

1 **Assessing site quality using the National Forest Inventory**

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35 **Abstract**

36 Site productivity of forests is often evaluated thorough the site quality. Different indices
37 can be used to measure site quality but the site index (relationship between dominant
38 height and age) is the most employed. However, site index can only be applied in even-
39 aged forests whereas the site form (height-diameter relationship) has been proved to be a
40 good measure of site quality in uneven-aged stands and multispecies forests. In this work,
41 we aim to develop national-scale site quality maps for five dominant species of Spanish
42 forests (*Fagus sylvatica*, *Pinus pinaster atlantica*, *Quercus pyrenaica*, *Pinus nigra*, *Pinus*
43 *sylvestris*) with landscape planning purposes. First, we develop site form non-linear
44 models using the Spanish National Forest Inventory. Then, we fit spatial additive models
45 entering topographic and climatic variables in order to predict the site quality over the
46 whole country. The accuracy of the models ranged from 38.2% to 47.9%. On the other
47 hand, our results fall well with the autoecology of the species studied. Thus, we confirm
48 the suitability of this approach to estimate the site quality in forest with different
49 structures, such as even or uneven stands. Finally, we suggest that this method can be
50 used in other countries to expand the current maps to the whole Europe.

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52 **Keywords:** European Forest Types, forest harmonization, sustainable forest management,
53 international forest policy

54

55 **Abbreviations:** AIC, Akaike's Information Criterion; B-R, Bertalanffy-Richards model;
56 EFT, European Forest Types; dbh, diameter at breast height; h, tree height; H-II, Hossfeld
57 II model; NFI, National Forest Inventory; SFI, Site Form Index.

58

59 **Highlights**

60 Site quality maps for five Spanish species based on the National Forest Inventory

61 Site form index as proxy of site productivity

62 Useful approach to provide international comparable forest data

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67 **1. Introduction**

68 The international forest policy community asks for more and deeper understanding
69 and knowledge of forest resources (FAO, 2015; Forest-Europe, 2015; Schuck et al.,
70 2004). One of the most interesting characteristics that define a forest is its productivity,
71 especially in the context of the European Bioeconomy Strategy (EC, 2012) that looks for
72 the efficient and sustainable use of renewable biological resources to produce goods and
73 services. International institutions and processes recommend supplying the information
74 on forest resources using international rather than national criteria such as harmonized as
75 would be possible (FAO, 2015; Gabler et al., 2012). Nevertheless, transforming national
76 criteria into international criteria requires great efforts for the different sources of data
77 available and methodologies applied. Some cases of harmonization of forest criteria can
78 be found in the literature such as the harmonization of estimations and methodology in
79 the European National Forest Inventories (NFIs) (Gabler et al., 2012; Vidal et al., 2016)
80 or the classifications of forest into homogeneous ecological units. NFIs are the broadest
81 source of knowledge about the status of the forest at national level in many countries
82 (Barbati et al., 2014). However, some methods of the NFI are non-standardized and
83 differences in the design, definitions or data gathered can be easily found among countries
84 (Tomppo et al., 2010). Despite of this, similarities can be found in the NFIs of different
85 countries. Hence, as mentioned above some European countries have made efforts to
86 harmonize inventory definitions in order to provide internationally comparable data
87 (Vidal et al., 2016). In general, NFIs include several variables used in forest management
88 such as estimation of wood production (Charru et al., 2010) and carbon storage (Woodall
89 et al., 2008), monitoring species distribution (Hernández et al., 2014; Moreno-Fernández
90 et al., 2016) or assessment of biodiversity (Andersson and Östlund, 2004) or abiotic
91 damages (Jalkanen and Mattila, 2000). Additionally, the NFIs have been used as dataset
92 in scientific studies to model recruitment (Lexerød, 2005), tree biomass (Ruiz-Peinado et
93 al., 2011), site quality (Adame et al., 2006) or deadwood volume (Crecente-Campo et al.,
94 2016).

95 The classification of forest into homogeneous ecological units aims to assess the state
96 of the forest biodiversity and monitor sustainable forest management practices at
97 international scales (Larsson, 2001). In this context, Barbati et al. (2007) and Barbati et
98 al. (2014) proposed a classification to categorize the forest of the Pan-European region
99 into 14 European Forest Types (EFTs) categories (category level) and the categories into
100 78 EFTs (type level) according to ecological sound units. The EFTs classification is

101 aimed as a tool to facilitate the analysis of forest features aggregating and averaging data
102 from NFIs into ecologically homogeneous strata of European relevance, i.e. the 14 EFTs
103 categories (deeper description of the EFTs can be found in Barbati et al., 2014).

104 The site quality has been used in forestry since long ago as proxy of site productivity.
105 This variable is not only of interest for predicting growth and yield of forest stands
106 (Álvarez-González et al., 2005; Clutter et al., 1983; Diéguez-Aranda et al., 2005) but also
107 for studies on ecological diversity (Franklin et al., 1989), forest structure (Larson et al.,
108 2008) and forest disturbances (Wei et al., 2003) among others. The site quality has
109 traditionally been expressed as the relationship between dominant height and age (site
110 index) for even aged forests. However, this definition is difficult to apply in forests with
111 an uneven distribution of ages or in mixed-species forests, where the height-diameter
112 relationship (site form) has been proved to be a good measure of site productivity (Huang
113 and Titus, 1993; Stout and Shumway, 1982; Vanclay, 1994). Site form can be also useful
114 to determinate the site quality of even-aged stands which the age is unknown, as in the
115 case of the NFIs of some countries (Tomppo et al., 2010).

116 In this work, we aim to assess and map site quality of Spanish five species included
117 in the EFTs using site form as reference index and the NFI as dataset. In a first step, we
118 develop site form models for the five species. In the second step, we model the site form
119 using spatial additive models entering environmental variables as predictors. Finally, we
120 use these spatial additive models to create site quality maps. Our results can be a tool for
121 forest managers in land use planning and for decision-makers in forest policy.
122 Additionally, this methodology is in line with the current demands of reporting forest
123 information according to international criteria and could be an interesting approach to
124 standardize the method used to estimate site quality to provide internationally comparable
125 data.

127 **2. Material and methods**

128 ***2.1. Species studied and National Forest Inventory dataset***

129 We used EFT classification to select the target species. We selected five widely
130 spread species in Spain which form genuine and monospecific forest according to the
131 EFT classification (Barbati et al., 2014, 2007): *Pinus pinaster* Ait. ssp *atlantica* (*P.*
132 *pinaster*, hereafter), *Fagus sylvatica* L., *Quercus pyrenaica* Willd., *Pinus nigra* Arn. and
133 *Pinus sylvestris* L. (Table 1). Hereafter, we name the EFT as the dominant species of each

134 EFT. All of the species mainly grow in montane areas, except *P. pinaster* which is quite
135 common at the sea level (e.g. Ruiz de la Torre, 2006).

136 The Third Spanish NFI, conducted between 1997 and 2007, was used to model and
137 predict the site quality in Spanish forests. The NFI plots were only installed in woodland
138 areas according to FAO definition (FAO, 2001) (i.e. none in non-forested areas) with an
139 intensity of one sampling point every 1 km² (1 x 1 km grid). At each sampling point,
140 diameter and height of the trees are measured in four concentric circular plots with
141 increasing radii from 5 to 25 m. In the 5 m radius plot, trees with a diameter at breast
142 height (dbh) ≥ 7.5 cm are measured. In the 10 m radius plot, trees with dbh ≥ 12.5 cm are
143 measured. In the 15 m radius plot, trees with dbh ≥ 22.5 cm are measured. Finally, in the
144 25 m radius plot, trees with dbh ≥ 42.5 cm are measured (Alberdi Asensio et al., 2010;
145 Hernández et al., 2014).

