Potential climatic influence on maximum stand carrying capacity for 15 Mediterranean coniferous and broadleaf species

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Abstract

Climate change projections for the Mediterranean basin predict a continuous increase in extreme drought and heat episodes, which will affect forest dynamics, structure and composition. Understanding how climate influences the maximum size-density relationship (MSDR) is therefore critical to designing adaptive silvicultural guidelines based on the potential stand carrying capacity of tree species. With this aim, data from the Third Spanish National Forest Inventory (3NFI) and WorldClim databases were used to analyze climate-related variations of the maximum stand carrying capacity for 15 species from the *Pinus*, *Fagus* and *Quercus* genera. First, basic MSDR were fitted using linear quantile regression and observed size-density data from monospecific 3NFI plots. Reference values for maximum stocking, expressed in terms of the Maximum Stand Density Index (SDI_{max}), were estimated by species. Then, climate-dependent MSDR models including 35 annual and seasonal climatic variables were fitted. The best climate-dependent models, based on the Akaike Information Criteria (AIC) index, were used to determine the climatic drivers affecting MSDR, to analyze general and species-specific patterns and to quantify the impact of climate on maximum stand carrying capacity. The results showed that all the selected climate-dependent models improved the goodness of fit over the basic models. Among the climatic variables, spring and summer maximum temperatures were found to be key drivers affecting MSDR for the species studied. A common trend was also found across species, linking warmer and drier conditions to smaller SDI_{max} values. Based on projected climate scenarios, this suggests potential reductions in maximum stocking for these species. In this study, a new index was proposed, the Q index, for evaluating the impact of

climate on maximum stand carrying capacity. Our findings highlight the importance of using specific climatic variables to better characterize how they affect MSDR. The models presented in this study will allow us to better explain interactions between climate and MSDR while also providing more precise estimates concerning maximum stocking for different Mediterranean coniferous and broadleaf tree species.

Keywords:

Self-thinning · Reineke · Maximum Stand Density Index · Forest management · National Forest Inventory data

Highlights

- MSDR and SDI_{max} estimations are significantly influenced by climate
- All selected climate-dependent MSDRs improved SDI_{max} estimations over the basic MSDRs
- Seasonal climatic variables better explain SDI_{max} variations than general climatic indexes
- Spring and summer climate changes are key drivers affecting the MSDR and SDI_{max}
- Lower values of SDI_{max} are linked to warmer and drier conditions

1.INTRODUCTION

Maximum stand carrying capacity is a key variable in forest management and commonly used to develop site resources for sustainable, healthy and optimal stand growth. Reineke (1933) was the first to address this concept when he proposed the Maximum Stand Density Index (SDI_{max}), an attribute that determines full site occupancy (Zeide, 2005). He discovered that for any given tree size (i.e. 25 cm), the physiological attributes of a species constrain the maximum number of trees that a fully stocked stand can support before natural mortality takes place. This relationship is widely recognized in forest science (Reineke, 1933; Drew and Flewelling, 1977) and ecology (Yoda et al., 1963; Fowler,1981) as the Maximum Size-Density Relationship (MSDR). Also known as the self-thinning line, its applications encompass studies related to habitat distribution (Moore and Deiter, 1992), risk assessment due to abiotic and biotic factors (Fettig et al., 2007; Ducey et al., 2017) or the carbon sink capacity of forests (Woodall et al., 2011; Brunet-Navarro et al., 2016). Its use also extends to the development of forest management tools such as forest growth models (Makela et al., 2000; Yang and Titus, 2002), density management diagrams (Long and Shaw, 2005; Valbuena et al., 2008) and forest management plans (Jack and Long, 1996; Churchill et al., 2013). Initially, Reineke (1933) and Yoda et al. (1963) claimed that the MSDR, and therefore the maximum stand carrying capacity, might not be influenced by environmental conditions or site quality. However, recent studies show that this relationship varies with site quality (Bi, 2001; Comeau et al., 2010), stand origin (Weiskittel et al., 2009), nutrient availability (Morris, 2003; Reyes-Hernandez et al., 2013) and stand age (Zeide,

96 2005). The influence of climate on MSDR deserves special attention, since it is
97 widely accepted that climate is changing. Forest stands are already experiencing
98 alterations in composition, structure and dynamics (IPCC, 2018). Relevant
99 projections suggest that climate change will continue to affect site conditions,
100 including stand carrying capacity, species distribution and niche suitability.
101 Recent studies confirm that the size-density relationship is affected by climate,
102 indicating an important decline in maximum stand carrying capacity associated
103 with potential drought conditions in different areas of the Mediterranean basin
104 (Condés et al., 2017; Aguirre et al., 2018). These studies frequently use annual
105 climatic variables, such as the De Martonne Index (1926), to study climatic
106 influences on MSDR. However, studies involving more precise (monthly or
107 seasonal) climatic variables are needed to better understand this relationship.
108 Kweon and Comeau (2017), for example, used periodic climatic variables such
109 us degree-days above 5 °C, degree-days below 0ºC or summer heat moisture
110 index (the ratio between mean warmest month temperature and mean summer
111 precipitation) to better characterize environmental conditions. They found that
112 higher temperatures and longer frost-free periods could negatively affect the
113 maximum stand carrying capacity. The effect of climate on MSDR has also been
114 widely studied in mixed stands (Condés et al., 2013; del Río et al., 2014; Pretzsch
115 and Biber, 2016; Andrews et al., 2018). Recent research has focused more on
116 estimating size-density relationships for coniferous species (Brunet-Navarro et
117 al., 2016; Aguirre et al., 2018), but less has been done in relation to broadleaf
118 species. Future work should focus on discovering potential changes in the
119 structure, composition and dynamics of monospecific broadleaf and mixed
120 conifer-broadleaf stands. Species composition and functional traits have also

been indicated as key drivers affecting the maximum stand carrying capacity (Ducey et al., 2017; Kimsey et al., 2019). All these works highlight the importance of considering a range of environmental conditions, to better understand regional landscape patterns that can inform the estimation of maximum stocking. To that end, National Forest Inventory (NFI) data has proven a suitable database for studying climatic influences on MSDRs, as it covers a wide variety of forest types, stand structures and species distributed along a gradient of environmental conditions (Condés et al., 2017; Andrews et al., 2018; Toigo et al., 2018). Previous studies have used NFI data and diverse statistical methods to fit basic and climate-dependent MSDR models (Zhang et al., 2005; Hann, 2014). Principal component analysis (Hutchings and Budd, 1981; Weller, 1987; Bégin et al., 2001), stochastic frontier analysis (Bi et al., 2000; Bi, 2004; Charru et al., 2012) and linear quantile regression (Zhang et al., 2013; Vospernik and Sterba, 2015) are the methods most commonly used to fit the self-thinning line. The linear quantile regression method was chosen for the study presented here, as it can provide statistical analysis and estimates for fitting linear models to either the conditional median or other quantiles of the response variable, without stringent assumptions on the error distribution (Koenker and Bassett, 1978). Exploring the relationship between climate and the maximum carrying capacity of a forest stand is therefore key to understanding the dynamics that can inform sustainable use and management of the products and services it provides. Accordingly, the main objective of this work was to study the influence of climate on the maximum stand carrying capacity (expressed as SDI_{max}) of 15 coniferous and broadleaf species in Spain (Table 1). The specific objectives of the study were: (i) to fit new basic and climate-dependent MSDR models and discover the key climatic drivers

146 influencing MSDR by species, (ii) to estimate the maximum stand carrying
147 capacity for these species with and without climate influence, and (iii) to analyze
148 and quantify general and species-specific trends in SDI_{max} variation for the
149 species studied.
150
151 **2.MATERIAL AND METHODS**
152
153 *2.1. Data*
154

155 Spanish Third National Forest Inventory (3NFI) plots were used for this study.
156 3NFI plots consist of four concentric circles with radii of 5,10,15 and 25 meters,
157 in each of which multiple tree-level variables for all trees over 7.5, 12.5, 22.5 and
158 42.5 cm diameter at breast height (1.3 m), respectively, were recorded from 1997
159 to 2007 (Herrero and Bravo, 2012; Alberdi et al., 2016). Expansion factors were
160 used to estimate stand variables from individual tree variables, such as density
161 (N), quadratic mean diameter (Dg), basal area (G) and dominant height (Ho).
162 3NFI plots located in monospecific stands of different coniferous and broadleaf
163 species (Table 1) were selected. Plots were considered monospecific when the
164 main species accounted for more than 90% of the total basal area. Low-density
165 plots were discarded under the hypothesis that the MSDR depends on the
166 climatic conditions following the methodology proposed by Condés et al. 2017. In
167 addition, plots with quadratic mean diameter outside the 10-60 cm range were
168 also dismissed to avoid including under-represented stands. Climatic data were
169 obtained from Worldclim 2 (Fick and Hijmans, 2017). Worldclim 2 is a high-
170 resolution global geo-database (30 arc seconds or ~ 1km at equator) of monthly

171 average data gathered from extensive climate observations and the NASA´s
172 Shuttle Radar Topography Mission (SRTM). Climatic variables of annual,
173 seasonal and monthly temperature and precipitation records over a 30-year
174 climate normal period (1970-2000) were included. Variables related to
175 temperature were expressed in Kelvin degrees (K), since the logarithmic models
176 fitted in this study do not accept negative values for independent variables. The
177 Temperature Annual Range (TAR), expressed as the difference between the
178 maximum and minimum annual temperature, and the De Martonne Index (M)
179 were also calculated. The De Martonne Index (De Martonne, 1926), calculated
180 as P/(T + 10) (where P is the total annual precipitation in mm, and T is the mean
181 annual temperature in °C), is a climatic index commonly used to describe aridity
182 or drought in a given area (Bielak et al., 2014; Condés et al., 2017; Aguirre et al.,
183 2018). Potential evapotranspiration data from the Global Potential
184 Evapotranspiration Geospatial Database (Trabucco and Zomer, 2009) were also
185 considered in this study. Altogether, 35 climatic variables were used in this study
186 to characterize climate annually and seasonally (Table 2). All climatic variables
187 were derived from selected monospecific plots using GIS software and plot-
188 specific latitude and longitude. Supplementary Tables 1 and 2 provide a complete
189 statistical summary of the climatic variables used in this study.

190

191 *2.2. Data modeling*

192 Firstly, basic MSDR models (without climatic influence) were fitted using
193 Reineke´s (1933) equation (Eq.1) after natural logarithmic transformation
194 (Eq.2), to obtain species-specific coefficients:

195

196 $$N_{max} = \alpha'_0 \cdot Dg^{\beta 0} \quad \text{(Eq.1)}$$

197 $$\ln(N_{max}) = \alpha_0 + \beta_0 \cdot \ln(Dg) \quad \text{(Eq.2)}$$

198

199 where: N_{max} is the maximum density (trees ha $^{-1}$), Dg is the mean quadratic
200 diameter (cm), α_0 is the species-specific intercept and β_0 is the species-specific
201 slope to be estimated.

