g_C}{r \times g_m}}\right]$ — ©Klein et al., 2016, *New Phytologist*; ©Seibt et al, 2008, *Oecologia*
- $GPP = WUE_{istand} \times g_C \times \dfrac{M_C}{10^6}$ — ©Klein et al., 2016, *New Phytologist*

Daily GPP comparison between PRELES and sap flux/isotopic method (1/3)

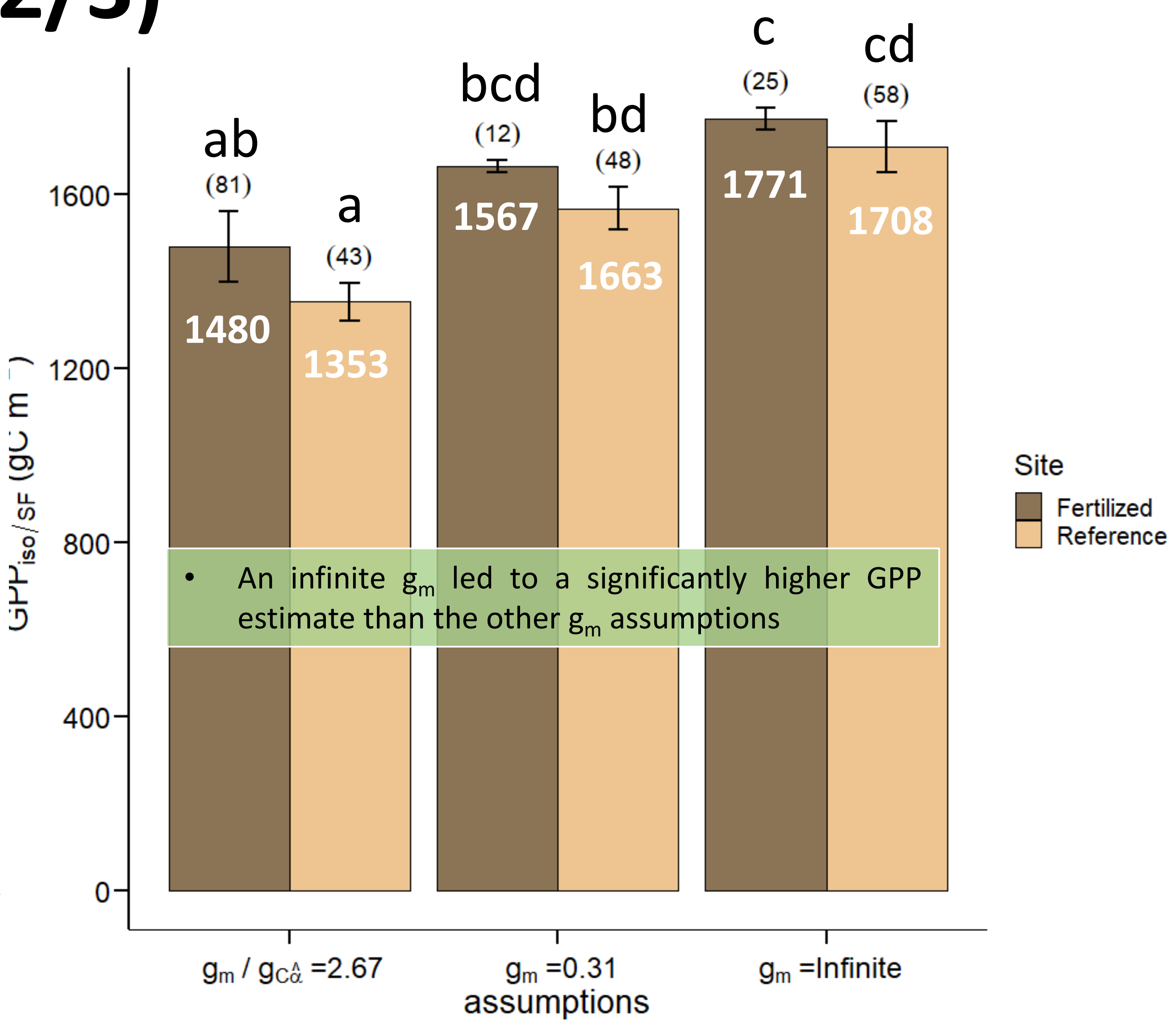


- Daily pattern of both methods matched well. Some discrepancies (like in spring and autumn) can be due to an inaccurate characterization of g_m seasonality.