146

147 **2.2. Site form models**

148 Site quality models were developed for each EFT by using the NFI plots with dominance
149 in basal area of the main species greater than 90% (Table 1). Site quality was estimated
150 by using stand level height-diameter relationships (Huang and Titus, 1993; Stout and
151 Shumway, 1982) which has been referred by Vanclay (1994) as site form when using
152 dominant diameter (D_0 , cm) and dominant height (H_0 , m). D_0 and H_0 were computed for
153 each NFI plot as the arithmetic mean of the dbh (cm) and tree height (h, m) respectively
154 in the 100 thickest trees per hectare. Due to we have only one measurement of these
155 variables for each sample plot, the site form models were developed in two steps by using
156 the guide-curve method (Clutter et al., 1983). In the first step a model was fitted to the
157 pairs of D_0 and H_0 , obtaining in this way the average H_0/D_0 relationship for each EFT. In
158 the second step, the family of site form curves were generated by making dependent any
159 of the model parameters on the site form, which is the value of H_0 at a given reference
160 value of D_0 . Thus, each base model generates as many site form family curves as
161 parameters has in the base model formulation. Two well-known base models in the
162 development of site quality models were considered in the fitting process: the Hossfeld II
163 model (H-II, Eq. (1)) and the Bertalanffy-Richards model (B-R, Eq. (2)), and all possible
164 resulting site form family curves were generated for each EFT. The base models were
165 adapted in order to get predictions of $H_0 = 1.3$ for $D_0 = 0$. The final model for each EFT
166 were selected based on the performance of the site form curves over the data by
167 considering as criteria the polymorphism of the resulting curves as well as the presence

168 of multiple asymptotes. The reference D_0 were selected to improve the accuracy of
 169 predictions reducing the prediction bias associated to stands with D_0 further from
 170 reference D_0 (Weiskittel et al., 2011); moreover, the range of the diameters observed in
 171 the different EFTs and the error of the model in different regions of the validity range of
 172 the model were also taken into account.

$$173 \quad H_0 = 1.3 + \frac{D_0^2}{(a + b \cdot D_0)^2} \quad (1)$$

174

$$175 \quad H_0 = 1.3 + a \cdot (1 - \exp(-b \cdot D_0))^c \quad (2)$$

176 where H_0 is the dominant height (m), D_0 is the dominant diameter (cm) and a , b and c are
 177 model parameters to be estimated.

178 After selecting the best models for each EFT, we estimated the site form value in
 179 the NFI plots. Then, the site form predictions for each EFT were divided into four site
 180 quality classes (*actual site quality*) using the minimum, the first quartile, the median, the
 181 third quartile and the maximum of the site form dataset as breakpoints. Class A represents
 182 the highest site quality class, class B and C are the high- and low-intermediate site quality
 183 classes respectively and, finally, class D the lowest site quality class.

184

185 **2.3. Spatial analysis**

186 In ecology and other fields as forestry, non-linear relationships between variables are
 187 common and, therefore, linear modelling often performs poorly (Faraway, 2006). So,
 188 approaches, such as additive models (Hastie and Tibshirani, 1989; Wood, 2006), which
 189 describe complex relationships between the response and the predictors are especially
 190 useful. Then, we fitted following spatial additive models to predict form index for each
 191 of the five EFT in Spain:

$$192 \quad SFI_i = \alpha + f(X_i, Y_i) + \sum_{j=1}^J f(x_{ij}) + \varepsilon_i \quad (3)$$

193 where SFI is the site form index, α represents the intercept of the model, $f(X_i, Y_i)$ is a
 194 spatial smooth function to account the spatial pattern of the SFI and eliminate the spatial
 195 correlation. X_i and Y_i are the coordinates in meters (UTM, datum ED50 zone 30N) of the
 196 i -th plot. $f(x_{ij})$ are smooth function (from $j=1$ to J) of physiographic (altitude in m, slope
 197 in degrees, and aspect in degrees) and climatic variables to be included in the model.
 198 Physiographic variables were extracted from a digital elevation model. We obtained the

199 climatic data from the 200 x 200 m Spanish climatic grid of Gonzalo (2010). This grid
200 provides both rainfall (total, summer, winter, spring and autumn rainfall) and temperature
201 variables. However, temperature variables were highly correlated to altitude and were not
202 considered in the analysis. The selection of the variables was carried out according to the
203 Akaike's Information Criterion (AIC) using a forward stepwise procedure setting a
204 reduction of five points of AIC as significant threshold. All the variables were entered as
205 smooth functions. Finally, ε_i is the error term of the model.

206 We represented the smooth functions using thin plate regression splines (Wood,
207 2003). These splines keep the basis and the penalty of the full thin plate splines (Duchon,
208 1977) but the basis is truncated to obtain low rank smoothers. This reduces the
209 computational requirements of the smoothing splines and avoids the problems of the knot
210 placement of the regression splines (Wood, 2003). We plotted semivariograms of the
211 residuals of each model to check if the spatial correlation had been eliminated.
212 Additionally, we created semivariogram envelopes after 99 permutations under the
213 assumption of no spatial correlation (Augustin et al., 2009).

214 Once models were fitted, we classified the form index predicted by the spatial
215 additive model into the four site quality classes (*predicted site quality*). Then, we
216 calculated the accuracy percentage as the ratio of the plots correctly classified and the
217 total number of plots.

218

219 **2.4. Site quality maps**

220 We used the spatial additive models fitted in the previous section (section 2.3.) to predict
221 the form index and the site quality in all the plots of the NFI where trees of the target
222 species were present (second column in Table 1).

223 We used following R packages (R Core Team, 2017) to carry out the statistical
224 analysis: "nl", "mgcv" (Wood, 2011) and "geoR". The maps were performed in ArcGis
225 10.2.2. (ESRI, 2014).

226

227 **3. Results**

228 The parameter estimation for the final site form models and the site-specific parameters
229 for each EFT are shown in Table 2. H-II was the model selected for all the EFTs except
230 for *P. nigra*. For this EFT, B-R was the selected choice. The site form family curves
231 represent reasonably well the data for the countrywide conditions covered in the NFI data
232 for each EFT (Fig 1).

233 The percentage of deviance explained by the spatial additive models (section 2.3)
234 ranged from 32.5 to 48.6 % (Table 3). The structure of the spatial additive models vary
235 according to EFT after the forward stepwise variables selection procedure (Table 3 and
236 4). The spatial smooth function ($f(X_i, Y_i)$) and the smooth function of altitude ($f(\text{altitude})$)
237 are included in all the models. In addition to contribute to the model performance, the
238 spatial term eliminates the spatial correlation of the residuals (see Appendix A).

239 The relationship between the altitude and the site form index varied in the five EFT.
240 In the case of *P. pinaster*, a species well represented from sea level till slightly above
241 1000 m of elevation, $f(\text{altitude})$ take maximum values at lower altitudes and decreased
242 progressively at higher altitudes (Fig. 2), with the largest values of the site form index
243 expected to appear at lower altitudes. In the case of more montane species (*P. sylvestris*,
244 *P. nigra* and *F. sylvatica*), the 95 % confidence intervals of the mean widen at the lower
245 elevations, and so the site form shows no significant differences for elevations lower than
246 700-800 m. For these three species, $f(\text{altitude})$ decreases from that limit with elevation,
247 but the confidence interval opens again for high elevations, with the threshold around
248 1500 m for beech and 1800 m for *P. nigra* and *P. sylvestris*. In the case of *Q. pyrenaica*,
249 a species well represented in the range of 400 to 1600 m, the pattern is different, and
250 $f(\text{altitude})$ shows a maximum plateau for elevations between 500 and 800 m, also with
251 opening of the confidence intervals for low and high elevations.

252 Additionally, we found a significant relationship between $f(\text{aspect})$ and site form
253 index in all the species, except in *P. pinaster*. Fig. 2 indicates that highest values of site
254 form index are expected to be found in northern exposures (*aspect* ranging from 300° to
255 360° and from 0 to 60 °) in *F. sylvatica*, *Q. pyrenaica*, *P. nigra* and *P. sylvestris* EFT.
256 Even so, the difference between the maximum and minimum values of $f(\text{aspect})$ is greater
257 in the cases of beech and *P. nigra*, whereas the influence of the aspect is slighter for *P.*
258 *sylvestris* and *Q. pyrenaica*. The variables selection procedure reveals a weak association
259 between site form index and slope in *F. sylvatica* (p-value=0.0400). With this regards,
260 $f(\text{slope})$ shows a bell-shaped pattern peaking at 22°. Finally, none of the climatic variables
261 reduce significantly the AIC (no more than five points).

262 The largest reductions of AIC in the five EFTs spatial models appear after entering
263 the spatial smooth. This means that the spatial structure accounts for larger percentage of
264 variance (Table 4). Then, the second most important variable in AIC reduction is
265 $f(\text{altitude})$. Finally, $f(\text{aspect})$ in *F. sylvatica*, *Q. pyrenaica*, *P. nigra* and *P. sylvestris*
266 models and $f(\text{slope})$ in *F. sylvatica* played a minor role. Hence, the estimated centered

267 smooth functions of *aspect* and *slope* are quite around zero and the range of variation of
268 these estimated centered smooth function are narrower than that of *altitude* leading to
269 stronger relationships between $f(\textit{altitude})$ and site quality (Fig. 2).

