FORGENIUS

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Deliverable D4.7

Multidimensional index of ecological resilience and vulnerability for a subset of the selected GCUs/species

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1 Summary

The objective of this deliverable was to provide a multidimensional description of climate risks for each GCU, which was achieved by integrating various datasets, including the spatial distribution and shape of individual GCUs, remote sensing data of vegetation properties and climate envelope models for individual tree species. The objectives of this work were threefold: i) to quantify the climatic marginality of each GCU, which is defined as the distance of the GCU from optimal climate conditions for a given species; ii) to quantify future trends in climatic suitability for each species/GCU combination using a dataset of future projections of tree species distribution in Europe; iii) to quantify the recent trends in two ecosystem performance metrics derived from remotely-sensed spectral information. The results of this analysis provide an analytical framework for describing the climate vulnerability of GCUs, which can be further refined once genomic and phenotypic data will become available.

2 Introduction

The work completed for deliverable D4.7 relies on two separate datasets produced by JRC in the framework of FORGENIUS. These include a dataset on the present and future distribution of the main tree species in Europe and a dataset comprising a large number of variables derived from satellite remote sensing. The latter dataset was produced as part of WP1.

In brief, the dataset on tree species distributions contains both current and future potential distributions for 67 tree species in Europe. The future distribution data includes information under two emission scenarios (RCP 4.5 and RCP 8.5) across three time steps (2035, 2065, 2095). These data-driven projections were generated using an ensemble of statistical and machine-learning models. The dataset is publicly available and has been published as a data paper (Mauri et al. 2022).

Regarding the remote sensing dataset, we used long-term trends at the GCU level for two spectral indices: the Normalised Difference Vegetation Index (NDVI) and Normalised Difference Water Index (NDWI). These indices are widely recognized as robust indicators of ecosystem performance. The data source for producing trends in spectral indices was MODIS. We used data from the years 2003 and 2021, which were aggregated for the growing season by calculating the mean value of each spectral index/GCU combination. As a result, we obtained one ecosystem-performance value per year for each GCU.

Climatic marginality for each GCU was quantified using a three step procedure: i) we first identified the full climatic niche of each species using the tree distribution data. Because the niche is inherently a multidimensional concept we used 9 climatic variables to quantify it appropriately (for list see Mauri et al. 2022). These were summarised into a low (two dimensions) dimensional space using Principal Components Analysis (PCA). We then used Kernel Density Estimation to calculate the portion of the climate space occupied by a given species; ii) we used climate values for each GCU/species combination to calculate new PCA

scores for every GCU; iii) we measured the distance of each GCU in climate space to the edge of the climatic niche space occupied by the species. This resulted in one marginality value per GCU. Note that this method leads to an index that is increasing at decreasing value of marginality.

To quantify trends in climatic suitability, we fitted a series of ordinary least squares regression models (OLS) to the climatic suitability scores, with year as a predictor, with the stage of the time series (current, 2035, 2065 and 2095) as a predictor. We performed this analysis for each species/GCU combination. As such the suitability trend shows the relative increase or decline in suitability between adjacent timesteps (for example a GCU exhibiting a trend of -0.2 shows a 20% decline in climate suitability from timestep to the next).

Finally, the trend in the ecosystem performance is evaluated via a linear least squares regression on the mean NDVI and, separately, the mean NDWI across the multi-year time series. For each GCU the trend is the average change in the NDVI and NDWI per year.

References:

Mauri, A., Girardello, M., Strona, G., Beck, P.S., Forzieri, G., Caudullo, G., Manca, F. and Cescatti, A., 2022. EU-Trees4F, a dataset on the future distribution of European tree species. Scientific data, 9(1), p.37.

3 Results

3.1 Results 1: Climatic marginality

Figure 1 displays the example results for the analysis of climatic marginality for three species: *Fagus sylvatica*, *Pinus sylvestris*, and *Picea Abies*.

