Responses of *Fagus sylvatica* growing in Southern Italy to climate change: insight from sap flow continuous monitoring

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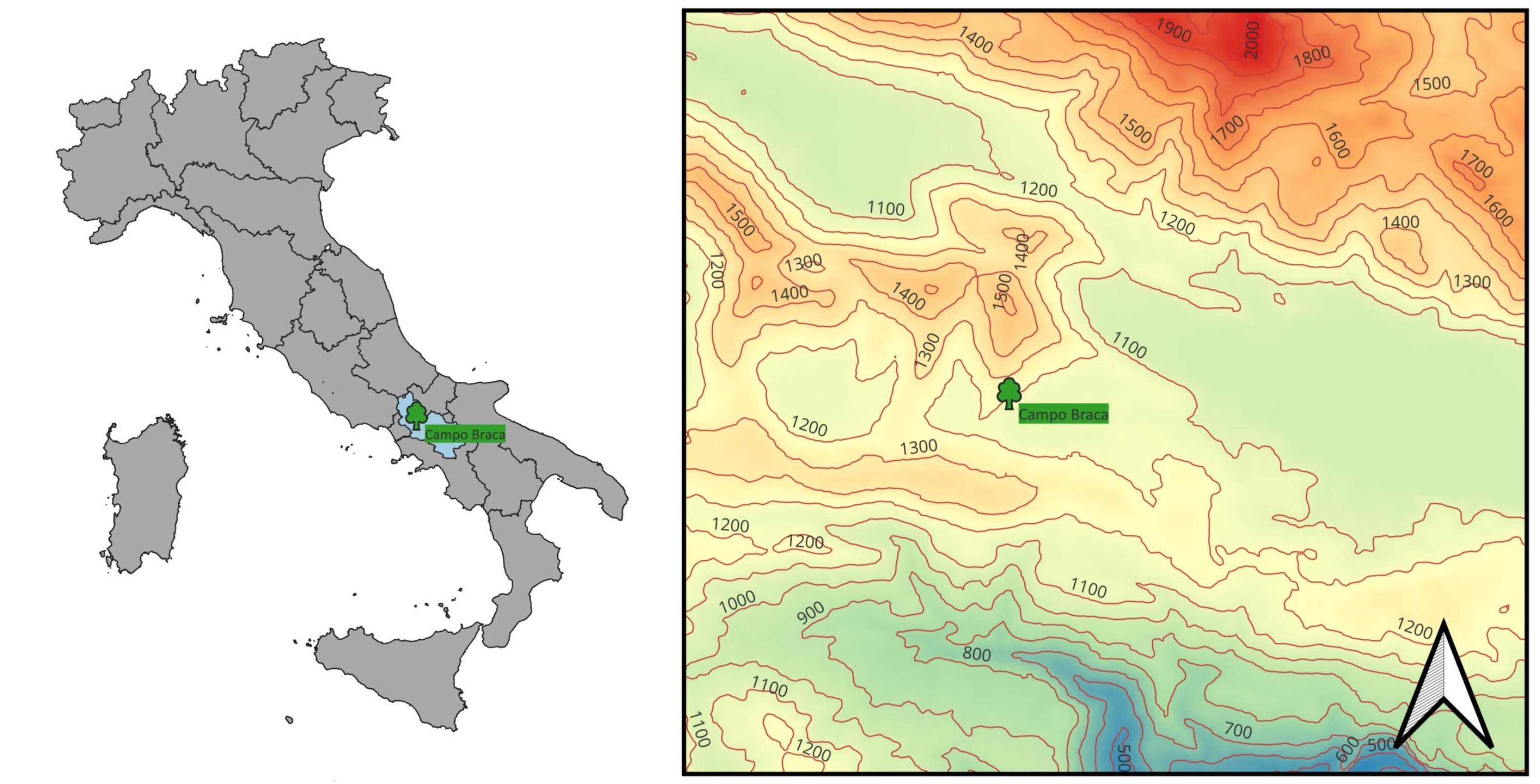
INTRODUCTION

Climate change is going to alter the functioning of most ecosystems on Earth. Forests provide irreplaceable ecosystem services, giving a crucial contribution to the carbon and water cycle on land (Jasechko et al. 2015). In this study we monitored a *Fagus sylvatica* forest located in the Matese Regional Park with the aim to unravel the responses of this widespread and important species to the environmental drivers and to climate stressors, such as drought. Our data represent a novelty, as no sap flow studies on *Fagus* from southern Italy exist, thus providing knowledge about its water use strategy near the southern edge of its areal distribution.



