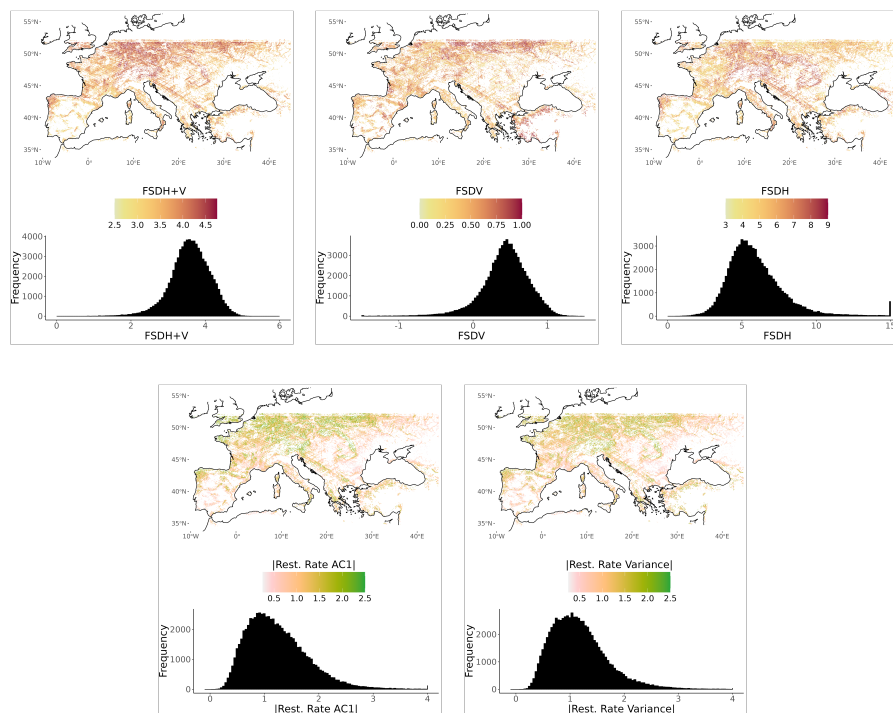


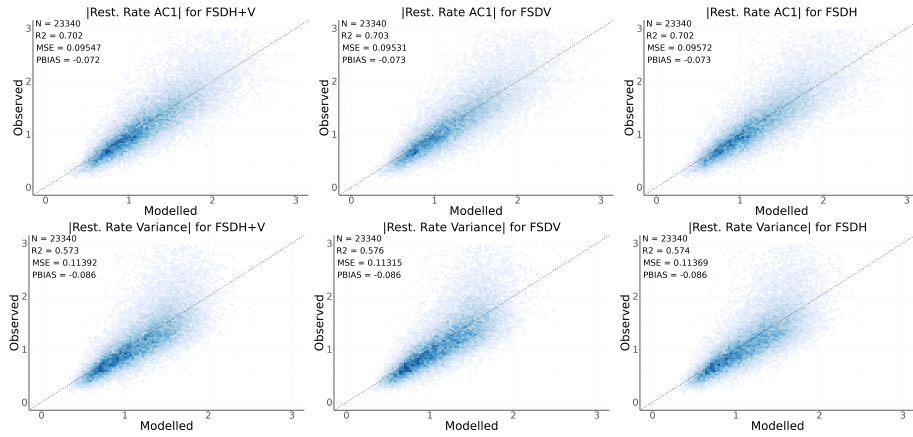
Supplementary Information: Enhanced structural diversity increases European forest resilience and potentially compensates for climate-driven declines