Our analysis was limited to a subset of the GCUs, specifically polygons containing a single species population. Polygons containing multiple species were excluded because they could not be matched unambiguously to the species distribution dataset. The final dataset included 1,706 GCUs, representing 42 different tree species.

The climatic marginality index ranges from -∞ to +1, with GCUs located outside the climate niche space having negative values, indicating greater marginality. In contrast, GCUs within the envelope have positive values.

Panel (a) in Figure 1 displays the climatic marginality scores in multivariate climate space. The first two axes of the PCA performed on the climate data accounted for 84% of the variability in the dataset. The first axis revealed a climatic gradient that was primarily positively correlated with mean annual temperature and negatively correlated with total summer precipitation. The second axis was positively correlated with continentality and negatively correlated with winter precipitation.

Marginality scores were also visualised in geographic space (Panel (b)). The maps show that GCUs occurring at the edge of their European distribution of a species are more marginal, as indicated by lower values.

Panel (c) presents density plots for the marginality values. Although there is a significant amount of variability in marginality across GCUs, they generally have positive marginality values. This suggests that, under current climate conditions, most GCUs occur in areas that are not outside the climatic niche of a given species.

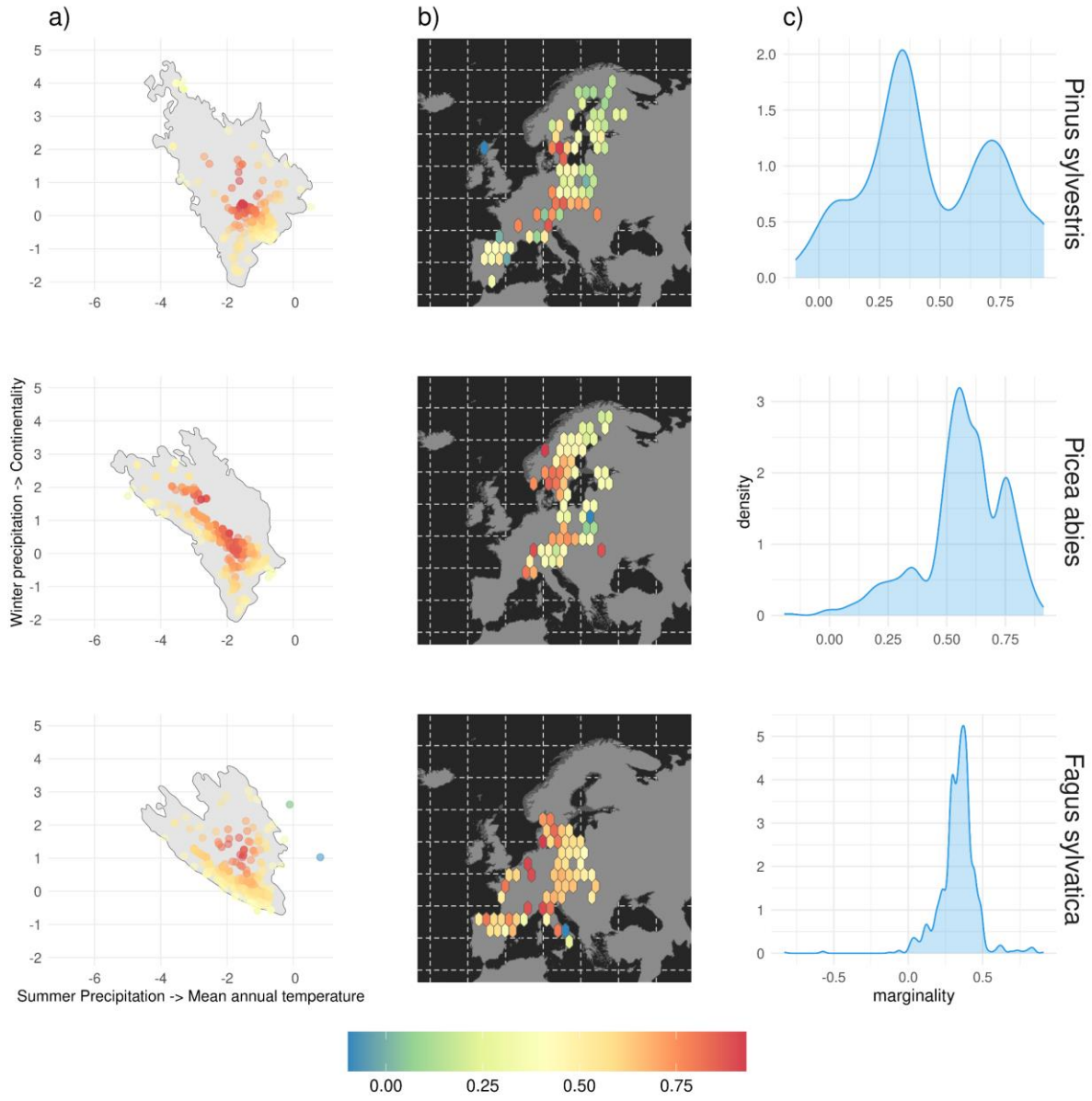

Figure 1: Climatic marginality of GCUs for three selected species. Panel (a) displays the marginality scores in multivariate climatic space, with darker colors indicating more marginal GCUs and warmer colors indicating less marginal GCUs. Panel (b) shows the marginality values in geographic space, aggregated using a two-degree hexagonal grid. Panel (c) presents smoothed density estimates for the marginality scores.

3.2 Results 2: Climate suitability

Figure 2 shows the locations of the GCUs currently residing in suitable and unsuitable climates for the target tree species. The figure also shows whether the climate suitability at each GCU is increasing or decreasing for each species and the distribution of the trends in the suitability.