202

203 Basic MSDR coefficients were estimated by linear quantile regression for each
204 species, using the quantreg R package (Koenker, 2015) on R software (R Core
205 Team, 2018). Models were fitted for the upper quantiles (95th, 97.5th and 99th)
206 since the MSDR is a limiting boundary (Ducey and Knapp, 2010; Aguirre et al.,
207 2018). Climate-dependent MSDR models were then fitted by species, to analyze
208 the influence of climate on MSDR and maximum stand carrying capacity.
209 Climate-dependent coefficients were obtained for each climatic variable using
210 linear quantile regression, by expanding the coefficients in Eq.(2) as a function of
211 climate:

212

213 $$\ln(N_{max}) = \alpha_0 + \alpha_1 \cdot \ln(Clim) + (\beta_0 + \beta_1 \cdot Clim) \cdot \ln(Dg) \quad \text{(Eq.3)}$$

214

215 where: Clim is a climatic variable from Table 2 and α_0, α_1, β_0 and β_1 are the model
216 parameters to be estimated.
217 As a result, 35 climate-dependent models were fitted for each species at the
218 same quantiles as the basic MSDR models. The F-test, based on the extra sum
219 of squares principle (Ratwosky, 1983), was used to test any statistically
220 significant improvement (at α=0.05 significance level) of these models over the

221 basic models. Finally, significant climate-dependent models were arranged
222 based on the Akaike Information Criterion (AIC) and pseudo-R^2 for quantile
223 regression (Koenker and Machado,1999), to determine the climatic variables that
224 most affect MSDR by species.
225
226

Table 1: Mean, standard deviation and range (minimum-maximum) of the main stand characteristics of the 3NFI plots selected to fit the MSDR models

Functional group	Species	n	Elev	N	Dg	G	Ho
Conifers	*Pinus canariensis*	1158	1286 ± 349 (246-2317)	359 ± 298 (20-1984)	29.49 ± 8.57 (11.84-50.00)	1.93 ± 1.34 (0.11-9.30)	15.31 ± 4.12 (4.50-30.50)
	Pinus halepensis	6074	641 ± 307 (0-1559)	413 ± 309 (33-2387)	20.51 ± 5.89 (10.01-49.30)	0.60 ± 0.43 (0.05-4.03)	9.13 ± 2.50 (2.50-25.50)
	Pinus nigra	2321	1101 ± 324 (183-2141)	768 ± 577 (81-4623)	20.42 ± 6.19 (10.17-53.73)	1.13 ± 0.86 (0.06-8.02)	11.1 ± 3.38 (4.00-27.79)
	Pinus pinaster	4427	776 ± 371 (4-1842)	512 ± 404 (20-2886)	25.86 ± 6.97 (10.06-49.93)	1.61 ± 1.15 (0.23-12.79)	12.99 ± 4.16 (4.89-36.88)
	Pinus pinea	1352	513 ± 289 (0-1144)	336 ± 330 (31-3233)	26.95 ± 8.27 (11.21-49.66)	1.06 ± 0.71 (0.26-7.48)	9.70 ± 2.67 (3.42-22.45)
	Pinus radiata	874	412 ± 249 (8-2013)	430 ± 261 (10-1678)	33.85 ± 8.83 (10.01-54.92)	3.75 ± 2.32 (0.04-12.3)	23.89 ± 5.76 (5.00-38.42)
	Pinus sylvestris	4082	1302 ± 329 (282-2428)	786 ± 545 (15-4333)	23.46 ± 6.99 (10.15-49.74)	1.85 ± 1.36 (0.01-11.45)	13.01 ± 3.95 (2.50-30.48)
	Pinus uncinata	385	1899 ± 196 (1337-2456)	746 ± 478 (40-2430)	23.73 ± 6.04 (13.21-45.27)	1.89 ± 1.00 (0.57-6.94)	11.56 ± 2.81 (5.60-20.70)
Broadleaf	*Fagus sylvatica*	1117	999 ± 283 (143-1943)	561 ± 414 (82-2544)	29.02 ± 9.40 (11.07-54.97)	28.01 ± 10.28 (4.03-64.84)	18.97 ± 5.00 (5.05-36.35)
	Quercus faginea	685	869 ± 221 (146-1552)	643 ± 590 (28-3088)	17.18 ± 6.54 (10.01-39.94)	0.58 ± 0.75 (0.02-5.82)	7.89 ± 2.38 (2.50-20.46)
	Quercus ilex	3609	661 ± 309 (57-1980)	281 ± 333 (41-2005)	23.57 ± 10.09 (10.00-49.98)	6.85 ± 3.75 (1.39-22.78)	6.18 ± 1.38 (0.95-11.75)
	Quercus petraea	201	1006 ± 302 (112-1622)	697 ± 565 (38-3392)	24.17 ± 8.81 (10.58-48.02)	2.13 ± 1.82 (0.40-13.35)	12.86 ± 4.07 (5.54-28.82)
	Quercus pyrenaica	1879	1029 ± 247 (150-1898)	751 ± 664 (33-5125)	18.91 ± 7.79 (10.01-49.85)	0.80 ± 0.97 (0.08-9.84)	10.33 ± 2.90 (2.64-22.52)
	Quercus robur	560	495 ± 236 (31-1598)	403 ± 316 (52-1791)	29.01 ± 9.59 (11.07-54.92)	20.42 ± 9.71 (3.75-61.49)	13.97 ± 4.11 (1.85-28.98)
	Quercus suber	687	398 ± 211 (18-1065)	243 ± 228 (41-1287)	31.9 ± 10.31 (12.06-54.09)	14.12 ± 6.92 (3.16-41.87)	8.13 ± 2.11 (2.38-15.55)

n - Number of monspecific plots, Elev - Plot altitude (m), N - Stand density (trees ha^{-1}), Dg - Quadratic mean diameter (cm), G - Basal area (m^2 ha^{-1}), H_o - Dominant height (m)

Table 2: List of climatic variables used in this study

Variable	Definition
T	Annual Mean Temperature (Kelvin degrees)
Ti	Mean Temperature (Kelvin) of the i Season (i = 1,2,3,4)
MNT	Annual mean Minimum Temperature (Kelvin degrees)
MNT_i	Minimum Temperature (Kelvin degrees) of the i Season (i = 1,2,3,4)
MXT	Annual Mean Maximum Temperature (Kelvin degrees)
MXT_i	Maximum Temperature (Kelvin degrees) of the i Season (i = 1,2,3,4)
MXTWM	Maximum Temperature of Warmest Month (Kelvin degrees)
MNTCM	Minimum Temperature of Coldest Month (Kelvin degrees)
TAR	Temperature Annual Range (Kelvin degrees) (MXTWM - MNTCM)
P	Total Annual Precipitation (mm)
P_i	Total Precipitation (mm) of the i Season (i = 1,2,3,4)
PWM	Precipitation of Wettest Month (mm)
PDM	Precipitation of Driest Month (mm)
M	Annual De Martonne Index (mm $ºC^{-1}$)
M_i	De Martonne Index (mm $ºC^{-1}$) of the i Season (i = 1,2,3,4)
PET	Annual Potential Evapotranspiration (mm)
PET_i	Potential Evapotranspiration (mm) of the i Season (i = 1,2,3,4)

i: 1=Autumn (October, November, December), 2=Winter (January, February, March), 3=Spring (April, May, June), 4=Summer (July, August, September)

2.3. Climatic influence on maximum stand carrying capacity

Maximum stand carrying capacity was expressed as the Maximum Stand Density Index (SDI_{max}), derived from Reineke´s (1933) equation. Reference values for SDI_{max} (SDI_{maxREF}) were calculated by species, using estimated coefficients from basic MSDR models (Eq.2).

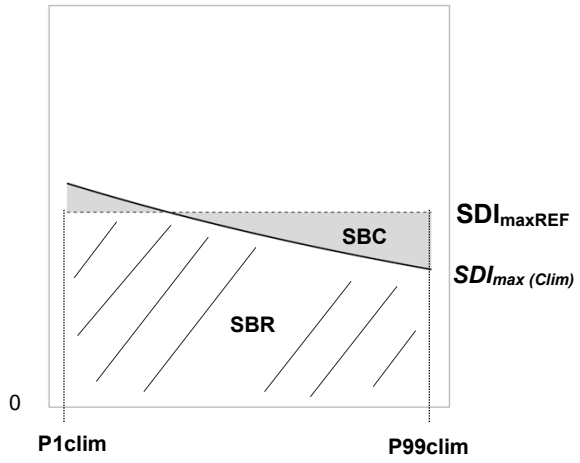
$$SDI_{maxREF} = e^{[\alpha 0 + \beta 0 \cdot \ln(25)]} \quad \text{(Eq.4)}$$

In a similar way, estimated coefficients from the selected climate-dependent models were used to calculate the climate-dependent SDI_{max} by species [Eq.5]:

$$SDI_{max}(Clim) = e^{[(\alpha 0 + \alpha 1 \cdot \ln(Clim)) + (\beta 0 + \beta 1 \cdot Clim) \cdot \ln(25)]} \quad \text{(Eq.5)}$$

where SDI_{max} *(Clim)* is the function of the maximum stand carrying capacity for each species and climatic variable *Clim* and $\alpha 0$, $\alpha 1$, $\beta 0$ and $\beta 1$ are the estimated coefficients from climate-dependent MSDR models.

To visually detect trends in SDI_{max} variation, SDI_{max} *(Clim)* values were obtained and plotted along the range of values (percentiles 1 to 99) for each climatic variable selected. Then, the Q index was proposed in order to quantify the SDI_{max} variation a species shows in a region along a range of different climatic conditions. First, the difference between SDI_{max} *(Clim)* values obtained from the climate-dependent models (Eq. 5) with respect to species-specific SDI_{maxREF} obtained from (Eq. 4) was considered (Figure 1). By integrating them between the 1st and the 99th percentile of the climatic variable, the area between the SDI_{max} *(Clim)* function and the y = SDI_{maxREF} line was then determined. This area is known as the Surface Between Curves (SBC). To relativize the SBC to the SDI_{maxREF} reference value and make it comparable among species and climatic drivers, the Q index was calculated as shown in Eq.6.



$$Q\ index = \frac{SBC}{SBR} \qquad \text{(Eq.6)}$$

Figure 1: Graphical representation of the Q index

where SBR (Surface Below Reference) represents the area below the reference line $y = SDI_{maxREF}$, i.e., $SBR = SDI_{maxREF} * (P99clim - P1clim)$ and P1clim and P99clim are the 1st and the 99th percentile of the climatic variable.

3.RESULTS

3.1. Basic MSDR models

The intercept (α_0) and slope (β_0) of the basic MSDRs were highly significant ($p < 0.001$) for all the coniferous (Table 3) and broadleaf species (Table 4) studied. Since SDI_{maxREF} estimate results were very low for the 95th and very high for the 99th quantiles compared to similar studies, the 97.5th quantile was selected as the reference for each model, to allow for comparison of results among all the species studied. The results of the basic MSDR models fitted at these quantiles are available in Supplementary Table 3. Of the coniferous species, *Pinus pinea* (-2.1855) and *Pinus pinaster* (-1.9063) presented the steepest slopes of the basic MSDRs, while *Pinus sylvestris* (-1.7524) and *Pinus uncinata* (-1.7336) presented the flattest slopes. Estimated SDI_{maxREF} values for the coniferous species ranged from 526 (*Pinus halepensis*) to 1178 (*Pinus radiata*) trees per hectare (Table 5). In general, broadleaf species presented smaller maximum stand carrying capacities (from 319 to 995 trees per hectare) than coniferous species. Results for these species fell along a gradient; *Quercus ilex* (-2.0951) had higher intercepts and shallower slopes, followed by *Quercus suber*, *Fagus sylvatica*, *Quercus pyrenaica*, *Quercus faginea, Quercus petraea*, and finally *Quercus robur*

333 with the least pronounced slope (-1.6698) (Table 4). Basic MSDR trajectories are
334 shown by species in Figures 2 and 3.
335
336 *3.2. Climate-dependent MSDR models*
337
338 Coefficients for the best climate-dependent MSDR models fitted at the 97.5th
339 quantile are presented in Table 3 (coniferous species) and Table 4 (broadleaf
340 species). A complete list of all fitted climate-dependent MSDR models is available
341 in Supplementary Table 4. The results indicated that climatic variables related to
342 temperature better explained the influence of climate on MSDR, for both conifers
343 and broadleaf species. Specifically, seasonal (MXT_i) and annual (MXT) maximum
344 temperatures were the most representative climatic variables among the 35
345 studied. Climate-dependent models including Maximum Summer Temperature
346 (MXT4) were selected in 8 (4 conifer and 4 broadleaf) of the 15 species, followed
347 by models including Maximum Spring Temperature (MXT3), Maximum
348 Temperature of the Warmest Month (MXTWM) and Maximum Annual
349 Temperature (MXT). For all species excepting, spring and summer consistently
350 appeared as key periods, with significant interaction between climate and MSDR.
351 Among the conifers studied, the models selected for *Pinus halepensis*, *Pinus*
352 *nigra*, *Pinus pinaster* and *Pinus sylvestris* indicated maximum temperatures as
353 key variables for explaining climatic influence on MSDR. In contrast, aridity,
354 precipitation and potential evapotranspiration was the variables that most
355 influenced MSDR for *Pinus canariensis, Pinus pinea*, *Pinus radiata* and *Pinus*
356 *uncinata* (Table 3). Only three climatic models were significant for *Pinus radiata*,
357 which may be due to a high concentration of selected monospecific plots in a