A The forest resilience and structural diversity metrics

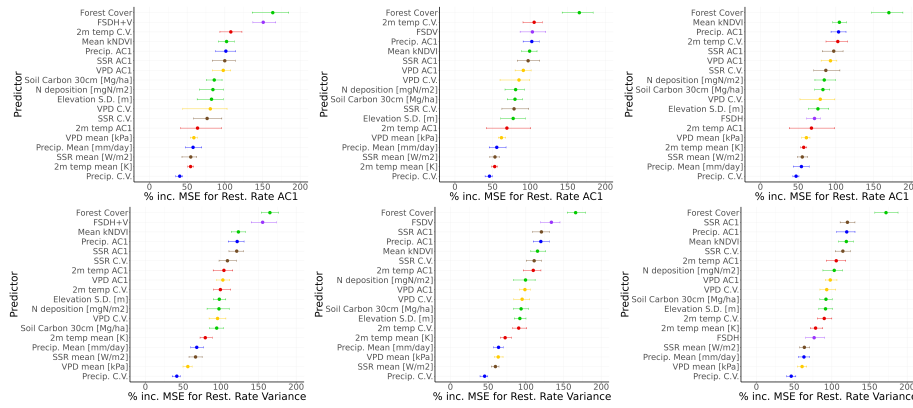


Supplementary Figure 1 Above: maps showing the structural diversity metrics: (left) Combined horizontal and vertical diversity (FSDH+V) of the relative forest heights and canopy cover, (centre) vertical diversity (FSDV), (right) horizontal diversity (FSDH). Below: maps showing the resilience metrics: the (left) AC1-derived and (right) variance-derived absolute restoration rates. Maps are shown at 0.05° resolution.

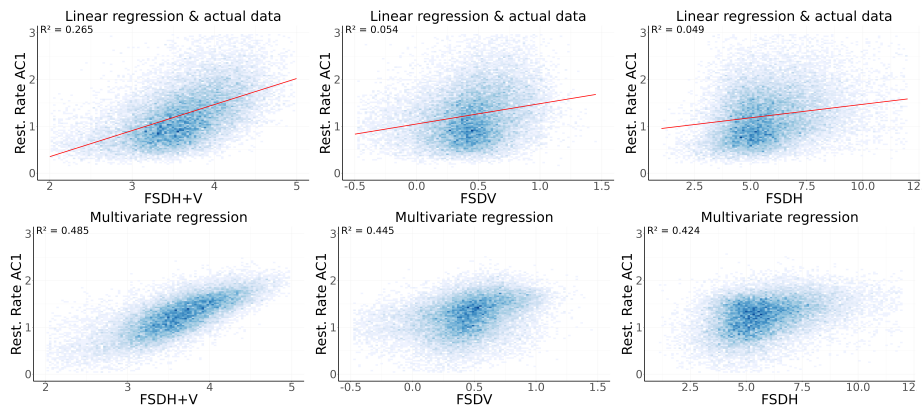
B The resilience model evaluation



Supplementary Figure 2 Performance of each Random Forest model, measured through comparison of the testing dataset modelled and observed (above) AC1-derived and (below) variance-derived restoration rates. Each model contains a different diversity metric (left to right): Combined horizontal and vertical diversity (FSDH+V), vertical diversity (FSDV) and horizontal diversity (FSDH).

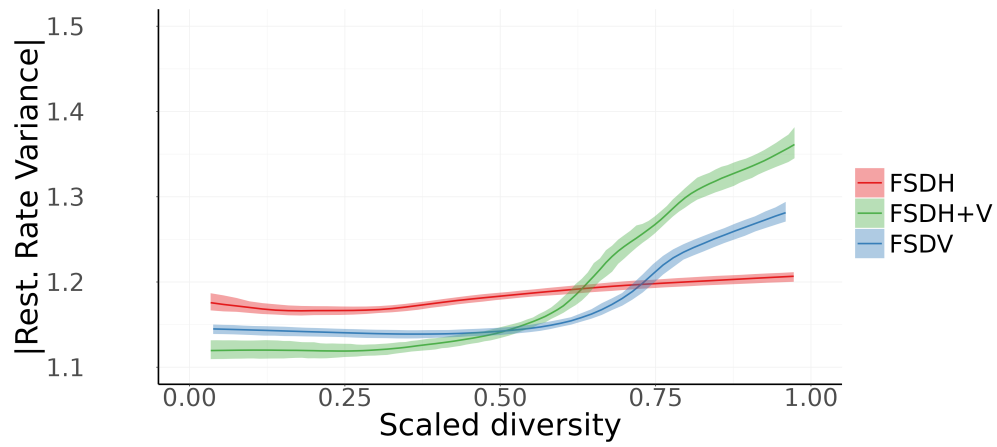


Supplementary Figure 3 Variable importance for the random forests predicting (above) AC1-derived and (below) variance-derived restoration rates. Each model contains a different diversity metric (left to right): Combined horizontal and vertical diversity (FSDH+V), Vertical diversity (FSDV) and horizontal diversity (FSDH). Importance is measured via the mean % increase in the mean square error in the out-of-bag data for each random forest model when permuting each predictor, and is normalised by the standard error. The value is the mean importance given by 100 bootstrapped models and the uncertainty bands show the 95% confidence intervals.