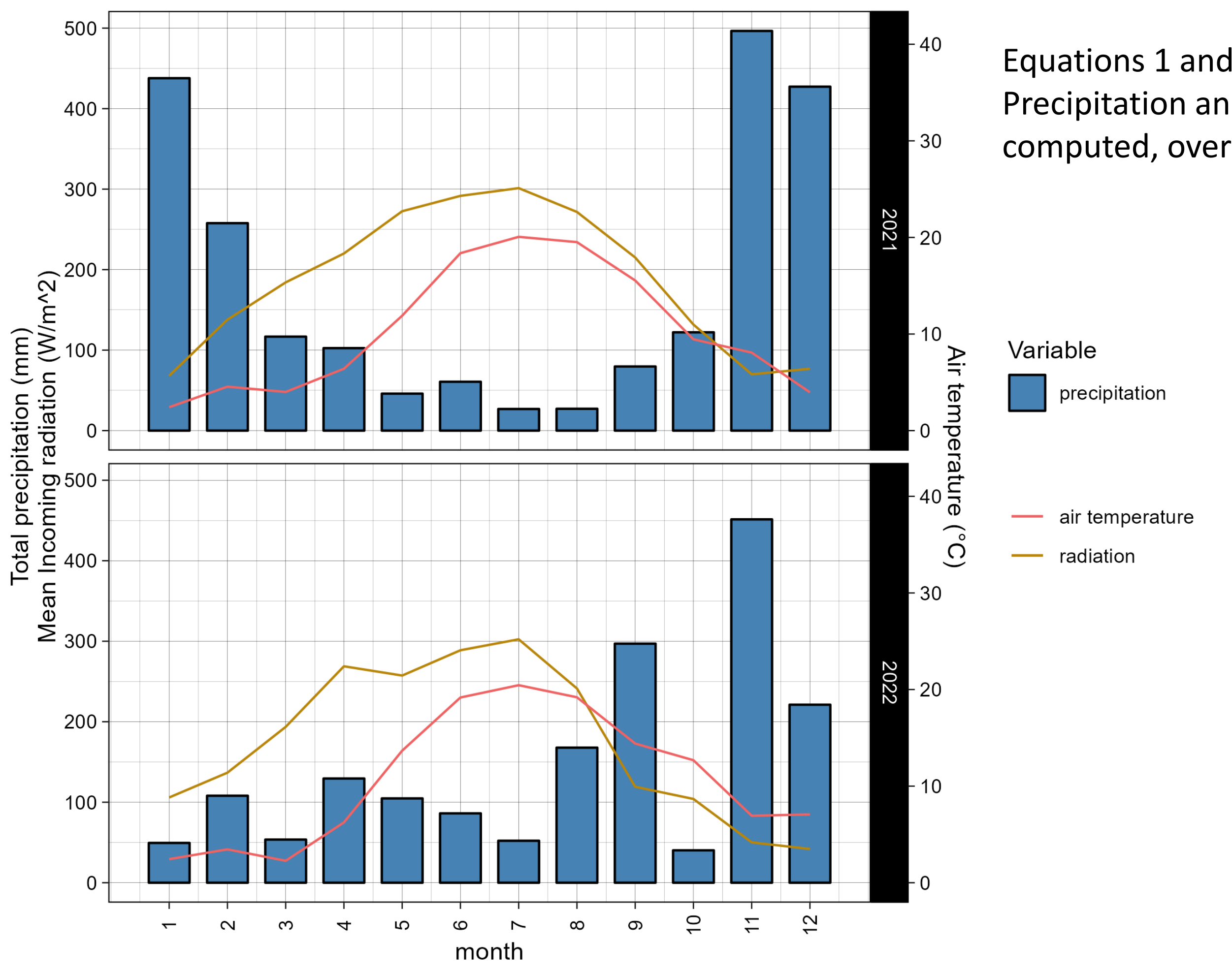
The study area is located in the Southern Appennines, in the Campania Region (41°25'00.22'N; 14°20'.27.43'E, 1141 m a.s.l), and is characterized by a mean annual temperature of 10.6 °C, an abundant total annual precipitation (1812 mm) concentrated mainly in late fall and winter (Fig. 2). Here we present the data of a *Fagus sylvatica* forest stand, where 20 individual trees (DBH 47±20 cm; height 25±5 m) were monitored during the growing seasons of 2021 and 2022. Each one was equipped with a Tree Talker device (manufactured by Nature 4.0), that record the sap flux through the Thermal Transient Dissipation Method (Do et al. 2011), along with the air temperature, air humidity, trunk temperature, stem water content, and incident solar radiation (Asgharinia et al. 2022, Niccoli et al. 2023).

