Modes of functional biodiversity control on tree productivity across the European continent

Modes of functional biodiversity control on tree productivity across the European continent (Ref. GEB-2015-0039.R1)

We thank the Editor in Chief and the Reviewer for their additional comments on our revised manuscript. We believe that the revised version addresses the Editor and Reviewer's concerns. We provide a point-by-point reply (indented) answering the Editor or Reviewer's comments (italics). The additional text in the revised version of the manuscript is marked in blue for easier identification. We have exceeded the word count limit (5042) with the new text; we hope that this is allowable.

List of major changes:
1. We have used a different line type in Figure 2 and different point shapes in Figure 3 for each variable.
2. We have estimated the proportion of the variance in the data that is explained by the model.
3. The trait data and species pool citation lists have been moved to Appendix 1 and 2, respectively, in the main manuscript.
4. A section has been added to the Results for the control analyses.

Reply to the Editor in Chief

In my comments on the first version of the manuscript, I mentioned the colour publication fees. Since then, it has come to my attention that the number of print copies is very, very small. The standard procedure will be to use colour on-line only, unless authors specifically want to have the figures printed in colour and to pay the colour publication charge.

It still makes sense, however, to have figures that are understandable when they are printed in black and white. For Fig. 2 and perhaps 3, could you not use different line styles as well as different colours?

> We thank you for the details of the standard procedure for colour figures. Following your suggestion we have added different line styles to Figure 2 and different point shapes to Figure 3. Both figures should be understandable in black and white. Unfortunately, there is nothing we can do about Figure 3 and we will pay for this figure to be printed in colour.

I confess that my knowledge of Bayesian statistics is very limited. However, I am still bothered that there is no way to indicate whether the effects you describe are large or small relative to the unexplained variation. You added Fig. S4.6, which is useful, but it still only shows relative effects without any indication of how much variance these variables capture. IS it truly impossible to estimate this in Bayesian models? At minimum, the legend of the figure could say something about the odds ratios. No?

> Following Korner-Nievergelt et al (2015) we have calculated the R^2 of the model as 1 minus the residual variance divided by the variance in the data. The calculation is averaged over the posterior distribution of the predicted values. The R^2 is 0.684. Not all the variance explained can be attributed to the predictors; some will be explained

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by the cluster and country effects.

The method for the calculation has been added to Appendix S3 under the Model fitting section, and the caption of Table S3.1 has been updated with the R^2 value.

GEB has had another change of policy. Because the references to the data sources in on-line appendices are not captured by the citation indexing services (e.g., the Web of Science), please now put them in Appendices after the biosketch (e.g. Appendix 1 References for the trait data used in this study:, Appendix 2, References used to estimate species pools". These will be printed in reduced font in the main paper.

We have moved the trait data and regional species pool citations lists to Appendix 1 and 2, respectively, in the main manuscript, and reordered the sections following the author guidelines.

We have removed the text at the end of the main citation list that indicated the additional trait data and species pool citations in the Supplementary Material.

Reply to Referee 1

The authors have done a fantastic job of revising the manuscript and arguing their case. I was impressed by several items.
(1)   The control analysis testing a different dispersion and distance measure.
(2)   The extended control analysis on the environmental drivers. Given the differences that were found between the MAT-MAP analysis and the first two PCA-axes of 19 variables in the boreal region, I would like to see a short note of this in the results section and/or discussion.

We have added a Control Analyses section to the end of the Results section (see lines 321 - 326). In addition, we have added a bit more text to the Control Analyses section of Appendix S3 describing the predicted difference in the importance of leaf nitrogen content between the different climate models.

(3)   Choices in the analysis were better justified.
(4)   A more refined discussion on functional identity and functional diversity
I enjoyed the open-minded and diligent consideration of my comments.
Well done.

Many thanks for your comments on the revised version of our manuscript.

Reference

Korner-Nievergelt, F., Roth, T., von Felten, S., Guélat, J., Almasi, B., & Korner-Nievergelt, P. (2015). *Bayesian Data Analysis in Ecology Using Linear Models with R, BUGS, and Stan*. Academic Press.

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40 **Short running-title**: Functional biodiversity control on tree growth

41 **Keywords**: climatic gradient, environmental filtering, forest succession, FunDivEUROPE,

42 landscape scale, plant functional traits, tree productivity.

43

44 Number of words in the Abstract: 287

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46 Number of references: 50

47

48   **ABSTRACT**

49   **Aim**

50   The relative contribution of community functional diversity and composition to ecosystem

51   functioning is a critical question in ecology in order to enable better predictions of how

52   ecosystems may respond to a changing climate. However there is little consensus of which

53   modes of functional biodiversity are most important for tree growth at large spatial scales.

54   Here we assessed the relative importance of climate, functional diversity and functional

55   identity (i.e. the community mean values of four key functional traits) for tree growth across

56   the European continent, spanning the northern boreal to the southern Mediterranean forests.

57   **Location**

58   Finland, Germany, Sweden, Spain and Wallonia (Belgium)

59   **Methods**

60   Using data from five European National Forest Inventories we applied a hierarchical linear

61   model to estimate the sensitivity of tree growth to changes in climate, functional diversity and

62   functional identity along a latitudinal gradient.

63   **Results**

64   Functional diversity was weakly related to tree growth in the temperate and boreal regions

65   and more strongly in the Mediterranean region. In the temperate region, where climate was

66   the most important predictor, functional diversity and identity had a similar importance for

67   tree growth. Functional identity was strongest at the latitudinal extremes of the continent,

68   largely driven by strong changes in the importance of maximum height along the latitudinal

69   gradient.

70 **Main conclusions**

71 Functional diversity was an important driver of tree growth in the Mediterranean region,

72 providing evidence that niche complementarity may be more important for tree growth in

73 water-limited forests. The strong influence of functional identity at the latitudinal extremes

74 indicates the importance of a particular trait composition for tree growth in harsh climates.

75 Furthermore, we speculate that this functional identity signal may reflect a trait-based

76 differentiation of successional stages rather than abiotic filtering due to water or energy

77 limitation.

78

INTRODUCTION

With the increasing threat of climate and land-use change there is deepening concern that continued biodiversity loss may jeopardise key ecosystem services (Cardinale *et al.*, 2012; Thomas *et al.*, 2013). Therefore it is becoming ever more critical to improve our understanding of the interplay between abiotic and biotic controls on ecosystem processes (Díaz *et al.*, 2007; Hillebrand & Matthiessen, 2009), especially at scales relevant to conservation policy makers (Thomas *et al.*, 2013; Violle *et al.*, 2014). The functional structure of a community (i.e. the distribution and relative abundance of plant functional traits) is known to directly influence ecosystem processes (Díaz *et al.*, 2007) and recently there have been several large-scale observational studies in forests with a focus on detecting an influence of diversity on tree productivity (e.g. Paquette & Messier, 2011; Vilà *et al.*, 2013; Ruiz-Benito *et al.*, 2014). However, the relative importance of functional diversity and composition for tree growth has received little attention at large spatial scales (Conti & Díaz, 2013), despite its importance for understanding how forests may respond to climate change (Violle *et al.,* 2014).

Two central mechanisms underpin how plant functional traits can influence ecosystem processes: the niche complementarity hypothesis (Tilman, 1994) and Grime's mass ratio hypothesis (Grime, 1998). Functional diversity (FD), i.e. the dispersion of trait values in a community (Laliberté & Legendre, 2010), is hypothesised to increase the ways in which species access and utilise resources, allowing a greater resource use and niche packing in more functionally diverse communities. Evidence from natural forests for the niche complementarity hypothesis is mixed, with both positive (Paquette & Messier, 2011; Ruiz-Benito *et al.*, 2014) and negative (Conti & Díaz, 2013) diversity effects found. Congruent with the mass ratio hypothesis, the functional identity (FI), i.e. community mean trait values (Violle *et al.*, 2007), are hypothesised to greatly influence community-level processes. FI has

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104 consistently been found to be a key component through which plant traits control

105 productivity, and is often found to be more important than the functional diversity of the

106 community (Mokany *et al.*, 2008; Conti & Díaz, 2013; but see Valencia *et al.*, 2015).

107 The European continent spans large gradients in climate and resource availability, from the

108 northern boreal latitudes where productivity is primarily limited by energy (i.e. temperature

109 and radiation; Körner 1998) to southern Mediterranean latitudes where water is the primary

110 limiting resource (Babst *et al.*, 2013). In the temperate mid-latitudes neither energy nor water

111 is strongly limiting, and, as a consequence, productivity peaks there (see Fig. 1). Thus

112 stressful climatic conditions predominate at the southern and northern extremes of the

113 European continent but are exerted by different environmental constraints (i.e. lack of water

114 versus a lack of energy). Along such a climatic gradient competitive interactions and abiotic

115 filtering assembly processes act on community functional structure (Maire *et al.*, 2012) and

116 thus ecosystem functioning (Spasojevic & Suding, 2012).

117 According to Harpole & Tilman (2007) the number of resource-related niche dimensions is

118 greater in stressful environments and more species with a particular specialisation in

119 acquiring resources are needed to maintain productivity. We therefore expect productivity at

120 the extremes of our latitudinal gradient to be most sensitive to functional trait diversity, as a

121 proxy for the potential degree of niche complementarity realised by a community. Recent

122 observational studies in forests support this view (Paquette & Messier, 2011; Jucker *et al.*,

123 2014a). However, the evidence is equivocal, and other studies have found no difference in the

124 importance of functional diversity for tree growth between regions with different productivity

125 rates (e.g. Zhang *et al.*, 2012; Ruiz-Benito *et al.*, 2014). Environmental filters increase the

126 functional similarity of species through abiotic constraints that select for particular trait

127 expressions generally characterising the locally most productive and best adapted tree species

128 (Wright *et al.*, 2005; Cornwell & Ackerly, 2009). At the same time, competition between

129   species with similar resource acquisition abilities can result in community trait convergence

130   (Mayfield & Levine, 2010; Kraft *et al.*, 2015). Given that abiotic filtering and competition

131   occur in all biomes, we predict functional identity to be important across the entire continent

132   but that the identity of the most influential trait may change, reflecting contrasting climate

133   and successional niches along the latitudinal gradient (Hillebrand & Matthiessen, 2009).

134   Using data from five European National Forest Inventories, we investigated the relative

135   influence of climate, functional diversity and functional identity for tree growth along a

136   multi-biome climate gradient. We tested the following hypotheses: i) climate drives tree

137   productivity across the entire gradient; ii) the relative importance of functional diversity for

138   tree growth increases with resource limitation; and iii) functional identity is important for tree

139   growth along the entire latitudinal gradient but the identity of the most important trait

140   changes. To this end, we map the relative influence of different modes of trait influence on

141   tree growth, elucidating the functional drivers of tree growth at a biogeographical scale

142   (Violle *et al.*, 2014).

143   **MATERIALS AND METHODS**

144   **Inventory data**

145   We compiled data from the National Forest Inventories (NFIs) of Finland, Germany, Spain,

146   Sweden and Wallonia, Belgium (see a detailed description of each NFI in Appendix S1 in

147   Supporting Information). To select comparable data from the different inventories we only

148   included those trees that had a diameter at breast height (d.b.h) of 10 cm or more and plots

149   with a basal area of 4 $m^2 ha^{-1}$ or greater in consecutive surveys. For each tree we compiled the

150   species (nomenclature follows the Atlas Florae Europaea), exotic status (following DAISIE:

151   http://www.europe-aliens.org, see Table S1.2 in Appendix S1), d.b.h. and status (ingrowth,

152   survivor, dead due to natural mortality or harvesting). In each plot we calculated the basal

153   area of each species (m^2 ha^{-1}), mean tree d.b.h. (mm), a single annual growth estimate (as the

154   sum of the basal area increments (m^2 ha^{-1} yr^{-1}) of all surviving and ingrowth trees) and the

155   annual natural mortality rate (m^2 ha^{-1} yr^{-1}). The plots were classified by biome (boreal,

156   temperate or Mediterranean) following Olson *et al.* (2001), see Figs S1.1 and S1.2 in

157   Appendix S1.

158   Plots in which trees had been harvested between surveys were excluded to reduce the

159   influence of recent stand structure changes on growth rates. From the available data we

160   excluded plots that had zero or negative growth (i.e. 154 of 39,604 plots), and selected those

161   with less than the 99.9% upper quantile to remove outliers (Table S1.3).

162   **Climate data**

163   We used the inventory plot coordinates to extract plot-level climatic variables from the

164   WorldClim database (Hijmans *et al.*, 2005). We selected mean annual precipitation (MAP,

165   mm) and mean annual temperature (MAT, °C) to describe the climate gradient. The variables

166   were weakly correlated in our dataset (Spearman rank coefficient: -0.18, p < 0.001), had

167   better predictive power than the first two axes of a PCA of 22 climatic variables (see

168   Appendix S2), and are easily interpretable across the large latitudinal gradient of this study.

169   **Community functional composition**

170   We compiled trait data from the TRY initiative (Kattge *et al.* 2011a) and additional published

171   data sources for the 138 species in the final analysis (Table S2.2 in Appendix S2). We

172   selected five key functional traits that are indicative of species' ecological strategies of

173   resource acquisition and growth: maximum tree height (m); leaf nitrogen content (mg g^{-1});

174   maximum tree lifespan (yrs); seed mass (mg); and wood density (g cm^{-3}). Maximum tree

175   height quantifies species' resource acquisition via light capture (Falster & Westoby, 2003).

176   Leaf N is a key trait of the leaf economics spectrum (LES); it characterises species' resource

177   use strategy from acquisitive, fast-growing to conservative and slow-growing (Wright *et al.*,

178   2004). Maximum tree lifespan reflects species' life history strategy and relates to their

179   defensive investment (Wirth & Lichstein, 2009). Seed mass relates to seedling survival rates

180   (Leishman et al., 2000) and species' resource use strategy and successional status. Finally,

181   wood density relates to efficient and safe water transport and allocation to mechanical

182   stability, correlates negatively with growth rates and mortality (Enquist *et al.*, 1999).

183   The functional diversity of each plot was quantified using the functional dispersion index

184   (FDis: Laliberté & Legendre 2010) using the five traits. FDis quantifies how species in a

185   community differ in their distance from the centre of the multi-trait functional space.

186   Functional identity was derived as the community-weighted mean of each trait for each plot

187   (FI_{mh}: maximum tree height; FI_{ln}: leaf N content; FI_{ls}: maximum tree life span; FI_{sm}: seed

188   mass; FI_{wd}: wood density). FI_{sm} and FI_{wd} were highly positively correlated (Spearman rank

189   coefficient: 0.74; $p < 0.001$) thus FI_{sm} was not considered further in the analysis. See

190   Appendix S2 for full details on the functional composition estimation of the plots.

191   Theoretical reasoning suggests that a region with a larger species pool, and thus potential for

192   larger trait ranges, is more likely to contain complementary species and/or species that are

193   well adapted and thus may be more productive. Therefore the regional species pool was

194   determined for each plot location from tree species distribution maps (see Appendix S2).

195   **Statistical methods**

196   We modelled plot-level growth (m^2 ha^{-1} yr^{-1}) using a linear model including the following

197   predictors: mean annual temperature (MAT, °C, log +7); mean annual precipitation (MAP,

198   mm); functional dispersion (FDis, square root transformed); and the four functional identity

199   measures. MAT value was incremented by 7 before logging to account for negative values.

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200 We also included four covariates: basal area (BA, m^2 ha^{-1}, log); mean d.b.h. (DBH, mm, log);

201 annual mortality rate (MR, m^2 ha^{-1} yr^{-1}); and the species pool (SP, log). Basal area and mean

202 tree size were included to account for stand density and developmental stage. The predictors

203 and covariates were transformed, as indicated, to linearise relationships with the response

204 variable. To investigate how the influence of the five biodiversity measures on tree growth

205 varied with climate, first-order interaction terms were included between both MAT and MAP

206 and each biodiversity measure. First-order interaction terms were also fitted between both

207 MAT and MAP and each of the covariates. All explanatory variables were centred on 0 and

208 scaled to 1 standard deviation to aid model interpretation.

209 Sample plots from the Finnish, Swedish and German NFIs are grouped in clusters, thus the

210 nested data structure required three hierarchical levels for data from these three inventories

211 (plot, cluster and NFI). We assumed that growth came from a lognormal distribution, such

212 that $G_i \sim Lognormal(\mu_i, \sigma_u)$, where i is an individual plot, G_i is the plot growth (sum of the

213 basal area increment, m^2 ha^{-1} yr^{-1} of all surviving and ingrowth trees), μ_i is the expected plot

214 growth rate and σ_u is the standard deviation, both on the log scale. μ_i was modelled using the

215 following equation:

$$
\begin{aligned}
\mu_i = \alpha_0 + \alpha_r &+ \beta_{MAT}.MAT_i + \beta_{MAP}.MAP_i \\
&+ \sum_{b=1}^{5}\left(\beta_b^{(z)} + \gamma_b^{(MAT)}.MAT_i + \gamma_b^{(MAP)}.MAP_i\right)Z_{bi} \\
&+ \sum_{k=1}^{4}\left(\beta_k^{(c)} + \delta_k^{(MAT)}.MAT_i + \delta_k^{(MAP)}.MAP_i\right)C_{ki}
\end{aligned}
$$

216   (1)

217 where α_0 is the expected plot growth rate under average conditions, α_r the cluster or NFI

218 intercept, Z_b are each of the biodiversity measures (i.e. FDis and four FI measures), C_k are the

219 four covariates (BA, DBH, MR and SP), β_{MAT}, β_{MAP}, β_b and β_k are the intercepts for MAT,

220 MAP, biodiversity variable b and covariate k, respectively, and γ_b and δ_k indicate interaction

221   terms between climate (MAT and MAP) and biodiversity variable *b* and covariate *k*,

222   respectively. The model was fitted in a Bayesian framework in using the 'rstan' R package

223   (Stan Development Team, 2013). Details of the model fitting and priors are in Appendix S3.

224   All analyses were performed in R version 3.0.2.

225   **Model evaluation**

226   Figs S3.1a, b & c in Appendix S3 map the growth, predicted growth and the model residuals,

227   respectively. There appears to be no strong spatial pattern in the residuals. Partial residual

228   plots for each of the predictor variables show satisfactory linear relationships between the

229   predictors and tree growth (Fig. S3.2). FDis was not strongly correlated with any of the FI

230   measures (largest correlation was with FI_{ln}, Spearman rank coefficient: 0.29; p < 0.001).

231   **Sensitivity of plot growth to changes in climate and biodiversity**

232   Assumptions that we made in our model (equation 1), namely that the biodiversity measures

233   (and covariates) are dependent on climate and that these dependencies are linear, allow us to

234   explore how the sensitivity of plot growth to changes in each biodiversity measure varies

235   with climate and, conversely, how the sensitivity of plot growth to changes in climate is

236   modified by the biotic conditions in each plot. As such the geographic signal comes from

237   model interaction terms between climate and the biodiversity and covariate variables.

238   *Biodiversity*

239   For a fixed MAT-MAP combination in plot *i* the predicted sensitivity of plot growth (S_{bi}) to

240   changes in biodiversity measure *b* can be estimated as $\beta_b + \gamma_b^{(MAT)}.MAT_i + \gamma_b^{(MAP)}.MAP_i$,

241   where β_b, $\gamma_b^{(MAT)}$ and $\gamma_b^{(MAP)}$ are the mean of the posterior distribution of the coefficients of *b*,

242   the interaction coefficient of *b* with MAT and the interaction coefficient of *b* with MAP,

243   respectively. MAT_i and MAP_i are the plot-level MAT and MAP values. Thus, S_{bi} is the

244   predicted sensitivity of the growth of plot i to changes in biodiversity measure b, modulated

245   by the plot-level climate conditions.