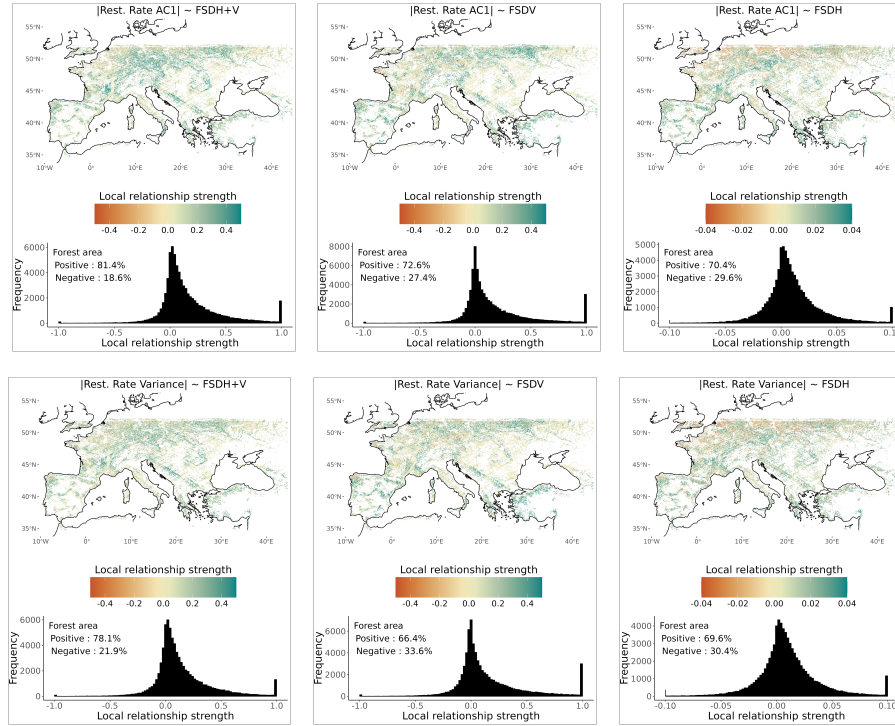
Supplementary Figure 4 Performance of simple linear (above) and multi-variate (below) models, measured through comparison of the testing dataset modelled and observed AC1-derived restoration rates. Each model contains a different diversity metric (left to right): Combined horizontal and vertical diversity (FSDH+V), vertical diversity (FSDV) and horizontal diversity (FSDH).

C The emergent relationship between European forest resilience and structural diversity



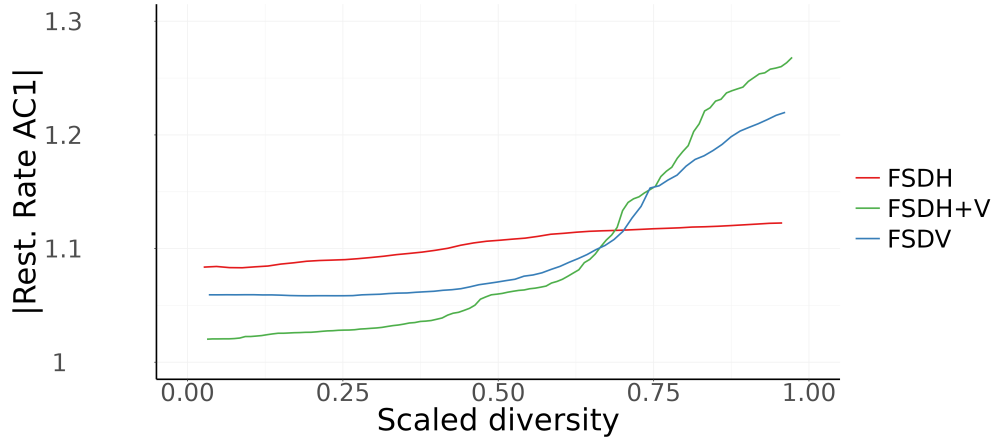
Supplementary Figure 5 The partial dependence of the variance-derived absolute restoration rate of vegetation, as a function of three metrics of structural diversity: horizontal (FSDH), vertical (FSDV) and combined horizontal and vertical (FSDH+V). The metrics are scaled to display 95% the variability observed across Europe. A 95% confidence-level band of model and FSD metric uncertainty is displayed via a bootstrapping process.

