Tracing Carbon Flux Dynamics and Ecosystem Functioning Along a Land Use Gradient: Long Term Eddy Covariance Observations in the western italian Alps.

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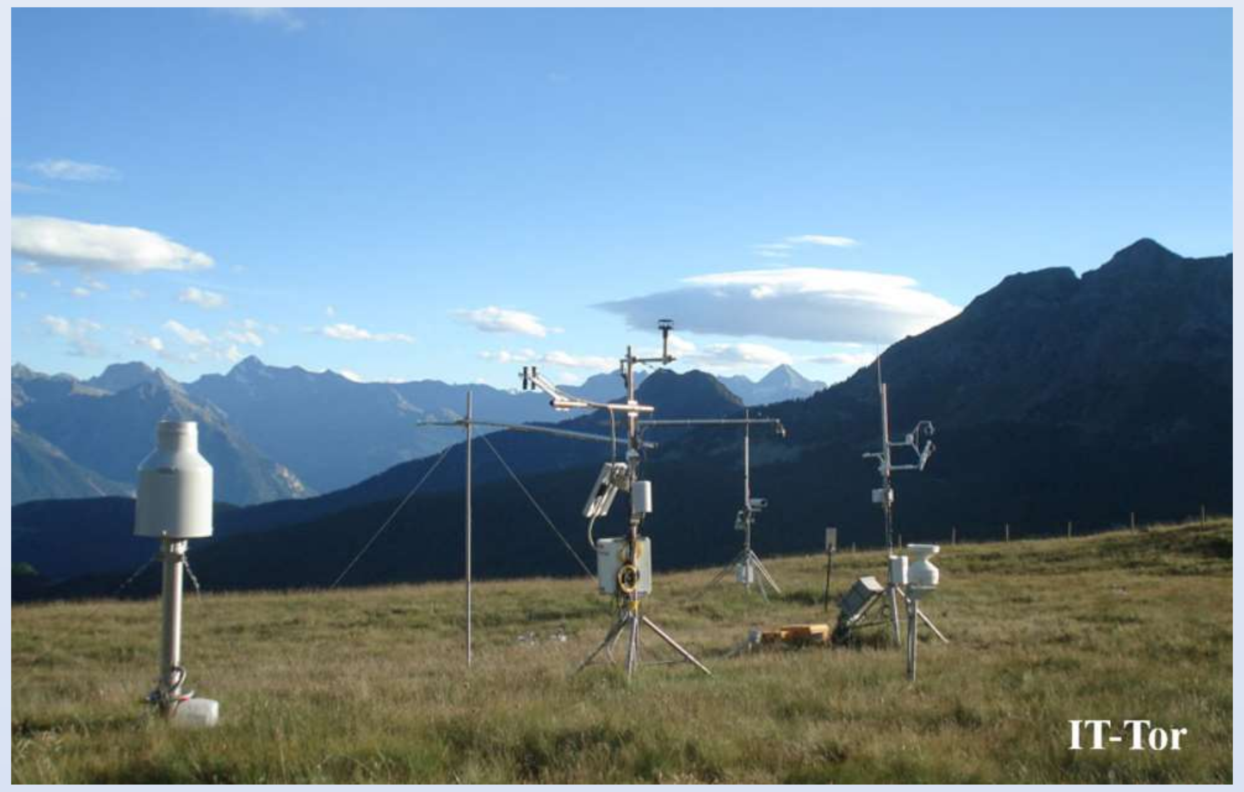
The three **Eddy Covariance** stations located in the Torgnon area, in the Aosta Valley, Italy, are managed by the regional agency **ARPA VdA**.
They belong to the **ICOS** networks (associated sites) under the following names:

- **IT-ToR**: installed in 2008 in the grassland of an abandoned pasture area.
- **IT-TrF**: installed in 2012 in a mature larch forest; the instruments are positioned above the vegetation at a height of 35 m.
- **IT-ToS**: installed in 2024 within an area undergoing recolonization by young larches and shrubs (still not in ICOS).

The three sites are also part of the **FLUXNET** and **LTER** networks.
They are situated at an altitude of **2100 m a.s.l.**, a few kilometers away from each other. The grassland, the encroached area and the forest represent the three stages of the process of forest recolonization on pastures abandoned by livestock and human management, a currently widespread phenomenon across the Alps.