246   *Climate*

247   For each plot the predicted sensitivity of plot growth to changes in MAT (S_{MAT}) and MAP

248   (S_{MAP}) can be estimated as, for MAT:

$$S_{MATi} = \beta_{MAT} + \sum_{b=1}^{5}\left(\gamma_b^{(MAT)}.Z_{bi}\right) + \sum_{k=1}^{4}\left(\delta_k^{(MAT)}.C_{ki}\right)$$

249   (2)

250   where the parameters are the same as in the full model (equation 1). Equation 2 can be used

251   to estimate S_{MAP} by replacing MAT with MAP. This gave us the predicted sensitivity of plot

252   growth to both climate variables, modified by the covariates and biodiversity measures.

253   **Relative importance calculation**

254   *Climate and biodiversity*

255   For each plot, the relative importance of MAT, MAP, FI and FDis were calculated from their

256   predicted sensitivities as, for example with MAT: $|S_{MATi}| \ / \ max(|S_{MATi}|,|S_{MAPi}|,|S_{FDisi}|,|S_{FIi}|)$,

257   where S_{MATi}, S_{MAPi} and S_{FDisi} are the sensitivities of growth to MAT, MAP and FDis in plot i,

258   respectively, and S_{FIi} is the mean of the absolute sensitivities of the four FI measures in plot i.

259   The variable with the greatest influence on growth in a plot had a relative importance of 1.

260   *Biodiversity*

261   In a similar vein, for each plot the relative importance of the five biodiversity measures (FDis

262   and the four FI measures) were calculated as the ratio of the absolute value of the biodiversity

263   sensitivity ($|S_b|$) and the maximum biodiversity sensitivity in the plot: $|S_b| \ / \ max(\{$

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264　$|S_m|\}_{m=1,\dots,5}$*). In contrast to the analysis above, where the four FI measures are treated in

265　aggregate, here we treat each FI measure separately to quantify their relative importance. In

266　both cases, however, the relative importance estimates are calculated from the coefficients of

267　the same model (Table S3.1 in Appendix S3).

268　**Control analyses**

269　We performed three control analyses to test the robustness of the model predictions and

270　inferences made thereof (see Appendix S3). Specifically, we tested for: (i) the influence of

271　climate variable selection; (ii) possible problems arising from collinearity between FI

272　measures; and (iii) the influence of exotic tree species, which are often more productive than

273　native species (Kawaletz *et al.*, 2013).

274　**RESULTS**

275　**Tree growth, climate and functional composition along the latitudinal gradient**

276　Mean plot-level tree growth rates ranged from 0.35 and 0.37 m^2 ha^{-1} yr^{-1} in the Mediterranean

277　and boreal regions, respectively, to 0.68 m^2 ha^{-1} yr^{-1} in the temperate mid-latitudes (Fig. 1,

278　Fig. S3a). Average mean annual temperature (MAT) ranged from 12 °C in the Mediterranean

279　to 2 °C in the boreal region, whilst mean annual precipitation (MAP) ranged from 596 mm in

280　the Mediterranean to 874 mm in the temperate zone.

281　Mean FDis was greatest across the temperate and southern boreal regions (Fig. S4.1a in

282　Appendix S4), despite a pronounced decline in the species pool with latitude and greater

283　maximum FDis in the Mediterranean. Mean FI values varied across the continent except FI_{ls},

284　which showed no clear pattern (Fig. S4.4a). FI_{mh} was highest in temperate and lowest in

285　Mediterranean (Fig. S4.2a). FI_{ln} was highest in temperate regions and low in both the

286　Mediterranean and boreal regions (Fig. S4.3a). The highest values of FI_{wd} were in the low to

287   mid-latitudes and levelled off at a mean of 0.55 g cm^{-3} in the northern temperate and boreal

288   regions (Fig. S4.5a).

Effects of stand structure, climate and functional composition on tree growth

290   Stand structure (BA and mean DBH) had a greater influence on growth than climate (MAT

291   and MAP) or any of the biodiversity measures (see Table S3.1 in Appendix 3 for the mean

292   and 95% credible intervals of the model parameters). Of the two climate variables, MAT had

293   the strongest influence on tree growth, exceeding those of the biodiversity measures. Across

294   the continent, tree growth was related to all of the biodiversity measures, with FI_{wd} and FI_{ls}

295   having the largest effect and FI_{ln} and FDis the smallest (Fig. S4.6 in Appendix 4). However a

296   change in either MAT or MAP altered the relationship between growth and all of the

297   biodiversity measures.

Relative importance of climate and functional composition for tree growth

299   We compared the relative importance of the mean sensitivity of the FI measures, FDis, MAT

300   and MAP across the latitudinal gradient (Fig. 2). The relative importance of FI was greatest at

301   low and high latitudes; in the Mediterranean region the average sensitivity of the FI measures

302   was more important than either MAT or MAP (0.78 compared with 0.71 and 0.59 for MAT

303   and MAP) and in the northern boreal region it was as important as MAT (Fig. 2). The

304   importance of FDis was highest in the Mediterranean region (0.49) and this importance

305   rapidly declined with increasing latitude, to a very low importance in the highest latitudes

306   (0.08).

Relative importance of each biodiversity component for tree growth

308   The relative importance of each FI measure varied across the continent and none of the

309   measures was the most important across the entire latitudinal gradient (Figs 3 & 4). The

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310   relative importance of FDis was constant across the Mediterranean and temperate regions

311   (0.38 and 0.36, respectively), becoming much less important in the boreal region (0.08). FI_{wd}

312   and FI_{ls} showed similar patterns of importance; both were very important in the lower and

313   especially mid latitudes and had a very low importance in the northern boreal region.

314   Increasing FI_{wd} and FI_{ls} had a negative effect on tree growth across the entire continent. At

315   either end of the latitudinal gradient FI_{mh} was the most important functional trait for tree

316   growth, however the influence of FI_{mh} on tree growth changed from positive in the lower and

317   mid-latitudes to negative in the boreal latitudes. FI_{ln} had the weakest effect on growth of all

318   the FI measures; its relative importance was very low across the entire continent until the

319   boreal latitudes where its importance exceeded that of FI_{wd} and FI_{ls}.

320   **Control Analyses**

321   The control analyses were consistent with the results and interpretation from the main

322   analysis (see Appendix S3, Figs S3.3 – 6). However, the model with alternative climate

323   variables predicted a reduced importance of FI_{mh}, and no large increase in the importance of

324   FI, in the boreal region (Fig. S3.3). Nevertheless, the general patterns of trait influence on

325   tree growth were robust between the different climate models.

326   **DISCUSSION**

327   We found that community functional composition was a relevant driver of tree growth across

328   the entire European continent. Functional diversity was more important in the Mediterranean

329   region, whilst functional identity effects were strongest at the latitudinal extremes of the

330   continent (Fig. 4).

331   **Relative importance of functional diversity and functional identity for tree growth**

15

We found a strong climatic control on tree productivity, as evidenced by high relative importance values of mean annual temperature and mean annual precipitation in the boreal and Mediterranean biome, respectively (Fig. 2). The relative importance of functional diversity was comparable with climate in the Mediterranean region, consistent with Ruiz-Benito *et al.* (2014). However we did not find an increase in the importance of functional diversity with increasing climatic constraints in the boreal region, in contrast to other studies (Paquette & Messier, 2011); the importance of functional diversity declined across the temperate region from south to north and was relatively unimportant for tree growth in the boreal region (Figs 2 & 3). The concept that abiotic stress may increase the number of available resource-related niche dimensions may not be true for all sorts of adversities (Harpole & Tilman, 2007), and in this real-world scenario water stress seems to be very relevant. This is consistent with recent pan-European study that found that tree diversity promotes water use efficiency, an indication of how species compete for water belowground, only in drought prone environments (Grossiord *et al.*, 2014).

Comparing just the relative importance of the individual biodiversity components (Figs 3 & 4), we found a similar importance of functional diversity in the Mediterranean and temperate regions (Fig. 3). The traits in our functional diversity measure (leaf N content, maximum height, maximum tree life span, seed mass and wood density) reflect species' life history, strategies of resource capture and growth (Falster & Westoby, 2003; Wright *et al.*, 2004; Chave *et al.*, 2009). We found that dissimilarity in life history and resource capture of coexisting trees can promote tree growth, adding to the growing evidence that complementarity effects through niche differentiation promotes productivity in certain forests (Paquette & Messier, 2011; Ruiz-Benito *et al.*, 2014). In our study we are unable to establish the mechanisms driving the potential complementarity effect; however, complementary light use strategies (Morin *et al.*, 2011; Jucker *et al.*, 2014b) and root architectures (Brassard *et al.*,

357   2013) have been linked with positive diversity effects in forests. In addition, more diverse

358   forests have been found to have greater stability in wood production over time (Jucker *et al.*,

359   2014a).

360   Consistent with other studies, we found functional identity to have a greater influence on

361   productivity than functional diversity (Mokany *et al.*, 2008; Ruiz-Benito *et al.*, 2014).

362   However, this relationship was not constant over the entire continent; the relative importance

363   of functional identity was greater at the latitudinal extremes of the continent (Fig. 2),

364   indicating the importance of trait identity for plant growth in harsh climates (Wright *et al.*,

365   2005; Spasojevic & Suding, 2012).

366   **Identity effects point to the relevance of successional differentiation**

367   Not only were identity effects stronger at the extreme ends of the gradient, but also the

368   relative importance of the traits underlying the identity control changed. What are the

369   biological underpinnings of this pattern?

370   In the Mediterranean biome, functional identity had a stronger influence on tree growth than

371   climate (Fig. 2) and was primarily controlled by maximum height and wood density (relative

372   importance *c*. 1) and maximum life span (relative importance *c*. 0.75, see Fig. 3). All else

373   being equal, Mediterranean forests composed of species with low wood densities, large

374   maximum heights and short maximum life spans exhibited the highest productivity. Low

375   wood density and short maximum life span are features typical of early successional species

376   (Bazzaz, 1979), who maximise resource acquisition and growth at the expense of chemical

377   and structural tissue protection and longevity (Wirth & Lichstein, 2009). Succession in the

378   Iberian Peninsula is leading to changes in the dominance of forests from gymnosperms to

379   angiosperms (Carnicer *et al.*, 2014). The strong influence of maximum height may also point

380   to a successional signature because some slow-growing, late-successional species in the

381   Mediterranean tend to be small statured (e.g. *Quercus ilex* or *Quercus suber*; maximum

382   height of *c.* 18 m), whilst early-successional pines are taller in stature (e.g. *Pinus halepensis,*

383   *Pinus pinaster* or *Pinus pinea*; maximum height of *c.* 26 m).

384   The situation in the temperate biome appears to follow a similar pattern to that in the

385   Mediterranean; forests dominated by species with low wood density and short maximum life

386   spans, i.e. pioneer species, tend to exhibit the highest growth rates. The relative influence of

387   maximum height decreased from south to north in temperate forests, perhaps reflecting that

388   fast growing pioneers such as *Salix caprea* and *Betula pendula* reach shorter maximum

389   heights than typical late successional forest species (e.g. *Fagus sylvatica* or *Quercus robur*).

390   A sharp change in trait control occurred towards the boreal biome; wood density and

391   maximum life span were no longer influential and maximum height resumed a strong

392   importance but its effect changed sign. Thus, forests with short statured species appear to

393   have higher growth rates in the boreal region than species with greater maximum heights.

394   Again, we postulate that this may be a successional signature because in the boreal region fast

395   growing pioneer species (e.g. *Betula pendula*, *Betula pubescens* and *Populus tremula*) reach

396   shorter maximum heights (*c.* 30 m) than the late successional, slower growing, conifers *Pinus*

397   *sylvestris* and *Picea abies* (*c.* 40 m). Succession in boreal regions usually progresses from

398   deciduous to coniferous species (Bergeron & Dansereau, 1993), thus from species with

399   intermediate and high wood densities to those with low wood density, in contrast to

400   succession in temperate and Mediterranean regions. The weakened negative effect of wood

401   density in the boreal region is likely to be due to the narrow range of wood density values

402   compared to the other regions (Fig. S4.7a). We found leaf nitrogen content to be relatively

403   unimportant for tree growth in Mediterranean and temperate regions but to be one of the

404   more important traits in the northern temperate and boreal regions (Fig. 3). There was a

405   transition from a positive influence of leaf nitrogen content on growth in the Mediterranean

biome to a negative effect elsewhere. This finding is unexpected, but in line with recent

studies, which have not found consistent trends in the shifts of leaf nitrogen content (and

other leaf traits) with succession (Douma *et al.*, 2012; Wilfahrt *et al.*, 2014).

In summary, the functional identity signal may reflect a trait-based differentiation of

successional stages (Huston & Smith, 1987; Wirth & Lichstein, 2009; Lasky *et al.*, 2014)

rather than an environmental filter reflecting drought or energy limitation at the southern and

northern climate extremes, respectively. In different regions late-successional communities

may have a lower or higher growth rate depending on the particular traits of the species,

driven in this study, one may speculate, by the dominant role of gymnosperms in the

Mediterranean and boreal biomes. It is important to note that this analysis controls, along the

entire gradient, for the structural effects of climate and forest succession with respect to basal

area and tree size, thereby isolating the successional identity effects. Nevertheless, our results

suggest that the successional transition from gymnosperms to angiosperms in the

Mediterranean and from angiosperms to gymnosperms in the boreal regions control the

functional identity effects on tree growth in these latitudes.

Limitations

Due to the different NFI sampling methods, we used a 10 cm d.b.h. threshold for including

trees in the study. This restriction is likely to have reduced the diversity of the plots,

especially in the Mediterranean region where much of the diversity is in the tall shrub layer.

In addition, plot size could not be standardised across the different inventories, and although

we allowed for random variation between inventories, this may have led to an

underrepresentation of the diversity of the boreal plots.

As with other large-scale trait analyses we were limited by the trait data available (Paquette

& Messier, 2011; Ruiz-Benito *et al.*, 2014). We selected five key traits that reflect plant life

430 history strategies, however including other traits, especially root traits or traits unrelated to

431 successional status, may provide additional insight. Our analysis ignored intraspecific trait

432 variation and applied the same trait value to individuals of the same species across the

433 continent. These factors are likely to have resulted in a conservative estimate of the relevance

434 of biodiversity. Due to limited data availability, we were not able to account for other

435 confounding factors that are known to influence tree growth, such as nutrient availability or

436 local hydrology (Pretzsch *et al.*, 2013) or to incorporate an estimate of the successional stage

437 of the plots (Lasky *et al.*, 2014).

438 This analysis was undertaken on a continent with a large and long-standing impact of forest

439 management (Bengtsson *et al.*, 2000), which is likely to leave a signature in our results.

440 Whilst the direct influence of recent management was accounted for, indirect and long-term

441 management effects are likely to persist. The tree species and functional composition of

442 managed forests may differ from natural assemblies due to planting and promoting of tree

443 species outside of their ecological niche, which could change the causal nature of species

444 identity on tree growth.

445 **CONCLUSIONS**

446 Our study contributes to the emerging field of functional biogeography (Violle *et al.*, 2014),

447 which explores the mechanisms underlying biogeographical patterns of biodiversity and

448 ecosystem functioning relationships. Functional diversity was an important driver of tree

449 growth in the Mediterranean region, providing evidence that niche complementarity may be

450 particularly important in water-limited forests. Across the temperate region the influence of

451 functional diversity and identity were comparable in magnitude, but were much less

452 important than climate. The strong influence of functional identity at the latitudinal extremes

453 of the continent indicates the importance of a particular trait composition for tree growth in

454   harsh climates. We have shown how different modes of trait influence vary in their

455   importance for tree growth along a large latitudinal gradient, contributing to a better

456   understanding of the functional drivers of ecosystem functioning across the forests of Europe.

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SUPPORTING INFORMATION

Appendix S1 National Forest Inventory Details

Appendix S2 Supplementary Information on Climate, Functional Composition and Species Pool Variables

Appendix S3 Supplementary Statistical Methods

Appendix S4 Supplementary Figures

BIOSKETCH

Sophia Ratcliffe is a postdoctoral researcher based at Leipzig University in Germany. She is interested in large-scale patterns in ecology, particularly in relation to biodiversity and ecosystem functioning, and functional biogeography. This research is part of the FunDivEUROPE project (http://www.fundiveurope.eu).

Author contributions: SR and PRB compiled the inventory data, ML and JK compiled the trait data, SR, JMC and CW designed the analysis, SR analysed the data, and SR and CW wrote the first draft of the manuscript, with comments from all authors.

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APPENDICES

Appendix 1 References for the trait data used in this study

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956

957 **FIGURE LEGENDS**

958 Figure 1. Climate gradients of mean annual temperature (MAT, ^{o}C) and mean annual

959 precipitation (MAP, mm) across the latitudinal gradient covered by the National Forest

960 Inventory plots. Mean plot basal area growth (Growth, $m^{2} ha^{-1} yr^{-1}$). Dotted lines indicate

961 95% confidence intervals. The white section depicts missing data. Values were calculated at a

962 2° latitude spatial resolution.

963 Figure 2. Predicted relative importance of mean annual precipitation, mean annual

964 temperature, functional identity (aggregated effect of the community mean value of the four

965 functional traits selected) and functional dispersion for tree growth. The sensitivity of plot

966 growth to changes in each variable was estimated from the hierarchical linear model; the

967 variable with the greatest influence in the plot has a relative importance of 1 and the other

968 variables are scaled accordingly. Values are aggregated at 0.5^{0} latitude thus the average

969 relative importance of each predictor is shown. White section depicts missing data. A version

970 with confidence bands is given in Appendix 4, Fig. S4.7.
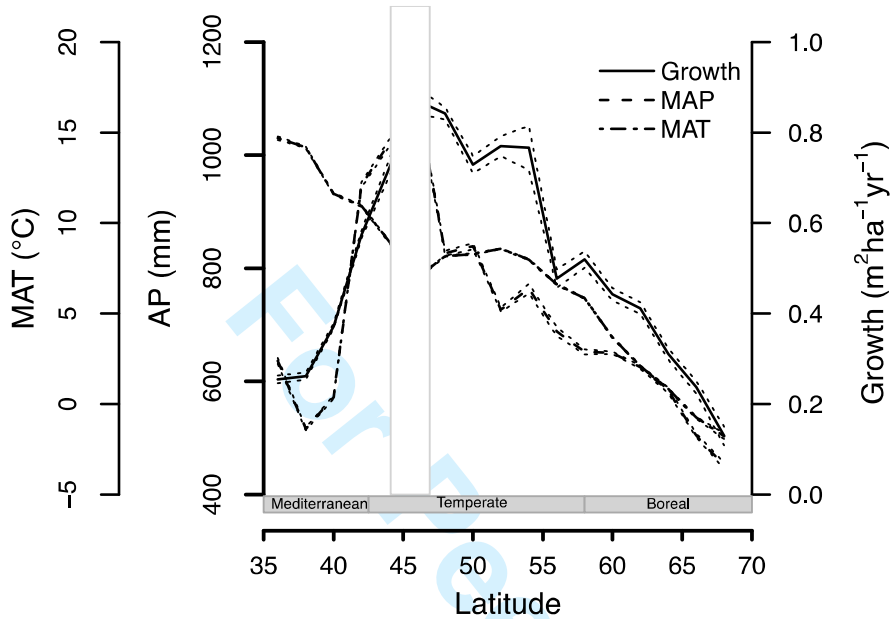
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972 Figure 3. Predicted relative importance of five components of functional biodiversity

973 (functional dispersion and the community weighted mean of four functional traits) for tree

974 growth. The sensitivity of plot growth to changes in each component was estimated from the

975 hierarchical linear model; the biodiversity component with the greatest influence in the plot

976 has a relative importance of 1 and the other measures are scaled accordingly. Values are

977 aggregated at 0.5^{0} latitude thus the average relative importance of each predictor is shown.