D The local relationship between forest resilience and structural diversity

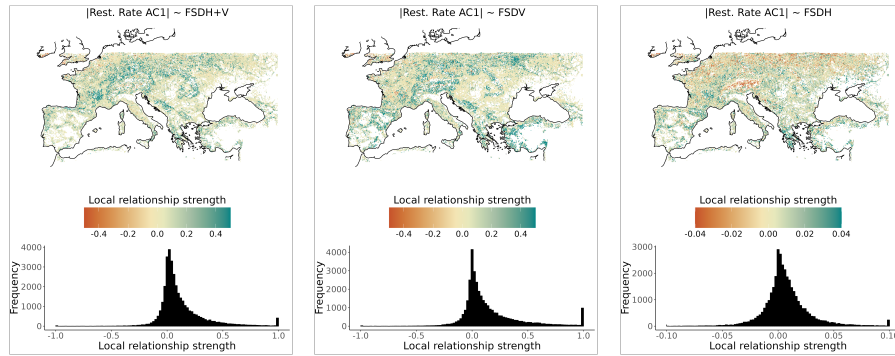


Supplementary Figure 6 The local-level relationships between the (top, AC1-driven, and, bottom, variance-driven) absolute restoration rates and: Left, the combined horizontal and vertical diversity (FSDH+V). Centre, vertical diversity (FSDV). Below, horizontal diversity (FSDH) - note the z-axis scale is tighter for the SD in RH98 figures. The relationship direction and magnitude is determined at each pixel by the derivative of the individual conditional expectation curves between the resilience and diversity metrics. The percentage of forest area showing a positive and negative relationship is also displayed.

E The relationship between forest structural diversity and resilience at 0.1° resolution

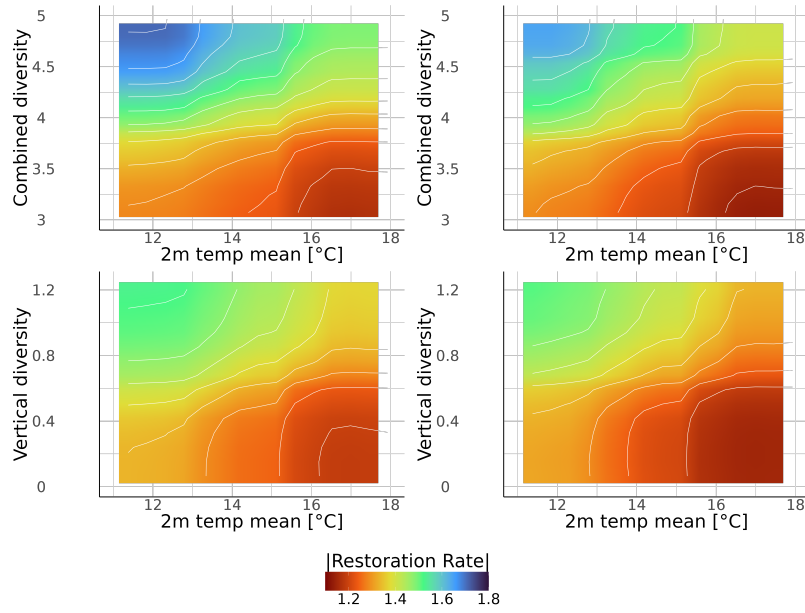


Supplementary Figure 7 The partial dependence of the AC1-derived absolute restoration rate of vegetation, as a function of three metrics of structural diversity at 0.1° resolution: horizontal (FSDH), vertical (FSDV) and combined horizontal and vertical (FSDH+V). The analysis is performed at a spatial resolution of 0.1°. The diversity metrics are scaled to display 95% of the variability observed across Europe.