358 specific area without a wide climatic variability. Among the broadleaf species
359 studied, temperature was also found to be a key driver affecting MSDR, since
360 most of the climate-dependent models selected were related to these variables
361 (Table 4). Maximum temperatures were found to be key drivers for *Quercus*
362 *petraea and Quercus pyrenaica*, while *Quercus robur* was affected by minimum
363 temperatures. The best models for *Quercus ilex* and Quercus suber indicated
364 that potential evapotranspiration played an important role in explaining changes
365 in MSDR and SDI_{max} for these species. Aridity also influenced the MSDR of
366 *Fagus sylvatica* and *Quercus faginea* according to the best models for these
367 species. However, the other selected models for *Quercus faginea* were related
368 to changes in summer temperatures. For all species, selected climate-dependent
369 MSDR significantly improved the goodness of fit, in terms of AIC and pseudo-R^2,
370 compared to the basic models. Among the coniferous species, *Pinus pinea* and
371 *Pinus radiata* selected models showed the highest pseudo-R^2 with values close
372 to 0.40 (Table 3). *Pinus canariensis* models showed the highest AIC reduction (Δ
373 AIC ranging -7 and -11.3%) with respect to the basic MSDR model. For *Pinus*
374 *nigra, Pinus sylvestris and Pinus radiata*, however, inclusion of a climatic variable
375 in the basic MSDR model did little to improve its efficiency (Δ AIC close to -2%).
376 Compared to conifers, broadleaf results generally presented higher pseudo-R^2
377 values and greater differences in AIC with respect to the basic MSDR models
378 (Table 4). Climate-dependent models for *Fagus sylvatica*, *Quercus ilex* and
379 *Quercus suber* presented the highest pseudo-R^2 values among the 15 species.
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381
382

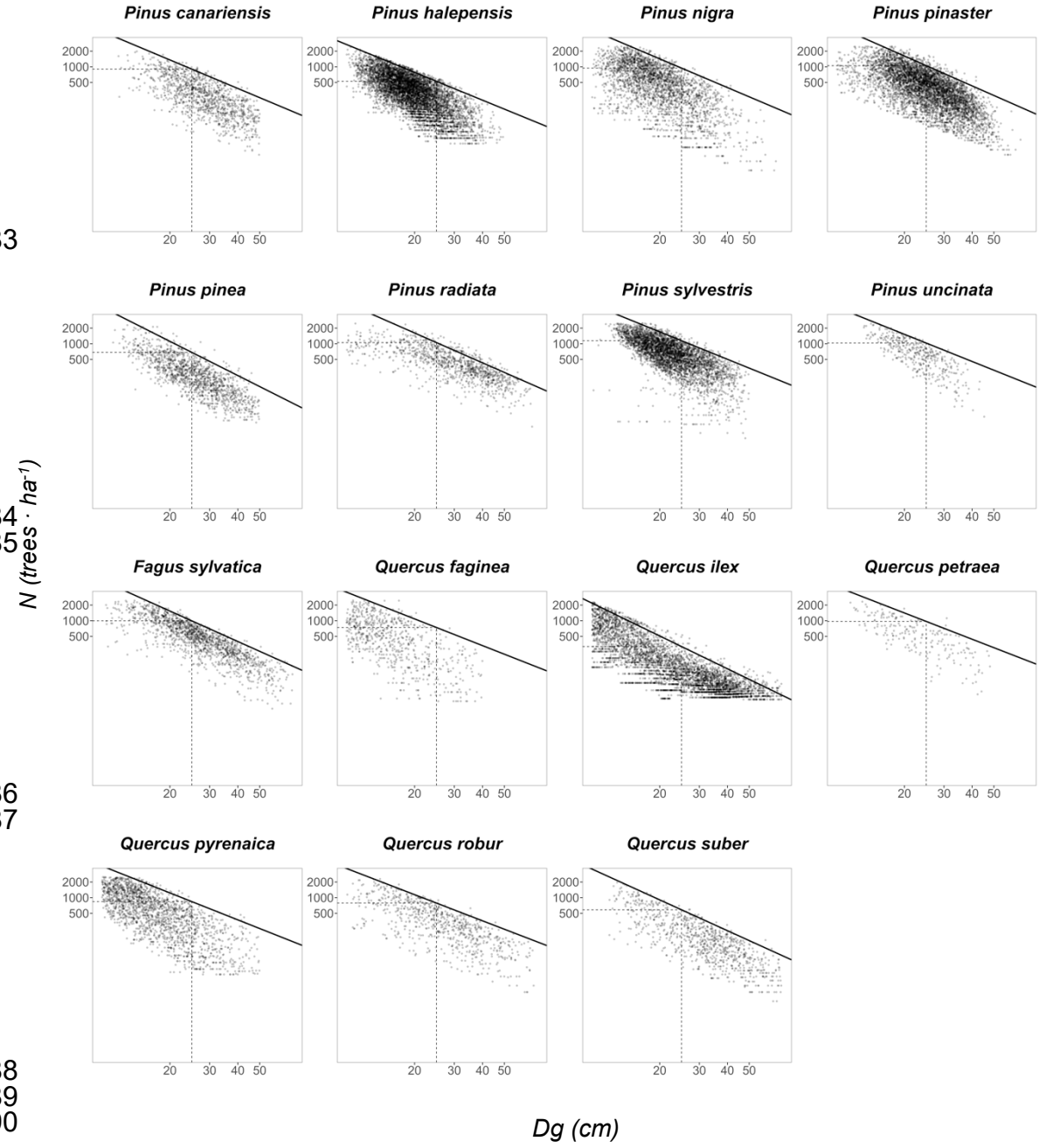

Figure 2: Maximum Size-Density Relationships (MSDR) for the 15 coniferous and broadleaf species studied, plotted on a log-log scale for the selected monospecific stands. Self-thinning boundary lines fitted by quantile regression (97.5th quantile) are represented by solid lines. Dashed lines represent the SDI_{maxREF} (maximum number of trees at a Dg reference of 25 cm).

Table 3: Species-specific coefficients, SDI_{max} estimates and goodness of fit in terms of Akaike's Information Criterion (AIC) and pseudo-R^2 coefficient for the basic and the top five climate-dependent MSDR models fitted by linear quantile regression (97.5th quantile) for coniferous species.

Species	Model	α_0	α_1	β_0	β_1	AIC	pseudo-R^2	Q index
Pinus canariensis	**basic**	**12.672 *****	**-**	**-1.8226 *****	**-**	**2616.9**	**0.3378**	**-**
	P1	3.639 ***	2.448 ***	-2.0891 ***	-	2320.8	0.4178	0.305
	PWM	4.176 ***	2.059 ***	-1.9567 ***	-	2347.4	0.4111	0.251
	P	13.161 ***	-	-2.6082 ***	0.0015 ***	2364.4	0.4067	0.245
	P2	12.989 ***	-	-2.3961 ***	0.0075 ***	2420.9	0.3921	0.189
	M1	11.738 ***	1.061 ***	-1.8500 ***	-	2431.5	0.3893	0.189
Pinus halepensis	**basic**	**11.982 *****	**-**	**-1.7760 *****	**-**	**12622.5**	**0.3388**	**-**
	M	9.241 ***	0.886 ***	-1.5559 ***	-0.0095 **	12325.5	0.3549	0.063
	MXT3	96.948 ***	-14.977 ***	-1.7045 ***	-	12368.1	0.3526	0.079
	MXT4	105.595 ***	-16.445 ***	-1.7171 ***	-	12383.7	0.3517	0.077
	MXTWM	100.504 ***	-15.542 ***	-1.7134 ***	-	12394.4	0.3512	0.073
	PWM	8.722 ***	0.784 ***	-1.6057 ***	-0.0026 *	12401.9	0.3509	0.051
Pinus nigra	**basic**	**12.756 *****	**-**	**-1.8346 *****	**-**	**5117.9**	**0.2965**	**-**
	MXT3	140.953 ***	-22.536 ***	-1.9324 ***	-	5010.9	0.3128	0.123
	MXT	154.667 ***	-24.995 ***	-1.9154 ***	-	5028.5	0.3102	0.119
	MXT4	104.610 ***	-16.094 **	-1.9119 ***	-	5045.9	0.3076	0.091
	MXT2	13.019 ***	-	5.7005 ***	-0.0268 ***	5046.7	0.3075	0.119
	P2	11.821 ***	0.290 ***	-1.8973 ***	-	5047.8	0.3073	0.098
Pinus pinaster	**basic**	**13.096 *****	**-**	**-1.9063 *****	**-**	**10593,0**	**0.2716**	**-**
	MXT	13.446 ***	-	4.1770 ***	-0.0213 ***	10229,0	0.3011	0.129
	MXT3	13.365 ***	-	3.5759 ***	-0.0190 ***	10241.6	0.3001	0.128
	T3	13.324 ***	-	3.9110 ***	-0.0206 ***	10296.4	0.2958	0.121
	MXT4	13.462 ***	-	2.6955 ***	-0.0159 ***	10307.5	0.2949	0.114
	MXT2	13.389 ***	-	3.3318 ***	-0.0187 ***	10317.1	0.2941	0.114
Pinus pinea	**basic**	**13.562 *****	**-**	**-2.1855 *****	**-**	**3270.9**	**0.3887**	**-**
	P4	15.072 ***	-0.460 *	-2.4379 ***	0.0093 ***	3139.5	0.4185	0.262
	M4	13.531 ***	-0.467 **	-2.4556 ***	0.2919 ***	3144,0	0.4176	0.257
	P	13.213 ***	-	-2.2271 ***	0.0003 **	3210.7	0.4026	0.131
	TAR	77.368 **	-11.127 *	-2.2790 ***	-	3213.2	0.4020	0.143
	M	13.304 ***	-	-2.2518 ***	0.0077 *	3216.7	0.4013	0.155
Pinus radiata	**basic**	**12.947 *****	**-**	**-1.8254 *****	**-**	**1432.8**	**0.3723**	**-**
	PET3	110.968 ***	-21.507 ***	-8.0490 ***	0.0652 ***	1402.4	0.3845	0.058
	PET4	88.959 ***	-16.269 **	-6.5496 ***	0.0441 **	1409.2	0.3821	0.062
	PET1	6.920 **	1.675 *	-1.3894 ***	-0.0119 **	1421.2	0.3778	0.020
Pinus sylvestris	**basic**	**12.685 *****	**-**	**-1.7524 *****	**-**	**7718.9**	**0.368**	**-**
	TAR	66.470 ***	-9.442 ***	-1.7478 ***	-	7594.7	0.3777	0.078
	MNTCM	617.791 ***	-108.147 ***	-40.0934 ***	0.1425 ***	7630.1	0.3751	0.109
	MXTWM	74.540 ***	-10.872 ***	-1.7675 ***	-	7637.6	0.3744	0.075
	MXT4	71.686 ***	-10.376 ***	-1.7699 ***	-	7643.9	0.3739	0.073
	MXT3	58.945 ***	-8.154 ***	-1.7767 ***	-	7653,0	0.3732	0.064
Pinus uncinata	**basic**	**12.519 *****	**-**	**-1.7336 *****	**-**	**556.6**	**0.4414**	**-**
	PET3	12.918 ***	-	-1.6378 ***	-0.0031 **	534.6	0.4586	0.068
	PET4	16.777 ***	-0.838 ***	-1.8979 ***	-	535.5	0.4580	0.063
	PET	12.899 ***	-	-1.6288 ***	-0.0004 **	535.6	0.4578	0.108
	PET2	12.908 ***	-	-1.6784 ***	-0.0077 **	536.7	0.4571	0.062
	P2	11.386 ***	0.364 ***	-1.9112 ***	-	538.1	0.4561	0.052

****p<0.001; **p<0.01; *p<0.05*

Note: Fewer than 5 significant climate-dependent MSDR models were found for Pinus radiata and Pinus uncinata.

Table 4: Species-specific coefficients, SDI_{max} estimates and goodness of fit in terms of Akaike's Information Criterion (AIC) and pseudo-R^2 coefficient for the basic and the best climate-dependent MSDR models fitted by linear quantile regression (97.5th quantile) for broadleaf species.