978 Solid lines indicate a positive influence of the biodiversity measure on plot growth, whilst

979 dashed lines indicate a negative influence. White section depicts missing data. A version with

980 confidence bands is given in Appendix 4, Fig. S4.8.

981   Figure 4. Predicted relative importance of a) FDis (functional diversity; red), FI_{ln}

982   (community-weighted mean (CWM) leaf N mass (mg^{-1} g); green) and FI_{wd} (CWM wood

983   density (g cm^{-3}); blue); b) FI_{mh} (CWM maximum height (m); red), FI_{ln} (CWM leaf N mass

984   (mg g^{-1}); green) and FI_{wd} (CWM wood density (g cm^{-3}); blue), for tree growth. The sensitivity

985   of plot growth to changes in each biodiversity component was estimated from a hierarchical

986   linear model using spatial maps of mean annual temperature and mean annual precipitation at

987   spatial resolution of 1 km^2; the biodiversity measure with the largest effect size in the grid has

988   a relative importance of 1 and the other two measures are scaled accordingly. The RGB cube

989   illustrates how the colour gradient reflects the changes in relative importance of the

990   biodiversity component, such that areas of white indicate an equal importance of all three

991   measures. The arrows indicate an increasing relative importance.

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3   993   **FIGURES**
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6   994   Figure 1.
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999   Figure 2.
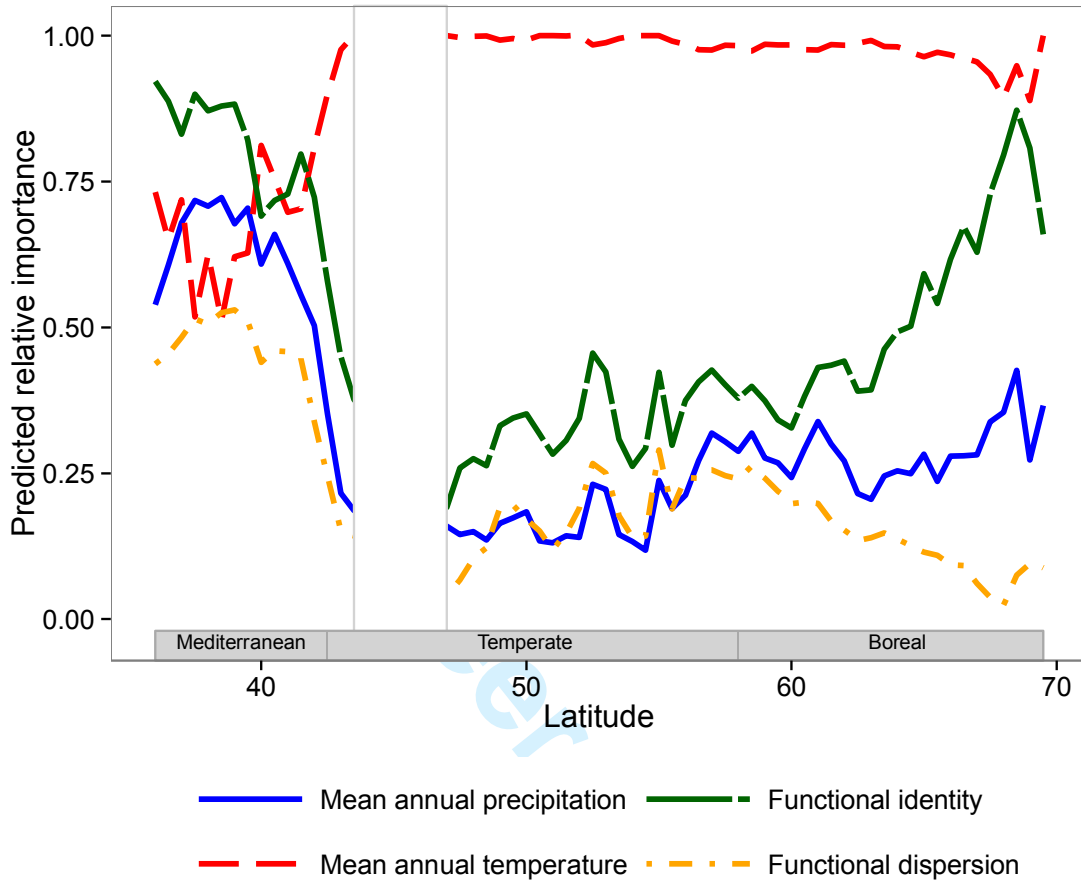
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1002   Figure 3.

1003

1004   Figure 4.

a)

FI_In

FI_wd

FDis

b)

FI_In

FI_wd

FI_mh
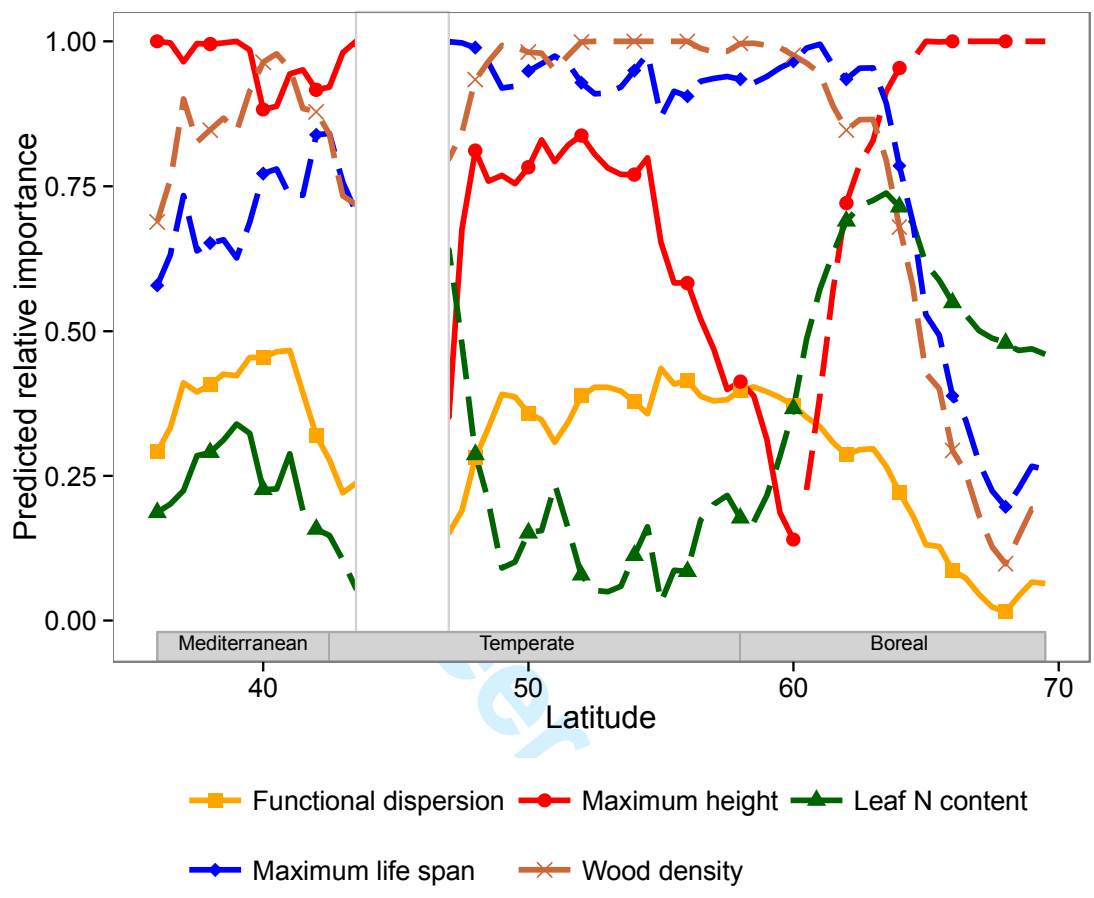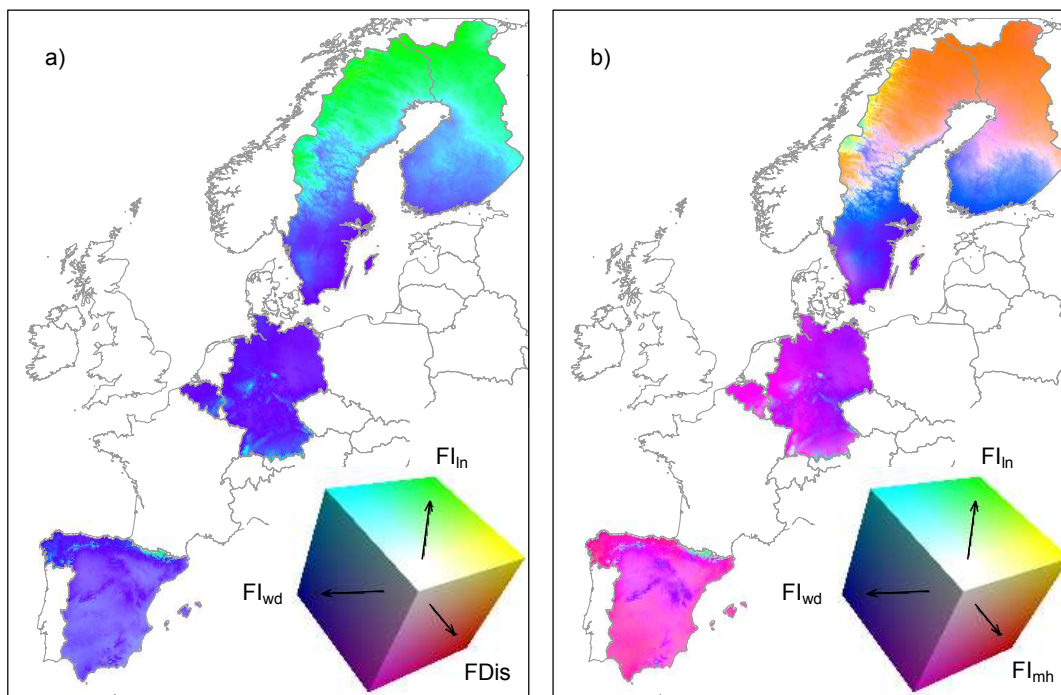
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Supporting Information Appendix S1

National Forest Inventory Details

We compiled data from the National Forest Inventories (NFIs) of Finland, Germany, Spain, Sweden and Wallonia, Belgium. Table S1.1 provides a summary of each NFI sampling design. To select comparable data from the different inventories we only included those trees that had a diameter at breast height (d.b.h) of 10 cm or more and plots with a basal area of 4 $m^2 ha^{-1}$ or greater in consecutive surveys. This resulted in 39554 plots with 138 species.

Table S1.1. Summary of the individual National Forest Inventory sampling designs

	Finland	**Germany**	**Spain**	**Sweden**	**Wallonia**
Survey dates	Subset of NFI 8: 1985-1986 and 1995	BWI 1 (1986-1990) and BWI 2 (2001-2002)	SFI 2 (1986-1996) and SFI 3 (1997-2007)	Inventories 2005-2007 and 2008-2010	Inventories 1994-2003 and 2008-2011
Sample plot design	Cluster design, number and grid size depend on location, see text for details	Cluster design, 4 subplots. Grid size depends on region. Standard grid size is 4 by 4 km	1 km by 1 km grid of single sample plots	Cluster design, number and grid size depend on region. Tract size is between 300-1800 m in length.	1km by 0.5 km grid of single sample plots
Sample tree survey design	Variable radius	Angle-count	Variable radius	Variable radius	Variable radius
Plot size (m^2)	100, 300	BAF 4 $m^2 ha^{-1}$	79, 315, 707, 1964	38, 314	63, 254, 1017
Minimum tree DBH (cm)	1	10 BWI1 7 BWI2	7.5	4	6.4

Finland

The Finnish data is from a subset of NFI8 from a network of permanent sample plots established to follow changes in forest vegetation. We were given data from two surveys: 1985 to 1986 and 1995. The sample plots are in a systematic grid across the country (Mäkipää & Heikkinen, 2003; Tomppo & Tuimainen, 2010), are located on forest land and form a regular network of clusters. The size of the grid and the number of plots within each cluster depends on the location. In Southern Finland the grid is 16 by 16 km square and there are four plots in each cluster, at 400 m intervals. In Northern Finland the grid is a 24 by 32 km rectangle with three plots per cluster, at 600 m intervals.

The plot size depends on the diameter at breast height (d.b.h.) of the sample trees; trees < 10.5 cm d.b.h. the plot size is 100 m^2, >10.5 cm d.b.h. the plot size is 300 m^2. The plots are in intensively managed forests, where suppressed trees are thinned.

Germany

We received data from the first two German NFIs. The first inventory (BWI1) was surveyed between 1986 and 1990 (undertaken in West Germany only) and the second (BWI2) between 2001 and 2002. The mean survey period was 12 years.

The German NFI is based on a systematic rectangular grid, the dimensions of which are determined by the Federal State; the standard size is 4 by 4 km and it is intensified in some States to either 2.83 by 2.83 km or 2 by 2 km (Polley *et al.*, 2010). In each grid square is a quadratic tract of 150 m in length. Each corner of the tract has a sample plot and the tracts are surveyed if at least one of the corners is in forest.

Trees with a minimum d.b.h. of 10 cm, in BWI1, and 7 cm, in BWI2, were surveyed based on callipered angle count sampling using a basal area factor (BAF) of 4 m^2 ha^{-1}.

Spain

We used data from the permanent sample plots of the second (NF12) and third (NFI3) Spanish NFIs. NFI2 was surveyed between 1986 and 1996 and NFI3 between 1997 and 2007, with a mean survey period of 10 years. The sample plots of the Spanish NFI are on a systematic 1 km^2 grid in forested areas of the country, and are not grouped in tracts but simply one plot in each grid square (Villaescusa & Diaz, 1998; Villanueva, 2005).

The Spanish NFI used a variable radius plot size depending on the d.b.h. of the sample trees; each plot has four nested subplots of 5, 10, 15 and 25 m radius and the minimum d.b.h. for a tree to be recorded within a subplot is 7.5 cm, 12.5 cm, 22.5 cm and 42.4 cm, respectively.

Sweden

We received data from the permanent sample tracts of the Swedish NFI. The inventory uses a randomly planned regular sampling grid and includes about 4,500 permanent tracts, each surveyed every five years (Axelsson *et al.* 2010). Plots in the first census were surveyed between 2003 and 2005 and plots in the second census were surveyed between 2008 and

2010. The tracts are rectangular and have different dimensions depending on the location within the country. Each tract has between 4 and 8 circular sample plots.

Trees greater than 1.3 m high are sampled in two different plot sizes depending on the d.b.h. of the tree: 40-99 mm d.b.h.: 3.5 m radius; and greater than 100 mm d.b.h.: 10 m radius.

Wallonia

The Walloon NFI follows a systematic non-stratified sampling methodology on a 1 km by 0.5 km grid (Rondeux *et al.* 2010). One circular sampling plot is located within each grid intersection. Areas are sampled if the area of land is greater than 0.1 ha and has at least 10% covered by a forest canopy (trees must be able to reach a minimum of 5 m). Plots in the first census were surveyed between 1994 and 2003 and plots in the second census were surveyed between 2008 and 2011.

The inventory employs a variable plot size depending on the circumference of the tree: Trees with a circumference between 20-69 cm: 4.5 m radius; 70-119 cm: 9 m radius; and greater than 120 cm: 18 m radius.

Figure S1.1. Biome classification of the selected inventory plots, following Olson *et al.* (2001). Blue: boreal; green: temperate; red: Mediterranean.
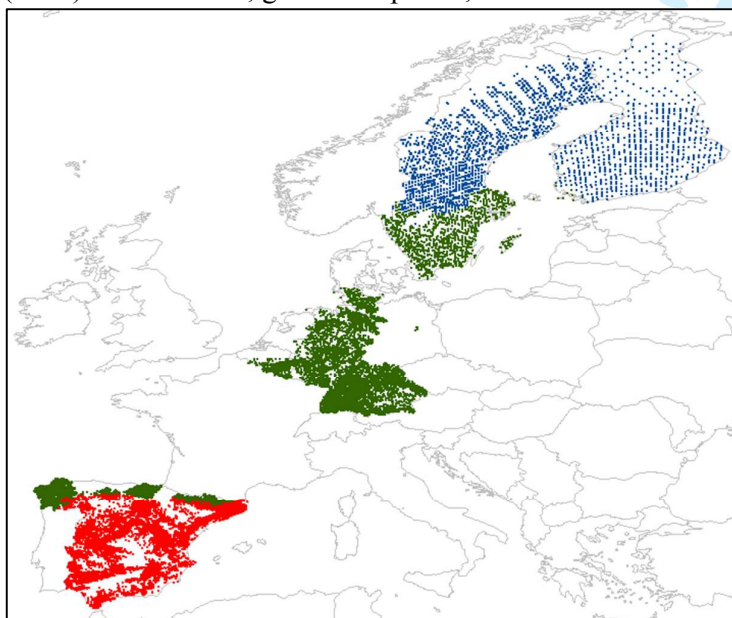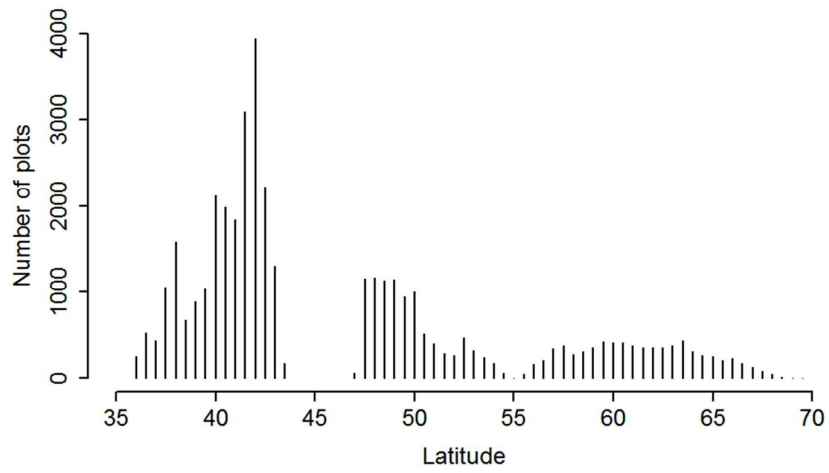
Figure S1.2. Latitudinal distribution of the selected National Forest Inventory plots across the continent.

Table S1.2. List of species names and families following, where possible, the nomenclature of *Atlas Florae Europaea.* NFI indicates which inventory the species was present in and the exotic status of the species is given where the species was found in the particular NFI (DE: Germany; ES: Spain; FI: Finland; SW: Sweden; and WA: Wallonia).