Daily GPP comparison between PRELES and sap flux/isotopic method (2/3)



- Averaging the annual sum of 2012 and 2013 for different methods, we did not see a significant difference between the F and the R plot PRELES and the isotopic method were not different



- An infinite g_m led to a significantly higher GPP estimate than the other g_m assumptions

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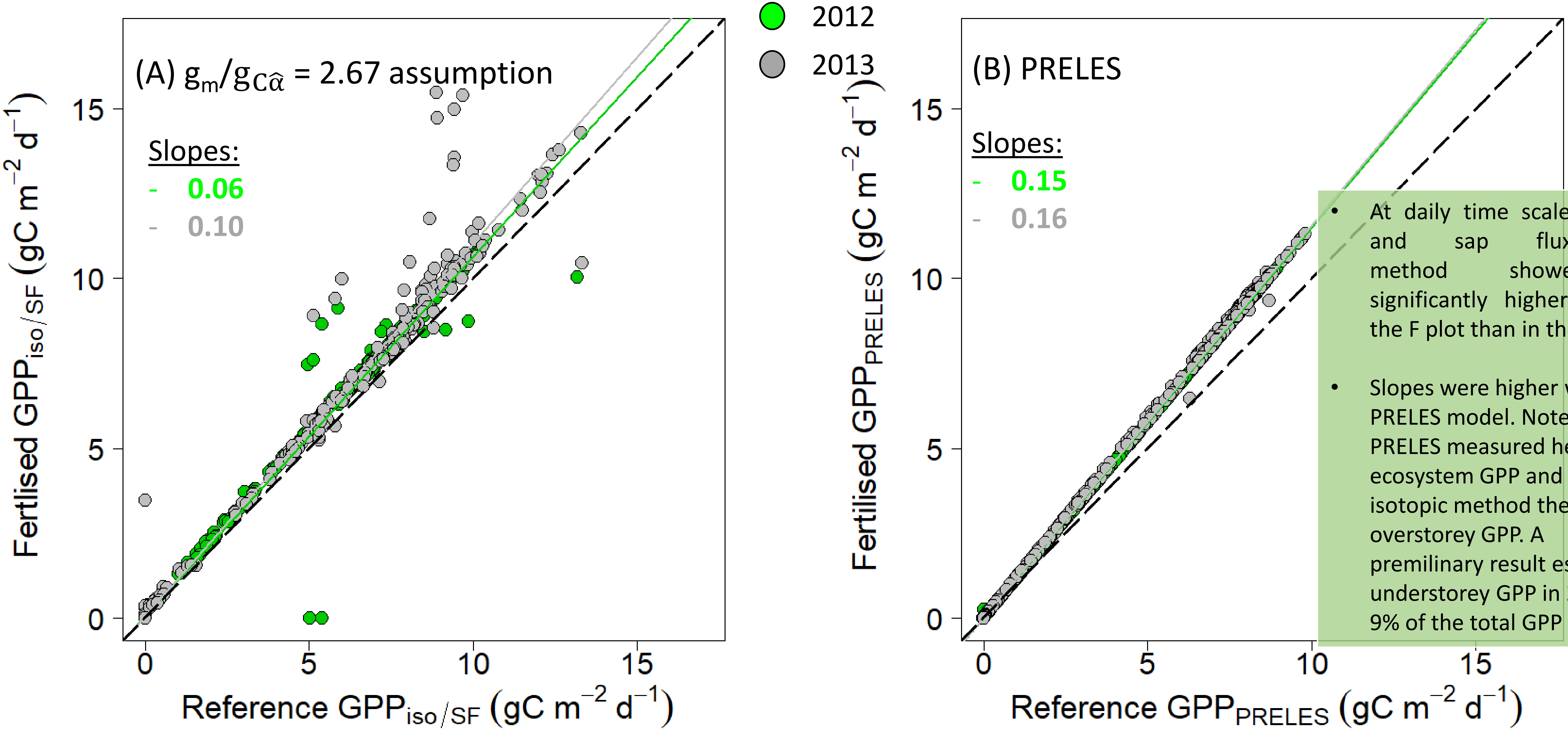
Daily GPP comparison between PRELES and sap flux/isotopic method (3/3)