Species	Model	α_0	α_1	β_0	β_1	AIC	pseudo-R^2	Q index
Fagus sylvatica	**basic**	**13.170 *****	**-**	**-1.9471 *****	**-**	**1577.1**	**0.5137**	**-**
	MXT3	12.870 ***	-	2.0880 ***	-0.0137 ***	1507.5	0.5290	0.085
	T3	12.813 ***	-	2.0872 *	-0.0138 ***	1510.2	0.5285	0.085
	MXT2	75.624 ***	-11.138 ***	-1.8360 ***	-	1512.2	0.5281	0.070
	PET1	12.911 ***	-	-1.5935 ***	-0.0085 ***	1514.5	0.5276	0.061
	M1	12.133 ***	0.671 ***	-2.0013 ***	-	1514.9	0.5275	0.135
Quercus faginea	**basic**	**12.097 *****	**-**	**-1.7055 *****	**-**	**2003.5**	**0.1811**	**-**
	MXTWM	247.037 ***	-41.233 ***	-1.7874 ***	-	1883.7	0.2508	0.315
	TAR	12.606 ***	-	12.9044 ***	-0.0495 ***	1886.9	0.2490	0.350
	MXT4	254.074 ***	-42.519 ***	-1.7485 ***	-	1899.6	0.2420	0.315
	T4	271.627 ***	-45.750 ***	-1.6856 ***	-	1910.6	0.2359	0.303
	M	9.667 ***	0.812 ***	-1.8657 ***	-	1915.9	0.2329	0.188
Quercus ilex	**basic**	**12.508 *****	**-**	**-2.0951 *****	**-**	**8099.8**	**0.5025**	**-**
	PET3	11.777 ***	-	-1.3094 ***	-0.0044 ***	7398.6	0.5487	0.211
	PET	11.773 ***	-	-1.4050 ***	-0.0004 ***	7449.7	0.5455	0.207
	MXT3	11.899 ***	-	5.0064 ***	-0.0234 ***	7474.1	0.5440	0.215
	MXTWM	11.969 ***	-	4.7651 ***	-0.0223 ***	7484.2	0.5433	0.172
	PET2	11.865 ***	-	-1.5025 ***	-0.0087 ***	7491.1	0.5429	0.159
Quercus petraea	**basic**	**12.277 *****	**-**	**-1.6777 *****	**-**	**431.3**	**0.3877**	**-**
	MXT	-489.861 ***	88.759 ***	36.5003 ***	-0.1334 ***	357.6	0.4954	0.242
	MXT4	12.593 ***	-	9.0312 ***	-0.0370 ***	358.5	0.4917	0.247
	MXT3	12.615 ***	-	7.5139 ***	-0.0323 ***	360,0	0.4899	0.230
	MXTWM	12.382 ***	-	8.8624 ***	-0.0360 ***	360.8	0.4889	0.227
	T4	12.674 ***	-	11.0925 ***	-0.0446 ***	361.6	0.4878	0.240
Quercus pyrenaica	**basic**	**12.271 *****	**-**	**-1.7203 *****	**-**	**4718.4**	**0.2962**	**-**
	T4	-187.581 *	35.255 *	17.946 ***	-0.0679 ***	4537.2	0.3300	0.213
	MNT4	12.312 ***	-	7.1163 ***	-0.0309 ***	4566.5	0.3244	0.186
	MXTWM	12.335 ***	-	5.6320 ***	-0.0250 ***	4570,0	0.3238	0.191
	MXT3	-310.973 *	57.023 *	24.1039 **	-0.0892 ***	4577.6	0.3228	0.204
	MXT4	12.328 ***	-	5.5596 ***	-0.0248 ***	4578.1	0.3223	0.182
Quercus robur	**basic**	**12.043 *****	**-**	**-1.6698 *****	**-**	**1017.7**	**0.4394**	**-**
	MNT3	-795.789 ***	143.317 ***	49.1578 ***	-0.1812 ***	974.7	0.4624	0.120
	MNT	-820.659 ***	147.740 ***	51.1787 ***	-0.1885 ***	981.1	0.4594	0.125
	MNT2	-605.574 ***	109.939 ***	37.8316 ***	-0.1435 ***	985.5	0.4572	0.123
	MNT4	-1112.201 ***	198.611 ***	70.2864 ***	-0.2505 ***	989.2	0.4554	0.131
	MNT1	-624.820 **	113.08 **	39.0364 **	-0.1458 **	993.6	0.4533	0.115
Quercus suber	**basic**	**12.704 *****	**-**	**-1.9674 *****	**-**	**1340.2**	**0.4839**	**-**
	PET3	11.948 ***	-	-1.2349 ***	-0.0043 ***	1233.6	0.5231	0.176
	MXTWM	12.097 ***	-	9.7879 ***	-0.0385 ***	1235.9	0.5223	0.208
	PET4	11.846 ***	-	-1.3656 ***	-0.0025 ***	1239.2	0.5211	0.150
	MXT4	-670.091 **	119.608 **	43.6583 ***	-0.1515 ***	1239.5	0.5217	0.147
	MXT3	12.343 ***	-	9.4775 **	-0.0384 ***	1243.8	0.5195	0.185

****p<0.001; **p<0.01; *p<0.05; ns non-significant*

3.3. Climatic influence on maximum stand carrying capacity

In this study, climate was found to have significant influence on MSDR, and therefore on the maximum stand carrying capacity (SDI_{max}). The best climate-

dependent models for each species revealed a common trend in SDI_{max} variation for coniferous and broadleaf species (Figure 4 and Figure 5). The results indicated that higher SDI_{max} values were negatively linked to temperature and positively linked to precipitation (Table 5). Accordingly, higher maximum temperatures led to smaller SDI_{max} values for *Pinus nigra*, *Pinus pinaster*, *Fagus sylvatica*, *Quercus faginea* and *Quercus petraea*, while increments in precipitation led to higher SDI_{max} values for *Pinus canariensis* and *Quercus pinea*. A particular behaviour of SDI_{max} variation was found for *Pinus pinea* and *Pinus radiata,* with a *SDI_{max} (Clim)* distribution presenting a parabolic shape with a minimum reached close to the median of the P4 (*Pinus pinea*) and PET3 (*Pinus radiata*) range.

Table 5: SDI_{max} estimates for the different percentiles of the selected climate variable (best climate-dependent model) and Q index for the species studied.

Functional Group	Species	Clim	SDI_{maxREF}	*$SDI_{max\ (Clim)}$*					Q index
				P_1	P_{25}	P_{50}	P_{75}	P_{99}	
Conifers	*Pinus canariensis*	P1	903	351	536	768	1051	1388	0.305
	Pinus halepensis	M	526	422	500	543	559	558	0.063
	Pinus nigra	MXT3	944	1204	1064	941	832	737	0.123
	Pinus pinaster	MXT	1053	1353	1190	1046	920	809	0.129
	Pinus pinea	P4	683	700	632	756	982	1325	0.262
	Pinus radiata	PET3	1178	1355	1197	1116	1093	1120	0.058
	Pinus sylvestris	TAR	1146	1342	1241	1148	1063	984	0.078
	Pinus uncinata	PET3	1031	1109	1043	981	923	869	0.068
Broadleaves	*Fagus sylvatica*	MXT3	995	1188	1093	1005	924	850	0.085
	Quercus faginea	MXTWM	740	999	725	527	384	281	0.315
	Quercus ilex	PET3	319	496	409	337	278	229	0.211
	Quercus petraea	MXT	969	1268	1001	787	616	480	0.242
	Quercus pyrenaica	T4	840	1021	838	686	561	458	0.213
	Quercus robur	MNT3	787	993	888	790	699	616	0.120
	Quercus suber	PET3	585	721	608	512	432	364	0.176

P - Percentile

Q indexes obtained for conifers (Tables 3, 4, 5) showed that the highest variations in SDI_{max} across different climatic conditions were obtained for *Pinus canariensis*

(0.305), followed by *Pinus pinea* (0.262). On the contrary, the lower values of Q index were found for *Pinus halepensis* (0.063) and *Pinus radiata* (0.058). Among broadleaf species, the lowest Q index was found for *Fagus sylvatica* (0.085) and the highest for *Quercus faginea* (0.315). The rest of the *Quercus* species presented similar values ranging from 0.11 to 0.24.

4.DISCUSSION

In this study, a significant influence of climate on the MSDR was found for the 15 Mediterranean species studied. Our results highlighted the need to consider different specific climatic variables to better predict this climatic influence as previous researchers (Aguirre et al. 2018; Condés et al. 2017; Brunet-Navarro et al. 2016; Charru et al., 2012). However, exact agreement with previously published studies (Aguirre et al. 2018; Brunet-Navarro et al. 2016) could not be expected for the same species and areas regarding the key drivers affecting the MSDR and the way they impact the maximum stand carrying capacity estimations. In addition, different approaches (Condés et al., 2017; Riofrio et al. 2017) in selecting monospecific plots could derive in a different plot samples and therefore in different results. As well as this, regarding the climate database, although other databases could also be used such as Gonzalo Jimenez (2010), the most updated (1970-2000) time period offered by WorldClim2 available for the whole study area was selected in order to consider a suitable range of different climatic conditions with high resolution (Abatzoglou et al. 2018; Poggio et al. 2018; Panagos et al. 2017).

4.1. Basic MSDRs and SDI_{max} reference values

Our findings showed significant differences in the coefficients of the basic MSDRs (Tables 3 and 4), confirming intra- and inter-specific variability among the selected coniferous and broadleaf species (Vospernik and Sterba, 2015). The range of the slopes fitted in the basic MSDR models for the coniferous species agreed with findings reported by Charru et al. (2012) and Aguirre et al. (2018). Those authors found shallower slopes for *Pinus sylvestris* than for other pines in Spain and France, showing the great ability of this species to grow and survive amidst intra-specific competition (Zeide, 1987; Pretzsch and Biber, 2005). The development of wide crown areas at older ages could explain the extreme value of the slope for *Pinus pinea* (Barbeito et al., 2008). Among the broadleaf species, *Quercus suber* (-1.9674) and *Quercus ilex* (-2.0951) presented the steepest MSDR slopes and the smallest SDI_{max} estimates. These outputs may be due to the ability of these species to support a great leaf area, so that fewer individuals are needed to fully occupy a stand (Woodall et al., 2005).

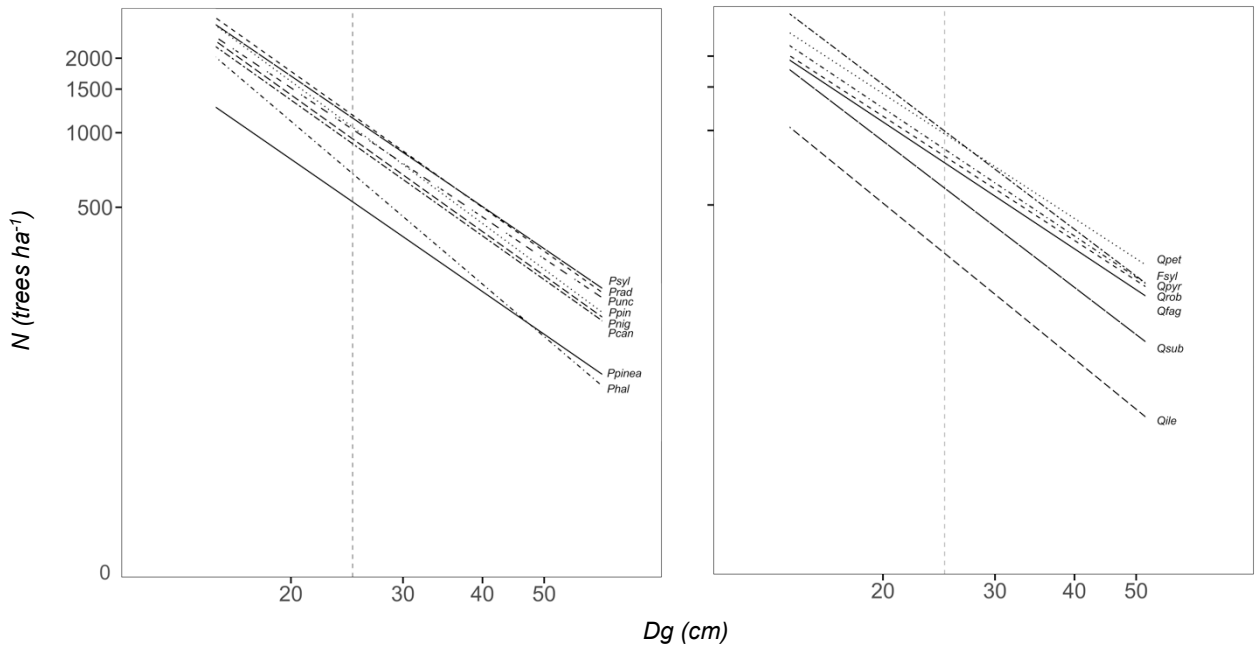

Figure 3: Basic MSDR fits plotted on a log-log scale for the **(a)** coniferous and **(b)** broadleaf species studied.