270 The accuracy of the site quality ranges from 38.2 % in *Q. pyrenaica* to 47.9 % in *P.*
271 *nigra* (Table 5). The predictions of the site form by the spatial additive models (section
272 2.3.) are mainly classified into intermediate quality site classes (B and C) whereas the
273 number of plots are classified into the highest and lowest quality classes (A and D,
274 respectively) was lower. These points to the difficulty of predicting the cases of
275 productivity levels well above or below the average.

276 The observed site quality classes are shown in Fig. 3. The predicted quality site maps
277 suggest that most of the stands of the five EFTs studied are located in intermediate site
278 quality areas (Fig 4 and Table 5). The distribution of the quality classes predicted shows
279 more clearly gradients that depend mainly on elevations and the aspect. Overall, the
280 correspondence between the predicted and observed maps of site qualities is clear (Fig. 3
281 and Fig. 4), even if the model fails to predict classes A and B that are in fact observed for
282 areas where other classes are more frequent.

283

284 **4. Discussion**

285 We estimated the site quality in the five most important EFTs of Spain expressed as
286 the dominant height and dominant diameter relationship and then, we created site quality
287 maps using spatial additive models. Other authors found larger accuracy percentage of
288 site index in Mediterranean species: from 64 % to 71% in *P. sylvestris* (Bravo and
289 Montero, 2001; Bueis et al., 2016) and from 61 to 75 % in *Pinus pinea* L. (Bravo-Oviedo
290 and Montero, 2005; Bravo et al., 2011). However, these studies were performed at finer
291 scales, local or regional, whereas we aimed to estimate the site quality at country scale.
292 With this regards, Chen et al. (2002) reported that the relationships between
293 environmental variables and site index are stronger at finer scales. All of this seems to
294 indicate our models estimate reasonably well the site quality of the EFTs studied over
295 Spain. Thus, we confirm the suitability of the site form as a proxy of site quality both in
296 even or uneven stands.

297 Our results are in concordance with the autoecology of the species confirming the
298 suitability of our approach from a biological point of view. The negative association
299 between the site form and altitude for *P. pinaster* had been already shown before (Eimil-
300 Fraga et al., 2014). This species is spread in areas of Atlantic climate with its central

301 habitat in terms of elevation ranging from 0 to 1000 m, well differentiated from the other
302 two pine species studied (Gandullo and Sánchez-Palomares, 1994). In distribution
303 models, altitude or other related variables such as temperature usually show a positive or
304 inverse U-shaped relationship with the occurrence of montane species (Hernández et al.,
305 2014; Moreno-Fernández et al., 2016), and that is the case observed for site productivity
306 of *Q. pyrenaica*. This species is known to grow in a range of elevations between 400 and
307 1400 m, with its optimum in northern areas at lower elevations than in the southern ones
308 (Díaz-Maroto et al., 2007; Sánchez-Palomares et al., 2008). An inverse U-shaped
309 relationship could have been expected to occur for the other three species, which have
310 also their central habitat for ranges of elevation classifiable as montane (Gandullo and
311 Sánchez-Palomares, 1994). The occurrence of *F. sylvatica* at low elevations in Spain is
312 mainly restricted to humid sites in the slope of northern Mountain ranges, where the
313 species is not restricted by droughts and shows good productivity rates for an elevation
314 range of 400-800 m (Sánchez-Palomares et al., 2004). Some stands of poor productivity
315 at elevation ranges below the central habitat of these species and placed in dryer areas
316 have in fact a mixed composition and thus have not been considered, because we only
317 used plots in which the main species of the EFT was dominant. Therefore, in these plots
318 the species grow in good enough conditions to form monospecific stands or have been
319 favored by forest management. Some factor associated to high elevation systems, such as
320 shorter grow periods (Beniston, 2003), may explain the general negative association.

321 The results obtained as regards the influence of aspect in the site form provide new
322 insights into the dependence of stand productivity from site parameters, with are
323 additional to the studies of species distribution or regeneration niches (Gómez-Aparicio
324 et al., 2006; Hernández et al., 2014). A clear effect of aspect in stand productivity was
325 found particularly for *F. sylvatica*, a shade tolerant species that grows better in northern
326 exposures with more humid conditions (Ruíz de la Torre, 2006). Hernández et al. (2014)
327 reported an increase of the presence of *F. sylvatica* in northern exposures in northern
328 Spain during the last 40 years. Such a clear positive effect of northern exposures on site
329 form was also observed for *P. nigra*, a species that has been considered as intermediately
330 shade tolerant, at least for the *salzmannii* subspecies (Ruiz de la Torre, 2006), but whose
331 regeneration has been shown to be more tolerant to high irradiances than several
332 broadleaved species (Gómez-Aparicio et al., 2006). The role of aspect on site quality
333 was found to be smaller for *Q. pyrenaica* and *P. sylvestris*, even if northern exposures
334 kept having significantly greater site forms. Cañellas et al. (2000) already showed that

335 the influence of aspect in *P. sylvestris* site index is expected to be more important for
336 stands in Mediterranean conditions. *P. pinaster* is a light-demanding species (Ruiz de la
337 Torre, 2006) and subspecies *atlantica* requires humid conditions for a good development
338 and mainly grows at relatively low altitudes close to the coast (Álvarez-González et al.,
339 2005) influenced by the Atlantic climate with mild summer temperatures (Elena Roselló,
340 1997); therefore, it is so not surprising that aspect had no statistically significant influence
341 on site quality of this species. The negative relationship of site quality of *P. pinaster* and
342 altitude is in concordance with Álvarez-Álvarez et al. (2011). They found that the greater
343 site productivities are below 513 m asl.

344 Other local variables, such as soil variables, are expected to influence the site index
345 (Bueis et al., 2016; Chen et al., 2002). However, gathering soil data for the whole country
346 would be highly time-consuming and expensive (McBratney et al., 2006). These
347 unmeasured variables could in fact explain the less ability of the model to classify
348 correctly some of the A and D productivity class plots. Nevertheless, the effect of
349 unmeasured environmental variables was partially accounted for by the spatial smooth
350 function. Additionally, the spatial smooth function eliminated the spatial correlation
351 minimizing the type I errors rates (Dormann et al., 2007). Moreover, if we consider the
352 strong rainfall gradients in Spain (Muñoz-Diaz and Rodrigo, 2004), the lack of significant
353 relationships between rainfall variables and site quality would be unexpected. However,
354 physiographical variables and the spatial smooth function can be in fact be absorbing the
355 effect of the rainfall.

356 Moreover, both *F. sylvatica* and *Q. pyrenaica* are able to sprout and thus can form
357 coppice forest (Ruiz de la Torre, 2006). Hence, coppice has been the most used
358 management alternative in Spanish stands of *Q. pyrenaica* (Adame et al., 2008). It is
359 known that the grow pattern of a given species is different for coppice and high forest,
360 with the first one showing a faster initial height growth but less sustained than the high
361 forest (Ciancio et al., 2006; Haneca et al., 2005). However, it is not clear the effect of the
362 stand structure on the site form. Further study is needed to address this concern and if it
363 is necessary to integrate stand structure in site quality models (Adame et al., 2008). On
364 the other hand, different subspecies of each species grow in its distribution area of Spain.
365 This is quite evident in the case of *P. nigra*, that presents high intraspecific variability in
366 natural stands (Ruiz de la Torre, 2006), which has been even enlarged by the use in
367 reforestation of the Corsican and Austrian provenances. This can lead to the attribution
368 of different site qualities for each subspecies at the same location when considering

369 dominant height and age as site quality criteria (Moreno-Fernández et al., 2014).
370 However, the fact that the *P. nigra* subspecies rarely grow close to each other can make
371 the spatial smooth capture the influence of the subspecies on site form. In addition, the
372 use of the dominant diameter instead of age can absorb part of the effect of the subspecies
373 differentiation if the subspecies just differed in growth rates.

374 This methodology can be used in other countries and expanding the current maps to
375 the whole Europe. Thus, one could assess the way in which site quality of main EFTs or
376 groups of EFTs, such as those dominated by *P. sylvestris* or *F. sylvatica*, varies over
377 Europe.