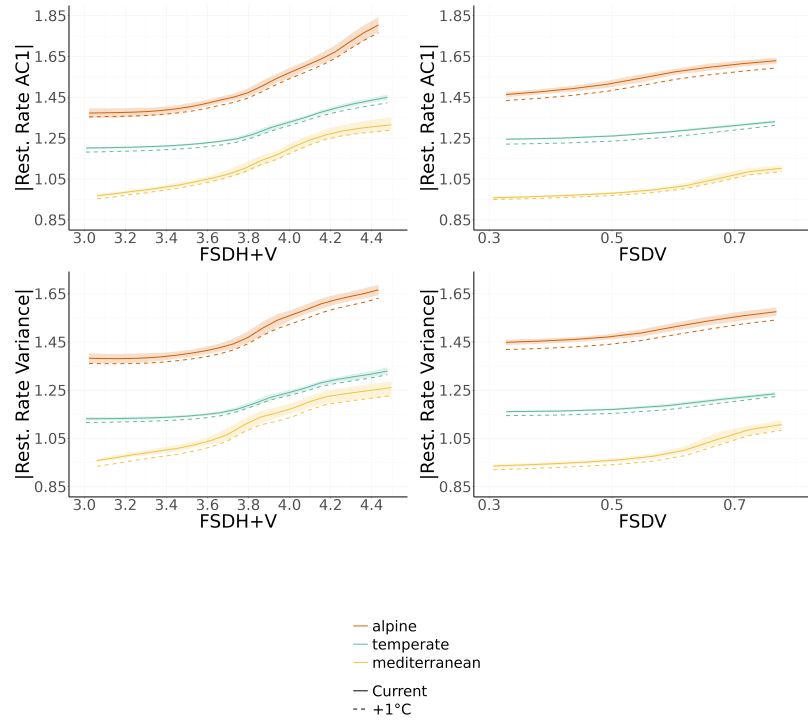


Supplementary Figure 8 The local-level relationships at 0.1° resolution between the AC1-driven absolute restoration rates and: Left, the combined horizontal and vertical diversity (FSDH+V). Centre, vertical diversity (FSDV). Right, horizontal diversity (FSDH) - note the z-axis scale is tighter for the SD in RH98 figures. The relationship direction and magnitude is determined at each pixel by the derivative of the individual conditional expectation curves between the resilience and diversity metrics.

F Interplay between forest resilience and structural diversity under climate warming

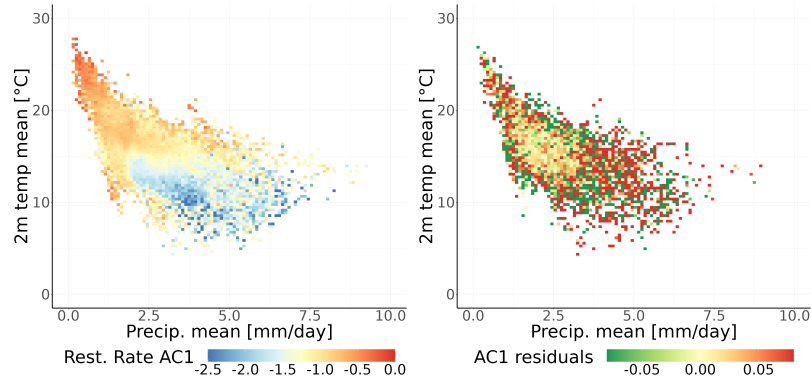


Supplementary Figure 9 Two-dimensional partial dependence plot of the (left, AC1-derived; right, variance-derived) restoration rate of European forests as a function of the mean background temperature and two different structural diversity metrics: (top) the combined horizontal and vertical diversity (shannon entropy) of the vegetation vertical profile and canopy cover; (bottom) the vertical diversity (excess kurtosis in the vertical profile).



Supplementary Figure 10 The partial dependence of the (above) AC1-derived and (below) variance-derived restoration rates of European forests as a function of two different forest structural diversity metrics: left, combined FSDH+V and right, vertical diversity FSDV. Two different mean background temperature scenarios are shown, the 2003-2019 mean (line) and a 1°C increase on this (dashed). A bootstrapping process is used to derive bands displaying the model and FSD metric uncertainty.