Note: Pcan - Pinus canariensis, Phal – Pinus halepensis, Pnig – Pinus nigra, Ppin – Pinus pinaster, Ppinea – Pinus pinea, Prad – Pinus radiata, Psyl – Pinus sylvestris, Punc – Pinus uncinata, Fsyl – Fagus sylvatica, Qfag – Quercus faginea, Qile – Quercus ilex, Qpet – Quercus petraea, Qpyr – Quercus pyrenaica, Qrob – Quercus robur, Qsub – Quercus suber

The SDI_{maxREF} values estimated in this study were compared to prior reference values from published studies in similar areas, to test the consistency of our models (Table 6). Agreement was generally good, as stands dominated by conifers showed relatively higher SDI_{maxREF} values when compared to those dominated by broadleaf species. The distinct values obtained in other studies for the same species may be due to the use of different approaches, methodologies and datasets (Hann, 2014). SDI_{maxREF} values were obtained by quantile regression in this study, whereas other relevant studies used different methodologies and types of statistical analysis, such as stochastic frontier analysis (e.g. Charru et al., 2012) or simple linear regression (e.g. Brunet-Navarro et al., 2012). Our findings were consistent with the theory that maximum stand density is known to be positively related to species shade tolerance (Jack and Long 1996, Woodall et al., 2005). However, SDI_{maxREF} values for light-demanding coniferous species such as *Pinus pinaster*, *Pinus uncinata* and *Pinus sylvestris* were unexpectedly high (Table 5), given their low shade-tolerance (Niinemets and Valladares, 2006). A similar trend was found by Andrews et al. (2018), who obtained smaller SDI_{maxREF} values for shade-tolerant species such as *Fagus grandifolia* and *Acer saccharum* than other light-demanding species in the northeastern United States. Prior to that, Dixon and Keyser (2017) reported

similar results when analyzing the maximum stand density of 15 coniferous and broadleaf species in the same area. Higher maximum carrying capacities for light-demanding species such as *Pinus sylvestris* than for *Fagus sylvatica* or *Quercus petraea* were also obtained by Charru et al. (2012) and Toigo et al. (2018) in France. These results suggest the existence of other drivers affecting the maximum carrying capacity of the species studied, such as silvicultural objectives, plant phenology, crown allometry, available growing space or climate.

4.2. Climatic influence on maximum stand carrying capacity

In this study, a significant influence of climate in the MSDR and the maximum stand carrying capacity of 15 Mediterranean tree species was found. Reductions in the maximum carrying capacity were generally linked to warmer and drier conditions, though the climatic drivers that best explained the influence of the climate on MSDR and SDI_{max} varied for conifer and broadleaf species.

4.2.1. Climatic influence on maximum stand carrying capacity for coniferous species

Results from the climate-dependent MSDR models suggest that temperature could be the main driver affecting the maximum stand carrying capacity for conifers (Table 3). For *Pinus nigra, Pinus pinaster* and *Pinus sylvestris*, most of the selected climate-dependent models included seasonal temperatures, especially seasonal maximum (MXTi) temperatures. SDI_{max} *(Clim)* estimates for these species suggest that significant reductions in the maximum carrying capacity might be expected as temperatures increase, especially during the spring season (Figure 4). Contrary to this trend, recent research on climate change and coniferous forest dynamics (Martin-Benito et al., 2008; Kurz-Besson et al., 2016) suggest that reducing the number of days below 5ºC could also

554 improve the growth and vitality of these species by enhancing processes such as
555 winter photosynthesis (Rathgeber et al., 2005), cambium and xylem formation
556 (Vieira et al., 2014) and the development of deeper roots during the colder
557 months of the year (Hansen and Beck, 1994). An increase in minimum
558 temperatures could also boost the growth of individuals in mountainous areas.
559 Smaller snowpack has been linked to higher soil water availability (Kreyling,
560 2010), lower mortality from root damage (Peterson and Peterson, 2001; Gedalof
561 and Smith, 2001) and less foliar erosion from wind-blown snow (Kajimoto et al.,
562 2002). The best climate-dependent models for *Pinus halepensis* indicated that
563 seasonal maximum temperatures (MXT_i), precipitation during the warmest month
564 (PWM) and aridity (expressed as M) were the key drivers affecting SDI_{max}. Small
565 Q indexes were obtained for this species based on these models (Table 3),
566 leading to small SDI_{max} variations along its climatic range (Table 5). These results
567 go in line with previous studies showing the high resilience and adaptation to
568 extreme drought and heat conditions of this Mediterranean species (Baquedano
569 and Castillo, 2007; Benito-Garzón et al., 2011; de Luis et al., 2013; Aguirre et al.
570 2018). *Pinus uncinata* and *Pinus radiata* also showed small variations in SDI_{max}
571 *(Clim)* along their distribution area according to their best climate-dependent
572 MSDR models and Q indexes (Table 5). Particularly, the best climate-dependent
573 model (PET3) for *Pinus radiata* presented an atypical behavior in which SDI_{max}
574 *(Clim)* was found to decrease between percentiles 75 and 99 of this variable. This
575 effect was also visible for *Pinus pinea*, which showed enhanced functioning at
576 the highest values of P4. This might be explained by the link between climate and
577 species traits, which is often too complex to adequately capture in a linear form
578 (Reich, 2012; Craigmile, 2017). For this reason, further studies should test

alternative model structures (i.e. multiple regression) with different combinations of climatic variables in order to better capture climate influences on MSDR and SDI_{max}. Results for *Pinus canariensis and Pinus pinea* revealed that seasonal (Pi) and annual precipitation (P) seemed to be key variables affecting their maximum stand carrying capacity. Indeed, these species showed the highest variation in SDI_{max} according to their Q index values (close to 0.3), suggesting that their maximum stand carrying capacity would be very sensitive to potential changes in precipitation regimes. In this context, climate change projections for the lower areas of the Mediterranean basin emphasize that precipitation will continue to decrease, especially during the warmest season (IPCC, 2018). Vitality (Sabaté et al., 2002; Climent et al., 2006; Sanchez-Salguero et al., 2012), growth reduction (Pasho et al., 2012; Gazol et al., 2017; Navarro-Cerillo et al., 2018; Peña-Gallardo et al., 2018) and even death from xylem embolism (López et al., 2013) due to increasing extreme drought events would be expected for Mediterranean conifers and would indirectly influence the maximum number of trees a stand could fully support in the future.

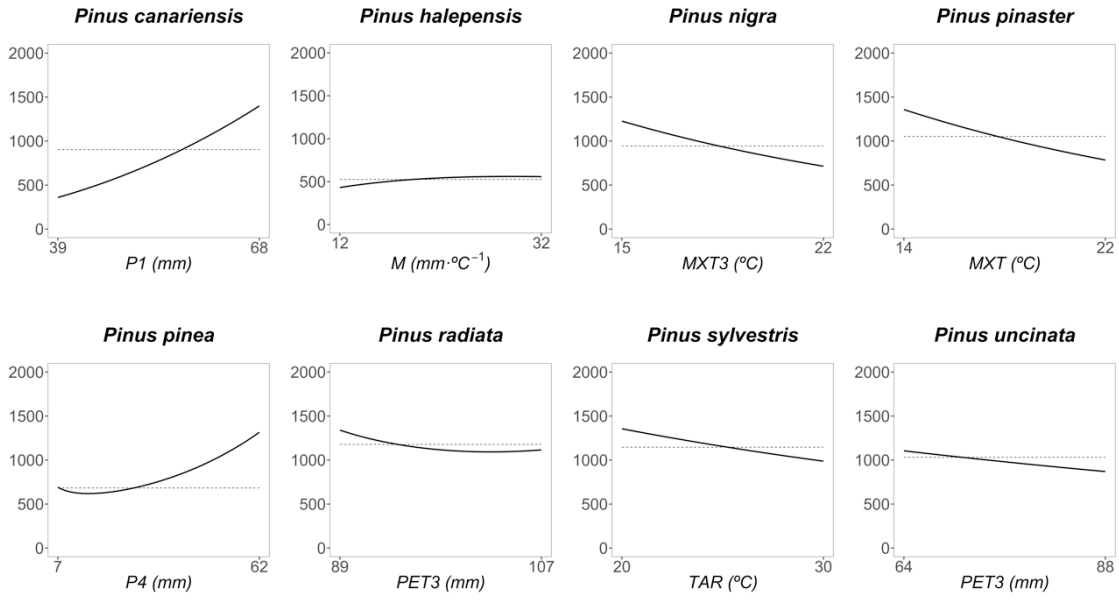

Figure 4: Climatic influence on the maximum stand carrying capacity (expressed as SDI_{max}) for conifers. Solid line corresponds to $SDI_{max\ (Clim)}$ prediction estimates using the best climate-dependent MSDR model by species. Dashed horizontal line represents the reference value of SDI_{maxREF}.

Note: Temperature has been transformed to degrees Celsius (ºC).

4.2.2. Climatic influence on maximum stand carrying capacity for broadleaf species

Similar to conifers, the influence of climate on MSDR was also found to be significant for all broadleaf species (Table 4). Selected climate-dependent models for *Fagus sylvatica* showed that higher SDI_{max} values were linked to wetter and milder conditions (Table 4). This result corroborates results obtained previously by Condés et al., (2017), who found a similar pattern when studying the influence of aridity on MSDR in *Fagus sylvatica* and *Pinus sylvestris* stands across a wide environmental gradient in Europe. Other studies (Friedrichs et al., 2009; Zimmermann et al., 2015) on growth dynamics have reported similar climatic impacts for this species.

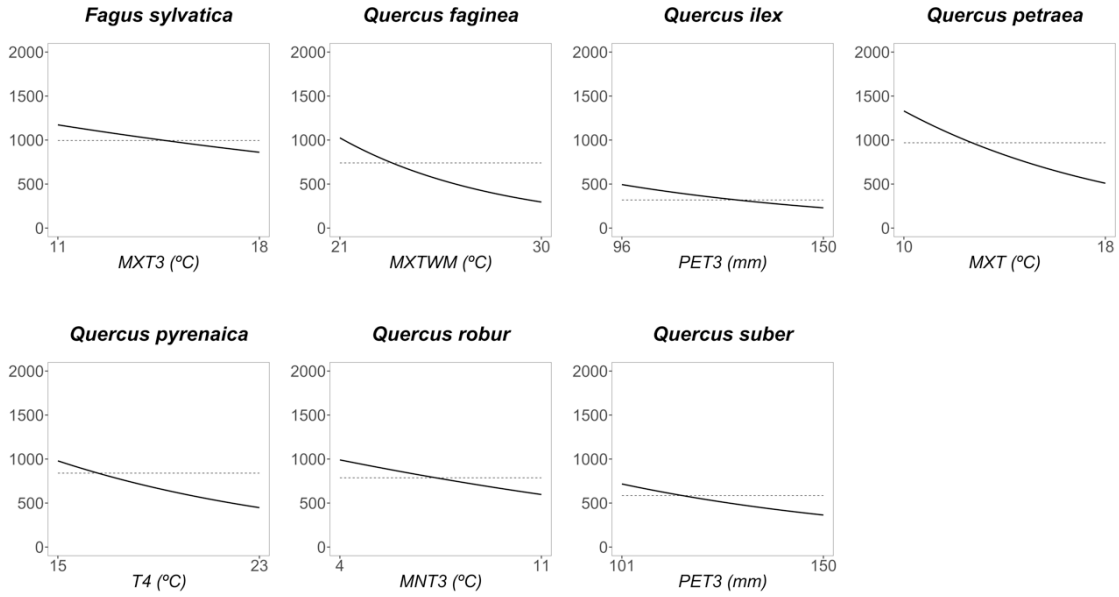

Figure 5: Climatic influence on the maximum stand carrying capacity (expressed as SDI_{max}) of broadleaf species. Solid line corresponds to $SDI_{max\ (Clim)}$ prediction estimates using the best climate-dependent MSDR model by species. Dashed horizontal line represents the reference value, SDI_{maxREF}.

Note: Temperature has been transformed to degrees Celsius (ºC).