378

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384

385 **References**

386 Adame, P., Cañellas, I., Roig, S., Río, M. Del, 2006. Modelling dominant height growth
387 and site index curves for rebollo oak (*Quercus pyrenaica* Willd.). Ann. For. Sci. 63,
388 929–940. doi:10.1051/forest:2006076

389 Adame, P., del Río, M., Cañellas, I., 2008. A mixed nonlinear height-diameter model for
390 pyrenean oak (*Quercus pyrenaica* Willd.). For. Ecol. Manage. 256, 88–98.
391 doi:10.1016/j.foreco.2008.04.006

392 Alberdi Asensio, I., Condés Ruiz, S., Millán, J., Saura Martínez de Toda, S., Sánchez
393 Peña, G., Pérez Martín, F., Villanueva Aranguren, J., Vallejo Bombín, R., 2010.
394 National Forest Inventories Report, Spain, in: Tomppo, E., Gschwantner, T.,
395 Lawrence, M., McRoberts, R. (Eds.), National Forest Inventories: Pathways for
396 Common Reporting. Springer, pp. 529–540.

397 Álvarez-Álvarez, P., Khouri, E.A., Cámara-Obregón, A., Castedo-Dorado, F., Barrio-
398 Anta, M., 2011. Effects of foliar nutrients and environmental factors on site
399 productivity in *Pinus pinaster* Ait. stands in Asturias (NW Spain). Ann. For. Sci. 68,
400 497–509. doi:10.1007/s13595-011-0047-5

401 Álvarez-González, J.G., Ruíz González, A.D., Rodríguez Soalleiro, R., Barrio Anta, M.,
402 2005. Ecoregional site index models for *Pinus pinaster* in Galicia (northwestern

403 Spain). *Ann. For. Sci.* 62, 115–127. doi:10.1051/forest:2005003

404 Andersson, R., Östlund, L., 2004. Spatial patterns, density changes and implications on
405 biodiversity for old trees in the boreal landscape of northern Sweden. *Biol. Conserv.*
406 118, 443–453. doi:10.1016/j.biocon.2003.09.020

407 Augustin, N.H., Musio, M., von Wilpert, K., Kublin, E., Wood, S.N., Schumacher, M.,
408 2009. Modeling spatiotemporal forest health monitoring data. *J. Am. Stat. Assoc.*
409 104, 899–911. doi:10.1198/jasa.2009.ap07058

410 Barbati, A., Corona, P., Marchetti, M., 2007. European forest types: Categories and types
411 for sustainable forest management reporting and policy, Second. ed. European
412 Environmental Agency, Copenhagen.

413 Barbati, A., Marchetti, M., Chirici, G., Corona, P., 2014. European Forest Types and
414 Forest Europe SFM indicators: Tools for monitoring progress on forest biodiversity
415 conservation. *For. Ecol. Manage.* 321, 145–157. doi:10.1016/j.foreco.2013.07.004

416 Beniston, M., 2003. Climatic change in mountain regions: a review of possible impacts,
417 in: *Climate Variability and Change in High Elevation Regions: Past, Present &*
418 *Future*. Springer Netherlands, pp. 5–31.

419 Bravo-Oviedo, A., Montero, G., 2005. Site index in relation to edaphic variables in stone
420 pine (*Pinus pinea* L.) stands in south west Spain. *Ann. For. Sci.* 62, 61–72.
421 doi:10.1051/forest:2004086

422 Bravo, F., Lucà, M., Mercurio, R., Sidari, M., Muscolo, A., 2011. Soil and forest
423 productivity: a case study from Stone pine (*Pinus pinea* L.) stands in Calabria
424 (southern Italy). *iforest* 4, 25. doi:10.3832/IFOR0559-004

425 Bravo, F., Montero, G., 2001. Site index estimation in Scots pine (*Pinus sylvestris* L.)
426 stands in the High Ebro Basin (northern Spain) using soil attributes. *Forestry* 74,
427 395–406.

428 Bueis, T., Bravo, F., Pando, V., Turrión, M.B., 2016. Relationship between
429 environmental parameters and *Pinus sylvestris* L. site index in forest plantations in
430 northern Spain acidic plateau. *IForest* 9, 394–401. doi:10.3832/ifor1600-008

431 Cañellas, I., García, F.M., Montero, G., 2000. Silviculture and dynamics of *Pinus*
432 *sylvestris* stands in Spain. *Investig. Agrar. Sist. y Recur. For. Fuera de s*, 233–253.

433 Charru, M., Seynave, I., Morneau, F., Bontemps, J.-D., 2010. Recent changes in forest
434 productivity: An analysis of national forest inventory data for common beech (*Fagus*
435 *sylvatica* L.) in north-eastern France. *For. Ecol. Manage.* 260, 864–874.
436 doi:10.1016/j.foreco.2010.06.005

- 437 Chen, H.Y., Krestov, P. V, Klinka, K., 2002. Trembling aspen site index in relation to
438 environmental measures of site quality at two spatial scales. *Can. J. For. Res.* 32,
439 112–119. doi:10.1139/x01-179
- 440 Ciancio, O., Corona, P., Lamonaca, A., Portoghesi, L., Travaglini, D., 2006. Conversion
441 of clearcut beech coppices into high forests with continuous cover: A case study in
442 central Italy. *For. Ecol. Manage.* 224, 235–240. doi:10.1016/j.foreco.2005.12.045
- 443 Clutter, J., Forston, J., Pienaar, L., Brister, G., Bailey, R., 1983. *Timber management: a*
444 *quantitative approach.* John Wiley & Sons, New York.
- 445 Crecente-Campo, F., Pasalodos-Tato, M., Alberdi, I., Hernández, L., Ibañez, J.J.,
446 Cañellas, I., 2016. Assessing and modelling the status and dynamics of deadwood
447 through national forest inventory data in Spain. *For. Ecol. Manage.* 360, 297–310.
448 doi:10.1016/j.foreco.2015.10.029
- 449 Diaz-Maroto, I., Vila-Lameiro, P., Guchu, E., Diaz-Maroto, M., 2007. A comparison of
450 the autecology of *Quercus robur* L. and *Q. pyrenaica* Wild.: present habitat in
451 Galicia, NW Spain. *Forestry* 80, 223–239. doi:10.1093/forestry/cpm019
- 452 Diéguez-Aranda, U., Álvarez-González, J.G., Barrio-Anta, M., Rojo Alboreca, A., 2005.
453 Site quality equations for *Pinus sylvestris* L. plantations in Galicia (northwestern
454 Spain). *Ann. For. Sci.* 62, 143–152. doi:10.1051/forest:2005006
- 455 Dormann, C.F., McPherson, J.M., Araújo, M.B., Bivand, R., Bolliger, J., Carl, G., Davies,
456 R.G., Hirzel, A., Jetz, W., Daniel Kissling, W., Kühn, I., Ohlemüller, R., Peres-Neto,
457 P.R., Reineking, B., Schröder, B., Schurr, F.M., Wilson, R., 2007. Methods to
458 account for spatial autocorrelation in the analysis of species distributional data: A
459 review. *Ecography (Cop.)*. 30, 609–628. doi:10.1111/j.2007.0906-7590.05171.x
- 460 Duchon, J., 1977. Splines minimizing rotation-invariant semi-norms in Sobolev spaces,
461 in: Schempp, W., Zeller, K. (Eds.), *Constructive Theory of Functions of Several*
462 *Variables: Proceedings of a Conference Held at Oberwolfach April 25 -- May 1,*
463 *1976.* Springer Berlin Heidelberg, Berlin, Heidelberg, pp. 85–100.
464 doi:10.1007/BFb0086566
- 465 EC, 2012. *Innovating for sustainable growth. A bioeconomy for Europe.* European
466 Commission, Brussels.
- 467 Eimil-Fraga, C., Rodríguez-Soalleiro, R., Sánchez-Rodríguez, F., Pérez-Cruzado, C.,
468 Álvarez-Rodríguez, E., 2014. Significance of bedrock as a site factor determining
469 nutritional status and growth of maritime pine. *For. Ecol. Manage.* 331, 19–24.
470 doi:10.1016/j.foreco.2014.07.024

471 Elena Roselló, R., 1997. Clasificación biogeoclimática de España Peninsular y Balear.
472 MAPA, Madrid.

473 ESRI, 2014. ArcGIS Desktop: Release 10.2.2. Redlands, CA: Environmental Systems
474 Research Institute.

475 FAO, 2015. Global Forest Resources Assessment 2015: How have the world's forests
476 change? Rome, Italy.

477 FAO, 2001. Global Forest Resources Assessment 2000: main report. FAO Forestry Paper
478 140. Rome, Italy.

479 Faraway, J.J., 2006. Extending the linear model with R: generalized linear, mixed effects
480 and nonparametric regression models, Chapman & Hall/CRC Texts in Statistical
481 Science Series. doi:10.1111/j.1541-0420.2006.00596_12.x

482 Forest-Europe, 2015. State of Europe's forests 2015.

483 Franklin, J., Perry, D., Schowalter, T., Harmon, M., McKee, A., Spies, T., 1989.
484 Importance of ecological diversity in maintaining long-term site productivity, in:
485 Perry, D., Meurisse, R., Thomas, B., Miller, R., Boyle, J., Means, J., Perry, C.,
486 Powers, R. (Eds.), Maintaining the Long-Term Productivity of Pacific Northwest
487 Forest Ecosystems. Timber press, Oregon, USA, pp. 82–97.