- At daily time scale, PRELES and sap flux/isotopic method showed a significantly higher GPP in the F plot than in the R plot.
- Slopes were higher with PRELES model. Note that PRELES measured here the ecosystem GPP and the isotopic method the overstorey GPP. A premilinary result estimated understorey GPP in 2013 to 9% of the total GPP

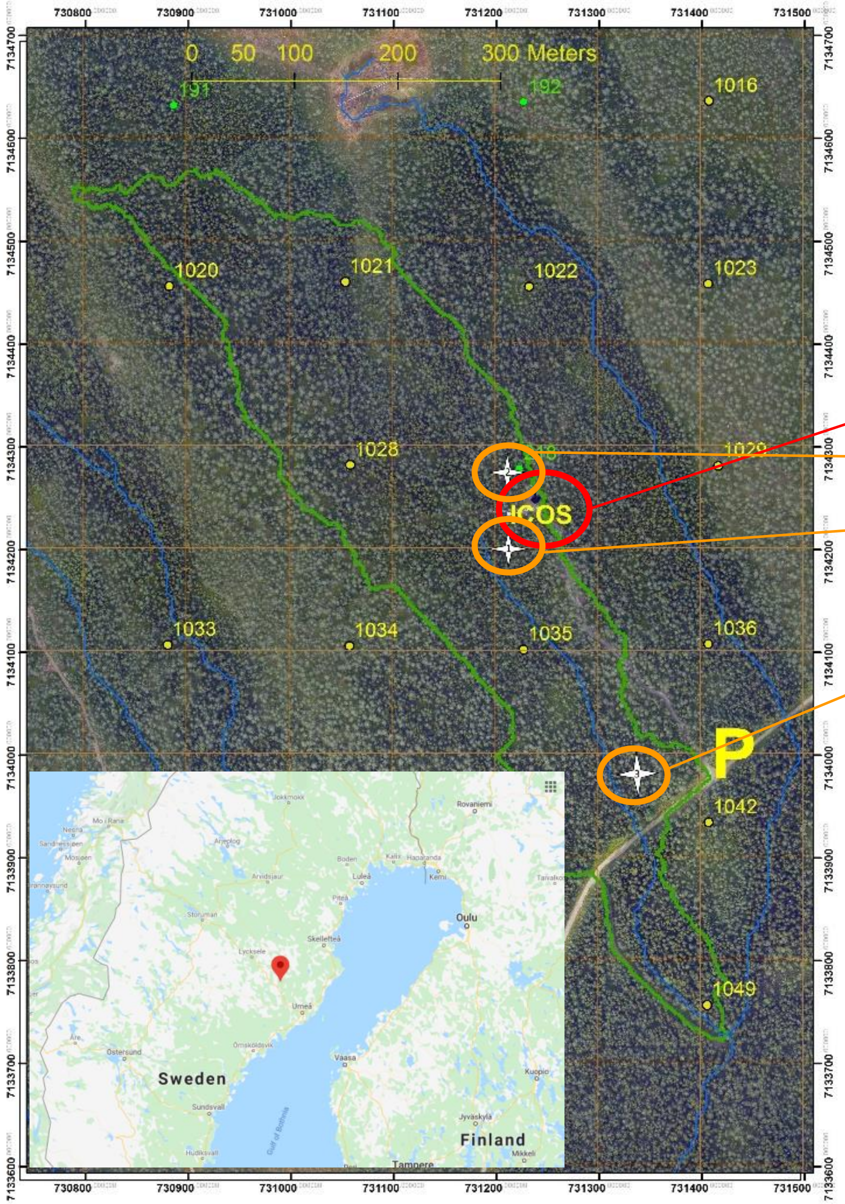
Main conclusions in a Scots pine monoculture

- The daily pattern and the annual sums gave similar results between PRELES and sap flux/isotopic method ➔ sap flux/isotopic method is an alternative method to EC-based estimates
- Can be used were EC requirements are not met (complex terrain, complex canopy structure, and non-turbulent atmospheres,…)
- g_m adjustment was necessary but need further researcher on its seasonal behaviour.
- Both methods gave similar estimates between the two fertilisation treatments with no clear higher GPP in the F plot

The sap flux/isotopic method in a mixed forest

- The method can help to determine the relative contribution of each species for different tree sizes to the stand GPP in a mixed forest.
- We can test if the stand GPP corresponds to the sum of the GPP of each species or if the sum of the GPP of each species differs to the global GPP (estimated by EC for instance)➔ agreement with the mass ratio hypothesis? (Grime, 1998; Garnier et al, 2004)
- In the following slides, some preliminary results of our GPP estimate in a mixed boreal forest (Svartberget, 3 species: *Betula pendula*, *Pinus sylvestris* and *Picea abies*)