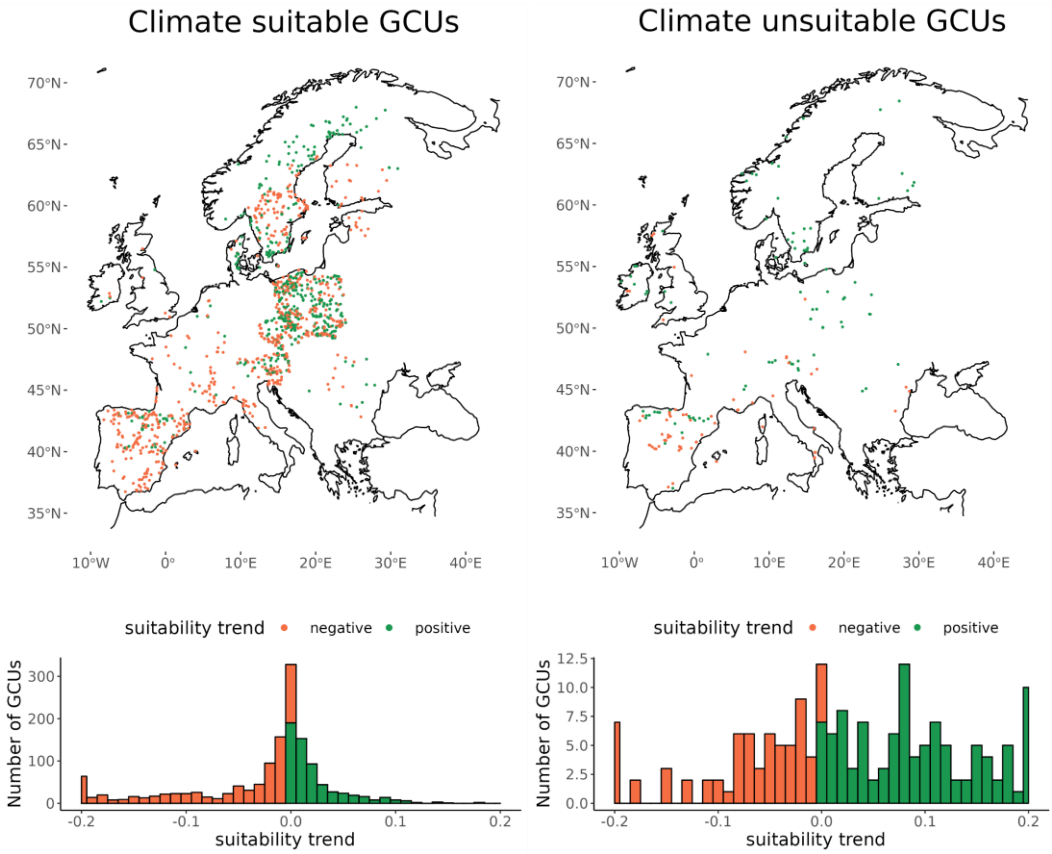

Figure 2: The trend in climate suitability for (left) GCUs that are currently residing within a suitable climate and (right) GCUs that are currently in an unsuitable climate.

Most of the GCUs (84%) reside in climates that are currently suitable for the species present, however 57% of these are projected to decline in suitability due to climate change. Whilst there are fewer GCUs that are in areas that are unsuitable, these are generally (61%) projected to improve in suitability. Whilst the current suitability of GCUs is generally spread across Europe, GCUs in the Mediterranean are expected to decline in climate suitability, whilst those in central Europe and Northern Scandinavia have a more positive trend. Interestingly in Southern Scandinavia (South Sweden and South Finland) a large share of GCUs show negative trends in climate suitability and should be carefully considered. Critical GCUs are those that are currently not in a suitable climate and that in addition show negative trends in suitability, like several located in Mediterranean countries.

Figure 3 shows the breakdown of the climate suitability trend in terms of the most common species within the GCUs. The species *Pinus sylvestris* and *Picea abies* are mostly found in GCUs that are expected to decline in suitability.