488 Gabler, K., Schadauer, K., Tomppo, E., Vidal, C., Bonhomme, C., McRoberts, R.E.,
489 Gschwantner, T., 2012. An enquiry on forest areas reported to the global forest
490 resources assessment—Is harmonization needed? For. Sci. 58, 201–213.
491 doi:10.5849/forsci.10-060

492 Gandullo, J., Sánchez-Palomares, O., 1994. Estaciones ecológicas de los pinares
493 españoles. ICONA, Madrid.

494 Gómez-Aparicio, L., Valladares, F., Zamora, R., 2006. Differential light responses of
495 Mediterranean tree saplings: linking ecophysiology with regeneration niche in four
496 co-occurring species. Tree Physiol. 26, 947–958. doi:10.1093/treephys/26.7.947

497 Gonzalo, J., 2010. Diagnóstico fitoclimático de la España peninsular. Hacia un modelo de
498 clasificación funcional de la vegetación y de los ecosistemas peninsulares españoles.
499 Ministerio de Medio ambiente y Medio Rural y Marino. Organismo Autónomo
500 Parques Nacionales.

501 Haneca, K., Acker, J. Van, Beeckman, H., 2005. Growth trends reveal the forest structure
502 during Roman and Medieval times in Western Europe: a comparison between
503 archaeological and actual oak ring series (*Quercus robur* and *Quercus petraea*).
504 Ann. For. Sci 62, 797–805. doi:10.1051/forest:2005085

505 Hastie, T., Tibshirani, R., 1989. Generalized additive models. *Stat. Sci.* 10, 297–318.
506 doi:10.1214/ss/1177013604

507 Hernández, L., Cañellas, I., Alberdi, I., Torres, I., Montes, F., 2014. Assessing changes
508 in species distribution from sequential large-scale forest inventories. *Ann. For. Sci.*
509 71, 161–171. doi:10.1007/s13595-013-0308-6

510 Huang, S., Titus, S.J., 1993. An index of site productivity for uneven-aged or mixed-
511 species stands. *Can. J. For. Res.* 23, 558–562. doi:10.1139/x93-074

512 Jalkanen, A., Mattila, U., 2000. Logistic regression models for wind and snow damage in
513 northern Finland based on the National Forest Inventory data. *For. Ecol. Manage.*
514 135, 315–330. doi:10.1016/S0378-1127(00)00289-9

515 Larson, A.J., Lutz, J.A., Gersonde, R.F., Franklin, J.F., Hietpasi, F.F., 2008. Potential site
516 productivity influences the rate of forest structural development. *Ecol. Appl.* 18,
517 899–910.

518 Larsson, T., 2001. Biodiversity evaluation tools for European forests. *Ecol. Bull.* 50.

519 Lexerød, N.L., 2005. Recruitment models for different tree species in Norway. *For. Ecol.*
520 *Manage.* 206, 91–108. doi:10.1016/j.foreco.2004.11.001

521 McBratney, A.B., Minasny, B., Viscarra Rossel, R., 2006. Spectral soil analysis and
522 inference systems: A powerful combination for solving the soil data crisis.
523 *Geoderma* 136, 272–278. doi:10.1016/j.geoderma.2006.03.051

524 Moreno-Fernández, D., Hernández, L., Sánchez-González, M., Cañellas, I., Montes, F.,
525 2016. Space – time modeling of changes in the abundance and distribution of tree
526 species. *For. Ecol. Manage.* 372, 206–216. doi:10.1016/j.foreco.2016.04.024

527 Moreno-Fernández, D., Sánchez-González, M., Álvarez-González, J.G., Hevia, A.,
528 Majada, J.P., Cañellas, I., Gea-Izquierdo, G., 2014. Response to the interaction of
529 thinning and pruning of pine species in Mediterranean mountains. *Eur. J. For. Res.*
530 133, 833–843. doi:10.1007/s10342-014-0800-z

531 Muñoz-Díaz, D., Rodrigo, F.S., 2004. Spatio-temporal patterns of seasonal rainfall in
532 Spain (1912 – 2000) using cluster and principal component analysis : comparison.
533 *Ann. Geophys.* 22, 1435–1448. doi:10.5194/angeo-22-1435-2004

534 R Core Team, 2017. R: A language and environment for statistical computing.

535 Ruiz-Peinado, R., Rio, M., Montero, G., 2011. New models for estimating the carbon sink
536 capacity of Spanish softwood species. *For. Syst.* 20, 176–188.

537 Ruiz de la Torre, J., 2006. *Flora Mayor*. Organismo Autónomo de Parques Nacionales.
538 Dirección General para la Biodiversidad, Madrid.

- 539 Sánchez-Palomares, O., Roig, S., del Río, M., Rubio, A., Gandullo, J., 2008. Las
540 estaciones ecológicas actuales y potenciales de los rebollares españoles.
541 Monografías INIA: Serie forestal nº 17, Madrid.
- 542 Sánchez-Palomares, O., Rubio Sánchez, A., Blanco, A., 2004. Definición y cartografía
543 de las áreas potenciales fisiográfico-climáticas de hayedo en España. *Investig.*
544 *Agrar. Sist. y Recur. For. Fuera de S*, 13–62.
- 545 Schuck, A., Meyer, P., Menke, N., Lier, M., Lindner, M., 2004. Forest biodiversity
546 indicator: dead wood - A proposed approach towards operationalising the MCPFE
547 indicator, in: *Monitoring and Indicators of Forest Biodiversity in Europe - From Ideas*
548 *to Operationality*. pp. 49–77.
- 549 Stout, B.B., Shumway, D.L., 1982. Site quality estimation using height and diameter. *For.*
550 *Sci.* 3, 639–645.
- 551 Tomppo, E., Gschwantner, T., Lawrence, M., McRoberts, R., 2010. *National Forest*
552 *Inventories. Pathways for common reporting*. Springer.
- 553 Vanclay, J.K., 1994. *Modelling forest growth and yield: applications to mixed tropical*
554 *forests*. CAB International, Wallingford.
- 555 Vidal, C., Alberdi, I., Redmond, J., Vestman, M., Lanz, A., Schadauer, K., 2016. The role
556 of European National Forest Inventories for international forestry reporting. *Ann.*
557 *For. Sci.* 793–806. doi:10.1007/s13595-016-0545-6
- 558 Wei, X., Kimmins, J.P., Zhou, G., 2003. Disturbances and the sustainability of long-term
559 site productivity in lodgepole pine forests in the central interior of British
560 Columbia—an ecosystem modeling approach. *Ecol. Modell.* 164, 239–256.
561 doi:10.1016/S0304-3800(03)00062-0
- 562 Weiskittel, A., Hann, D.W., Kershaw, J., Vanclay, J.K., 2011. *Forest growth and yield*
563 *modelling*. Wiley-Blackwell, Oxford, England.
- 564 Wood, S.N., 2011. Fast stable restricted maximum likelihood and marginal likelihood
565 estimation of semiparametric generalized linear models. *J. R. Stat. Soc. Ser. B Stat.*
566 *Methodol.* 73, 3–36. doi:10.1111/j.1467-9868.2010.00749.x
- 567 Wood, S.N., 2006. *Generalized Additive Models: an Introduction with R*. CRC Press,
568 United States of America.
- 569 Wood, S.N., 2003. Thin-plate regression splines. *J. R. Stat. Soc.* 65, 95–114.
570 doi:10.1111/1467-9868.00374
- 571 Woodall, C.W., Heath, L.S., Smith, J.E., 2008. National inventories of down and dead
572 woody material forest carbon stocks in the United States: Challenges and

573 opportunities. For. Ecol. Manage. 256, 221–228. doi:10.1016/j.foreco.2008.04.003

574 **Tables**

575 **Table 1.** Number of plots of the National Forest Inventory (N), number of plots with basal
576 area larger than 90% ($N_{G \geq 90\%}$), mean basal area (G in $\text{m}^2 \text{ha}^{-1}$), mean dominant height
577 (H_0 in m) and mean dominant diameter (D_0 in m) in the selected European Forest Types.
578 Within brackets minimum and maximum values.