For *Quercus* species, temperature was found to be the key driver affecting the maximum stand carrying capacity (Table 5). Based on the selected climate-dependent models by species, maximum temperatures in spring (MXT3) and summer (MXT4) influenced SDI_{max} for all *Quercus* species except *Quercus robur*, which was more affected by potential changes in minimum temperatures (Table 4). Similar to the results obtained for *Pinus* species, higher temperatures (both maximum and minimum) were linked to smaller SDI_{max} estimates (Table 5). This is consistent with what has been found in previous studies (Fernandez-Marin et al., 2017; Gentilesca et al., 2017; Gil-Pelegrín et al., 2017; Kunz et al., 2018), suggesting that extreme heat and heat-induced drought conditions in the future would affect the vitality of oak stands in the Mediterranean basin. However, different responses in SDI_{max} variation as effect of potential changes in temperature (Tables 4 and 5) were obtained among the *Quercus* species. The best climate-dependent models for *Quercus faginea and Quercus pyrenaica* suggest that a small increment in the temperatures of the warmest months would lead to a great decrease in the SDI_{max} of this species (Figure 5). Indeed, *Quercus faginea* presented the highest Q index (0.315) among the studied oak species (Table 5) due to changes in MXTWM. Expected reductions in soil water reserves in the distribution area of this species could also foster its progressive substitution in the future by more drought-resistant species such as *Quercus suber* or *Quercus ilex* (Peñuelas et al., 2001). However, previous studies have revealed the great resilience and adaptability of *Quercus faginea* for surviving in extreme conditions, such as those expected in the Mediterranean Basin (Camarero et al., 2015). For this area, a pronounced warming is also predicted, giving rise to higher

rates of evapotranspiration with subsequent decreases in soil water availability and increases in drought episodes (IPCC,2018). Several authors have shown that these new conditions will drastically affect the growth and vitality of the main Mediterranean broadleaf species (Sabaté et al., 2002; Baquedano and Castillo, 2007; Gea-Izquierdo et al. 2013; Gentilesca et al., 2017; Peña-Gallardo et al., 2018). In this context, different adaptation mechanisms such as leaf area reduction may be decisive for these oak species in order to reduce water loss and survive under these new conditions (Peguero-Pina et al., 2016). For *Quercus petraea*, maximum temperatures seemed to be also relevant climatic variables explaining potential reductions on the SDI_{max} (Figure 5) according to the best climate-dependent MSDR models obtained for this species (Table 4). Similar climatic influence was also reported by Michelot et al. (2012), who studied growth dynamics for *Quercus petraea* in France. However, positive impacts on growth (Kellomäki et al., 2008) and seed production (Caignard et al., 2017) could be expected in cold and mild areas, such as boreal and temperate forests, as an effect of global warming. As Spain is the western limit of *Quercus petraea* distribution, future climate change impacts could be more determinant for this oak species. As cited before, differences in SDI_{max} *for Quercus robur* could well be explained by changes in seasonal minimum temperatures (Table 4). However, a small climatic impact on SDI_{max} could be expected for this species linked to potential increments of minimum temperatures, according to its Q index (Table 5). In this study, new climate-dependent MSDR models have been fitted and new SDI_{maxREF} and SDI_{max} *(Clim)* for different broadleaf species have been estimated. However, further studies focused on these species are needed in order to better

672 understand and predict potential changes in the maximum stand carrying
673 capacity under different climate change scenarios.

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702 **Table 6:** Comparison of the MSDR slope and SDI_{maxREF} values obtained for the species studied in this paper
703 and in similar works.
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Functional Group	Species	β_0	SDI_{maxREF}	Area	Statistical analysis	Reference
Conifers	*Pinus halepensis*	-1.881	637	France	SFA	Charru et al., 2012
		-1.777	732	Catalonia	SLR	Brunet-Navarro et al., 2016
		-1.829	619	Spain	QR (97.5th percentile)	Aguirre et al., 2018
		-1.920	780	France	QR	Toigo et al., 2018
		-1.776	***526***	***Spain***	**QR (97.5th percentile)**	***This study***
	Pinus nigra	-1.653	881	France	SFA	Charru et al., 2012
		-1.787	600	Catalonia	SLR	Brunet-Navarro et al., 2016
		-1.794	960	Spain	QR (97.5th percentile)	Aguirre et al., 2018
		-1.810	1181	France	QR	Toigo et al., 2018
		-1.835	***944***	***Spain***	**QR (97.5th percentile)**	***This study***
	Pinus pinaster	-1.711	648	France	SFA	Charru et al., 2012
		-1.929	1104	Spain	QR (95th percentile)	Riofrio et al., 2016
		-1.983	1053	Spain	QR (97.5th percentile)	Aguirre et al., 2018
		-1.860	807	France	QR	Toigo et al., 2018
		-1.906	***1053***	***Spain***	**QR (97.5th percentile)**	***This study***
	Pinus pinea	-1.857	1040	South Spain	SLR	Montero et al., 1998
		-2.122	702	Spain	QR (97.5th percentile)	Aguirre et al., 2018
		-2.186	***683***	***Spain***	**QR (97.5th percentile)**	***This study***
	Pinus sylvestris	-1.750	1444	Central Spain	NLR	Rio et al., 2001
		-1.615	893	France	SFA	Charru et al., 2012
		-1.750	1297	Navarra. Spain	NLR	Condés et al., 2013

		-1.789	1144	Spain	QR (95th percentile)	Riofrio et al., 2016
		-1.647	579	Catalonia. Spain	SLR	Brunet-Navarro et al., 2016
		-1.634	1078	Europe*	NLQR (97.5th percentile)	Condés et al., 2017
		-1.726	1154	Spain	QR (97.5th percentile)	Aguirre et al., 2018
		-2.020	1000	France	QR	Toigo et al., 2018
		-1.752	***1146***	***Spain***	**QR (97.5th percentile)**	***This study***
	Pinus uncinata	-1.665	581	Catalonia	SLR	Brunet-Navarro et al., 2016
		-1.734	***1031***	***Spain***	**QR (97.5th percentile)**	***This study***
	Pinus canariensis	***-1.823***	***903***	***Spain***	**QR (97.5th percentile)**	***This study***
	Pinus radiata	***-1.825***	***1178***	***Spain***	**QR (97.5th percentile)**	***This study***
Broadleaves	*Fagus sylvatica*	-1.941	814	France	SFA	Charru et al., 2012
		-1.943	1184	Europe*	NLQR (97.5th percentile)	Condés et al., 2017
		-1.923	952	Spain	NLQR (97.5th percentile)	Condés et al., 2017
		-1.790	991	France	QR	Toigo et al., 2018
		-1.947	***995***	***Spain***	**QR (97.5th percentile)**	***This study***
	Quercus petraea	-1.911	685	France	SFA	Charru et al., 2012
		-2.080	776	France	QR	Toigo et al., 2018
		-1.678	***969***	***Spain***	**QR (97.5th percentile)**	***This study***
	Quercus robur	-1.758	651	France	SFA	Charru et al., 2012
		-1.540	760	France	QR	Toigo et al., 2018
		-1.670	***787***	***Spain***	**QR (97.5th percentile)**	***This study***
	Quercus faginea	***-1.706***	***740***	***Spain***	**QR (97.5th percentile)**	***This study***
	Quercus ilex	***-2.095***	***319***	***Spain***	**QR (97.5th percentile)**	***This study***
	Quercus pyrenaica	***-1.720***	***840***	***Spain***	**QR (97.5th percentile)**	***This study***
	Quercus suber	***-1.967***	***585***	***Spain***	**QR (97.5th percentile)**	***This study***

Note: SFA – Stochastic Frontier Analysis; QR – Quantile Regression; NLQR – Non-Linear Quantile Regression; SLR – Simple Linear Regression; NLR – Non-Lineal Regression
** Europe: Austria, France, Spain, Germany and Poland*

CONCLUSIONS

In this study, new reference and climate-dependent MSDR models and SDI_{max} values are presented for 15 coniferous and broadleaf Mediterranean tree species. For all of them, a significant climatic influence on the MSDR and the maximum stand carrying capacity was found. Maximum temperatures, especially those related to spring and summer seasons, were found to be key drivers affecting the MSDR in most of the species studied. A general trend linking smaller SDI_{max} values to warmer and drier conditions was found, suggesting that potential increments in temperatures and drought episodes would limit the maximum stand carrying capacity for these species. Climate impact on the maximum stand carrying capacity varied among species. However, according to the proposed Q index, the impact of climate on SDI_{max} was found to be homogeneous among *Quercus* species, while conifers presented greater disparity. All the selected

climate-dependent models improved the goodness of fit over the basic models, highlighting the importance of using specific climatic variables to better characterize climatic impacts on MSDR. The climate-dependent MSDR models presented in this study will allow us to more precisely estimate maximum carrying capacity, providing an advanced tool for managing pure and mixed stands based on current and future climatic conditions in the Mediterranean Basin. Along these lines, further studies that include more tree species and a wider range of specific climatic conditions are necessary to better understand the complex interaction between climate and the potential stocking of Mediterranean forests.

CRediT AUTHOR STATEMENT

Diego Rodríguez de Prado: Conceptualization, Methodology, Formal Analysis, Investigation, Data curation, Visualization, Writing-Original Draft, Writing – Review and Editing. Roberto San Martín: Formal analysis, Writing – Review and Editing. Felipe Bravo: Conceptualization, Writing – Review and Editing, Supervision. Celia Herrero de Aza: Conceptualization, Writing – Review and Editing, Supervision, Project administration.

DECLARATION OF COMPETING INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper

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Supplementary material

Supplementary Table 1 Mean ± standard deviation and range (minimum-maximum) of the climatic variables used to fit the climate-dependent MSDR models for coniferous species