Name	Family	NFI	Exotic
Abies alba Mill.	*Pinaceae*	DE, ES, WA	
Abies grandis (D.Don) Lindl.	*Pinaceae*	DE, WA	DE, WA
Abies pinsapo Boiss.	*Pinaceae*	ES	
Abies procera Rehder	*Pinaceae*	DE	DE
Abies spp.	*Pinaceae*	DE, SW	
Acacia dealbata Link	*Leguminosae*	ES	ES
Acacia melanoxylon R.Br.	*Leguminosae*	ES	ES
Acacia spp.	*Leguminosae*	ES	ES
Acer campestre L.	*Aceraceae*	DE, ES, WA	
Acer monspessulanum L.	*Aceraceae*	DE, ES	
Acer negundo L.	*Aceraceae*	DE, ES	DE, ES
Acer opalus Mill.	*Aceraceae*	ES	
Acer platanoides L.	*Aceraceae*	DE, ES, SW, WA	ES
Acer pseudoplatanus L.	*Aceraceae*	DE, ES, SW, WA	
Aesculus hippocastanum L.	*Hippocastanaceae*	DE, WA	DE, WA
Ailanthus altissima (Mill.) Swingle	*Simaroubacae*	ES	ES
Alnus glutinosa (L.) Gaertn.	*Betulaceae*	DE, ES, SW, WA	
Alnus incana (L.) Moench	*Betulaceae*	DE, FI, SW, WA	
Alnus spp.	*Betulaceae*	FI	
Alnus viridis (Chaix) DC.	*Betulaceae*	DE	
Arbutus unedo L.	*Ericaceae*	ES	
Betula pendula Roth	*Betulaceae*	DE, ES, FI, SW	
Betula pubescens Ehrh.	*Betulaceae*	DE, FI, SW	
Betula spp.	*Betulaceae*	ES, SW, WA	
Buxus sempervirens L.	*Buxaceae*	ES	
Carpinus betulus L.	*Betulaceae*	DE, ES, SW, WA	
Castanea sativa Mill.	*Fagaceae*	DE, ES, WA	
Cedrus atlantica (Endl.) Carrière	*Pinaceae*	ES	ES
Cedrus deodara (D.Don) G.Don	*Pinaceae*	ES	ES
Cedrus libani A.Rich.	*Pinaceae*	ES	ES
Celtis australis L.	*Ulmaceae*	ES	
Ceratonia siliqua L.	*Leguminosae*	ES	
Chamaecyparis lawsoniana (A.Murray bis) Parl.	*Cupressaceae*	DE, ES	DE, ES
Corylus avellana L.	*Betulaceae*	ES	
Crataegus laciniata Ucria	*Rosaceae*	ES	
Crataegus monogyna Jacq.	*Rosaceae*	ES	
Crataegus spp.	*Rosaceae*	ES, WA	
Cupressus arizonica Greene	*Cupressaceae*	ES	ES
Cupressus lusitanica Mill.	*Cupressaceae*	ES	ES
Cupressus macrocarpa Hartw.	*Cupressaceae*	ES	ES
Cupressus sempervirens L.	*Cupressaceae*	ES	ES

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Name	Family	NFI	Exotic
Eucalyptus camaldulensis Dehnh.	*Myrtaceae*	ES	ES
Eucalyptus globulus Labill.	*Myrtaceae*	ES	ES
Eucalyptus gomphocephalus DC.	*Myrtaceae*	ES	ES
Eucalyptus nitens (H.Deane & Maiden) Maiden	*Myrtaceae*	ES	ES
Eucalyptus viminalis Labill.	*Myrtaceae*	ES	ES
Euonymus europaeus L.	Celastraceae	ES	
Fagus sylvatica L.	*Fagaceae*	DE, ES, SW, WA	
Frangula alnus Mill.	*Rhamnaceae*	DE, ES	
Fraxinus americana L.	*Oleaceae*	DE	
Fraxinus angustifolia Vahl	*Oleaceae*	ES	
Fraxinus excelsior L.	*Oleaceae*	DE, ES, SW, WA	
Fraxinus ornus L.	*Oleaceae*	ES	
Ilex aquifolium L.	*Aquifoliaceae*	DE, ES	
Juglans regia L.	*Juglandaceae*	DE, ES, WA	DE, ES, WA
Juniperus communis L.	*Cupressaceae*	ES	
Juniperus oxycedrus L.	*Cupressaceae*	ES	
Juniperus phoenicea L.	*Cupressaceae*	ES	
Juniperus spp.	*Cupressaceae*	DE, FI	
Juniperus thurifera L.	*Cupressaceae*	ES	
Larix decidua Mill.	*Pinaceae*	DE, ES	ES
Larix kaempferi (Lamb.) Carrière sec. Franco	*Pinaceae*	DE, ES	DE, ES
Larix spp.	*Pinaceae*	DE, ES, SW, WA	
Laurus nobilis L.	*Lauraceae*	ES	
Malus sylvestris Mill.	*Rosaceae*	DE, ES	
Morus alba L.	*Moraceae*	DE, ES	
Olea europaea L.	*Oleaceae*	ES	
Phillyrea latifolia L.	*Oleaceae*	ES	
Picea abies (L.) H.Karst.	*Pinaceae*	DE, ES, FI, SW, WA	ES
Picea omorika (PancKicA) Purk.	*Pinaceae*	DE	
Picea pungens Engelm.	*Pinaceae*	DE	DE
Picea sitchensis (Bong.) Carrière	*Pinaceae*	DE, WA	DE, WA
Picea spp.	*Pinaceae*	DE, SW	
Pinus canariensis Sweet ex Spreng.	*Pinaceae*	ES	
Pinus contorta Douglas ex Loudon	*Pinaceae*	DE, SW	DE, SW
Pinus halepensis Mill.	*Pinaceae*	DE	
Pinus mugo Turra	*Pinaceae*	DE, SW	
Pinus nigra J.F.Arnold	*Pinaceae*	DE, ES	
Pinus pinaster Aiton	*Pinaceae*	ES	
Pinus pinea L.	*Pinaceae*	ES	
Pinus ponderosa Douglas ex P.Lawson & C.Lawson	*Pinaceae*	DE	DE
Pinus radiata D.Don	*Pinaceae*	ES	ES
Pinus spp.	*Pinaceae*	DE, SW	
Pinus strobus L.	*Pinaceae*	DE	DE

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Name	Family	NFI	Exotic
Pinus sylvestris L.	*Pinaceae*	DE, ES, FI, SW, WA	
Pinus uncinata Mill. ex Mirb.	*Pinaceae*	ES	
Pistacia terebinthus L.	*Anacardiaceae*	ES	
Platanus hispanica Ten.	*Platanaceae*	ES	
Populus alba L.	*Salicaceae*	DE, ES	
Populus balsamifera Brayshaw	*Salicaceae*	DE	DE
Populus nigra L.	*Salicaceae*	DE, ES	
Populus spp.	*Salicaceae*	DE, WA	
Populus tremula L.	*Salicaceae*	DE, ES, FI, SW, WA	
Populus x canadensis Moench	*Salicaceae*	DE, ES	DE, ES
Prunus avium L.	*Rosaceae*	DE, ES, SW, WA	
Prunus lusitanica L.	*Rosaceae*	ES	
Prunus padus L.	*Rosaceae*	DE, ES	
Prunus serotina Ehrh.	*Rosaceae*	DE	DE
Prunus spinosa L.	*Rosaceae*	ES	
Prunus spp.	*Rosaceae*	ES, WA	
Pseudotsuga menziesii (Mirb.) Franco	*Pinaceae*	DE, ES, WA	DE, ES, WA
Pyrus spp.	*Rosaceae*	DE, ES	
Quercus canariensis Willd.	*Fagaceae*	DE	
Quercus faginea Lam.	*Fagaceae*	DE	
Quercus ilex L.	*Fagaceae*	DE	
Quercus palustris Münchh.	*Fagaceae*	DE	DE
Quercus petraea (Matt.) Liebl.	*Fagaceae*	DE, ES	
Quercus pubescens Willd. (Q. Humilis)	*Fagaceae*	DE	
Quercus pyrenaica Willd.	*Fagaceae*	DE	
Quercus robur L.	*Fagaceae*	DE, ES	
Quercus rubra L.	*Fagaceae*	DE, ES, WA	DE, ES, WA
Quercus spp.	*Fagaceae*	DE, ES, SW, WA	
Quercus suber L.	*Fagaceae*	ES	
Rhamnus alaternus L.	*Rhamnaceae*	ES	
Robinia pseudacacia L.	*Leguminosae*	DE, ES, WA	DE, ES, WA
Salix alba L.	*Salicaceae*	ES	
Salix atrocinerea Brot.	*Salicaceae*	ES	
Salix caprea L.	*Salicaceae*	DE, ES, SW, WA	
Salix elaeagnos Scop.	*Salicaceae*	ES	
Salix fragilis L.	*Salicaceae*	ES	
Salix spp.	*Salicaceae*	DE, ES, FI, WA	
Sambucus nigra L.	*Caprifoliaceae*	ES	
Sambucus racemosa L.	*Caprifoliaceae*	ES	
Sorbus aria (L.) Crantz	*Rosaceae*	DE, ES	
Sorbus aucuparia L.	*Rosaceae*	DE, ES, SW, WA	
Sorbus domestica L.	*Rosaceae*	DE, ES	
Sorbus intermedia (Ehrh.) Pers.	*Rosaceae*	SW	

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Name	Family	NFI	Exotic
Sorbus spp.	*Rosaceae*	DE, ES, FI	
Sorbus torminalis (L.) Crantz	*Rosaceae*	DE, ES	
Taxus baccata L.	*Taxaceae*	DE, ES	
Thuja spp.	*Cupressaceae*	DE, ES	DE, ES
Tilia cordata Mill.	*Tiliaceae*	ES	
Tilia platyphyllos Scop.	*Tiliaceae*	ES	
Tilia spp.	*Tiliaceae*	DE, ES, SW, WA	
Tsuga spp.	*Pinaceae*	DE, WA	DE, WA
Ulmus glabra Huds.	*Ulmaceae*	ES	
Ulmus minor Mill.	*Ulmaceae*	ES	
Ulmus spp.	*Ulmaceae*	DE, SW, WA	

Table S1.3. Summary statistics of the selected plots from each National Forest Inventory. BA: mean basal area (m² ha⁻¹); DBH: mean d.b.h. (mm); MR: annual natural mortality rate (m² ha⁻¹ yr⁻¹); SP: species pool; FDis: functional dispersion; FI_{mh}: CWM maximum height (m); FI_{ln}: CWM leaf N mass (mg⁻¹ g); FI_{ls}: CWM maximum tree life span (yr); FI_{wd}: CWM wood density (g cm⁻³).

	Spain	Germany	Sweden	Finland	Wallonia (Belgium)
Number of plots	22989	8821	6083	1174	488
Growth (m² ha⁻¹ yr⁻¹)	0.41 (0.04 – 1.30)	0.82 (0.18 – 1.99)	0.42 (0.05 – 1.18)	0.43 (0.06 – 0.99)	0.52 (0.15 – 1.51)
BA (m² ha⁻¹)	15.52 (4.85 – 39.07)	30.54 (8.00 – 62.71)	17.60 (4.95 – 41.02)	16.41 (5.60 – 34.08)	23.04 (8.63 – 52.24)
DBH (mm)	290.07 (146 - 618.43)	327.94 (146 – 618.7)	198.33 (130.3 – 351.6)	192.84 (133.7 – 306.4)	405.03 (158.3 – 638)
MR (m² ha⁻¹ yr⁻¹)	1.37 (0.0 – 11.81)	0.33 (0.0 – 3.44)	0.33 (0.0 – 3.00)	0.16 (0.0 – 1.68)	0.22 (0.0 – 2.49)
SP	62.25 (4 - 108)	71.22 (8 - 101)	33.32 (8 - 53)	28.68 (8 - 41)	71.37 (52 - 94)
Monocultures (%)	52.2	32.0	19.5	26.5	28.7
FDis	0.03 (0.0 – 0.27)	0.05 (0.0 – 0.19)	0.05 (0.0 – 0.21)	0.05 (0.0 – 0.14)	0.06 (0.0 – 0.19)
FI_{mh} (m)	30.08 (18.67 – 40.25)	40.48 (25.00 – 56.54)	35.32 (22.76 - 50)	35.32 (20.07 - 50)	32.02 (21.51 – 50)
FI_{ln} (mg g⁻¹)	13.54 (10.04 – 23.1)	17.57 (12.44 – 26.92)	14.80 (12.44 – 24.25)	14.67 (12.44 – 23.87)	19.35 (12.44 – 25.0)
FI_{ls} (yr)	473.39 (2 - 1000)	479.79 (120 - 800)	430.97 (126 - 600)	437.61 (155 - 600)	428.84 (138 - 581)
FI_{wd} (g cm⁻³)	0.65 (0.48 – 0.9)	0.55 (0.44 – 0.72)	0.51 (0.44 – 0.60)	0.51 (0.44 – 0.56)	0.69 (0.44 – 0.86)

For species pool (SP) and functional diversity (FDis) the mean and range (maximum and minimum) are given. For all the other variables the mean and 2.5 and 97.5 percentiles are presented.

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Appendix S1

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Supporting Information Appendix S2 Climate, Functional Composition and Species Pool Variables

Climate variable selection

We used the inventory plot coordinates to extract plot-level climatic variables from the WorldClim database (Hijmans *et al.*, 2005) and potential evapotranspiration (PET; mm yr^{-1}) and an aridity index (MAP / PET, where MAP is mean annual precipitation) from CGIAR-CSI (Trabucco & Zomer, 2009). WorldClim database includes 19 climatic variables based on temperature and precipitation over the period 1950-2000, including seasonal variability indices. In addition, we calculated a water availability index (WAI) as the proportion of water available with respect to water climate demand (i.e. WAI = (MAP - PET) / PET).

Rather than perform a length model selection process testing each climate variable, we performed a dimension reduction using a principal component analysis (PCA) on all 22 climate variables, to determine which variables best represent the climate data cloud. The first axis accounted for 52.25% of the variation in the climate data and the second axis 26.53%. PET and WAI both loaded strongly to the first axis (0.97 and 0.93, respectively) and temperature seasonality (standard deviation of yearly MAT values) loaded strongly on the second axis (0.91). MAT and MAP also loaded strongly to the two PCA axes (0.85 and 0.73, respectively).

The model (equation 1 in the manuscript) was refitted replacing MAT and MAP in the equation with:

1. the scores of the first two PCA axes;
2. PET and temperature seasonality;
3. WAI and temperature seasonality.

The deviance information criterion (DIC) values for each model are listed in Table S2.1, where the model with the smallest DIC is considered a better model fit, based on the number of parameters in the model and the model fit (Spiegelhalter *et al.*, 2002). We included the WAI and temperature seasonality model because PET and temperature seasonality were moderately correlated (Spearman rank coefficient = -0.35), which is not ideal, and WAI and TS were not correlated (Spearman rank coefficient = -0.004). MAT and MAP were weakly correlated (Spearman rank coefficient: -0.18, $p < 0.001$).

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Table S2.1. Comparison of growth models based on DIC parameterised using different climate variables. Climate variables are MAT (mean annual temperature; °C), MAP (mean annual precipitation; mm), PCA1 (first axis of the PCA), PCA2 (second axis of the PCA), PET (potential evapotranspiration; mm), and temperature seasonality (standard deviation of yearly MAT values). Deviance Information Criterion (DIC) and ΔDIC are shown.

Climate variables	DIC	ΔDIC
MAT and MAP	-29361.72	0.00
PCA1 and PCA2	-29316.62	45.10
PET and temperature seasonality	-28980.64	381.08
WAI and temperature seasonality	-28890.31	471.41

MAT and MAP were selected as the climate variables due to their better predictive power

(by DIC comparison) and parsimony over the first two PCA axes of the 22 climate variables.

References

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Spiegelhalter, D.J., Best, N.G., Carlin, B.P. & van der Linde, A. (2002) Bayesian measures of model complexity and fit. *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, **64**, 583–639.

Trabucco, A. & Zomer, R.J. (2009) *Global Aridity Index (Global-Aridity) and Global Potential Evapo-Transpiration (Global-PET) Geospatial Database*.

Table S2.2. References for the trait data used in the study

The trait matrix, for the 138 species in the final analysis, was 87% complete. We increased this to 94% by computing genus-level means. Genus-level trait values were taken as the average values of the available species. Plots with species groups such as 'other conifers' were excluded. The reference list is given in Appendix 1 of the main manuscript.

Reference	Accessed from TRY	Leaf N	Maximum height	Maximum tree life span	Seed mass	Wood density
Aas 1999				X		
Atkin *et al.* 1999	Yes	X				
Bahn 1999	Yes	X				
Briemle *et al.* 2002	Yes				X	
Campbell *et al.* 2007	Yes	X				
Castro-Díez *et al.* 1998	Yes	X	X		X	X
Castro-Díez *et al.* 2000	Yes	X	X		X	X
Chave *et al.* 2009	Yes					X
Cornelissen 1996	Yes	X	X		X	X
Cornelissen *et al.* 1996	Yes	X	X		X	X
Cornelissen *et al.* 1999	Yes	X	X		X	X
Cornelissen *et al.* 2001	Yes	X	X		X	X
Cornelissen *et al.* 2003	Yes	X	X		X	X
Cornelissen *et al.* 2004	Yes	X	X		X	X
Cornwell *et al.* 2006	Yes	X	X		X	X
Cornwell *et al.* 2008	Yes	X	X		X	X
Craine *et al.* 2009	Yes	X				
Dabernig 1996				X		
Díaz *et al.* 2004	Yes	X	X		X	X
Durka 2002	Yes				X	
Fischer *et al.* 2008				X		
Fitschen 2007			X	X		
Fonseca *et al.* 2000	Yes	X	X			
Freschet *et al.* 2010a	Yes	X				
Freschet *et al.* 2010b	Yes	X				
Garnier *et al.* 2007	Yes	X			X	
Godet 2006						X
Green 2009	Yes				X	
Han *et al.* 2005	Yes	X				
He *et al.* 2006	Yes	X				
Hecker 2012				X		
Jordano 2007					X	
Kattge *et al.* 2009	Yes	X				
Kattge *et al.* 2011a	Yes	X	X		X	
Kattge *et al.* 2011b			X	X	X	X
Kerkhoff *et al.* 2006	Yes	X				
Kirkup *et al.* 2005	Yes		X			
Kleyer *et al.* 2008	Yes		X		X	X
Klotz *et al.* 2002	Yes				X	
Krumbiegel 2002	Yes				X	
Kühn *et al.* 2004	Yes				X	
Laughlin *et al.* 2010	Yes	X	X		X	
Loveys *et al.* 2003	Yes	X				
McDonald *et al.* 2003	Yes	X	X			
Medlyn *et al.* 1999	Yes	X				
Moles *et al.* 2004	Yes		X	X	X	
Niinemets 2001	Yes	X				
Ogaya & Peñuelas 2003	Yes	X	X			X
Ogaya & Peñuelas 2006	Yes	X	X			X
Ordoñez *et al.* 2010a	Yes	X	X			X

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Ordoñez *et al.* 2010b	Yes	X	X			X
Otto 2002	Yes				X	
Pakeman *et al.* 2008	Yes	X			X	
Paula *et al.* 2009	Yes		X		X	
Paula & Pausas 2008	Yes				X	
Peñuelas *et al.* 2010a	Yes	X	X			X
Peñuelas *et al.* 2010b	Yes	X	X			X
Preston *et al.* 2006	Yes	X	X		X	X
Quested *et al.* 2003	Yes	X	X		X	X
Reich *et al.* 2008	Yes	X				X
Reich *et al.* 2009	Yes	X				X
Roloff *et al.* 1994				X		X
Royal Botanical Gardens Kew 2008	Yes				X	
Schütt *et al.* 2002			X	X		
Seifert 1971				X		
USDA, NRCS 2011			X			
van Bodegom *et al.* 2005	Yes	X				
van Bodegom *et al.* 2008	Yes	X				
Vorreiter 1949						X
Wächtershäuser & Trageser 2011					X	
Wagenführ & Scheiber 1985					X	
Willis *et al.* 2010	Yes	X				X
Wirth & Lichstein 2009	Yes		X	X		
Wohlfahrt *et al.* 1999	Yes	X				
Wright *et al.* 2004	Yes	X	X			
Wright *et al.* 2006	Yes	X	X			
Zanne *et al.* 2009						X

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Functional Composition Estimation

The functional diversity of each plot was quantified using the functional dispersion index (FDis) of Laliberté & Legendre (2010) using the five traits selected and weighted by their relative abundance: maximum tree height (m); leaf nitrogen content (mg g^{-1}); maximum tree lifespan (yrs); seed mass (mg); and wood density (g cm^{-3})).