Figure 1: Study site location.

MATHERIALS AND METHODS

Sap flux data, that are recorded at an hourly timescale by the devices, were handled with the dedicated *ttprocessing* package (Kabala et al. 2022). An hourly average was produced, and daily sums were computed. Meteo data were obtained from a high resolution (1 km) grid dataset, provided by the CIMA foundation, with hourly records of air temperature, incoming radiation, precipitation and relative humidity. The time series have been extracted, and daily summaries were compared with the daily sap flow average of the study site. As no direct measures of soil water potential were available, we created a simple water balance index, to represent soil water status (Dennison et al. 2003). This index is the difference between precipitation and potential evapotranspiration, as is done for the SPEI calculation (Begueria et al. 2010), but in this case we calculate the difference at a daily time scale. Potential Evapotranspiration has been calculated from the meteo variables, using the Pennman-Montheit method implemented in the FAO56 R package. Similarly, as is done for the SPEI, we aggregated the difference index by averaging it over different time intervals in days (from 1 to 100). Generalized Additive Model (hereafter GAM) are a widespread tool in ecological data analysis and are used in place of linear models to explain relationships between variables, when those are not linear, but can be represented as a continuous function. We tested which time interval of aggregation is the best to explain sap flux, by estimating GAM models on the 2021 data, with VPD, Radiation and this Water Balance Index as explanatory variables, and Sap Flux as response. The model with the best fit was then analysed more in detail. The normality of the residuals was tested by the Jarque-Bera test. Then a GAM model with the same formulation was fitted on the 2022 data.

$$(1)\ D_i = P_i - PET_i \qquad (2)\ WBI_n = \sum_{i=1}^{n} \frac{D_i}{n}$$



Equations 1 and 2: Calculation of the Water Balance Index: At first the difference between Precipitation and Potential Evapotranspiration of each day is calculated. Than the average is computed, over the last n days, depending on the timescale desired.