G Resilience and aridity



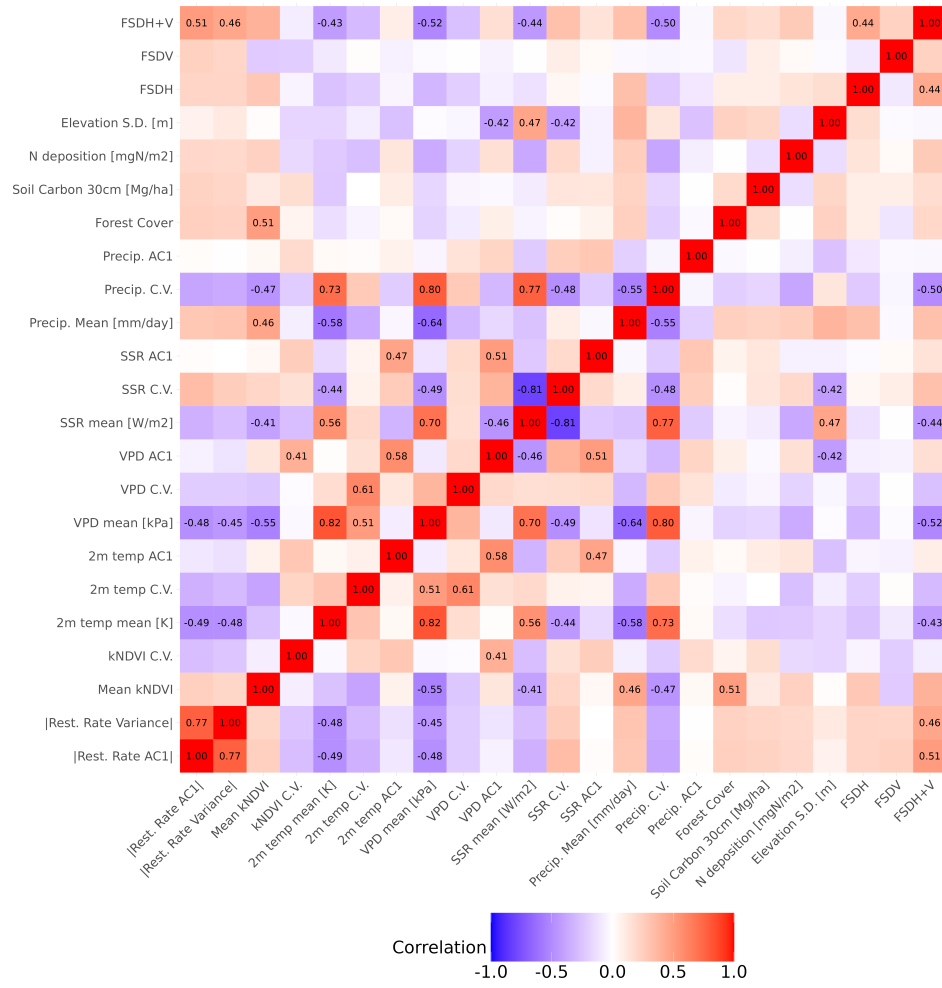
Supplementary Figure 11 The (left) AC1-based restoration rate and (right) the residuals of the random forest model, distributed in a climate space composed of mean daily 2m air temperature and mean daily precipitation. The figure shows that the restoration rate is highly dependent on environmental factors, before being accounted for by the RF model.

H Metrics used in Random Forest model

Supplementary Table 1 Overview of the resilience predictor metrics used in each Random Forest model.

Variable	Metrics	Data source
Vegetation index	kNDVI mean	MODIS
Forest cover	Forest cover	Hansen tree cover 2000
Temperature	2-metre temperature mean, coefficient of variation, and temporal autocorrelation	ERA5
Precipitation	Total precipitation mean, mean, coefficient of variation, and temporal autocorrelation	ERA5
Solar radiation	Surface net solar radiation mean, coefficient of variation, and temporal autocorrelation	ERA5
VPD	Vapour pressure deficit mean, coefficient of variation, and temporal autocorrelation	ERA5-derived
topography	Elevation standard deviation	SRTM digital elevation
Soil carbon	30cm soil organic carbon content	OpenLandMap
FSD	Horizontal (FSDH), vertical (FSDV), or combined horizontal and vertical (FSDH+V) structural diversity metrics (only one of each per model)	GED1 and M. Girardello et al. (2025)

I Correlation between model variables



Supplementary Figure 12 Correlation matrix between the input and response variables of the Random Forest used to predict the relationship between structural diversity metrics and the resilience metrics. Correlation values are shown when greater than 0.4.