Due to the very low species richness of the plots we were limited in the choice of functional diversity indices available to use. The FDis can be calculated for communities with two or more singular species, i.e. species that differ in one or more traits. It is also possible with Rao's quadratic entropy (Botta-Dukát, 2005). Other functional diversity indices such functional divergence (Mason *et al.*, 2005) and functional evenness were not possible to calculate for a large number of the plots in our dataset, where the number of traits exceed the number of species in the plot. Both FDis and Rao's Q include elements of evenness and divergence (Mason *et al.*, 2013), which together have been shown to be important for estimating complementarity in communities.

We used the Gower distance matrix, rather than a Euclidean matrix, even though the traits are all continuous, because the Gower distance matrix is more stable against missing values (Pavoine *et al.*, 2009) of which there were 6% in the trait matrix. The trait variables were transformed (either log or square root) following Botta-Dukát (2005) and Pavoine *et al.* (2009), to ensure that where the distribution of traits is highly skewed extreme values do not exert a greater effect.

The functional identity was derived as the community-weighted mean of each trait for each plot (FI_{mh}: maximum tree height; FI_{ln}: leaf N content; FI_{ls}: maximum tree life span; FI_{sm}: seed mass; FI_{wd}: wood density). FDis and FI were calculated using the 'FD' package in R (Laliberté & Shipley, 2011). FI_{sm} and FI_{wd} were highly positively correlated (Spearman rank coefficient: 0.74; $p < 0.001$) thus FI_{sm} was not considered further in the analysis.

References

De Bello, F., Carmona, C.P., Mason, N.W.H., Sebastià, M.-T. & Lepš, J. (2012) Which trait dissimilarity for functional diversity: trait means or trait overlap? *Journal of Vegetation Science*, 1–14.

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Botta-Dukát, Z. (2005) Rao's quadratic entropy as a measure of functional diversity based on multiple traits. *Journal of Vegetation Science*, **16**, 533–540.

Laliberté, E. & Legendre, P. (2010) A distance-based framework for measuring functional diversity from multiple traits. *Ecology*, **91**, 299–305.

Mason, N.W.H., de Bello, F., Mouillot, D., Pavoine, S. & Dray, S. (2013) A guide for using functional diversity indices to reveal changes in assembly processes along ecological gradients. *Journal of Vegetation Science*, **24**, 794–806.

Mason, N.W.H., Mouillot, D., Lee, W.G. & Wilson, J.B. (2005) Functional richness, functional evenness and functional divergence : the primary components of functional diversity. *Oikos*, **1**, 112–118.

Pavoine, S., Vallet, J., Dufour, A.-B., Gachet, S. & Daniel, H. (2009) On the challenge of treating various types of variables: application for improving the measurement of functional diversity. *Oikos*, **118**, 391–402.

Laliberté, E. & Shipley, B. (2011) FD: measuring functional diversity from multiple traits, and other tools for functional ecology.

Species Pool Estimation

The species pool was estimated from tree species distribution maps. The distribution maps were provided by Martin Freiberg from the Botanical Gardens, Leipzig and Erik Welk from the Botanical Gardens, Halle, and compiled for the FunDivEUROPE project (http://www.fundiveurope.eu) by Mario Liebergesell at 5 arc minute resolution. Nomenclature follows the *Atlas Florae Europaea*.

The reference list for the tree species distribution maps is given in Appendix 2 in the main manuscript.

Appendix S3

Supporting Information Appendix S3 Supplementary Statistical Methods

Model fitting and prior information

For data from Finland, Sweden and Germany the random intercepts (α_r) were cluster-level intercepts ($\alpha_{cluster}$) modelled from a normal distribution, such that

$$\alpha_{cluster} \sim Normal(\alpha_{nfi}, \sigma_{cluster})$$

where α_{nfi} is the NFI-level mean growth and $\sigma_{cluster}$ the cluster-level s.d.. For the data from Spain and Wallonia the random intercepts (α_r) were NFI-level intercepts (α_{nfi}). The NFI-level intercepts (α_{nfi}), from all five inventories, were modelled such that:

$$\alpha_{nfi} \sim Normal(0, \sigma_{nfi})$$

where σ_{nfi} is the standard deviation.

We tested for model convergence by running three chains with different starting values and checked the Rhat statistic, where a value of <1.1 indicates convergence (Gelman *et al.*, 2004). The following priors were used:

$$\alpha_0, \alpha_{cluster}, \alpha_{nfi,} \beta_{1-29} \sim Normal(0, 10)$$

$$\sigma_\mu, \sigma_{cluster}, \sigma_{nfi} \sim Uniform(0, 1)$$

Convergence took between 250 and 500 iterations; we ran the model for 500 iterations of warm up and an additional 10,000 iterations for sampling. Samples were taken every 10 iterations. The Deviance information criterion (DIC) was calculated as the model fit statistic following (Spiegelhalter *et al.*, 2002). A simple model was tested that only included an nfi-level random intercept (no cluster-level) but the DIC comparison indicated that the more complex model was justified (ΔDIC > 1000). A more complicated model was also tested allowing a different $\sigma_{cluster}$ for Finland, Germany and Sweden but $\sigma_{cluster}$ parameters did not converge.

The proportion of the variance in plot-level growth explained by the final model was estimated as 1 minus the residual variance divided by the variance in the data. The calculation was averaged over the posterior distribution of the predicted values (Korner-Nievergelt *et al.*, 2015).

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References

Gelman, A., Carlin, J.B., Stern, H.S. & Rubin, D.B. (2004) *Bayesian Data Analysis*, Second edi. Chapman and Hall/CRC, Boca Raton, Florida, USA.

Korner-Nievergelt, F., Roth, T., von Felten, S., Guélat, J., Almasi, B., & Korner-Nievergelt, P. (2015). *Bayesian Data Analysis in Ecology Using Linear Models with R, BUGS, and Stan*. Academic Press.

Spiegelhalter, D.J., Best, N.G., Carlin, B.P. & van der Linde, A. (2002) Bayesian measures of model complexity and fit. *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, **64**, 583–639.

Model Evaluation

Table S3.1. Mean and 95% credible intervals of the posterior distribution of the model parameters. The model predicts plot-level growth rate (m^2 ha^{-1} yr^{-1}) depending on structural, climatic and biodiversity variables. Predictor variables were centred on 0 and scaled to 1 standard deviation. The proportion of the variance in plot-level growth explained by the final model was 0.684. Not all of the variance explained can be attributed to the predictors; some will be explained by the cluster and country effects. *

Variable	Model coefficient	Mean	2.5 %	97.5 %
	α_0	-0.911	-1.07	-0.802
MAT	β_{MAT}	0.205	0.191	0.217
MAP	β_{AP}	0.067	0.060	0.074
BA	$\beta_1^{(c)}$	0.490	0.484	0.496
DBH	$\beta_2^{(c)}$	-0.314	-0.320	-0.308
MR	$\beta_3^{(c)}$	-0.074	-0.082	-0.066
SP	$\beta_4^{(c)}$	0.064	0.054	0.074
FDis	$\beta_1^{(z)}$	0.054	0.049	0.060
FI_{wd}	$\beta_2^{(z)}$	-0.134	-0.145	-0.123
FI_{mh}	$\beta_3^{(z)}$	0.113	0.106	0.120
FI_{ls}	$\beta_4^{(z)}$	-0.120	-0.130	-0.111
FI_{ln}	$\beta_5^{(z)}$	-0.001	-0.007	0.008
BA x MAT	$\delta_1^{(MAT)}$	0.014	0.007	0.020
DBH x MAT	$\delta_2^{(MAT)}$	0.048	0.041	0.056
MR x MAT	$\delta_3^{(MAT)}$	0.028	0.018	0.036
SP x MAT	$\delta_4^{(MAT)}$	-0.010	-0.016	-0.004
BA x MAP	$\delta_1^{(AP)}$	-0.037	-0.043	-0.031
DBH x MAP	$\delta_2^{(AP)}$	0.010	0.004	0.015
MR x MAP	$\delta_3^{(AP)}$	-0.014	-0.017	-0.010
SP x AP	$\delta_4^{(AP)}$	0.013	0.004	0.022
FDis x MAT	$\gamma_1^{(MAT)}$	0.017	0.010	0.023
FDis x MAP	$\gamma_1^{(AP)}$	-0.013	-0.018	-0.008
FI_{wd} x MAT	$\gamma_2^{(MAT)}$	-0.028	-0.042	-0.015
FI_{wd} x MAP	$\gamma_2^{(AP)}$	0.007	0.0002	0.015
FI_{mh} x MAT	$\gamma_3^{(MAT)}$	0.096	0.087	0.103
FI_{mh} x MAP	$\gamma_3^{(AP)}$	0.011	0.005	0.017
FI_{ls} x MAT	$\gamma_4^{(MAT)}$	-0.014	-0.025	-0.002
FI_{ls} x MAP	$\gamma_4^{(AP)}$	-0.008	-0.015	-0.001
FI_{ln} x MAT	$\gamma_5^{(MAT)}$	0.040	0.031	0.050
FI_{ln} x MAP	$\gamma_5^{(AP)}$	-0.024	-0.031	-0.018
	σ_μ	0.451	0.447	0.454
	$\sigma_{cluster}$	0.223	0.212	0.233
	σ_{nfi}	0.171	0.089	0.277

* MAT: mean annual temperature (°C, log+7); MAP: mean annual precipitation (mm); BA: mean basal area (m^2 ha^{-1}, log); DBH: mean d.b.h. (mm, log); MR: annual natural mortality rate (m^2 ha^{-1} yr^{-1});

SP: regional species pool (log); FDis: functional dispersion (sqrt); FI_{wd}: CWM wood density (g^{-1} cm^3); FI_{mh}: CWM maximum height (m); FI_{ls}: CWM maximum tree life span (yr); FI_{ln}: CWM leaf N mass (mg^{-1} g); α_0: expected plot growth rate under average conditions (log scale); σ_μ: residual standard deviation (log scale); $\sigma_{cluster}$: cluster-level standard deviation (log scale); σ_{nfi}: inventory-level standard deviation (log scale). α_r has not been included in the table for brevity as there are 8493 cluster values estimated in the model.

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Figure S3.1. Growth ($m^2 ha^{-1} yr^{-1}$) (a); predicted growth ($m^2 ha^{-1} yr^{-1}$) (b); and the model residuals ($m^2 ha^{-1} yr^{-1}$) (c) in each inventory plot.
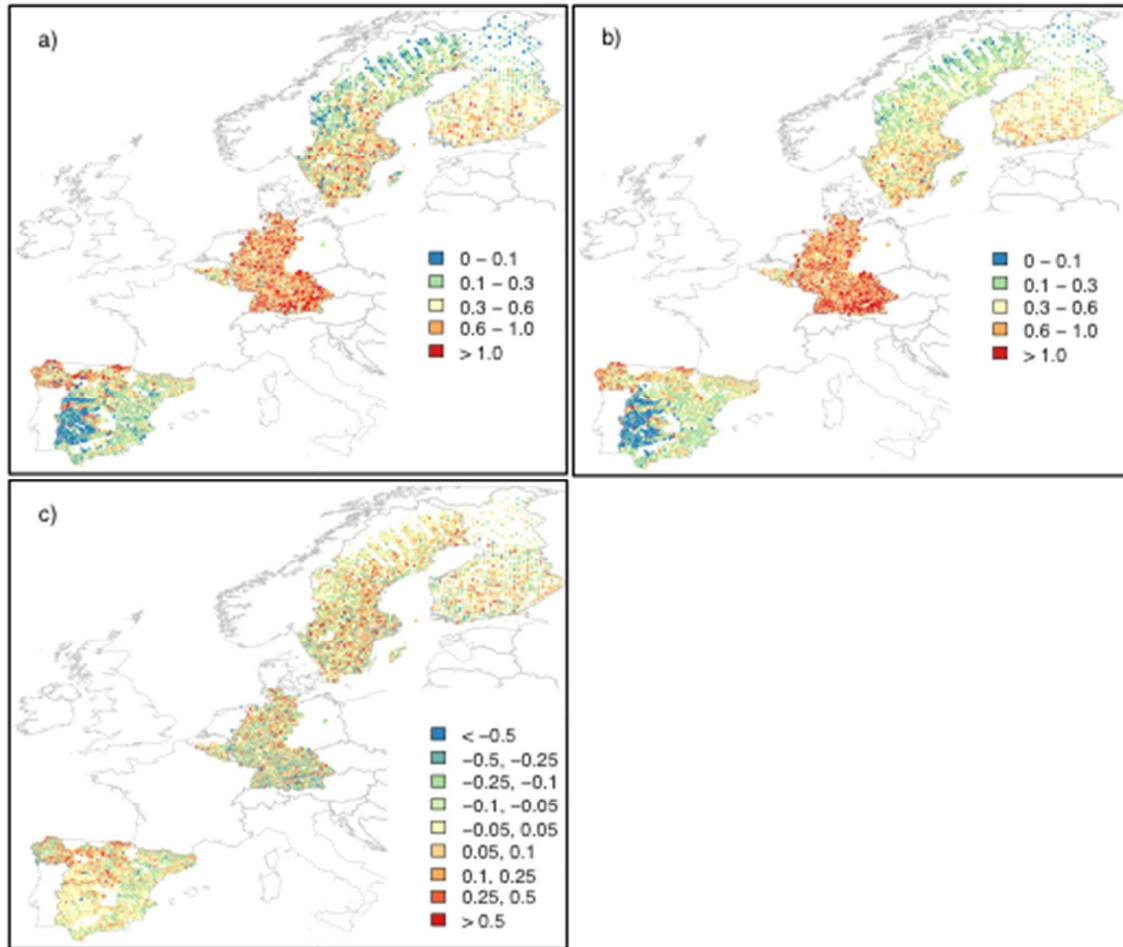
Figure S3.2. Partial residual plots for each predictor in the full model. The partial residual was calculated in each plot (*i*) as *residual$_i$ + β$_i$X$_i$*, where *residual$_i$* is the residual for plot *i*, *β$_i$* is the mean of the posterior distribution of predictor *X* and *X$_i$* is the value of predictor *X* in plot *i*. The blue line is the lowess smoothing line. The plots illustrate the relationship between each of the predictor variables and tree growth once all the other predictors have been accounted for in the model and they are useful to identify non-linear relationships. In each case, after appropriate transformations, no large deviations from linear relationships were observed and the linear approximations justified.
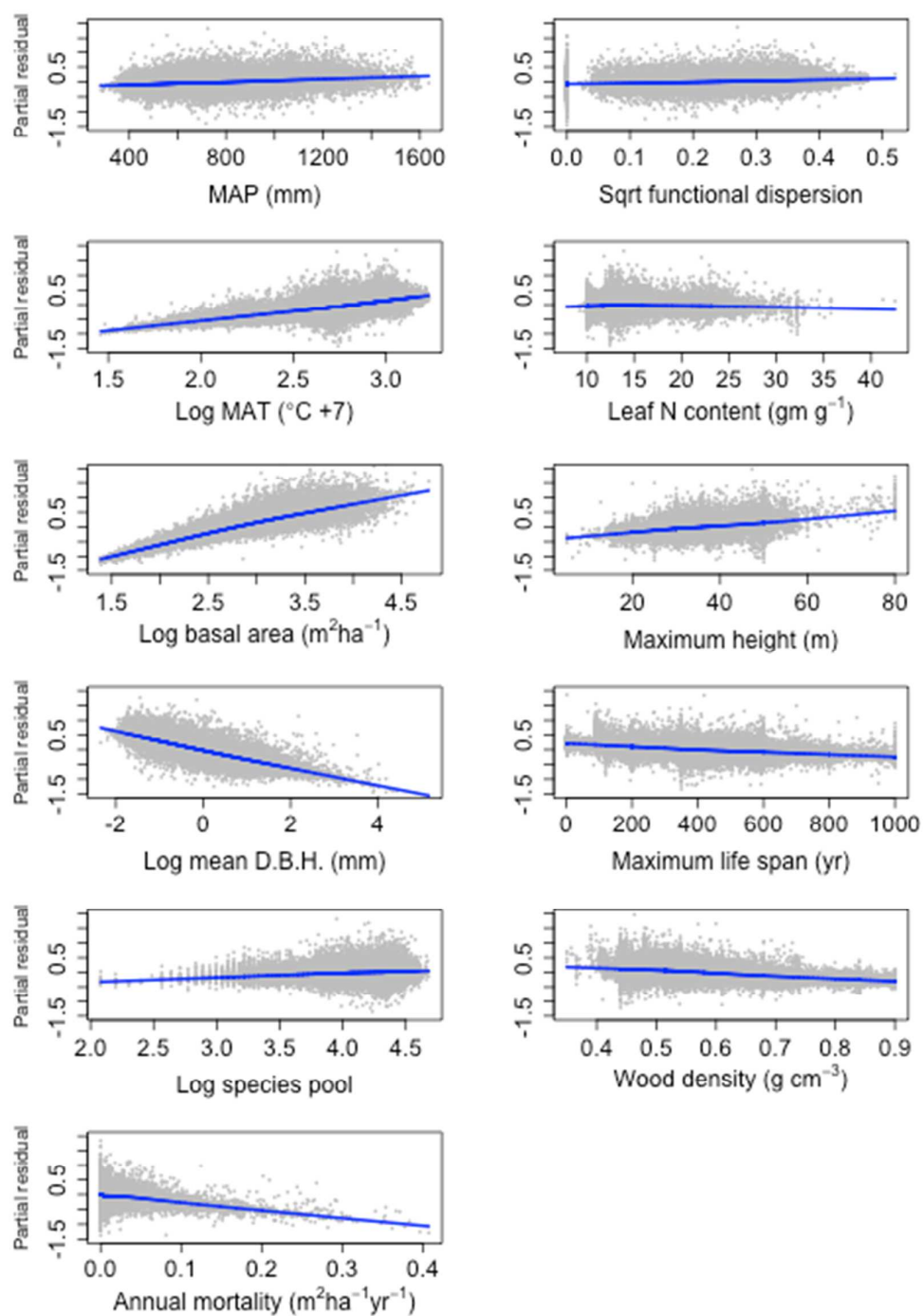
Control Analyses

We performed three additional control analyses to test the robustness of the model predictions and inferences made thereof. Specifically, we tested for: (i) the influence of climate variable selection; (ii) possible problems arising from collinearity between the functional identity measures; and (iii) the influence of exotic tree species, which are often more productive than native species (Kawaletz *et al.*, 2013).

Influence of climate variable selection

As a further sensitivity study we repeated the analysis where the climate variables (mean annual temperature and mean annual precipitation) were replaced by the scores of the first two axes of a PCA analysis of 22 climate variables (see Appendix S2). The patterns are robust in the Mediterranean and temperate regions (Fig S3.3a & b); however the PCA model does not predict a large increase in the importance of functional identity in the boreal region (Fig S3.3b). The reason is because the PCA model does not predict such a drastic increase in the relative importance of FI_{mh} in the boreal region as the MAT-MAP model (Figs S3.3b and S3.4). In addition, the PCA model does not predict an increase in the importance of FI_{ln} in the boreal region. With this in mind, we treat our findings in the boreal region with caution.

