Supporting Information

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SI Methods

Specifications of Statistical Models. The data from which the models are produced come from records in the hth country, $h = 1, \ldots, m$; including the ith genus, $i = 1, \ldots, n_h$; with the jth species, $j = 1, \ldots, n_{hi}$; which are recorded the kth year, $k = 1, \ldots, n_{hij}$; with the lth record, $l = 1, \ldots, n_{hijk}$.

The ordinal date Y_{hijkl} is scaled so $Y_{hijkl} = 1$ is March 1, and January and February are days of late records for the previous year. Before the analysis the ordinal dates were normalized to the geographical trends within each country separately. This normalization compensated for considerable geographical variability in seasonality within each country; hence an offset procedure is used to solve this particular problem. We simply regress the fruiting date (Y_{hijkl}) on the geographical positions by a Gam procedure, using cubic smooth spline (1), and subsequently use the residuals as the basis for our focus of further analyses:

$$Y_{hijkl} = f(\text{latitude}, \text{longitude}) + \varepsilon_{hijkl}.$$

The residuals (ε_{hijkl}) then signify the normalized observation, i.e., deviations from the geographical pattern in fruiting time (Fig. S4).

We are interested in the distribution of the normalized variables across years, and therefore we focus on the season start (2.5th percentiles), arithmetic mean, and season end (97.5th percentiles). This method provides three response variables that are handled independently but through similar approaches throughout the study, $y_{hijkl} = \varepsilon_{hijkl}$ and $y_{.hijkl} \in (y_{S,hijkl}, y_{M,hijkl}, y_{E,hijkl})$, for start (S), mean (M), and end (E). In addition to the response variables, we have the variables year (year of record), Nut (nutritional mode as saprotrophic or ECM), N (number of records per country per species per year), and genus and species. The year and nutritional mode are target fixed effects, whereas a nonlinear component of N ($\ln(N + 1)$) was included to investigate the influence of sampling intensity. In addition, we applied genera and species as random contributions representing the clustering of the records, to handle taxonomic constraints.

The investigation continued along two similar paths: (*i*) generalized least-squares (GLS) (2, 3) analyses of individual species per country (2, 3) and (*ii*) amalgamating data across species and countries into one dataset and analyzing the relationships by a linear mixed-effect model (LME) (2).

Along the first path we investigate the temporal trend of each species with respect to season start and season end. From the model we extract the influence of year for each species to be investigated graphically across species and nations (Fig. 1 and Fig. S3), and the entire model is used for providing predictions behind the long-term changes in fruiting (Figs. 3 and 4):

$$y = \mathbf{X}\boldsymbol{\beta} + \boldsymbol{\Sigma}.$$

β is a fixed effect to be investigated for the matrix $\mathbf{X}$ including intercept vector, year, and $\ln(N + 1)$, and $\boldsymbol{\Sigma}$ is the residual contribution; $\boldsymbol{\Sigma} \sim N(\mathbf{0}, \sigma^2\mathbf{W}\lambda)$, where $\mathbf{W}$ is the weight matrix of sampling intensity (N), handling uncertainties by differentiated number of records per year per species, and λ is the autoregressive AR1 process with an off-diagonal decay in correlation (ρ) as a function of distance, $\lambda_{ij} = \rho^{|i-j|}$. We use the AR1 process as the records are time series with regular intervals.

The second procedure is just slightly more complicated as here we include information from all nations and all species:
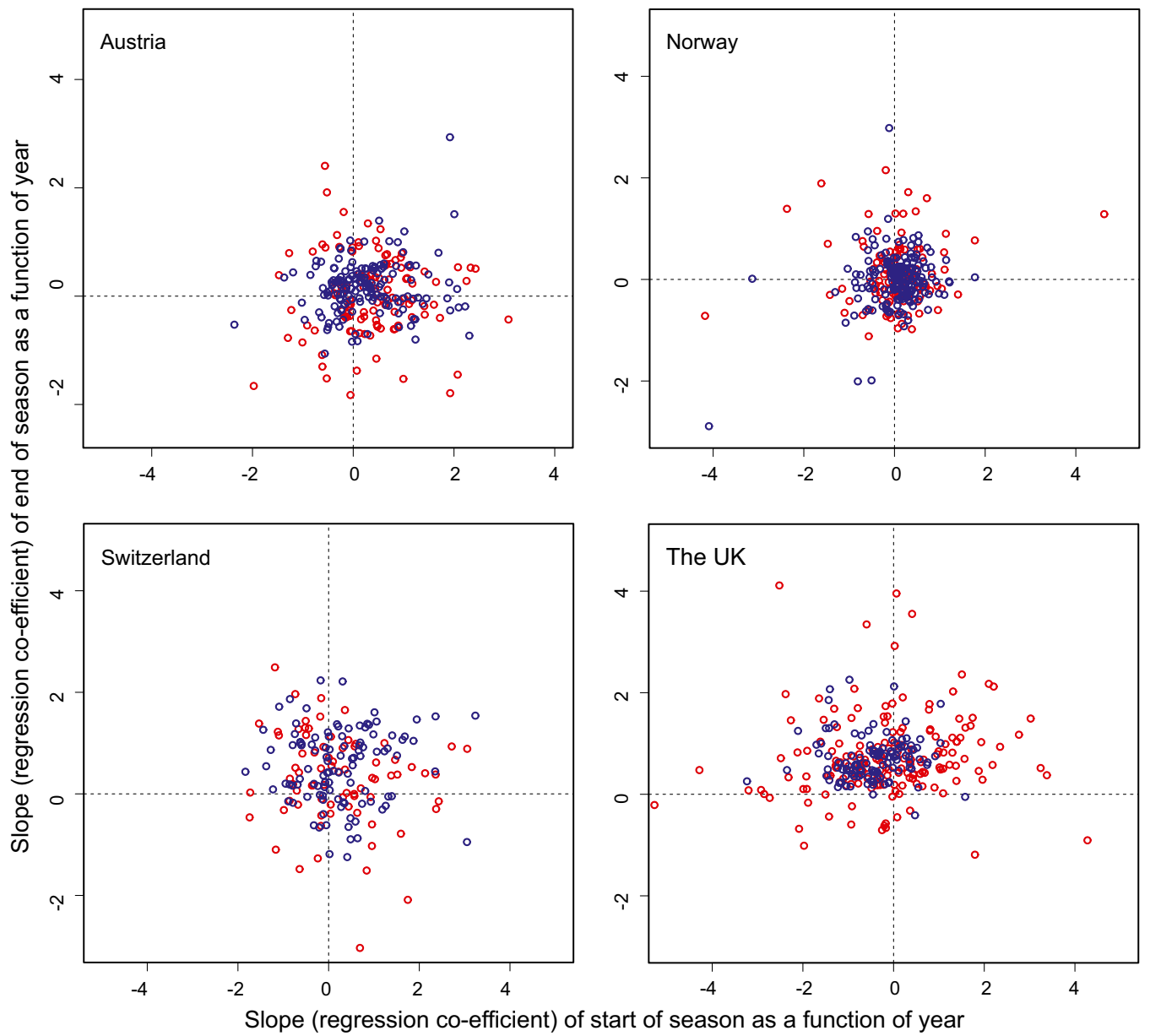
$$y_{hijk} = \beta_0 + b_{0i} + b_{0ij} + (\beta_1 + b_{1i} + b_{1ij})\text{year}_{hijk} + \beta_2\ln(N + 1)_{hijk}$$
$$+ \beta_3\text{Nut}_{hijk} + \sum_{k+1}^{m-1}\beta_k\text{Nation}_{hijk} + \ldots + \varepsilon_{hijk}.$$