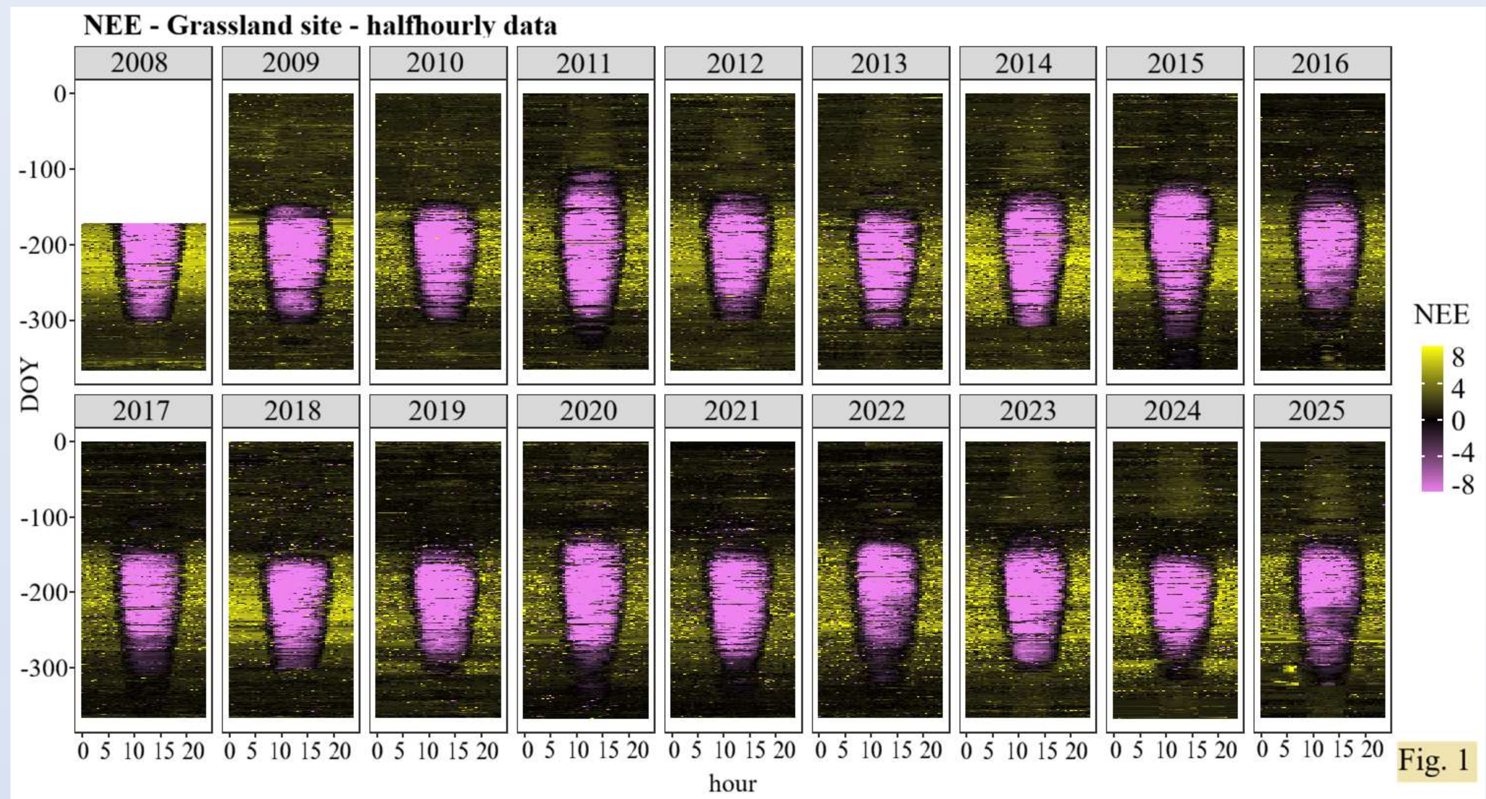


Fig. 1

The fingerprint plots (*Fig. 1 and 2*) illustrate the trends of half-hourly Net Ecosystem Exchange (NEE) data for pasture and forest sites. The graphs on the right panels display comparative analyses between the pasture and the forest sites.
The bottom panel presents a comparison between the pasture and the encroached site (NEE trend).