European Forest Type	N	$N_{G \geq 90\%}$	G	H_0	D_0
2.7 Atlantic maritime pine forest (<i>Pinus pinaster atlantica</i>)	3410	1568	18.0 (0.4-85.0)	15.2 (2.0-29.3)	30.5 (7.5-71.9)
7.1 South western European mountainous beech forest (<i>Fagus sylvatica</i>)	4449	1915	25.5 (0.4-64.2)	18.8 (3.7-36.5)	40.9 (7.5-158.8)
8.3 Pyrenean oak forest (<i>Quercus pyrenaica</i>)	5528	2889	10.9 (0.4-72.5)	9.9 (0.4-23.3)	24.2 (7.5-134.4)
10.2 Mediterranean and Anatolian black pine forest (<i>Pinus nigra</i>)	8352	3212	15.1 (0.4-80.4)	10.4 (2.6-33.3)	26.5 (7.5-100.3)
10.4 Mediterranean and Anatolian Scots pine forest (<i>Pinus sylvestris</i>)	10919	5171	22.7 (0.4-83.8)	12.1 (2.0-30.5)	29.9 (7.5-64.8)

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598 **Table 2.** Base model, site specific parameter and site specific parameter for each site form
 599 family curves.

Species	Base model	Parameter		Equation
		Estimate	Pr(> t)	
<i>P. pinaster</i>	H-II	b	= <2e-16	$SFI = 1.3 + \frac{D_{0ref}^2}{\left[\frac{D_0}{\sqrt{H_0 - 1.3}} + b(D_{0ref} - D_0) \right]^2}$
		0.13035		
<i>F. sylvatica</i>	H-II	a	= <2e-16	$SFI = 1.3 + \frac{D_{0ref}^2}{\left[a + \left(\frac{D_0}{\sqrt{H_0 - 1.3}} - a \right) \frac{D_{0ref}}{D_0} \right]^2}$
		2.5473		
<i>Q. pyrenaica</i>	H-II	a	= <2e-16	$SFI = 1.3 + \frac{D_{0ref}^2}{\left[a + \left(\frac{D_0}{\sqrt{H_0 - 1.3}} - a \right) \frac{D_{0ref}}{D_0} \right]^2}$
		2.0539		
<i>P. nigra</i>	B-R	b	= <2e-16	$SFI = 1.3 + (H_0 - 1.3) \left[\frac{1 - e^{-bD_{0ref}}}{1 - e^{-bD_0}} \right]^c$
		0.05405	<2e-16	
		c	= 2.2316	
<i>P. sylvestris</i>	H-II	b	= <2e-16	$SFI = 1.3 + \frac{D_{0ref}^2}{\left[\frac{D_0}{\sqrt{H_0 - 1.3}} + b(D_{0ref} - D_0) \right]^2}$
		0.1386		

600 B-R: Bertalanffy-Richard; H-II: Hossfeld-II; SIF: Site Form Index

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Table 3. p-values of the model components and percentage of deviance explained by the spatial additive model for each European Forest Types.

Species	Intercept	$f(X_i, Y_i)$	$f(\text{altitude})$	$f(\text{aspect})$	$f(\text{slope})$	Deviance (%)
<i>P. pinaster</i>	<0.0001	<0.0001	<0.0001	n.s.	n.s.	39.6
<i>F. sylvatica</i>	<0.0001	<0.0001	<0.0001	<0.0007	0.0400	37.3
<i>Q. pyrenaica</i>	<0.0001	<0.0001	<0.0001	0.0192	n.s.	32.5
<i>P. nigra</i>	<0.0001	<0.0001	<0.0001	<0.0001	n.s.	48.6
<i>P. sylvestris</i>	<0.0001	<0.0001	<0.0001	<0.0001	n.s.	42.0

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Table 4. Model selection and Akaike’s Information Criterion for each European Type Forests. In bold the selected model.

Model	Model terms	<i>P. pinaster</i>	<i>F. sylvatica</i>	<i>Q. pyrenaica</i>	<i>P. nigra</i>	<i>P. sylvestris</i>
(1)	α	7766.51	10254.05	14607.96	15852.38	27476.10
(2)	(1) + $f(X_i, Y_i)$	7332.67	9805.29	13951.03	14592.00	25631.34
(3)	(2) + $f(\text{altitude})$	7151.53	9720.40	13906.19	14335.19	25333.93
(4)	(3) + $f(\text{aspect})$	7146.83	9699.32	13896.34	14301.22	25312.09
(5)	(5) + $f(\text{slope})$	7146.00	9692.03	13892.92	14302.42	25311.93

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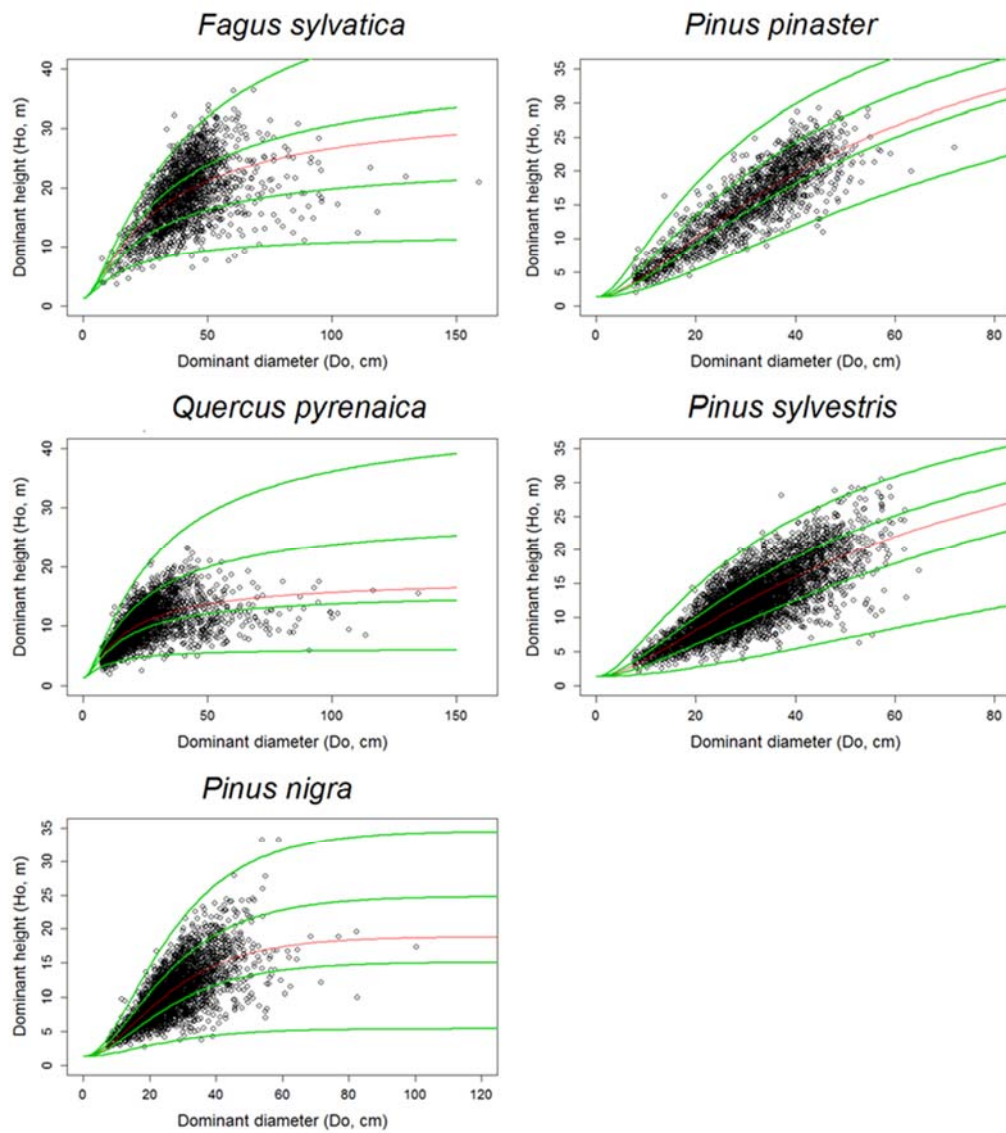
Table 5. Confusion matrix for each European Forest Type. Accuracy percentage is shown within brackets.