Figure S3.3. a) Predicted relative importance of climate, represented by two PCA axes (PCA 1 and PCA 2) of 22 climate variables, functional identity (aggregated effect of the community mean value of four functional traits) and functional dispersion for tree growth. b) Predicted relative importance of five components of functional biodiversity (functional dispersion and the community weighted mean of four functional traits) for tree growth.
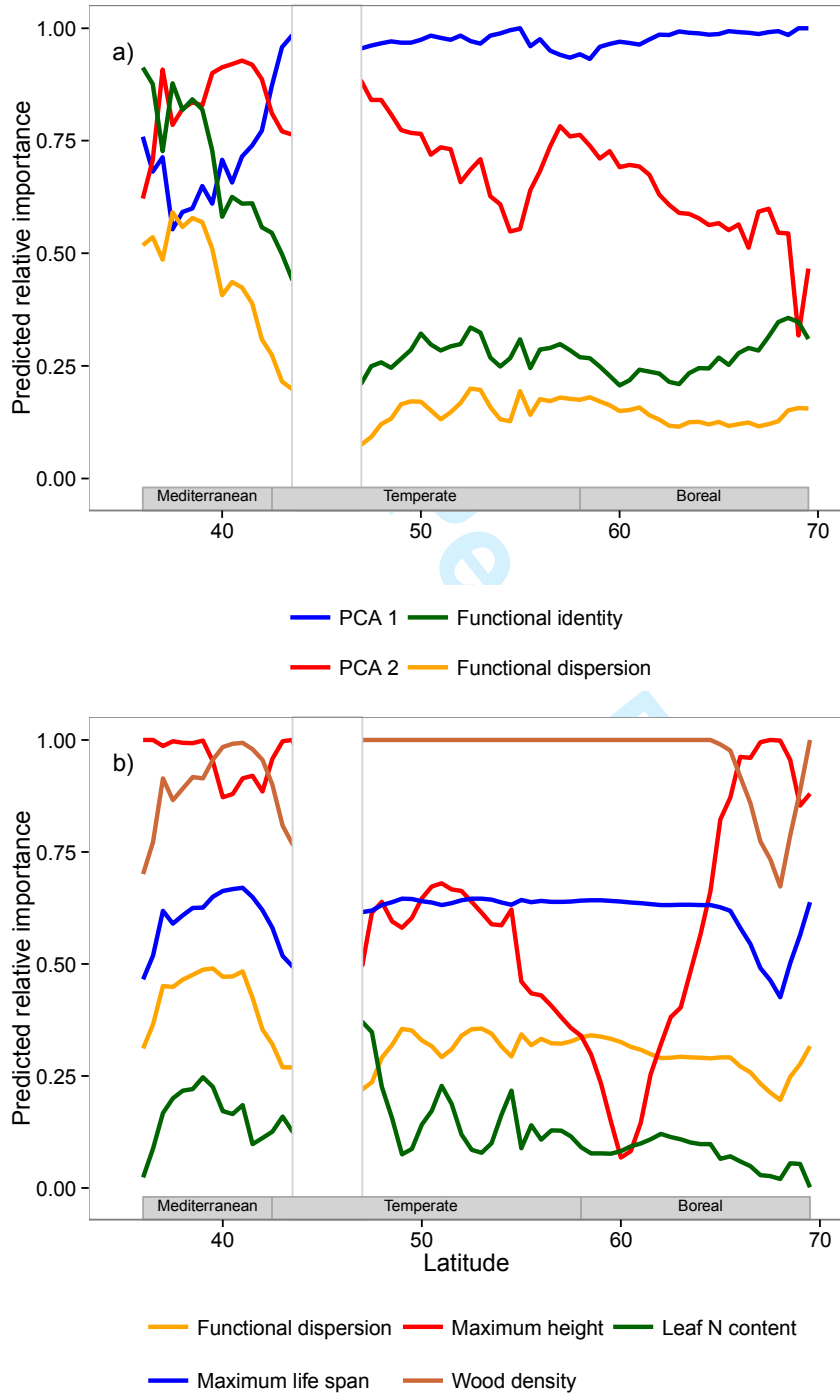
Figure S3.4. The absolute influence of each predictor on plot-level tree growth (m^2 ha^{-1} yr^{-1}) across the continent. The predictors are: the first PCA axis (PCA 1); second PCA axis (PCA 2); functional dispersion; community-weighted mean (CWM) maximum height; CWM leaf N content; CWM maximum life span; and CWM wood density. The covariates (plot basal area (m^2 ha^{-1}), mean tree size (mm), species pool and natural mortality rate (m^2 ha^{-1} yr^{-1}) have been group together in grey and labeled covariates.
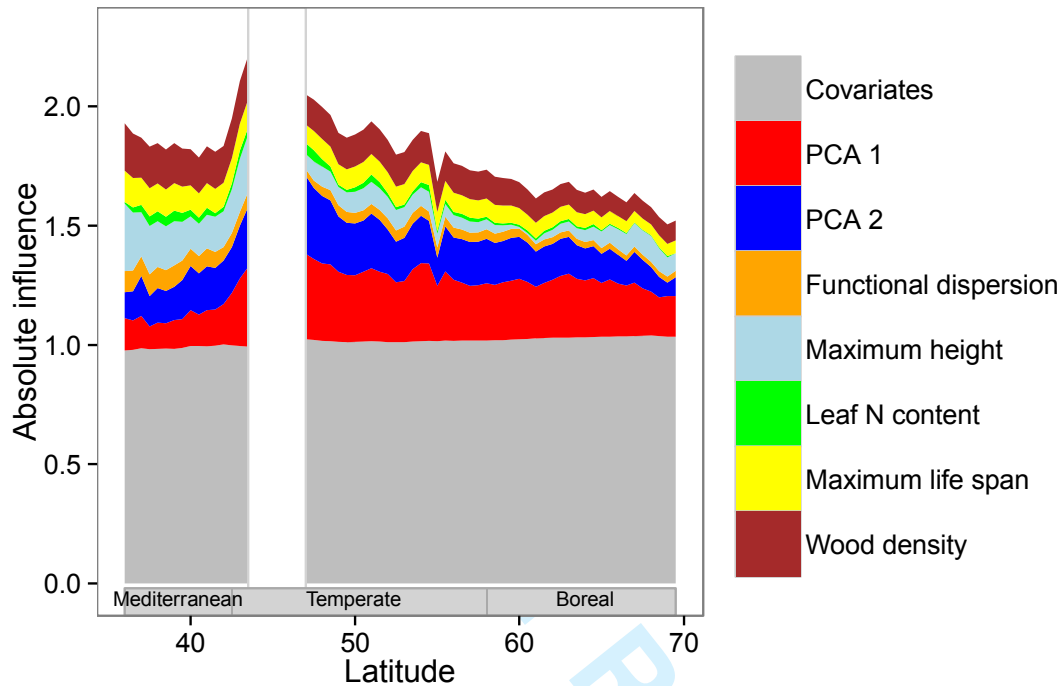
Influence of multicollinearity

We found that the importance of FI_{wd} and FI_{ls} for tree growth changed in concert across the continent (Fig. 3). Given that their FI values were moderately correlated (Spearman rank coefficient = 0.5; p < 0.001) and in order to separate their individual influences, the analysis was repeated excluding FI_{wd} from the model. The general patterns of importance of the predictors left in the model remained the same across the continent (Fig S3.5a & b).

Figure S3.5. a) Predicted relative importance of mean annual temperature, mean annual precipitation, functional identity variables (aggregated effect of the community mean value of three functional traits) and functional dispersion for tree growth; b) Predicted relative importance of four biodiversity measures (functional dispersion and the community weighted mean of three functional traits). The community weighted mean of wood density was excluded from the model.
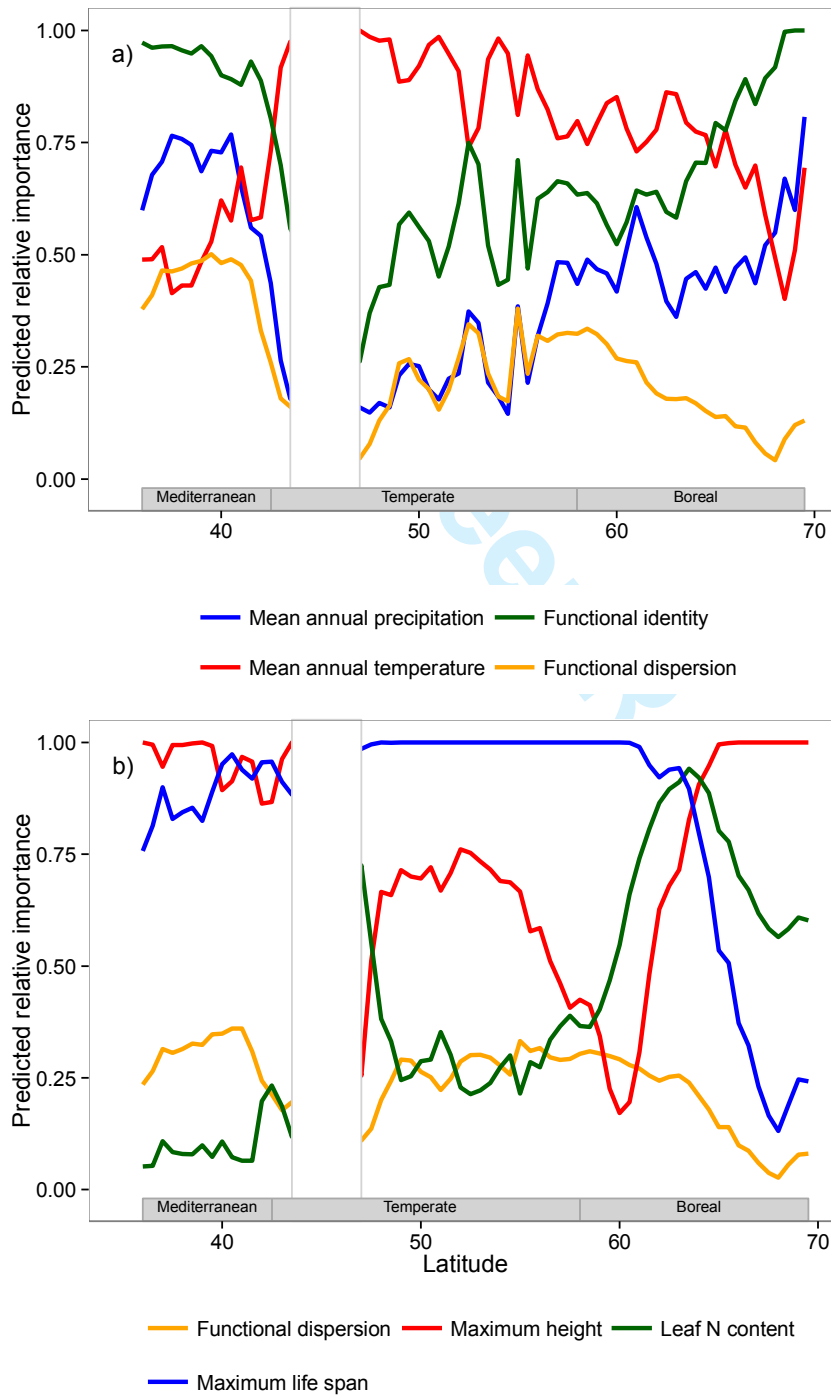
Influence of exotic tree species

Exotic tree species are often more productive than native species (Kawaletz *et al.*, 2013). To ensure that dominance of exotic species did not influence the results, we repeated the analysis excluding plots with greater than 80% basal area of non-native species. The general patterns of importance across the continent remained the same (Fig S3.6a & b).

Figure S3.6. a) Predicted relative importance of mean annual precipitation, mean annual temperature, functional identity (aggregated effect of the community mean value of four functional traits) and functional dispersion; b) Predicted relative importance of five components of functional biodiversity (functional dispersion and the community weighted mean of four functional traits). Plots with greater than 80% basal area of non-native tree species were excluded from the analysis.

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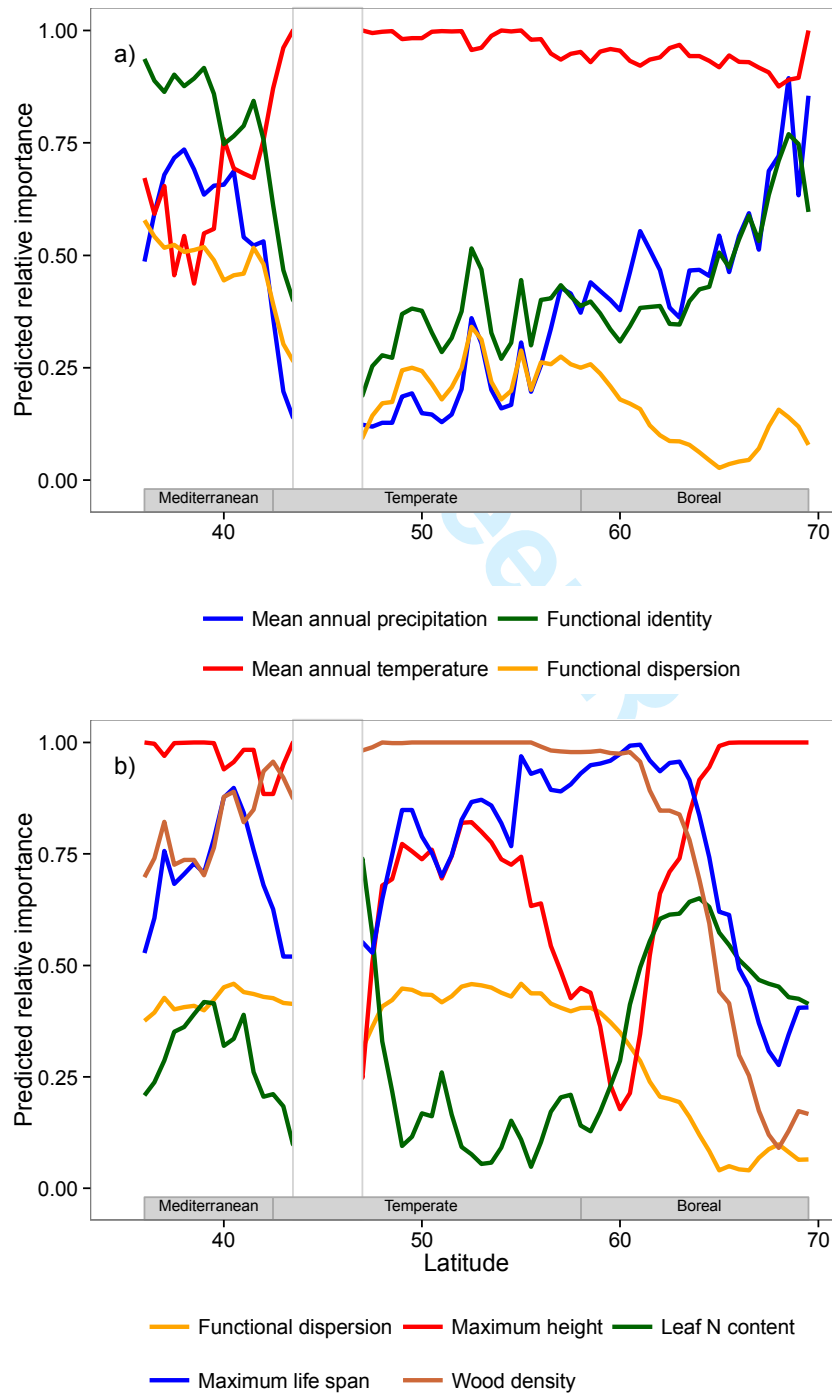
References

Kawaletz, H., Molder, I., Zerbe, S., Annighöfer, P., Terwei, A. & Ammer, C. (2013) Exotic
tree seedlings are much more competitive than natives but show underyielding when
growing together. *Journal of Plant Ecology*, 1–11.