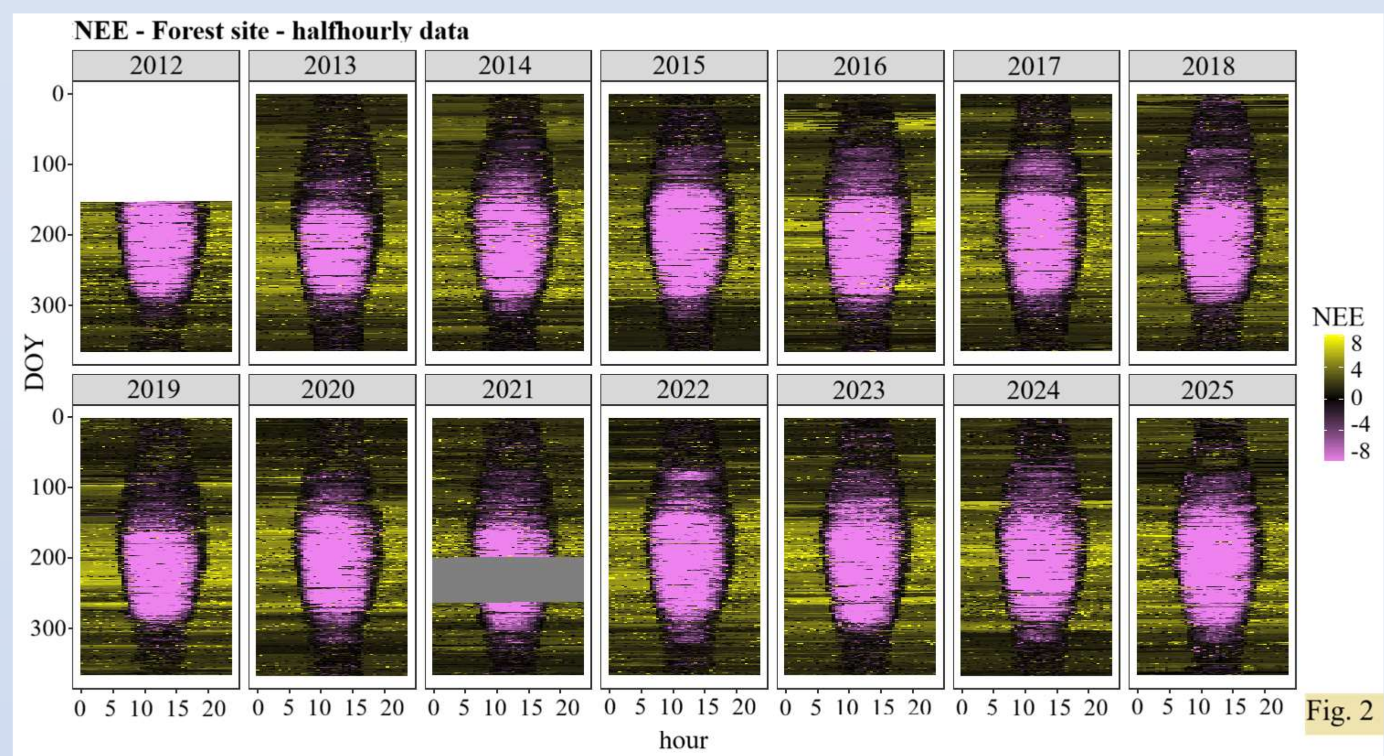


Fig. 2

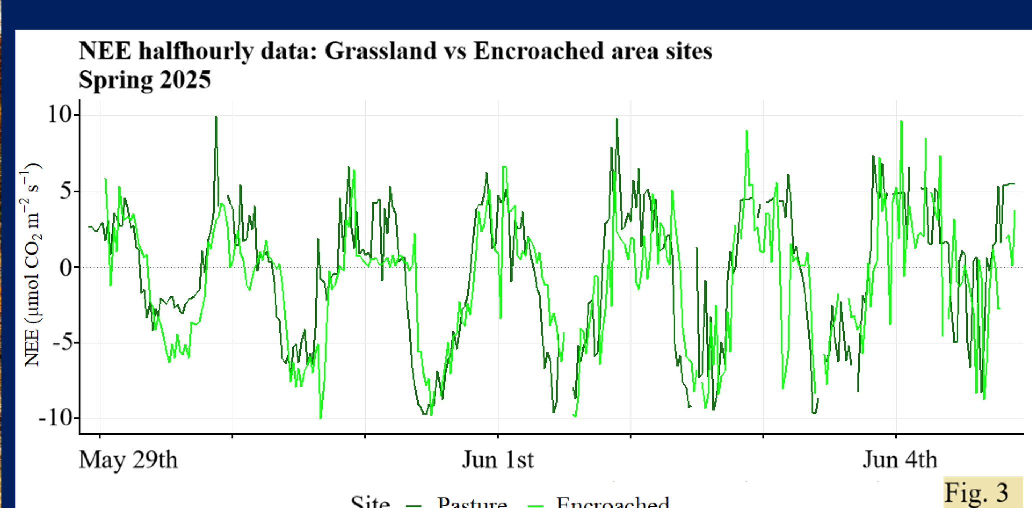


Fig. 3

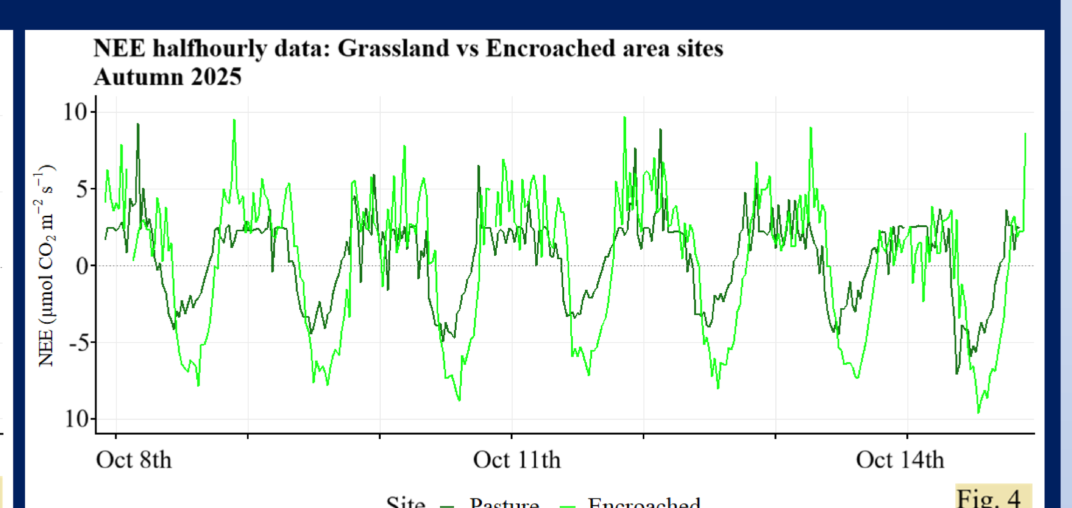


Fig. 4

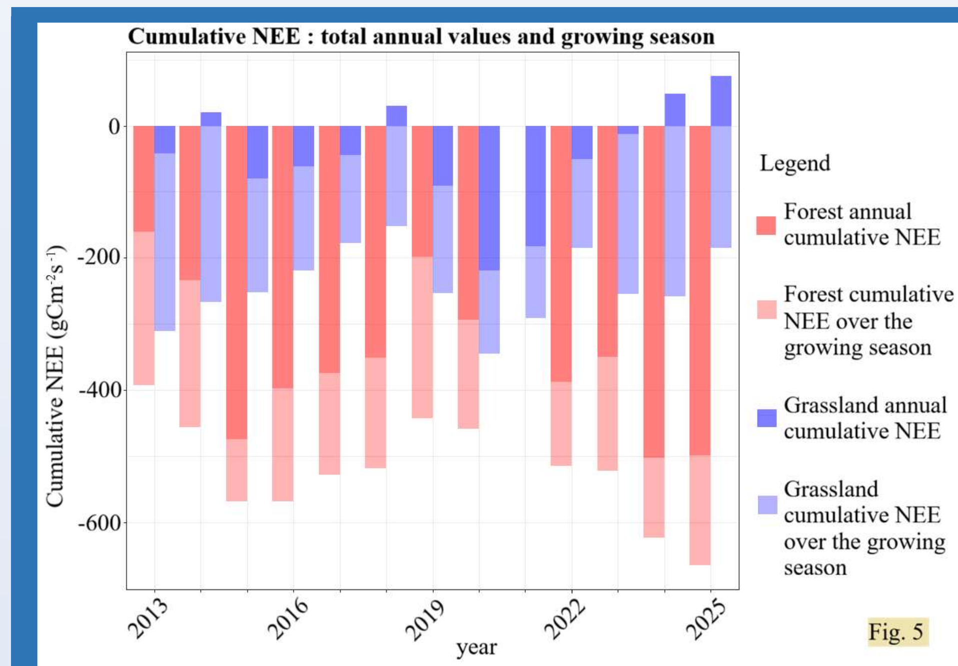


Fig. 5

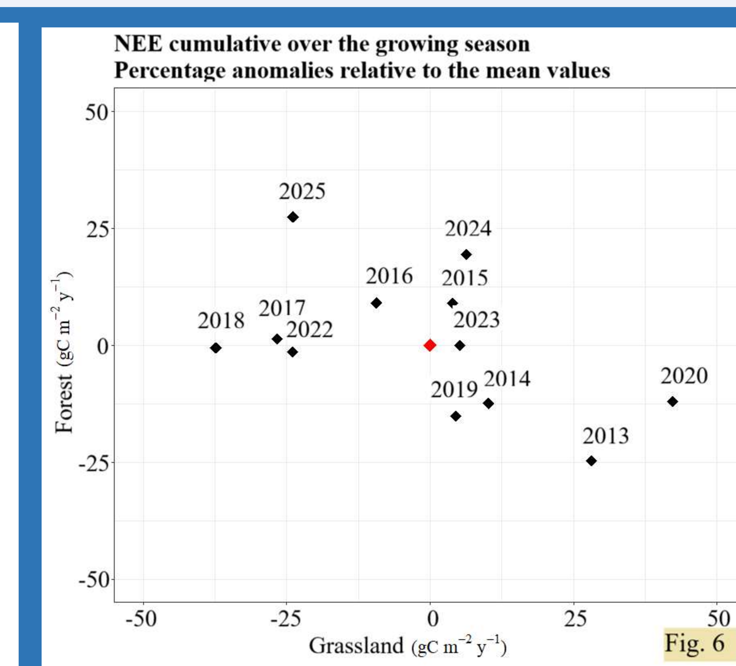


Fig. 6

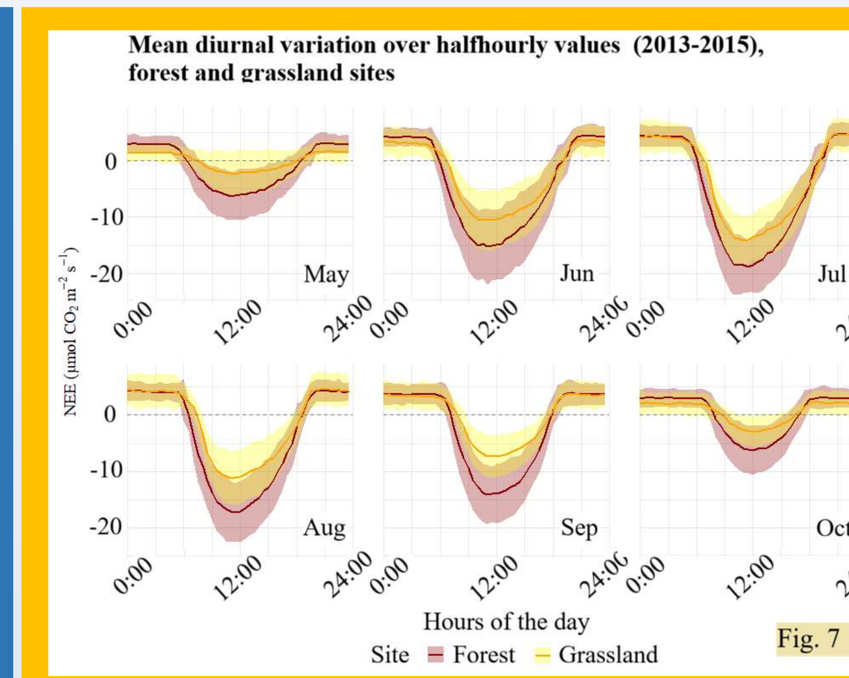


Fig. 7