Species		Site form model	Spatial additive model			
			A	B	C	D
<i>Pinus pinaster</i> (45.4 %)	A	139	121	44	1	
	B	37	145	114	10	
	C	11	109	159	26	
	D	2	59	133	112	
<i>Fagus sylvatica</i> (42.7 %)	A	135	270	73	1	
	B	34	274	157	13	
	C	13	193	220	53	
	D	2	79	209	189	
<i>Quercus pyrenaica</i> (38.2 %)	A	179	428	113	0	
	B	50	373	296	3	
	C	19	255	409	39	
	D	11	153	417	142	
<i>Pinus nigra</i> (47.9 %)	A	418	309	72	4	
	B	120	388	253	42	
	C	31	277	406	89	
	D	6	117	354	326	
<i>Pinus sylvestris</i> (45.2 %)	A	654	464	161	13	
	B	197	659	400	36	
	C	47	468	664	113	
	D	11	225	696	360	

672 A=high quality site, B=intermediate-high quality site, C=intermediate-low quality site,
 673 D=low quality site.

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675 **Figures**

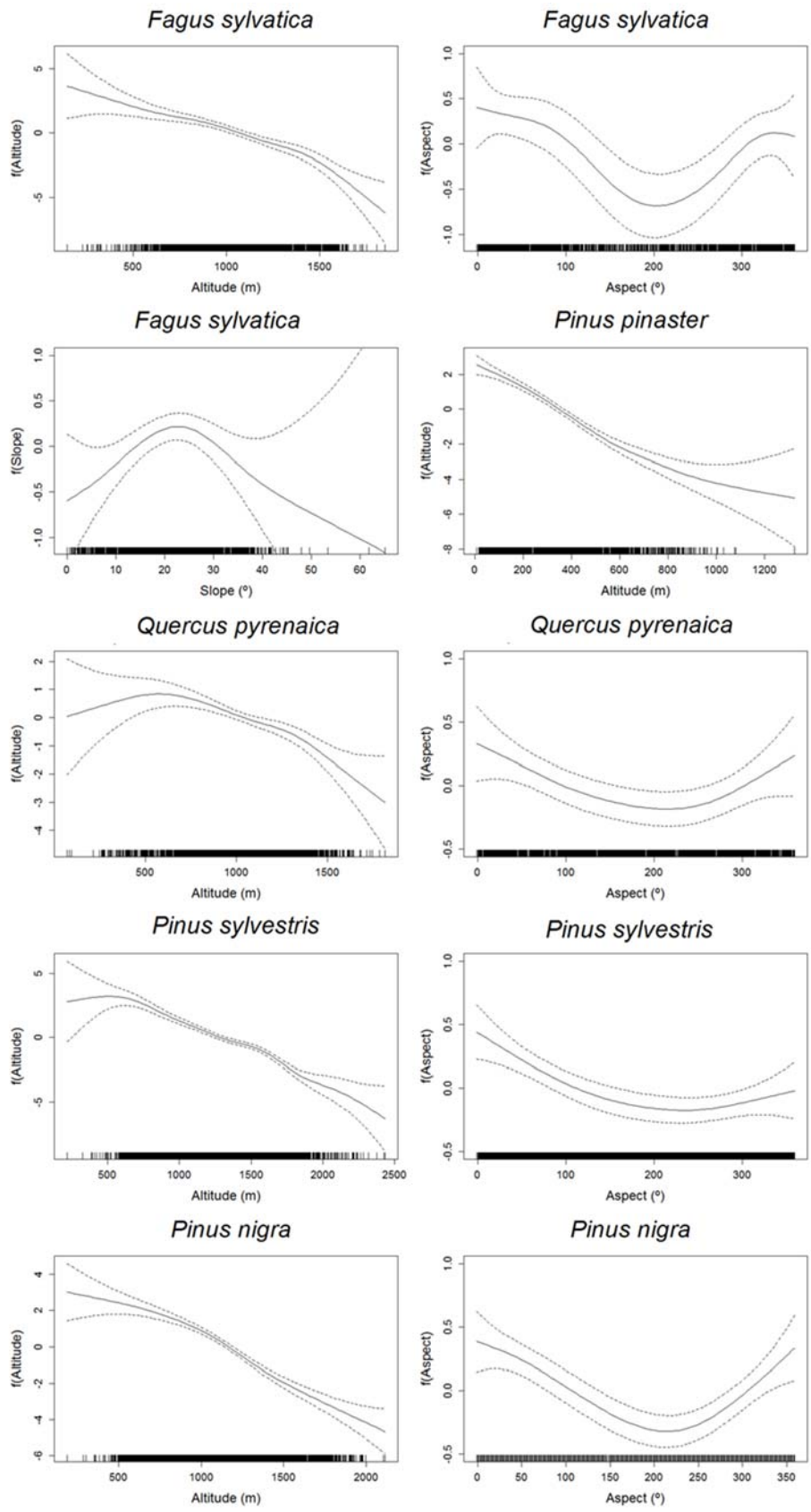


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677 **Fig. 1.** Site form family curves for the European Forest Types studied.

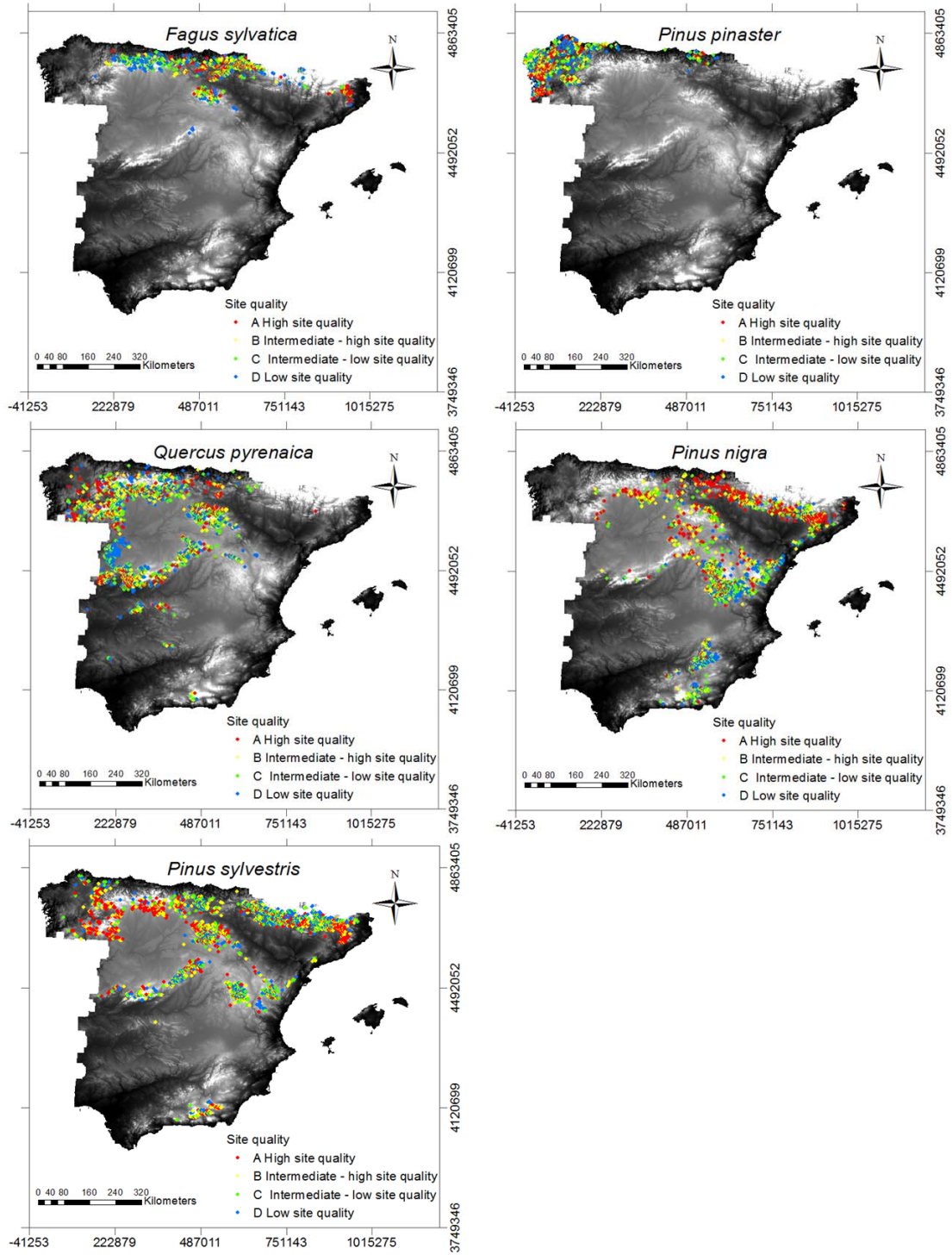
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681 **Fig. 2.** Estimated centered smooth functions and 95 % confidence intervals of the
 682 physiographic for the site form spatial additive models of the European Forest Types
 683 studied.