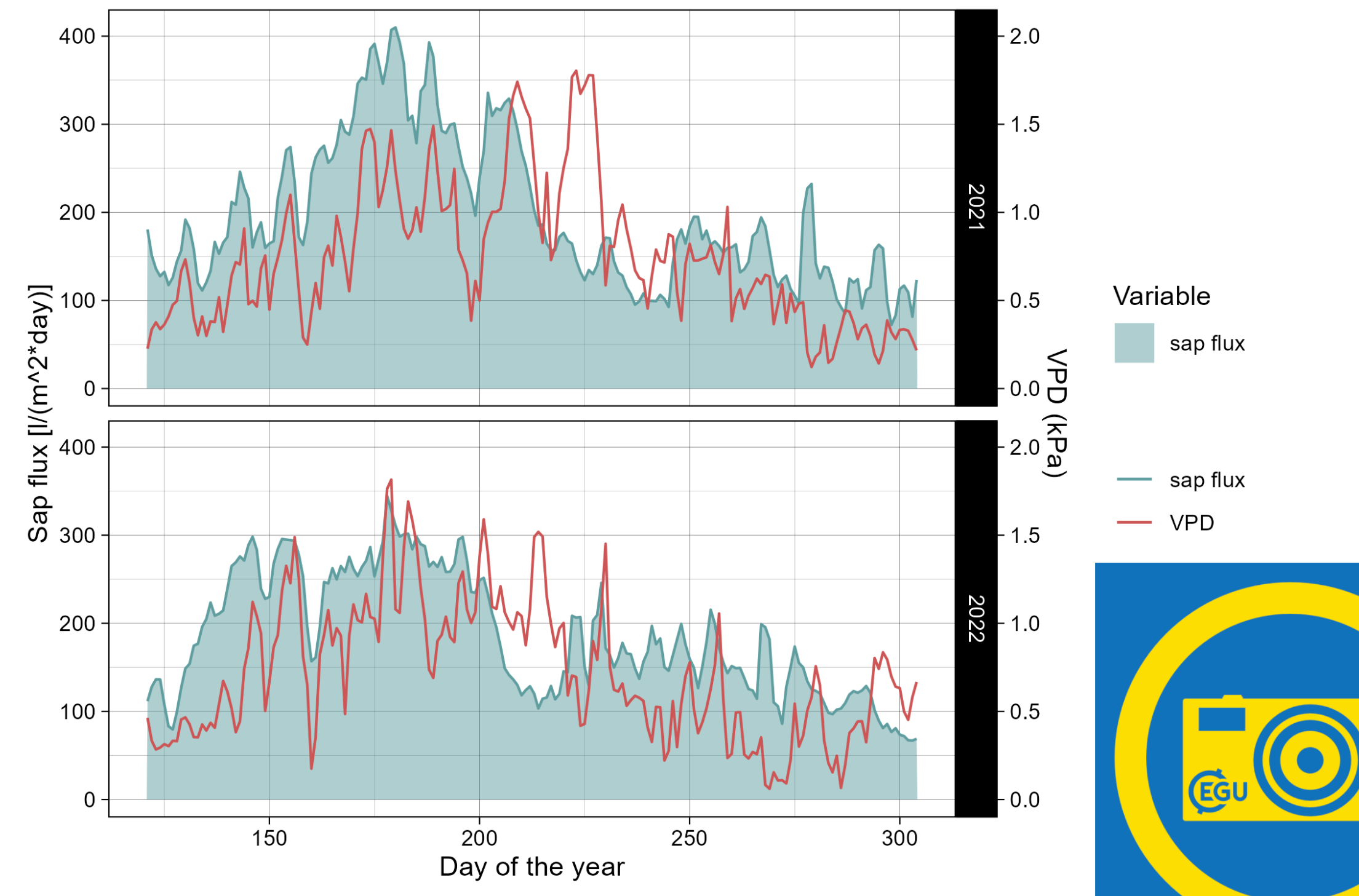


Figure 2: Air temperature, precipitation, incoming radiation, sap flux and VPD in Campo Braca during the 2021 and 2022 years.

RESULTS AND DISCUSSION

The response of sap flux to VPD is linear and positive when the plants have abundant water availability. Our data showed a positive relationship but with a low R^2; in Fig. 3A two different trends are present, that are differentiated by the WBI (different color in the figure). The sap flow during the 2022 season is lower as compared with 2021. The relationship between incoming radiation and VPD is also positive, but with much deviation from linearity due to the effects of VPD and water availability (Fig. 3B). This suggests that the sap flow is influenced by the interactions of the variables considered, and supports the usage of GAM models, which allow to consider those interactions and potential nonlinearities.