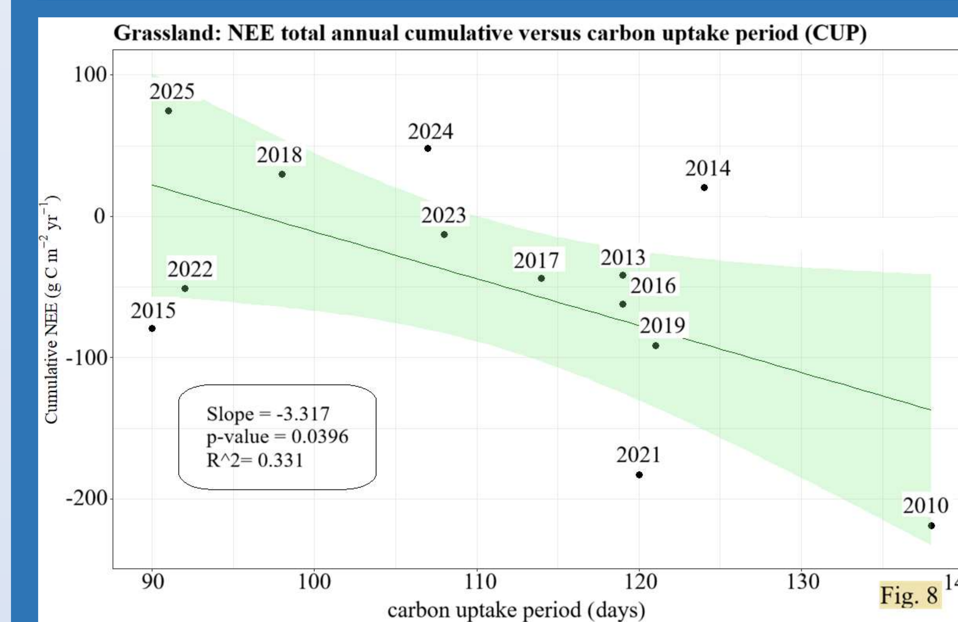


Fig. 8

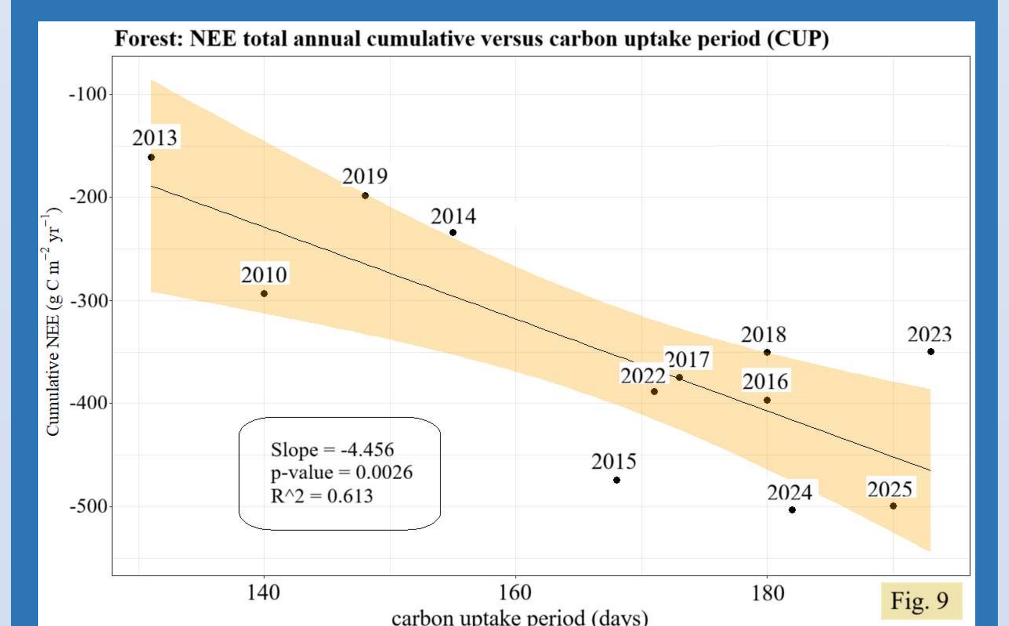


Fig. 9

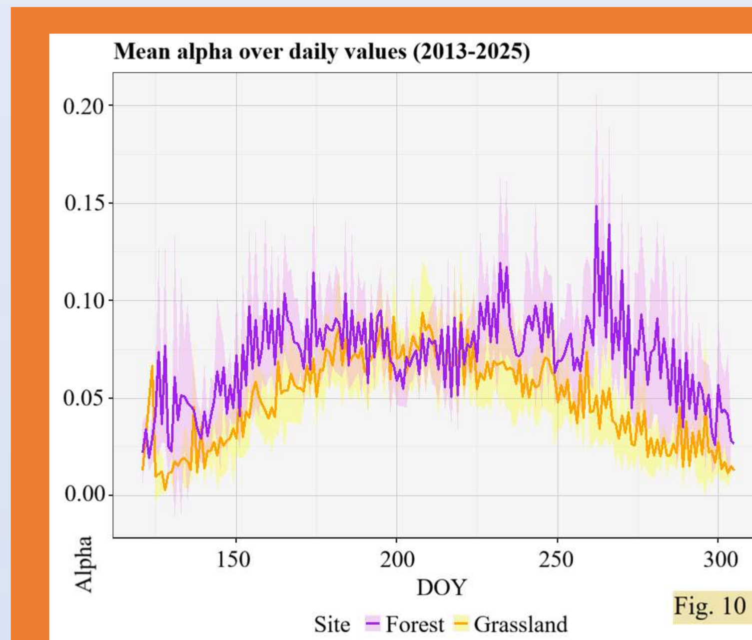


Fig. 10

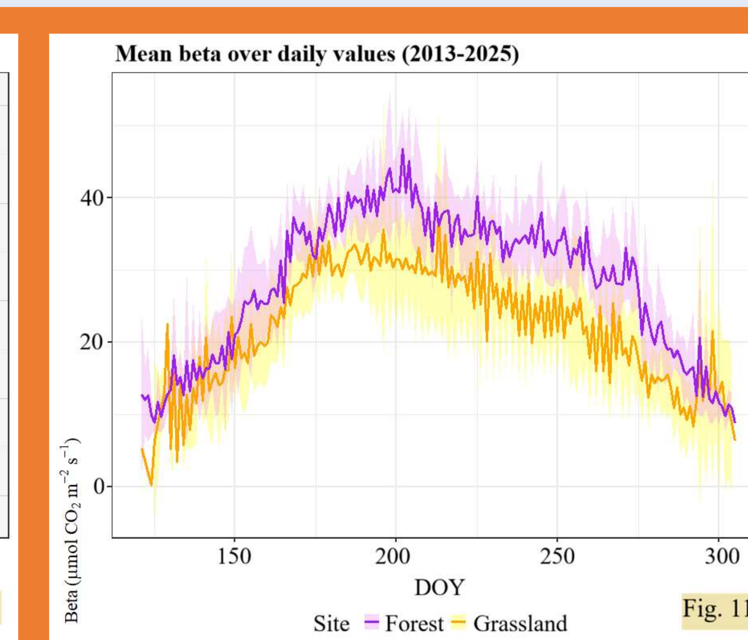


Fig. 11

Overall, the analysis of photosynthetic variables (where negative NEE indicates CO_2 uptake) highlights two primary features distinguishing pasture from forest sites: forested areas shows higher CO_2 sequestration capacity and greater ecosystem resilience.
The forest site exhibits superior stability against drought years, shorter winters, and interannual climatic variability. The higher absolute values of annual cumulative NEE (*Fig. 5*) and diurnal fluxes (MDV plots, *Fig. 7*) report higher CO_2 sequestration capacity of the forest.

The forest's resilience is further evidenced by smaller magnitudes of flux anomalies (*Fig. 6*), a weaker correlation between cumulative NEE and the duration of the Carbon Uptake Period (CUP) (*Fig. 8 and 9*), and a decrease in Water Use Efficiency (WUE) as water availability increases (*Fig. 12 and 13*).
Moreover, observing the recolonization process in the comparison on weekly NEE data from spring and autumn reveals higher rates of both uptake and respiration in the encroached area compared to the pasture (*Fig. 3 and 4*).