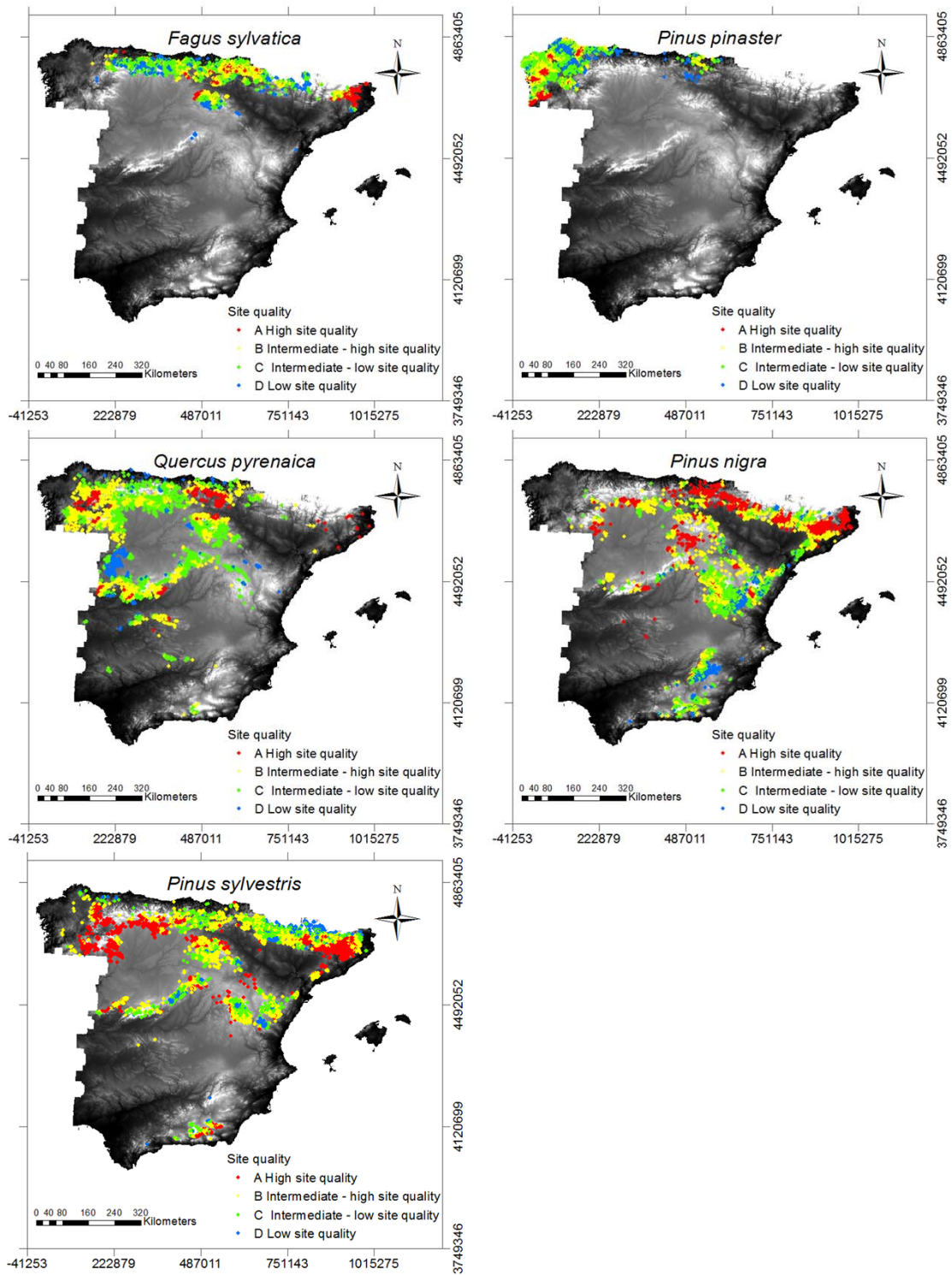


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685 **Fig. 3.** Observed site quality of the European Forest Types studied.

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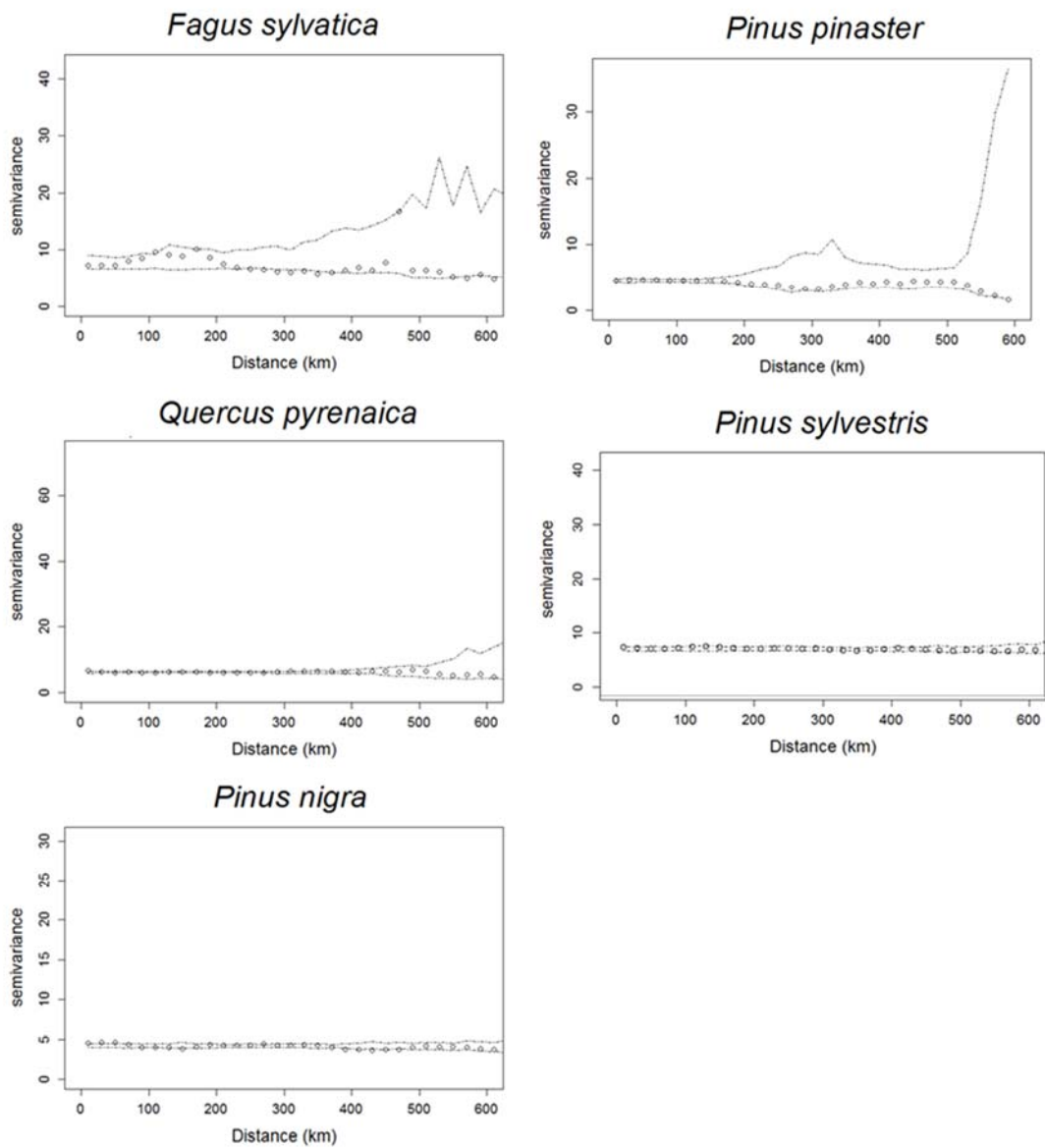
689 **Fig. 4.** Estimated site quality of the European Forest Types studied. Darker colors indicate
 690 low altitudes whereas light intensities high altitudes.

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694 **Appendix A. Supplementary material**



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696 **Fig. A-1.** Semivariograms and envelopes of the residuals from the site form spatial
697 additive models for each European Forest Types.

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