	Pinus canariensis	*Pinus halepensis*	*Pinus nigra*	*Pinus pinea*	*Pinus pinaster*	*Pinus radiata*	*Pinus sylvestris*	*Pinus uncinata*
Plots	1158	6074	2321	4427	1352	874	4082	385
T (ºC)	14.1 ± 1.8 (10-18.9)	14.1 ± 1.5 (10.5-18.1)	10.7 ± 1.1 (6.7-14.3)	12.4 ± 1.6 (7.9-17.4)	14.7 ± 2 (11.3-18.1)	12.6 ± 0.9 (9.5-17.2)	8.7 ± 1.4 (3.6-13.7)	5.2 ± 1 (2.5-7.7)
T1 (ºC)	13.3 ± 2.1 (7.9-18.9)	10.4 ± 1.9 (6.4-16)	7.3 ± 1.2 (3.6-11)	9.2 ± 2 (4.7-15.2)	11.2 ± 2.5 (7.6-16.4)	10.7 ± 1.2 (7-17.2)	5.9 ± 1.4 (1.5-10.4)	3 ± 0.9 (0.7-5.3)
T2 (ºC)	10.4 ± 2.1 (5.2-16.1)	7.7 ± 1.7 (3.4-12.6)	4.3 ± 1.2 (0.3-8.3)	6.6 ± 2.1 (1.6-12.3)	8.6 ± 2.4 (4.9-13.2)	7.9 ± 1.2 (4.2-14.2)	2.8 ± 1.5 (-1.8-7.7)	-0.1 ± 0.9 (-2.5-2.5)
T3 (ºC)	13.8 ± 1.7 (10.2-18.3)	15.9 ± 1.3 (12.2-19.3)	12.1 ± 1.2 (7.1-15.9)	13.7 ± 1.6 (8.9-18.5)	16.3 ± 1.8 (12.9-19.2)	13.3 ± 0.7 (10.6-16.7)	9.8 ± 1.6 (3.1-15.4)	5.3 ± 1.3 (1.5-8.4)
T4 (ºC)	19 ± 1.3 (16-22.7)	22.5 ± 1.3 (18.4-25.5)	19.1 ± 1.3 (13.2-23.1)	19.9 ± 1.9 (15.9-25.3)	22.7 ± 1.8 (19.5-25.7)	18.3 ± 0.7 (15.7-22)	16.4 ± 1.3 (11.1-21.3)	12.6 ± 1.1 (9.5-15.2)
MNT (ºC)	10.5 ± 1.8 (6.2-15.6)	8.2 ± 1.9 (3.9-13.6)	5 ± 1.2 (1.8-9)	7.2 ± 2 (2.4-13.8)	9.1 ± 2.3 (5.4-14.7)	8.6 ± 1 (5.4-13.9)	4 ± 1.3 (0.2-8.5)	1.7 ± 0.8 (-0.6-3.9)
MNT1 (ºC)	9.9 ± 2.2 (5.1-15.8)	5.6 ± 2.2 (1.4-12.6)	2.6 ± 1.2 (-0.3-7.5)	5 ± 2.3 (0.2-11.6)	6.6 ± 2.6 (2.8-13.1)	7.3 ± 1.2 (3.4-14.4)	2 ± 1.2 (-1-6.9)	0.4 ± 0.7 (-1.8-2.5)
MNT2 (ºC)	6.4 ± 2.2 (0.6-12.8)	0.7 ± 2.4 (-4.6-8.2)	-2.3 ± 1.6 (-6.8-3.6)	0.5 ± 3 (-5.5-8.7)	2 ± 3 (-2.1-10)	3.4 ± 1.5 (-0.4-10.4)	-2.7 ± 1.5 (-7.5-3.6)	-4.5 ± 1.2 (-7.7--1.6)
MNT3 (ºC)	9.8 ± 1.7 (5.6-15)	8.9 ± 1.8 (4.2-14.3)	5.5 ± 1.5 (1.6-10)	7.6 ± 2 (2.1-14.5)	9.7 ± 2.2 (6-15.3)	8.8 ± 0.9 (5.7-12.8)	4.2 ± 1.5 (-0.6-9.4)	0.9 ± 1 (-1.5-3.4)
MNT4 (ºC)	15.7 ± 1.3 (13.3-19)	17.7 ± 1.5 (13.2-21)	14.3 ± 1.2 (10.6-18)	15.6 ± 1.7 (12.1-20.2)	18.1 ± 1.8 (14.6-20.6)	14.9 ± 0.6 (12.4-18.1)	12.5 ± 1.1 (8.9-16.9)	9.9 ± 0.8 (7.9-12.2)
MXT (ºC)	17.8 ± 1.8 (12.9-22.7)	20 ± 1.3 (16-23.8)	16.4 ± 1.3 (9.9-20.1)	17.6 ± 1.6 (12.7-23.2)	20.3 ± 1.9 (16.9-24)	16.6 ± 0.9 (13.5-20.6)	13.5 ± 1.7 (6.2-18.9)	8.7 ± 1.4 (4.7-12.2)
MXT1 (ºC)	16.6 ± 2.1 (10.7-22.2)	15.3 ± 1.7 (11.1-20.9)	12 ± 1.3 (6.9-15.6)	13.5 ± 1.7 (8.3-18.8)	15.9 ± 2.5 (11.8-20.4)	14.1 ± 1.2 (10.3-20.3)	9.8 ± 1.7 (3.4-14.9)	5.6 ± 1.3 (2.2-9.1)
MXT2 (ºC)	14.4 ± 2.1 (9-19.8)	14.6 ± 1.4 (10.2-18.4)	11 ± 1.2 (5.5-14.3)	12.7 ± 1.6 (7.3-18)	15.2 ± 2 (11.3-19.2)	12.5 ± 1.1 (8.7-18.1)	8.4 ± 1.7 (1.9-13.6)	4.3 ± 1.1 (1.1-7.1)
MXT3 (ºC)	17.9 ± 1.8 (12.9-22.8)	22.8 ± 1.4 (17.5-26.1)	18.8 ± 1.4 (10.9-23.4)	19.9 ± 1.9 (14.5-26)	22.8 ± 1.7 (19.1-26.5)	17.9 ± 0.9 (14.4-21.7)	15.3 ± 2 (6.5-21.4)	9.7 ± 1.8 (4.5-13.7)
MXT4 (ºC)	22.3 ± 1.4 (17.9-26.7)	27.4 ± 1.3 (22.4-30.8)	23.8 ± 1.6 (15.9-28.2)	24.1 ± 2.2 (19.2-30.7)	27.4 ± 1.9 (23.7-30.9)	21.7 ± 0.8 (18.7-26.5)	20.3 ± 1.7 (13.1-26.1)	15.2 ± 1.6 (10.9-19)
MXTWM (ºC)	23.1 ± 1.4 (18.7-27.3)	28.8 ± 1.3 (23.5-32.1)	25.3 ± 1.8 (17-30)	25.3 ± 2.5 (20-32.1)	28.7 ± 1.9 (24.9-32.3)	22.4 ± 0.8 (19.7-27.7)	21.5 ± 1.7 (14.6-27.2)	16.5 ± 1.5 (12.3-20.3)
MNTCM (ºC)	5.9 ± 2.4 (-0.1-12.6)	-0.9 ± 2.7 (-6.1-7.6)	-3.8 ± 1.5 (-8.1-2.9)	-1 ± 3.2 (-7-7.8)	0.3 ± 3.3 (-4.1-9)	2.5 ± 1.7 (-1.9-10.2)	-3.9 ± 1.3 (-8.2-3)	-5 ± 1.2 (-8.2--2.1)
TAR (ºC)	290.3 ± 2 (285.2-294.6)	302.7 ± 2.9 (289.3-307.3)	302 ± 2.3 (291.9-307.2)	299.3 ± 4.8 (287.6-307.1)	301.4 ± 3 (291.8-306.4)	293 ± 1.7 (285.9-299.6)	298.4 ± 1.9 (290.6-305)	294.6 ± 1.8 (291.4-299.1)
P (mm)	406.8 ± 46.2 (258-516)	453.8 ± 99.6 (273-868)	599.6 ± 126.4 (373-1364)	769.9 ± 436.5 (329-1988)	489.4 ± 108.9 (326-891)	1120.2 ± 214.7 (318-1802)	799.6 ± 187.9 (393-1597)	1222.4 ± 109.8 (683-1474)
P1 (mm)	54.5 ± 6.7 (34.3-69.3)	48.6 ± 13.2 (28-109.7)	59.7 ± 13.6 (28.3-149.7)	90 ± 55.4 (30.3-252)	61.3 ± 17.6 (36.3-121.3)	116.8 ± 25.2 (46-211.7)	80.7 ± 23.2 (31-190.7)	121.9 ± 12.4 (59-153)
P2 (mm)	59.5 ± 7.3 (37-75.7)	35.5 ± 12.2 (18-119.7)	45.8 ± 13.6 (17-128)	76 ± 53.2 (20-236.7)	45.6 ± 16.6 (24-136.3)	100.8 ± 22.6 (45-213)	63 ± 19.7 (21.7-171.3)	96.8 ± 11.6 (47.7-124)
P3 (mm)	15.5 ± 1.7 (9.7-19.7)	42.6 ± 8.9 (15.7-81.7)	59.8 ± 11 (39-115.3)	60.5 ± 23.4 (30-128.3)	39.6 ± 7.4 (27.3-76.3)	91.3 ± 18 (10-119.3)	76.1 ± 13.6 (40-122)	110 ± 8.8 (77-129.7)
P4 (mm)	6.2 ± 0.9 (3.7-9.7)	24.6 ± 12.1 (6-72)	34.7 ± 16.2 (10.7-90.3)	30.1 ± 17.4 (7.3-94.7)	16.7 ± 11.6 (6.3-69.7)	64.5 ± 15.5 (4.7-99.3)	46.8 ± 16.7 (12-86)	78.8 ± 5.3 (44-88)
PWM (mm)	73.4 ± 8.7 (46-90)	59.3 ± 14.5 (37-129)	73 ± 12.6 (43-178)	104.3 ± 64.5 (38-303)	70.3 ± 21.9 (38-147)	129.3 ± 28.8 (63-260)	94 ± 22 (45-220)	131.9 ± 11.8 (91-163)
PDM (mm)	1.1 ± 0.6 (0-2)	13.5 ± 7.7 (0-46)	24.2 ± 11.6 (5-79)	19.5 ± 11.3 (1-83)	9.7 ± 8 (0-46)	53.7 ± 14.9 (0-86)	36.9 ± 13.6 (5-73)	66 ± 4.8 (37-74)
M (mm ºC^{-1})	17 ± 2.9 (9.1-24.9)	18.9 ± 4.5 (10.1-39.8)	29 ± 6.3 (16.7-61.8)	34.2 ± 18.7 (13.3-84.4)	19.8 ± 4 (13.4-36.7)	49.8 ± 9.8 (11.7-81)	43.1 ± 11.7 (18.3-98.6)	81.3 ± 12.1 (40.9-118)
M1 (mm ºC^{-1})	2.4 ± 0.4 (1.3-3.5)	2.4 ± 0.6 (1.3-6)	3.6 ± 0.9 (1.5-8.9)	4.7 ± 2.6 (1.7-12.5)	2.9 ± 0.6 (1.8-5.4)	5.8 ± 1.3 (1.7-10.8)	5.3 ± 1.7 (1.8-13.4)	9.7 ± 1.6 (4.3-14.3)
M2 (mm ºC^{-1})	3 ± 0.6 (1.5-4.6)	2 ± 0.7 (1-7.8)	3.3 ± 1.1 (1.1-8.9)	4.5 ± 2.8 (1.2-12.4)	2.5 ± 0.7 (1.4-6.6)	5.7 ± 1.3 (1.9-11.7)	5.1 ± 1.8 (1.5-12.9)	10 ± 1.9 (4.5-15.4)
M3 (mm ºC^{-1})	0.7 ± 0.1 (0.4-1)	1.7 ± 0.4 (0.7-3.6)	2.8 ± 0.5 (1.6-5.6)	2.7 ± 1 (1.1-5.5)	1.6 ± 0.3 (1-3.3)	4.1 ± 0.8 (0.4-5.3)	4.1 ± 1 (1.8-10.1)	7.7 ± 1.3 (4.6-12.4)
M4 (mm ºC^{-1})	0.2 ± 0 (0.1-0.4)	0.8 ± 0.4 (0.2-2.5)	1.2 ± 0.6 (0.4-3.2)	1.1 ± 0.6 (0.2-3.4)	0.5 ± 0.4 (0.2-2.3)	2.3 ± 0.5 (0.2-3.5)	1.8 ± 0.7 (0.4-4)	3.5 ± 0.4 (1.8-4.5)
PET (mm)	963.8 ± 44.5 (849-1095)	1068.5 ± 96 (817-1298)	974 ± 84.4 (747-1183)	1011.3 ± 131.5 (754-1340)	1129.6 ± 110.9 (827-1370)	839.1 ± 50.6 (748-1116)	860.9 ± 78.4 (592-1132)	640.8 ± 44.6 (522-831)
PET1 (mm)	56 ± 3.5 (47.7-65.7)	45.8 ± 5.5 (32.7-59.7)	38.4 ± 3.8 (28.3-49)	39.8 ± 5 (31-54.7)	46.1 ± 6.2 (33-57.3)	35.9 ± 4.8 (31-61)	32.4 ± 3 (22-46.7)	24.2 ± 1.8 (19.7-32.3)
PET2 (mm)	55.3 ± 3.7 (46-65.7)	47.5 ± 4.9 (35-62)	39.5 ± 3.3 (29.3-50.7)	41.8 ± 4.7 (32.7-56.3)	47.8 ± 5.4 (35.3-59)	38.4 ± 4.2 (32.7-61)	33.7 ± 3 (22-46.7)	24.3 ± 2.2 (18.7-31)
PET3 (mm)	95.9 ± 4.5 (83.7-109)	121.8 ± 8.9 (96.7-145.7)	112.1 ± 7.5 (89-132.3)	116.9 ± 13.7 (88.3-152)	129.8 ± 11.4 (98.3-154.3)	97.2 ± 4.8 (87-122)	100.2 ± 8.3 (69-128.3)	75.2 ± 5.4 (60.3-95.7)
PET4 (mm)	114.1 ± 3.6 (104.3-124.7)	141.1 ± 15.1 (108-178.7)	134.7 ± 14.6 (100-166.3)	138.6 ± 22.1 (92.3-184.7)	152.9 ± 18.3 (108.7-186.3)	108.2 ± 6.8 (92.3-148.7)	120.7 ± 12.9 (84.3-161)	90 ± 5.6 (75.3-121.7)

Supplementary Table 2 Mean ± standard deviation and range (minimum-maximum) of the climatic variables used to fit the climate-dependent MSDR models for broadleaf species.