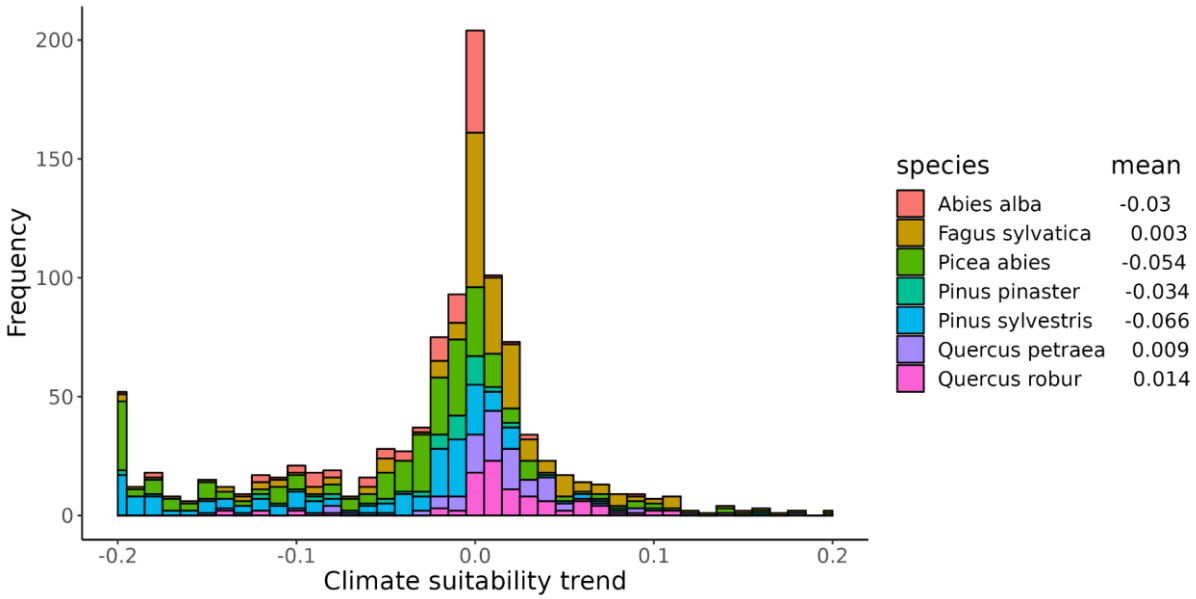

Figure 3: The trend in the climate suitability of some of the most common species present in the GCUs. The mean trend in the climate suitability across the GCUs is shown for each species.

3.3 Results 3: Performance trends

There is a positive trend in NDVI and NDWI in 74% and 50% of GCUs respectively, values that are, for the most part, approximately equally divided between currently suitable and unsuitable climate GCUs. Figure 4 shows the trend in the NDVI and NDWI averaged across the GCUs within two-degree grid cells. In most regions, and particularly the Mediterranean, the NDVI has shown a positive trend over the previous 20 years. This is likely the result of increases in CO_2 in the atmosphere, which has disproportionately benefited more arid regions. This trend is similarly observed in the NDWI.

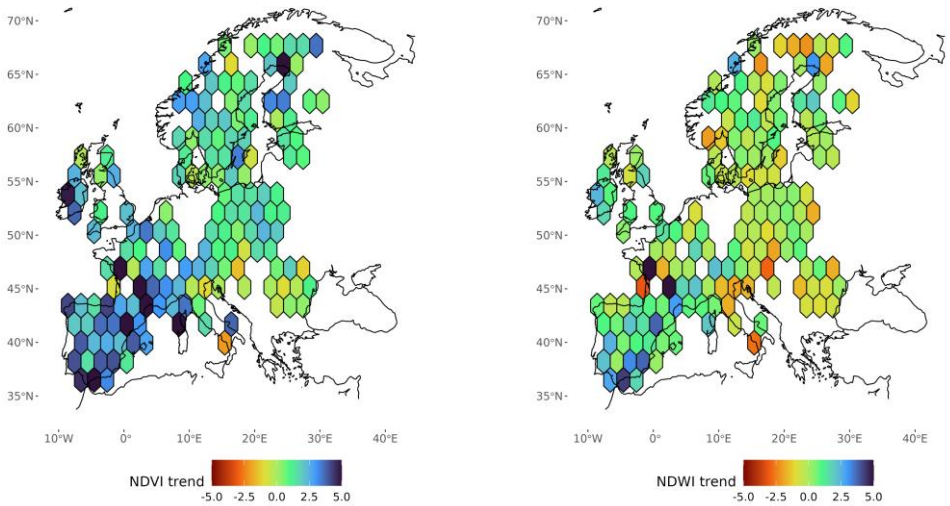

Figure 4: The mean trend in the NDVI (left) and NDWI (right) across GCUs aggregated within a two-degree hexagonal grid. The trend is given by the slope coefficient of a multi-year linear regression of mean NDVI/NDWI.

4 Conclusions

We have successfully developed a framework for quantifying a multidimensional index of vulnerability of tree species within GCUs, allowing us to quantify climatic risk for GCUs. These analyses form the foundation for a better data integration framework that is not solely based on species distribution and environmental data. In the future, with the availability of genomic and phenotypic data, this framework can be further refined to create a multidisciplinary and multidimensional index, describing GCU properties.

5 Partners involved in the work

Both the species distribution and remote sensing datasets were produced by JRC. The analyses of the dataset were led by JRC. INRAE collected and harmonised the geographical data of the GCUs (polygons describing the contours). CNR was involved in the coordination of the work in the workpackage.

6 Annexes

A1 Excel file containing the list of species included in the dataset on the future distribution of European tree species (EU-Trees4F).

A2. Dataset in a shapefile format of a set of vulnerability and performance indicators for each GCU.