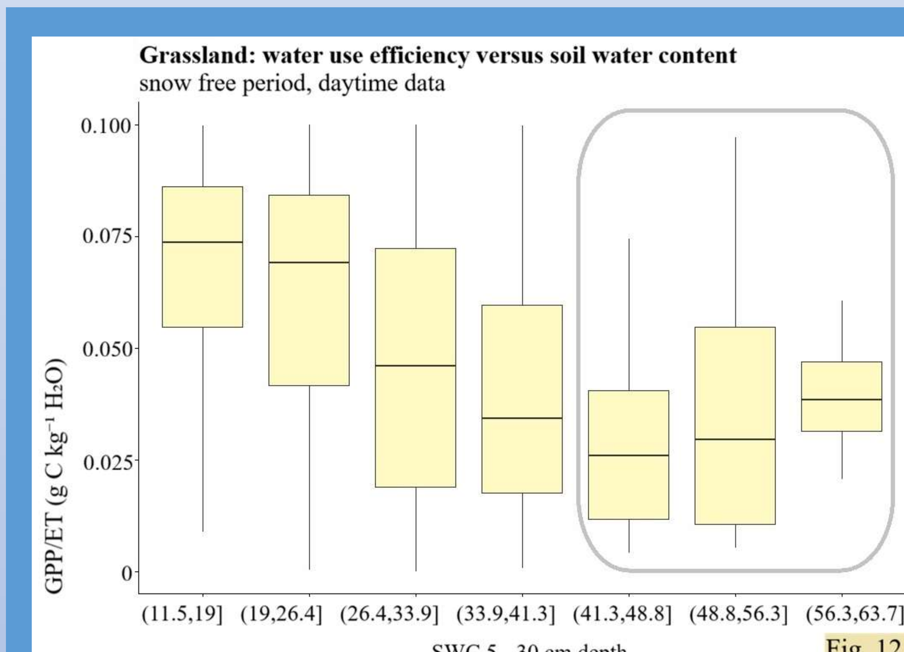


Fig. 12

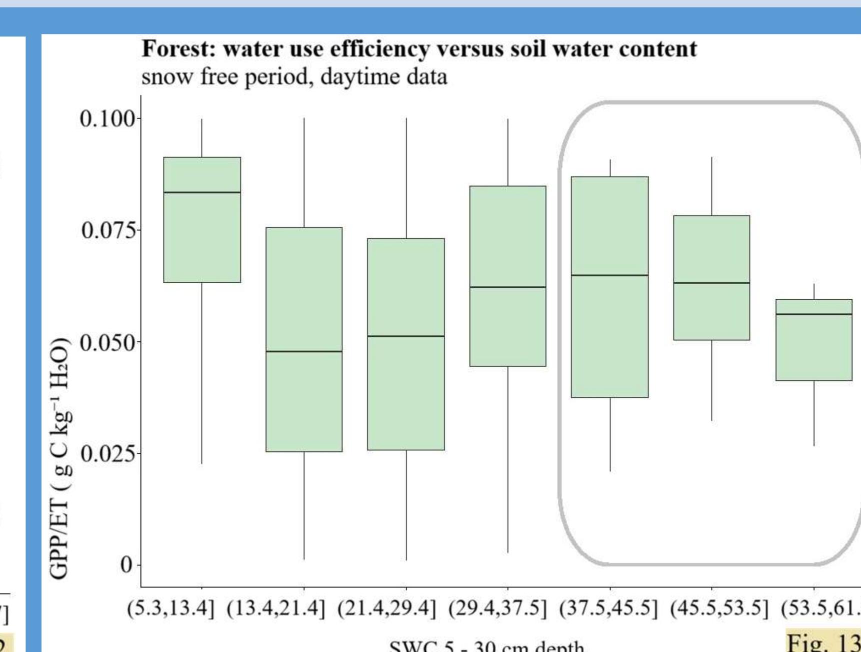


Fig. 13

***Future perspectives*. The comparison between land-use change dynamics, specifically reforestation after pasture abandonment, aims to broaden the understanding of long-term carbon budgets, providing essential insights for land management policies in the Alps. In this context, the greater resilience of forested sites may play a crucial role in stabilizing carbon sinks under future climatic uncertainty.**