Supporting Information Appendix S4 Supplementary Figures

Figure S4.1. Mean and range of functional dispersion (FDis) across the continent at 2⁰ resolution (a); the predicted effect size (b); and the relative importance (c) of functional dispersion for tree growth; and the predicted growth ($m^2 ha^{-1} yr^{-1}$) by functional dispersion in the three biomes (d). When calculating the predicted growth, predictor variables were kept at their mean values for each biome (blue: boreal; green: temperate; red: Mediterranean).
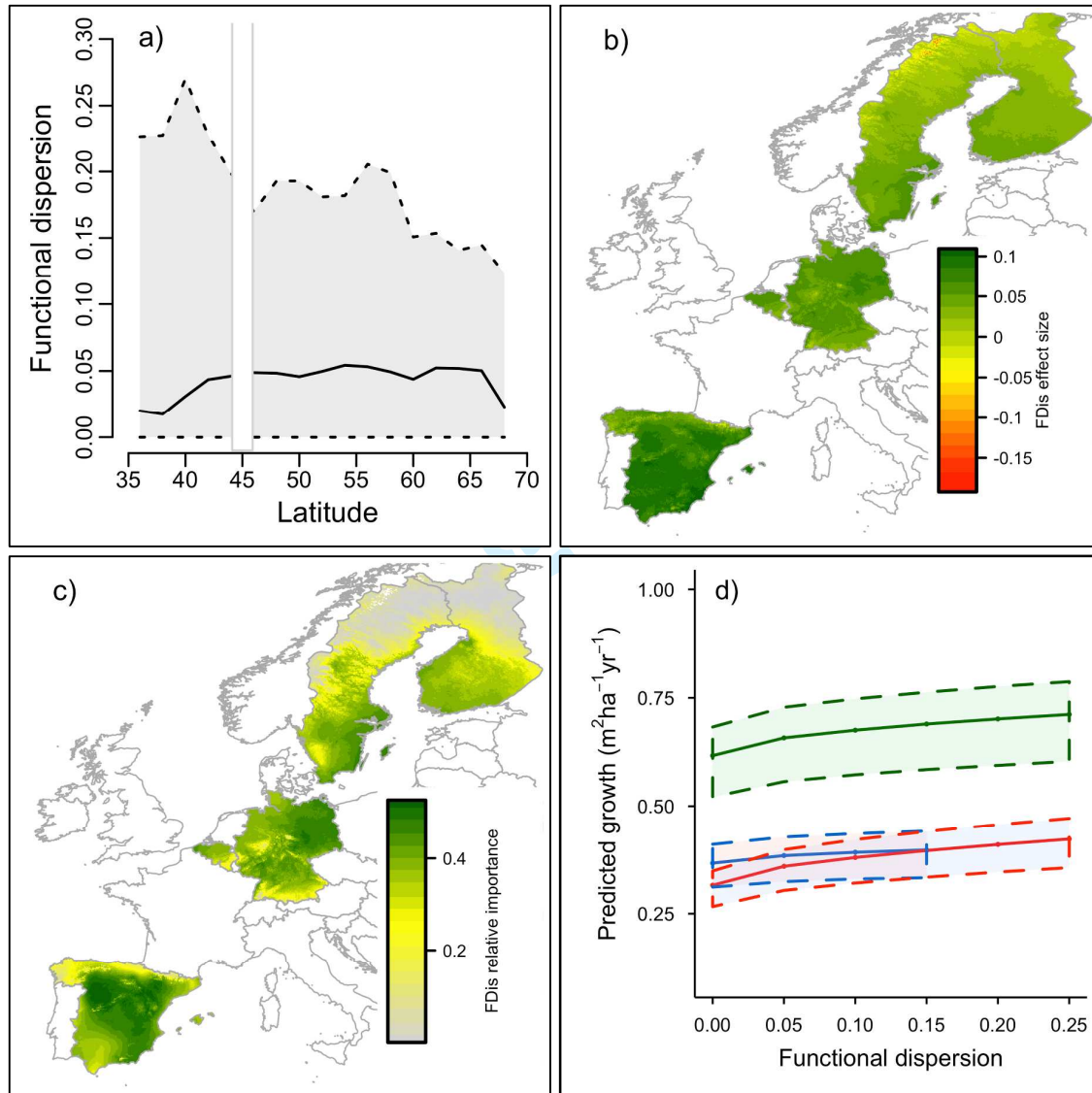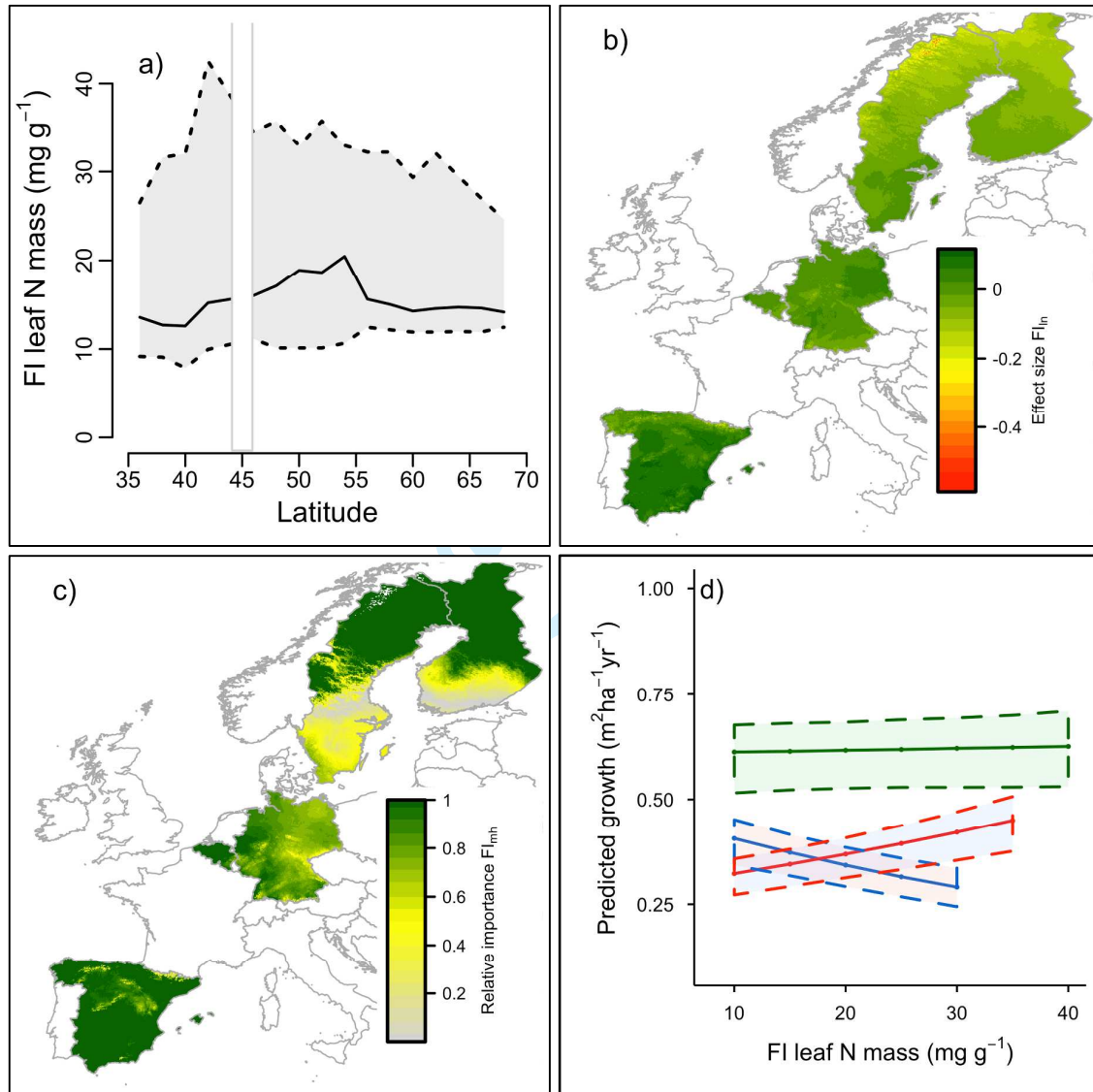
Figure S4.2. Mean and range of community weighted mean of maximum height (FI_{mh}) across the continent at 2° resolution (a); the predicted effect size (b); and the predicted relative importance (c) of FI_{mh} for tree growth; and the predicted growth ($m^2 ha^{-1} yr^{-1}$) by FI_{mh} in the three biomes (d). When calculating the predicted growth all predictor variables were kept at their mean value for each biome (blue: boreal; green: temperate; red: Mediterranean).
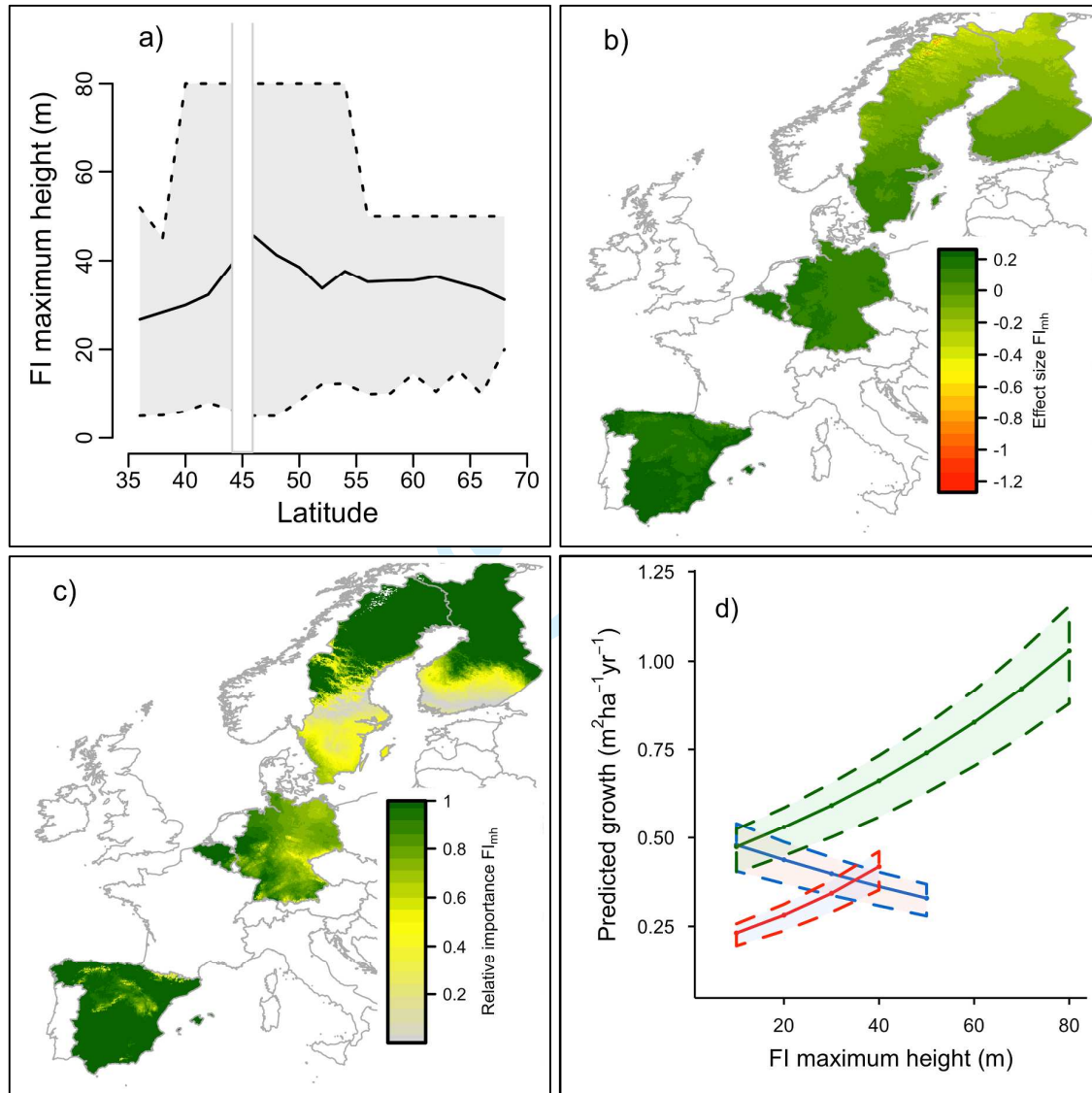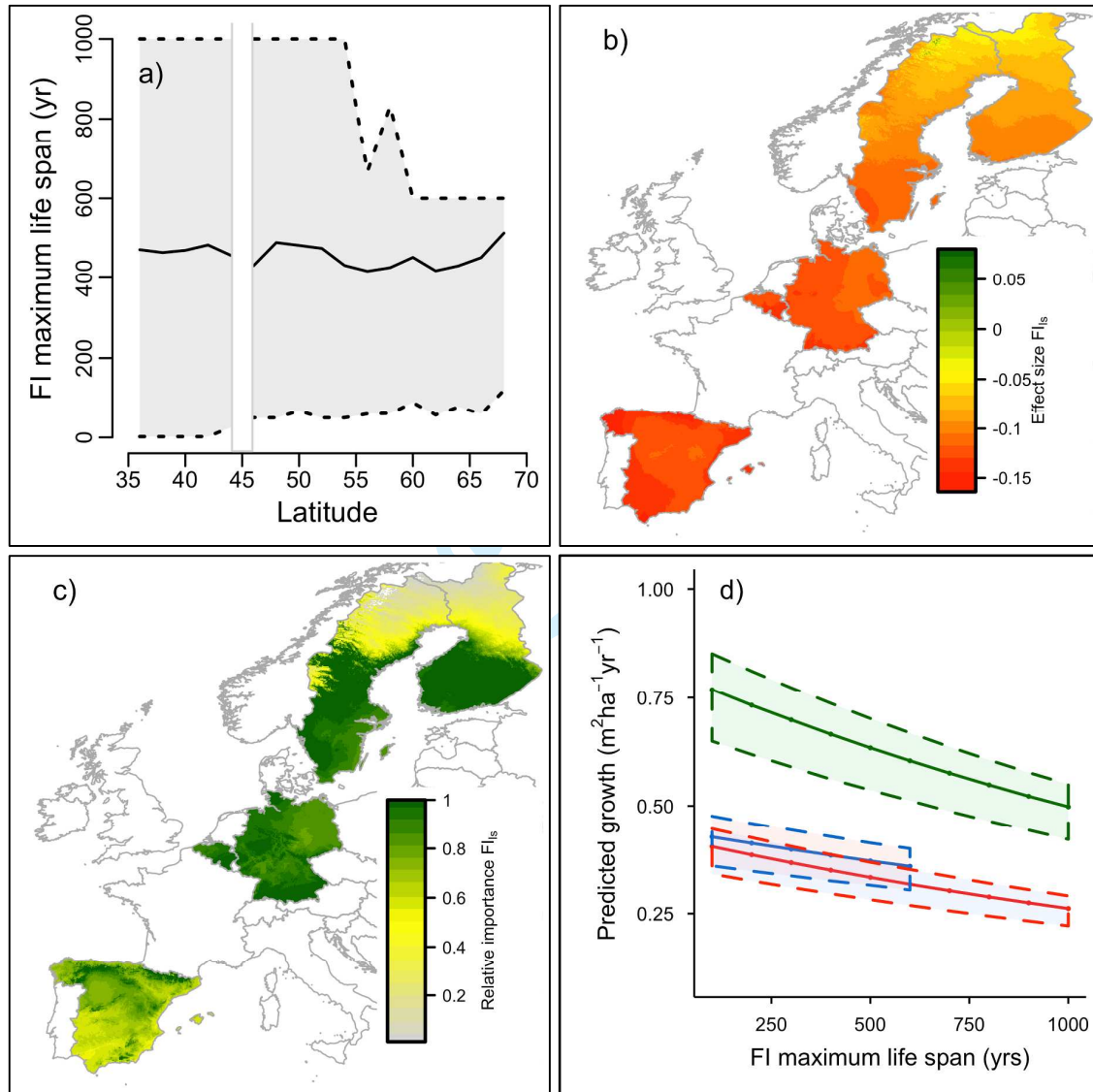
Figure S4.3. Mean and range of community weighted mean leaf N (FI$_{ln}$) across the continent at 2° resolution (a); the predicted effect size (b); and the predicted relative importance (c) of FI$_{ln}$ for tree growth; and the predicted growth (m^2 ha^{-1} yr^{-1}) by FI$_{ln}$ in the three biomes (d). When calculating the predicted growth all predictor variables were kept at their mean value for each biome (blue: boreal; green: temperate; red: Mediterranean).

Figure S4.4. Mean and range of community weighted mean maximum life span (FI$_{ls}$) across the continent at 2$^\mathbf{o}$ resolution (a) and the predicted relative importance (b) of FI$_{ls}$ for tree growth; and the predicted growth (m^2 ha^{-1} yr^{-1}) by FI$_{ls}$ in the three biomes (c). When calculating the predicted growth all predictor variables were kept at their mean values for each biome (blue: boreal; green: temperate; red: Mediterranean).