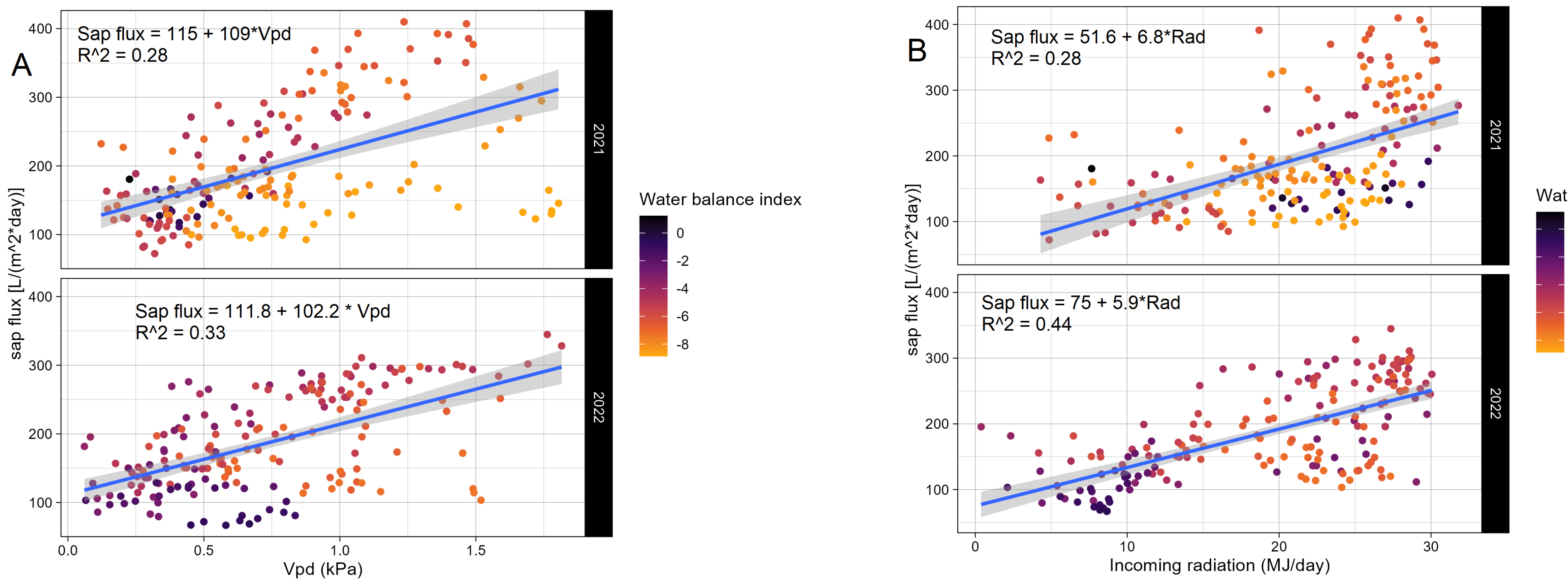


Figure 3: Scatterplots of sap flux vs VPD and incoming radiation, Points are colored according to the WBI

In the proposed GAM models incoming radiation, VPD and the Water Balance Index were used as explanatory variables. Incoming radiation was included in the model as a linear term, while VPD and WBI were transformed to z scores, and used together to estimate a smoothing spline, to take into account their joint effects, and to account for the fact they are expressed in a different unit of measure.
The best timescale was chosen considering the model quality indicators in Tab. 1, that all consistently indicated that the water balance in the last 100 days had the greatest explanatory power, suggesting that the water balance dynamics are able to influence sap flux with a lag up to 100 days in the studied forest.

Table 1: Metrics of the GAM models, using the WBI at different timescales

WBI timescale (days)	1	7	10	20	30	40	60	100
N. Obs.	179	179	179	179	179	179	179	179
R^2	0.505	0.577	0.554	0.568	0.668	0.620	0.719	0.862
AIC	1986.3	1964.2	1973.7	1967.1	1925.1	1946.9	1890.9	1766.4
BIC	2030.9	2033.4	2043.7	2032.6	2011.6	2023.2	1960.1	1847.7
RMSE	57.27	51.69	53.01	52.44	45.00	48.67	42.12	29.14

Table 2: Summary of the GAM models estimated for 2021 and 2022 respectively

	Variable	edf	Ref.df	F	p-value	sign
GAM 2021	Radiation	1		2.95	0.09	.
Deviance explained 88%	s(WBI100, VPD)	22.51	26.62	27.48	<2e-16	***
GAM 2022	Radiation	1		7.315	0.00757	**
Deviance explained 79.8 %	s(WBI100, VPD)	20.12	24.82	10.63	<2e-16	***