The βs are fixed effects to be estimated on the vectors year, N (investigating sampling intensity), Nut (nutritional mode), and Nation, and the "…" indicates the full-model inclusion of the three-way interaction terms of the variables year, Nut, and Nation. Further, the bs are the cluster-specific random contributions for genera (b_{0i} and b_{1i}), and species in genera (b_{0ij} and b_{1ij}) with respect to average timing (b_0s) and effect of year (b_1s). The bs follow a normal distribution, $b \sim N(0, [\sigma_{0i}^2, \sigma_{0ij}^2, \sigma_{1i}^2, \sigma_{1ij}^2])$. The bs represent the clustering elements in accordance with the genera and species in genera, i.e., a taxonomic constraint. Further, the residuals ε_{hijk} are easier described by the residual covariance matrix $\boldsymbol{\Sigma}$, which is similar to the one found for the GLS approach. $\boldsymbol{\Sigma} \sim N(\mathbf{0}, \sigma^2\mathbf{W}\lambda)$, where $\mathbf{W}$ is the weight matrix of sampling intensity (n = number of records) in combination with the difference in residual variance conditioned on nutritional mode, and λ is the autoregressive AR1 process with an off-diagonal decay in interrecord correlation (ρ) as a function of distance, $\lambda_{ij} = \rho^{|i-j|}$. We use the AR1 process as the records are time series with regular intervals.

1. Wood SN (2006) *Generalized Additive Models: An Introduction with R* (CRC, Boca Raton, FL).
2. Pinheiro JC, Bates DM (2000) *Mixed-Effects Models in S and S-PLUS* (Springer, New York), 1st Ed.
3. Zuur AF, Ieno EN, Walker NJ, Saveliev AA, Smith GM (2009) *Mixed Effects Models and Extensions in Ecology with R* (Springer, New York).

Fig. S1. Monthly mean temperatures for Austria, Norway, Switzerland, and the United Kingdom based on 1971–2000 averages. The data were obtained from the Tyndall Centre for Climate Change Research (http://www.cru.uea.ac.uk/timm/cty/obs/TYN_CY_1_1.html).

Fig. S2. A cubic smooth spline of average number of frost-free days after August 1 in Austria, Norway, Switzerland, and the United Kingdom, where a station-specific random intercept is included. Apart from the cold winters in the early 1990s, the number of frost-free days has increased in all of the four countries. The calculations were based on data from 55, 153, 35, and 23 weather stations in Austria, Norway, Switzerland, and the United Kingdom, respectively.

Fig. S3. Changes in the start of season plotted against changes in the end of season for all species during the period 1970–2007. Changes in the start and end of season are shown as the regression coefficients of the 2.5th and 97.5th percentiles as a function of year. Red circles indicate saprotrophic species and blue circles, ECM species. The upper left quadrants represent species with earlier start and later end dates.

Fig. S4. Spatial patterns in mean day of fruiting in Austria, Norway, Switzerland, and the United Kingdom, respectively. The black isoclines (which represent iso-lines with the SEs in red and green, respectively) indicate areas with a similar average day of fruiting. Dots represent the records included in the study. The effect of geographic location was estimated as smooth functions of longitude and latitude (cubic smooth spline regression) on the basis of all data.

Other Supporting Information Files

Table S1 (DOCX)
Table S2 (DOCX)
Table S3 (DOCX)
Table S4 (DOCX)
Table S5 (DOCX)