Figure S4.5. Mean and range of community weighted mean wood density (FI$_{wd}$) across the continent at 2° resolution (a); the predicted effect size (b); and the relative importance (c) of FI$_{wd}$ for tree growth; and the predicted growth (m^2 ha^{-1} yr^{-1}) by FI$_{wd}$ in the three biomes (d). When calculating the predicted growth all predictor variables were kept at their mean value for each biome (blue: boreal; green: temperate; red: Mediterranean).
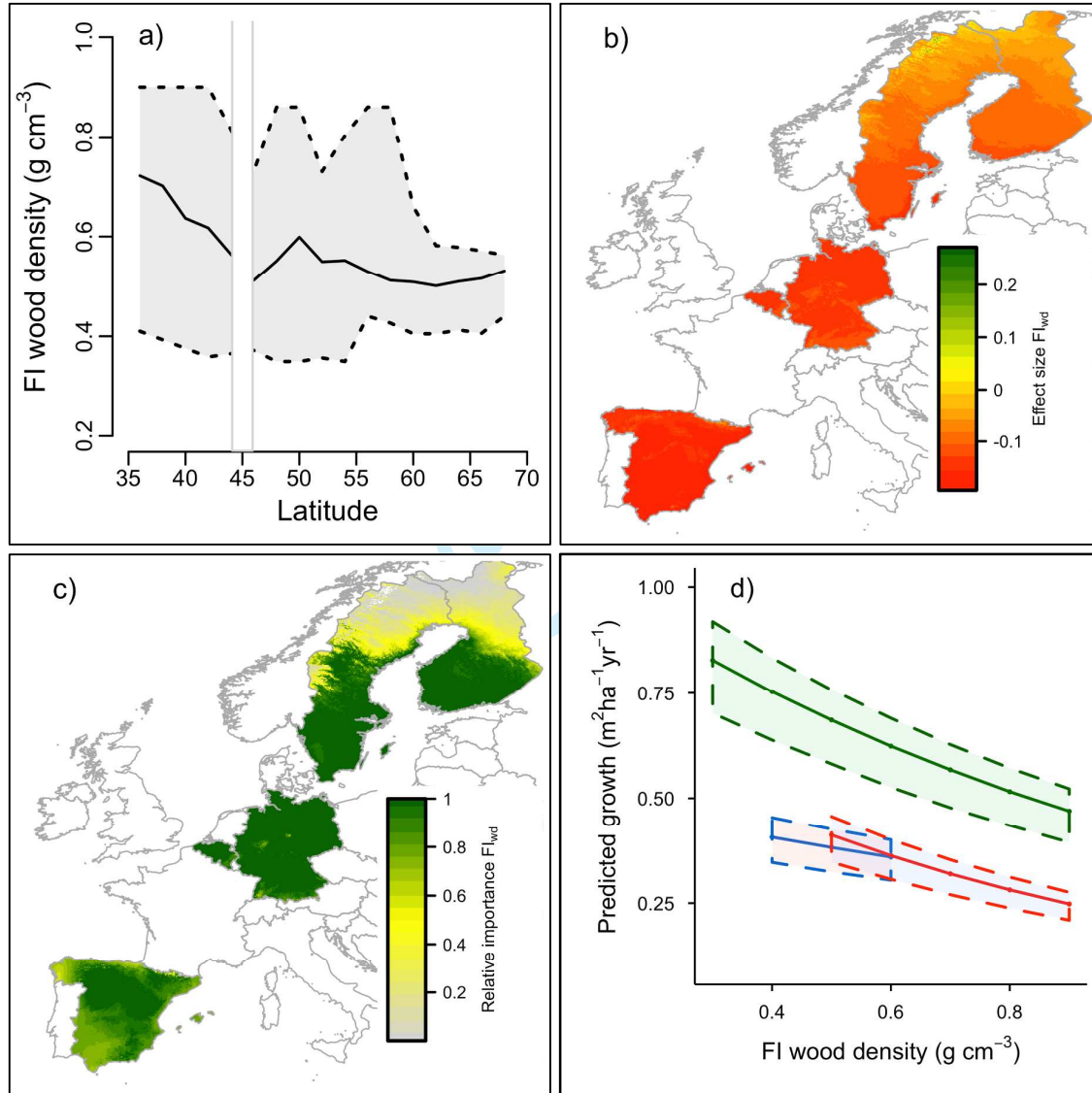
Figure S4.6. The absolute influence of each predictor on plot-level tree growth (m^2 ha^{-1} yr^{-1}) across the continent. The predictors are: annual mean temperature; mean annual precipitation; functional dispersion; community-weighted mean (CWM) maximum height; CWM leaf N content; CWM maximum life span; and CWM wood density. The covariates (plot basal area (m^2 ha^{-1}), mean tree size (mm), species pool and natural mortality rate (m^2 ha^{-1} yr^{-1}) have been group together in grey and labeled covariates. The white panel indicates missing values. The data is aggregated at 1° latitude.
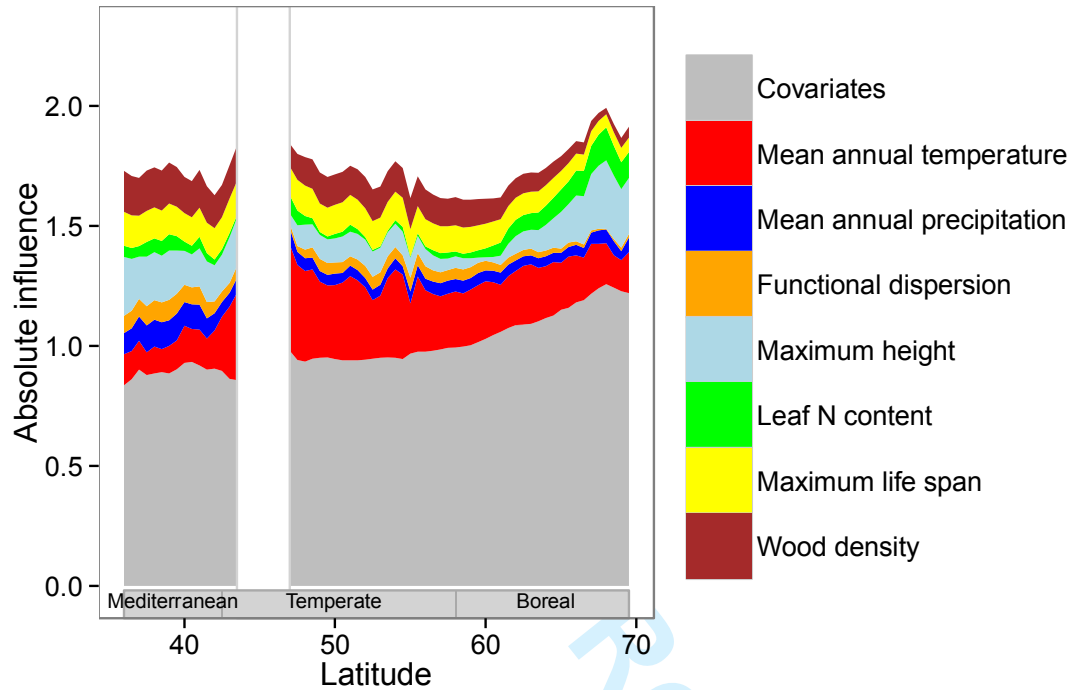
Figure S4.7. Predicted mean relative importance (solid lines) and 95% confidence intervals (dotted lines) of mean annual precipitation, mean annual temperature, functional identity (aggregated effect of the community mean value of the four functional traits selected) and functional dispersion for tree growth. The sensitivity of plot growth to changes in each variable was estimated from the hierarchical linear model; the variable with the greatest influence in the plot has a relative importance of 1 and the other variables are scaled accordingly. Values are aggregated at 0.5^0 latitude thus the average relative importance of each predictor is shown. The white section depicts missing data.
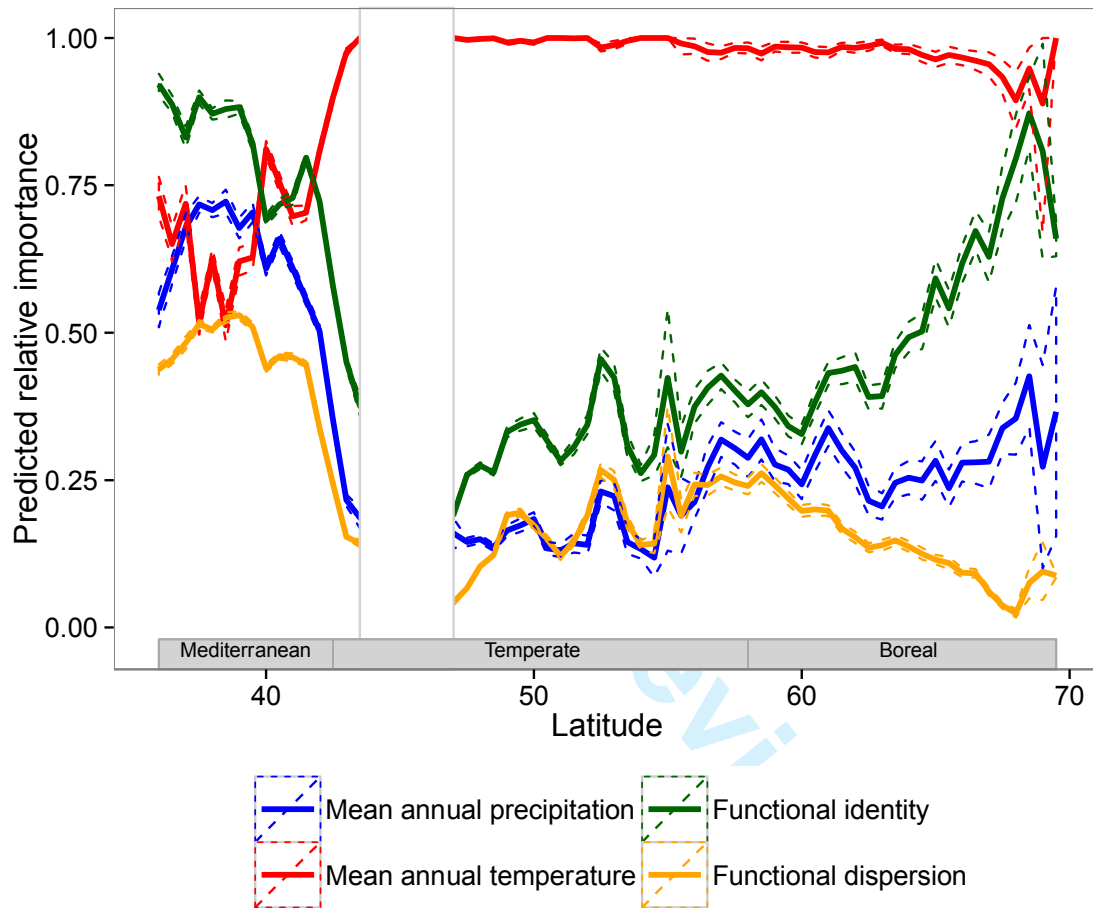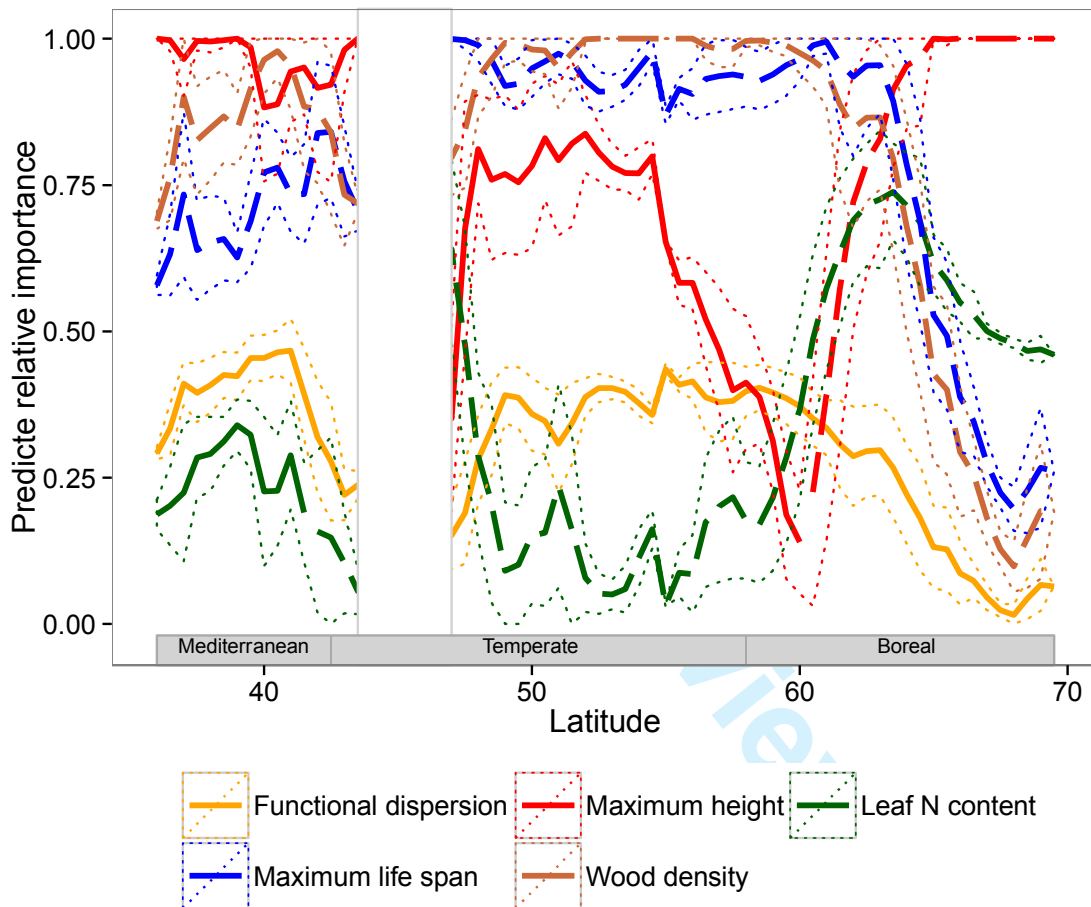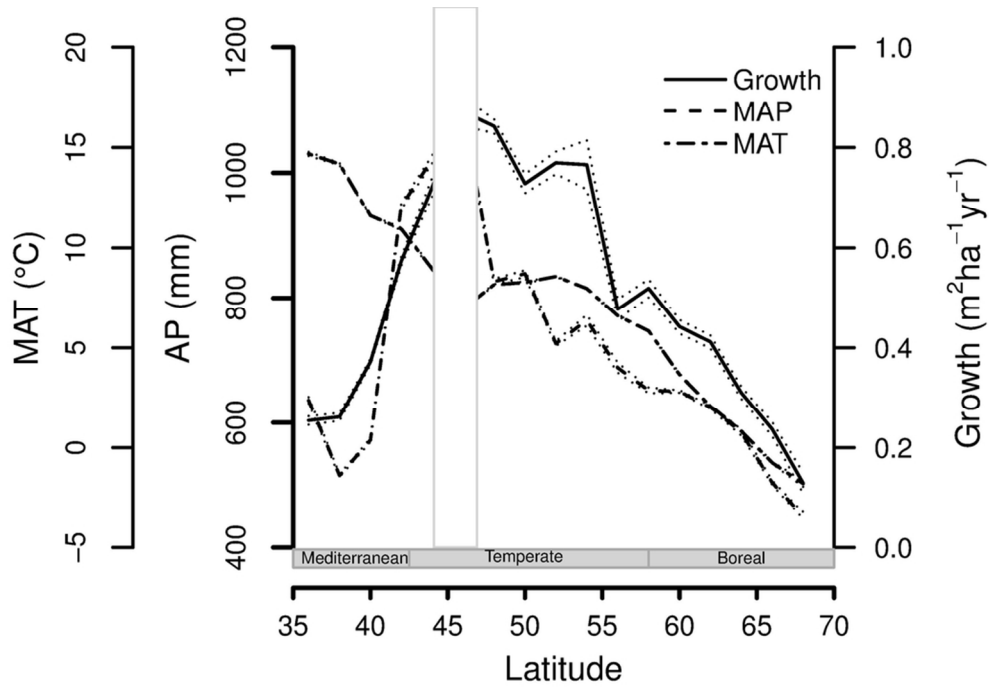
Appendix S4

Figure S4.8. Mean predicted relative importance (solid and dashed lines) and 95% confidence intervals (dotted lines) of five components of functional biodiversity (functional dispersion and the community weighted mean of four functional traits) for tree growth. The sensitivity of plot growth to changes in each variable was estimated from a hierarchical linear model; the biodiversity measure with the greatest influence in the plot has a relative importance of 1 and the other measures are scaled accordingly. Values are aggregated at 0.5^0 latitude thus the average relative importance of each predictor is shown. Solid lines indicate a positive influence of the biodiversity measure on plot growth, whilst dashed lines indicate a negative influence. The white section depicts missing data.
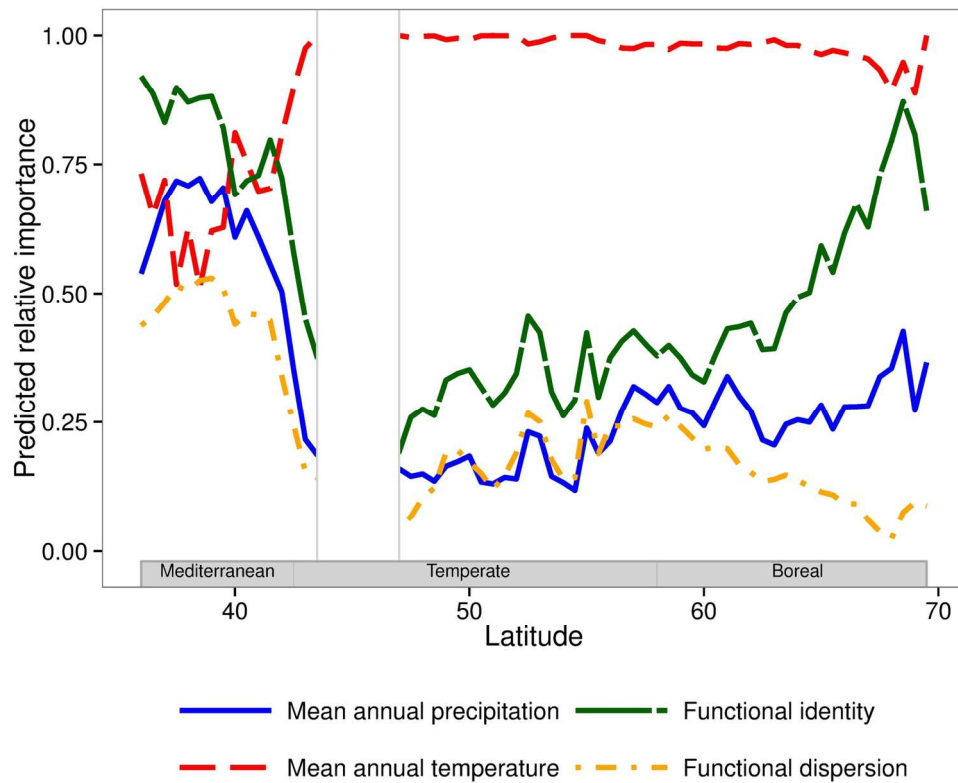
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Climate gradients of mean annual temperature (MAT, ^{0}C) and mean annual precipitation (MAP, mm) across the latitudinal gradient covered by the National Forest Inventory plots. Mean plot basal area growth (Growth, m2 ha-1 yr-1). Dotted lines indicate 95% confidence intervals. The white section depicts missing data. Values were calculated at a 2° latitude spatial resolution.
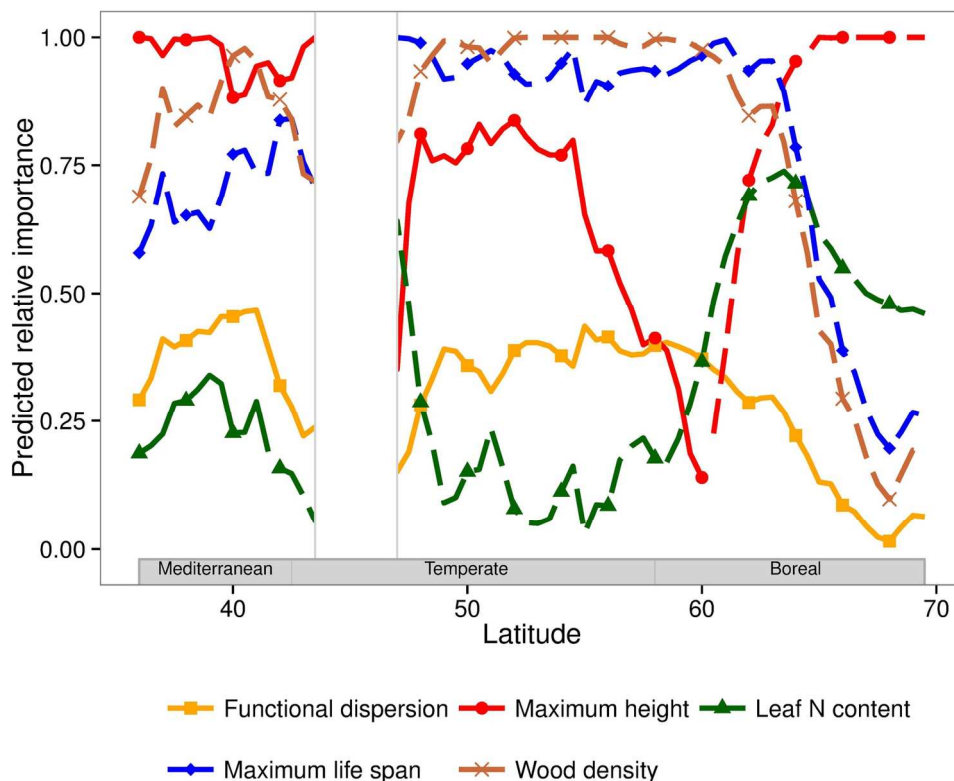88x62mm (300 x 300 DPI)

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Predicted relative importance of mean annual precipitation, mean annual temperature, functional identity (aggregated effect of the community mean value of the four functional traits selected) and functional dispersion for tree growth. The sensitivity of plot growth to changes in each variable was estimated from the hierarchical linear model; the variable with the greatest influence in the plot has a relative importance of 1 and the other variables are scaled accordingly. Values are aggregated at 0.5^0 latitude thus the average relative importance of each predictor is shown. White section depicts missing data. A version with confidence bands is given in Appendix 4, Fig. S4.7.
152x130mm (300 x 300 DPI)

Predicted relative importance of five components of functional biodiversity (functional dispersion and the community weighted mean of four functional traits) for tree growth. The sensitivity of plot growth to changes in each component was estimated from the hierarchical linear model; the biodiversity component with the greatest influence in the plot has a relative importance of 1 and the other measures are scaled accordingly. Values are aggregated at 0.5^0 latitude thus the average relative importance of each predictor is shown. Solid lines indicate a positive influence of the biodiversity measure on plot growth, whilst dashed lines indicate a negative influence. White section depicts missing data. A version with confidence bands is given in Appendix 4, Fig. S4.8.

152x130mm (300 x 300 DPI)
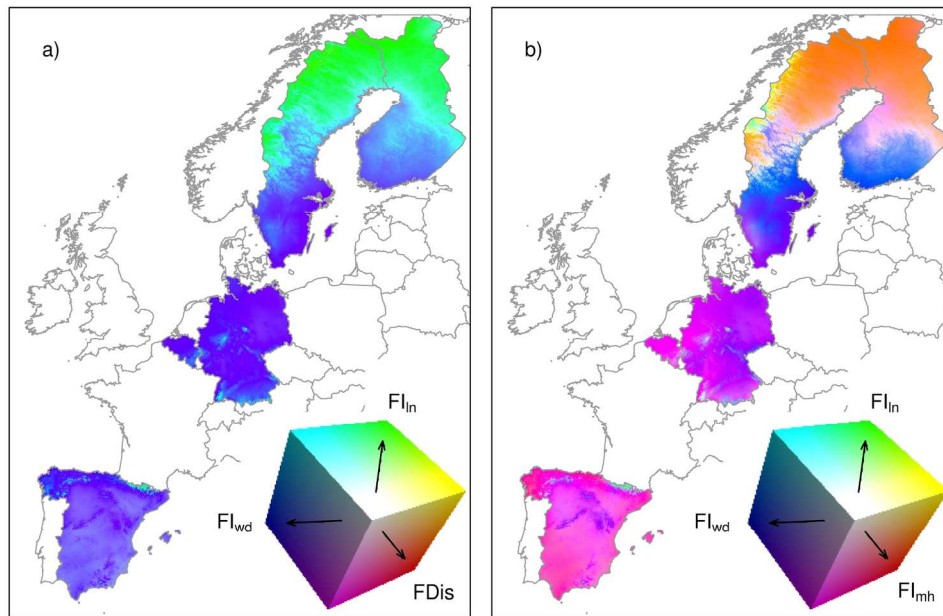
Predicted relative importance of a) FDis (functional diversity; red), FIln (community-weighted mean (CWM) leaf N mass (mg-1 g); green) and FIwd (CWM wood density (g cm-3); blue); b) FImh (CWM maximum height (m); red), FIln (CWM leaf N mass (mg g-1); green) and FIwd (CWM wood density (g cm-3); blue), for tree growth. The sensitivity of plot growth to changes in each biodiversity component was estimated from a hierarchical linear model using spatial maps of mean annual temperature and mean annual precipitation at spatial resolution of 1 km2; the biodiversity measure with the largest effect size in the grid has a relative importance of 1 and the other two measures are scaled accordingly. The RGB cube illustrates how the colour gradient reflects the changes in relative importance of the biodiversity component, such that areas of white indicate an equal importance of all three measures. The arrows indicate an increasing relative importance.
177x113mm (300 x 300 DPI)