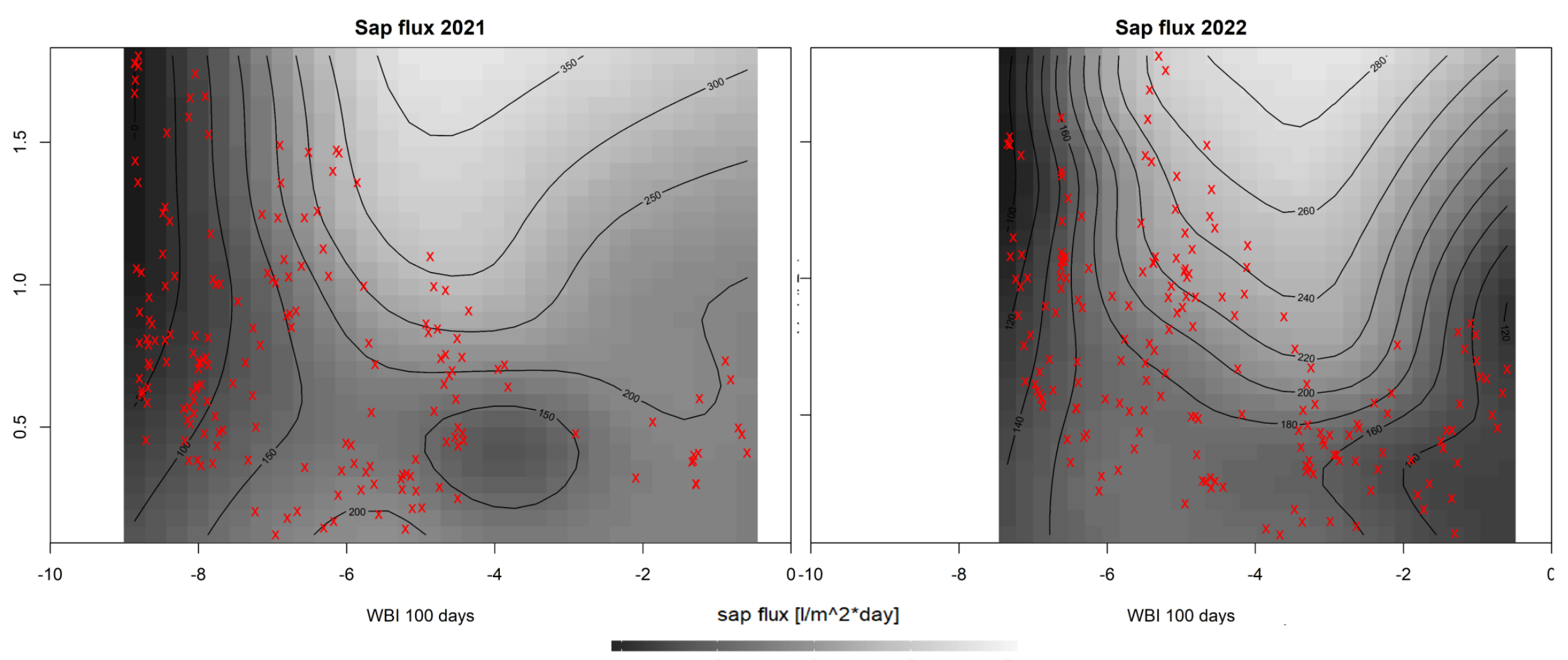


Figure 4: Values predicted by the GAM model with WBI 100 days, for the range of VPD and WBI recorded during the two vegetative seasons. The real observations are marked with the red crosses.

The monitored trees increased their transpiration with VPD when the water deficit index was moderate, while the transpiration was lowered at high water deficit values, indicating a reduction in transpiration during the most droughty periods. In 2022 sap flux was generally lower, even if the response to VPD and water deficit appears to be the same (Fig. 4). The contribution of incoming radiation was significant in 2022, while not in 2021 (Tab 2). The transpiration of the *Fagus* trees in the beech forest appears to be limited by the low water availability, when in summer there is shortage of water resources.

CONCLUSIONS

The monitored beech forest is located in an environment with high precipitation, but also high evaporative demand. During mid-late summer the plants transpiration appears to be limited by the low water availability, during periods of high VPD. The prosecution of the monitoring will clarify more details about the long-term trends in the hydraulic behaviour of Mediterranean *Fagus* forests, and potential implications of it on the plant health and growth.

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