Ongoing experiment in a mixed forest



- Environmental data
- Sap flux measurements
- EC measurements

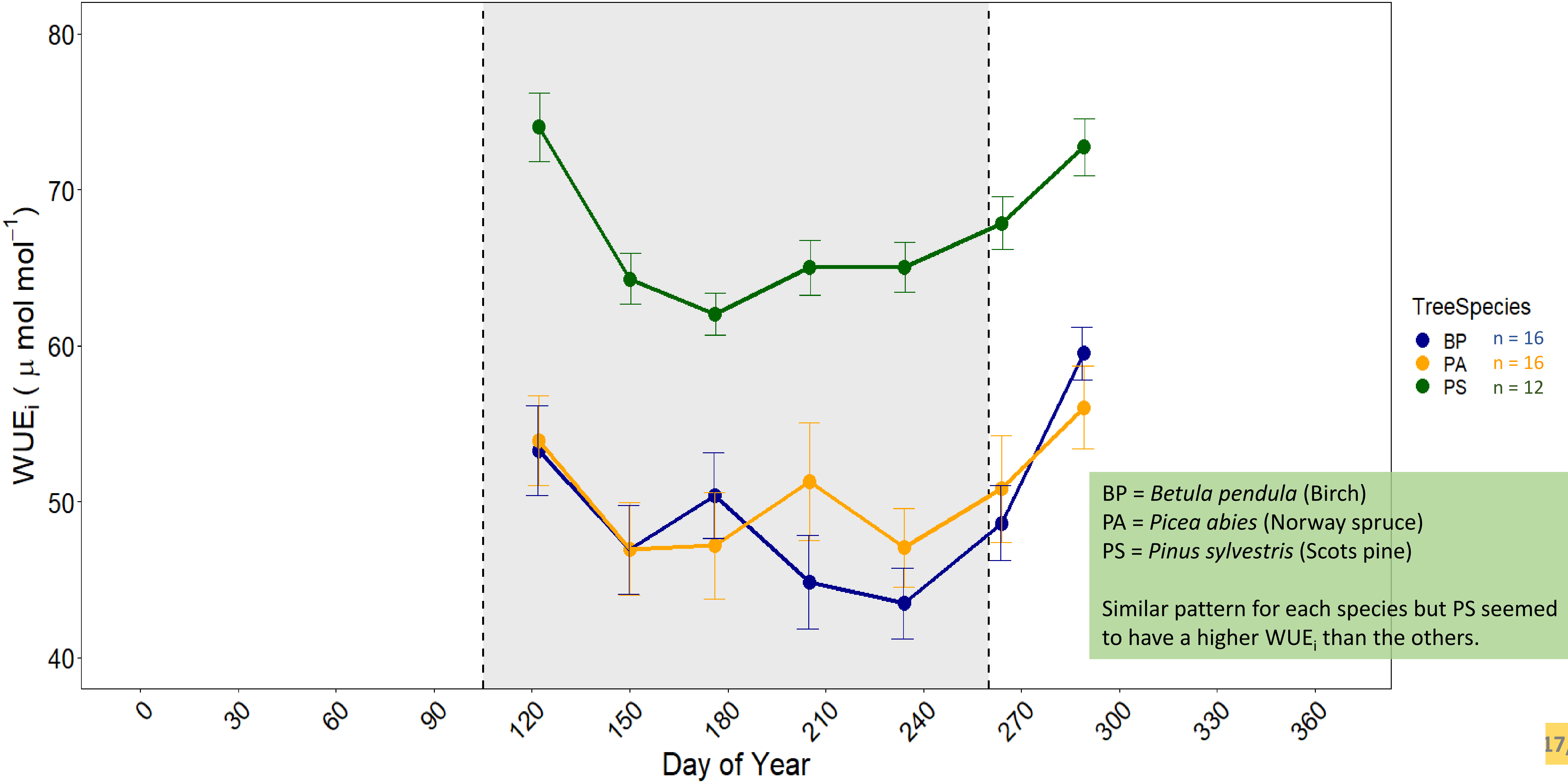
} Half-hourly time scale

- $\delta^{13}C$ in the phloem

⬄ 4 trees x 3 spp x 3 plots = 36 samples per sampling date

} Sampling every 4 weeks from May to October

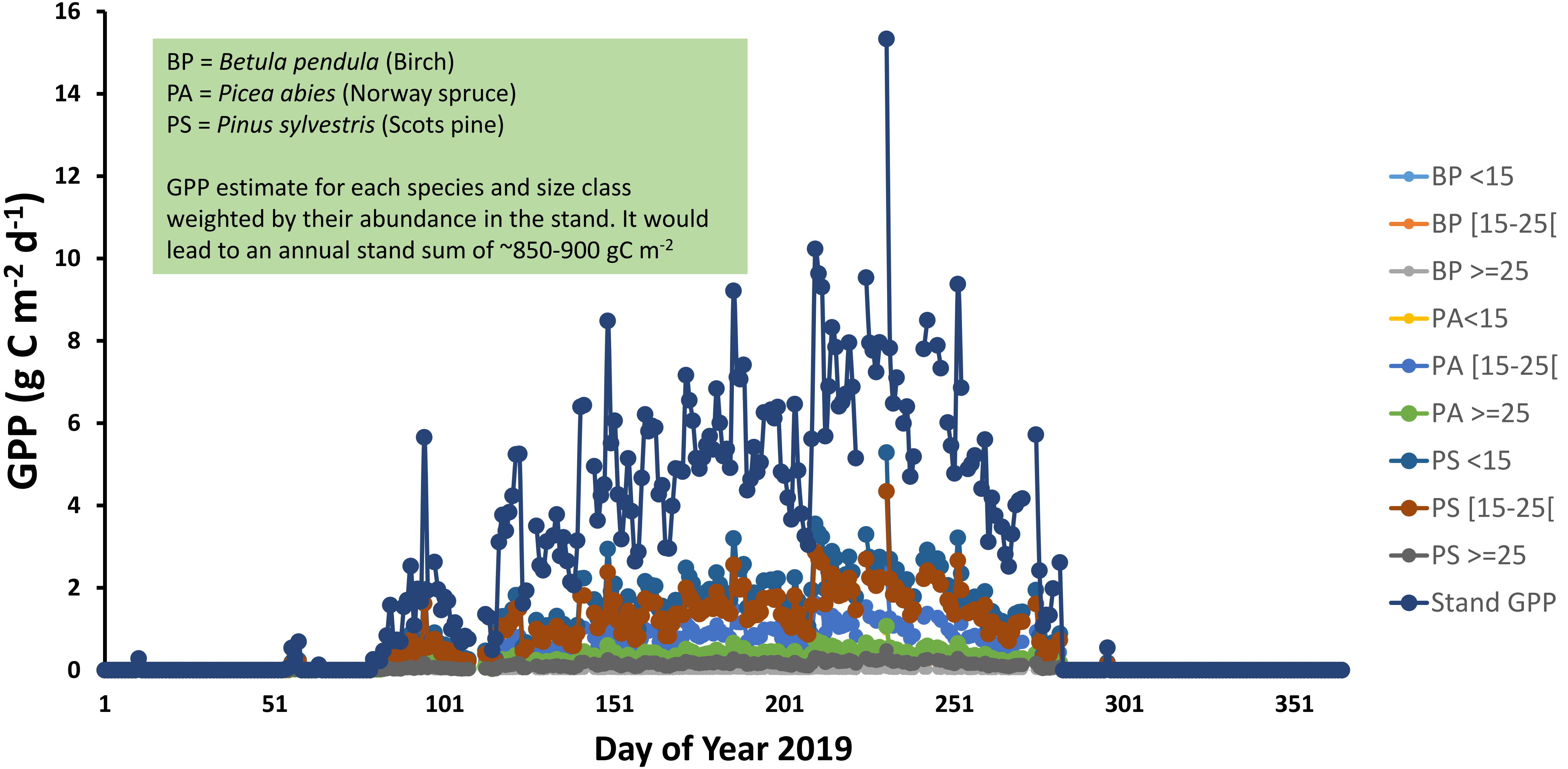
Preliminary results: WUE_i of the 3 species (1/2)



BP = *Betula pendula* (Birch)
PA = *Picea abies* (Norway spruce)
PS = *Pinus sylvestris* (Scots pine)

Similar pattern for each species but PS seemed to have a higher WUE_i than the others.

Preliminary results: GPP of the 3 species and different diameter size class (cm) (2/2)



Thank you for your attention!

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