	Fagus sylvatica	*Quercus faginea*	*Quercus ilex*	*Quercus petraea*	*Quercus pyrenaica*	*Quercus robur*	*Quercus suber*
Plots	1117	685	3609	201	1879	560	687
T (ºC)	9.4 ± 1.3 (5.1-14)	11.2 ± 1.3 (8.2-17.6)	14 ± 2.2 (6.6-17.7)	9.5 ± 1.4 (6.5-14.6)	10.4 ± 1.5 (6-15.7)	12.1 ± 1.2 (6.1-14.5)	15.5 ± 1.3 (11.4-18)
T1 (ºC)	7 ± 1.4 (2.9-12.4)	8 ± 1.2 (5.5-15)	10.5 ± 2.2 (3.4-15.2)	7 ± 1.4 (4-11.3)	7.4 ± 1.5 (3.2-12.2)	10 ± 1.4 (3.8-13.5)	12.7 ± 1.7 (7.8-16.2)
T2 (ºC)	4 ± 1.4 (-0.3-9.6)	5.2 ± 1.2 (2.3-11.9)	7.7 ± 2.2 (0.1-12)	4 ± 1.4 (1-8.7)	4.7 ± 1.6 (0.1-9.7)	7.5 ± 1.4 (0.8-11)	9.8 ± 1.6 (5.3-13.1)
T3 (ºC)	10.4 ± 1.5 (5.2-14.5)	12.6 ± 1.4 (9.1-18.4)	15.5 ± 2.2 (7.6-19.1)	10.6 ± 1.6 (6.8-16.1)	11.6 ± 1.6 (6.9-17.2)	12.9 ± 1.2 (6.2-15.8)	16.7 ± 1.1 (12.9-18.9)
T4 (ºC)	16.2 ± 1.2 (12.5-19.4)	19 ± 1.7 (15.7-25)	22.4 ± 2.3 (14.5-25.7)	16.3 ± 1.5 (13.2-22.2)	17.9 ± 1.7 (13.3-24.3)	17.8 ± 1 (13.5-20.5)	23 ± 1.2 (18.3-25.9)
MNT (ºC)	5.3 ± 1.2 (1.6-10.3)	5.8 ± 1.3 (2.7-11.9)	8.2 ± 2.1 (2-13.3)	5.2 ± 1.1 (2.7-9.4)	5.6 ± 1.5 (1.8-10.3)	7.8 ± 1.1 (2.5-11.2)	10.5 ± 1.6 (6.1-14.4)
MNT1 (ºC)	3.4 ± 1.3 (0.1-8.8)	3.5 ± 1.3 (0.6-10.3)	5.8 ± 2.2 (0.4-11.4)	3.3 ± 1.1 (0.8-6.9)	3.4 ± 1.5 (-0.4-8)	6.4 ± 1.3 (0.9-10.5)	8.5 ± 1.8 (3.9-12.3)
MNT2 (ºC)	-0.8 ± 1.4 (-4.9-5.9)	-1 ± 1.4 (-4.8-6.5)	0.8 ± 2.2 (-6.4-7.7)	-0.9 ± 1.3 (-4-3.9)	-1 ± 1.7 (-5.9-4.5)	2.6 ± 1.5 (-4-7.5)	4 ± 2.3 (-1.3-9.9)
MNT3 (ºC)	5.7 ± 1.4 (0.9-10.7)	6.4 ± 1.4 (2.7-12.6)	8.6 ± 2 (1.3-13.9)	5.6 ± 1.3 (2.7-10.6)	6 ± 1.5 (1.8-10.7)	8 ± 1.2 (1.8-11.3)	10.9 ± 1.6 (6.3-15.2)
MNT4 (ºC)	12.7 ± 1 (10.1-15.8)	14.5 ± 1.6 (11.5-20.3)	17.7 ± 2.2 (10.8-20.6)	12.7 ± 1.1 (10.7-17.3)	13.9 ± 1.6 (10.6-20)	14.2 ± 0.8 (10.9-16.2)	18.8 ± 1.1 (14.3-20.7)
MXT (ºC)	13.5 ± 1.6 (8.6-18.3)	16.6 ± 1.6 (12.9-23.5)	19.8 ± 2.4 (11.2-24)	13.8 ± 1.9 (9.8-19.8)	15.3 ± 1.7 (9.8-21.3)	16.4 ± 1.4 (9.6-19.2)	20.6 ± 1.4 (16.6-24.2)
MXT1 (ºC)	10.5 ± 1.6 (5.4-16)	12.5 ± 1.3 (9.7-19.7)	15.1 ± 2.3 (6.3-19.9)	10.6 ± 1.8 (6.9-16.3)	11.4 ± 1.6 (6.1-16.8)	13.7 ± 1.5 (6.4-16.8)	16.9 ± 1.7 (11.7-20.1)
MXT2 (ºC)	8.7 ± 1.6 (4-14.3)	11.5 ± 1.4 (7.6-19)	14.7 ± 2.4 (6.4-19.1)	9 ± 1.8 (5.6-14.2)	10.4 ± 1.8 (5.1-16.3)	12.5 ± 1.6 (5.3-15.3)	15.6 ± 1.5 (11.8-19.4)
MXT3 (ºC)	15.2 ± 1.7 (9.4-19.4)	18.9 ± 1.8 (14.5-25.6)	22.5 ± 2.5 (13.1-26.3)	15.5 ± 2.1 (10.8-21.6)	17.3 ± 1.9 (11.1-23.7)	17.9 ± 1.4 (10.7-21.5)	22.5 ± 1.5 (19.1-26.5)
MXT4 (ºC)	19.8 ± 1.4 (14.8-23.4)	23.5 ± 2 (19.6-30.2)	27 ± 2.5 (18.1-31.2)	20 ± 2 (15.6-27.1)	21.9 ± 1.9 (16.1-28.6)	21.4 ± 1.2 (16.2-24.8)	27.2 ± 1.5 (22.3-31.1)
MXTWM (ºC)	20.8 ± 1.4 (15.9-24.1)	24.7 ± 2.1 (20.7-31.7)	28.4 ± 2.5 (19.4-32.7)	21 ± 1.9 (16.7-28.3)	23 ± 2 (17.3-30)	22.2 ± 1.1 (17.5-25.5)	28.3 ± 1.5 (22.9-32.2)
MNTCM (ºC)	-1.9 ± 1.3 (-5.7-5.2)	-2.7 ± 1.4 (-5.9-5.4)	-0.9 ± 2.2 (-7.2-6.6)	-2 ± 1.1 (-5.1-2.7)	-2.4 ± 1.7 (-7.5-4.1)	1.5 ± 1.6 (-5.1-6.8)	2.7 ± 2.5 (-3.2-8.9)
TAR (ºC)	295.7 ± 1.5 (290.9-299.4)	300.4 ± 2.4 (294-306.5)	302.3 ± 2 (290.4-307.4)	296 ± 2 (292.2-300.5)	298.4 ± 2.2 (290.1-303.9)	293.6 ± 1.4 (288-298)	298.5 ± 3.1 (292.6-304.8)
P (mm)	1009.1 ± 122.6 (702-1396)	643.4 ± 173.2 (381-1041)	557.8 ± 142.3 (317-1567)	927 ± 155.5 (492-1405)	764.5 ± 244 (339-1763)	1371.7 ± 274.7 (753-1827)	683.8 ± 137.1 (359-1665)
P1 (mm)	101.2 ± 12.7 (68.7-161.3)	65.7 ± 17.9 (32-129)	67.9 ± 19.4 (30.7-199.7)	95.3 ± 21.6 (47.3-162.7)	86.8 ± 33.6 (37-218)	158 ± 40.8 (80.3-220.7)	89.3 ± 21.1 (40-205)
P2 (mm)	85.6 ± 12.6 (53.3-135)	52 ± 17.8 (20.3-119.7)	52.7 ± 18.5 (20.7-169.7)	77.1 ± 18.9 (39.3-138.3)	70.8 ± 30.3 (25.7-194.7)	139.6 ± 41.1 (64.3-216.7)	76.8 ± 27.7 (25.3-182.7)
P3 (mm)	90.5 ± 8.9 (67.7-117.7)	61.3 ± 14.4 (32.7-93.7)	46 ± 11.4 (30.3-99.7)	81.8 ± 9.9 (51-107)	65.1 ± 13.5 (30.7-114.7)	98.5 ± 10.7 (62.3-122.3)	43.6 ± 10.4 (29.7-108)
P4 (mm)	59.1 ± 9.5 (35-93.7)	35.5 ± 14.2 (7.7-76)	19.4 ± 13.2 (7.3-77)	54.7 ± 10.9 (26-85)	32.1 ± 11.1 (11-71.3)	61.1 ± 8.6 (39.7-102)	18.2 ± 16.6 (7-65)
PWM (mm)	109.1 ± 11.9 (84-174)	74.9 ± 18.4 (42-159)	78.5 ± 23.3 (38-216)	104.9 ± 20.1 (58-176)	98.4 ± 37.3 (40-251)	179.1 ± 51.8 (88-268)	105.7 ± 25.5 (44-240)
PDM (mm)	51.7 ± 8.3 (26-80)	28.7 ± 12.9 (1-59)	12 ± 10.9 (1-64)	45.1 ± 8.2 (19-71)	24.7 ± 10.5 (5-59)	43.5 ± 11.2 (22-87)	8.2 ± 10.8 (0-42)
M (mm ºC^{-1})	52.1 ± 6.4 (40-82.7)	30.5 ± 8.8 (16.9-53.8)	23.5 ± 7.1 (12.5-65.8)	47.9 ± 9.4 (24.7-81.1)	37.6 ± 11.9 (14.1-80.2)	62.2 ± 12.1 (37.3-83.9)	26.9 ± 5.8 (14-72.9)
M1 (mm ºC^{-1})	6.2 ± 0.8 (4.3-10.4)	3.7 ± 1 (1.8-7)	3.4 ± 1 (1.6-9.6)	5.8 ± 1.5 (2.9-11.4)	5.2 ± 1.9 (1.8-11.5)	8.1 ± 2.1 (4.3-11.8)	4 ± 0.9 (2-10)
M2 (mm ºC^{-1})	6.2 ± 1 (3.7-11)	3.5 ± 1.1 (1.3-7.4)	3.1 ± 1.1 (1.3-9.9)	5.6 ± 1.5 (2.6-11.5)	4.9 ± 1.9 (1.5-11.8)	8 ± 2.3 (4-12.1)	3.9 ± 1.3 (1.4-10)
M3 (mm ºC^{-1})	4.6 ± 0.5 (3.5-8.2)	2.8 ± 0.8 (1.2-4.8)	1.9 ± 0.6 (1.1-5.3)	4.2 ± 0.7 (2.5-6.2)	3.2 ± 0.8 (1.2-6.4)	4.5 ± 0.5 (2.5-7.1)	1.7 ± 0.5 (1.1-4.7)
M4 (mm ºC^{-1})	2.3 ± 0.3 (1.4-3.7)	1.3 ± 0.5 (0.2-2.9)	0.6 ± 0.5 (0.2-3)	2.1 ± 0.4 (1-3.3)	1.2 ± 0.4 (0.4-2.6)	2.2 ± 0.3 (1.5-3.6)	0.6 ± 0.5 (0.2-2.3)
PET (mm)	848.4 ± 41.8 (645-937)	957.5 ± 93.7 (782-1332)	1132.9 ± 132.6 (719-1373)	850.8 ± 45.9 (727-952)	963.6 ± 80 (748-1215)	860.1 ± 47.6 (674-982)	1094.3 ± 125.3 (837-1379)
PET1 (mm)	32.7 ± 2.1 (24.3-38)	36.8 ± 3.9 (29.3-54)	44.8 ± 6.4 (27-57)	32.7 ± 2 (27.7-38)	35.9 ± 3.2 (28.3-48.3)	35.1 ± 1.7 (25.3-39.3)	47.8 ± 5.8 (34-58)
PET2 (mm)	34 ± 2.5 (24.3-41)	38.5 ± 4 (31.3-55.7)	46.6 ± 6 (28.3-59)	33.9 ± 2.4 (28.7-39)	37.5 ± 3.5 (29-49.7)	37.9 ± 2.2 (26-42.7)	49.4 ± 5.5 (36-59.7)
PET3 (mm)	99.1 ± 4.8 (76-109.7)	111.7 ± 10.1 (92.7-150.7)	130.1 ± 13.8 (85-154.7)	100 ± 5.2 (86-111)	112.1 ± 8.8 (87.7-140.7)	101 ± 5.9 (79.7-117)	123.5 ± 13.7 (99.3-155)
PET4 (mm)	117 ± 5.9 (90.3-129.7)	132.2 ± 14.3 (102.7-183.7)	156.2 ± 19 (99.3-187)	117 ± 6.9 (100-136)	135.7 ± 11.9 (96.3-172.3)	112.7 ± 7.7 (91-131)	144 ± 21.8 (109.3-187)

Supplementary Table 3: Species-specific coefficients, goodness of fits in terms of Akaike's Information Criterion (AIC) and pseudo-R^2 coefficient and SDI_{max} estimations for the basic MSDR models fitted by linear quantile regression at the 95th and 99th quantiles.

Functional group	Species	tau	α_0	β_0	SDI_{max}	AIC	pseudo-R^2
Coniferous	*Pinus canariensis*	0.95	12.694 ***	-1.8631 ***	810	2514.7	0.3210
		0.99	12.493 ***	-1.7431 ***	975	2710.5	0.3676
	Pinus halepensis	0.95	11.971 ***	-1.8037 ***	476	12307.3	0.3151
		0.99	11.738 ***	-1.6708 ***	578	12867.2	0.3665
	Pinus nigra	0.95	12.516 ***	-1.7924 ***	851	4807.8	0.2971
		0.99	12.892 ***	-1.8327 ***	1089	5484.2	0.2965
	Pinus pinaster	0.95	13.213 ***	-1.9787 ***	938	10046.5	0.2744
		0.99	13.065 ***	-1.8502 ***	1223	11170.9	0.2724
	Pinus pinea	0.95	13.645 ***	-2.2517 ***	600	3002.5	0.3876
		0.99	13.558 ***	-2.1227 ***	833	3599.1	0.3769
	Pinus radiata	0.95	12.498 ***	-1.7161 ***	1069	1305.9	0.3624
		0.99	13.233 ***	-1.8652 ***	1379	1571.5	0.3846
	Pinus sylvestris	0.95	12.471 ***	-1.7118 ***	1055	7229.2	0.3550
		0.99	12.736 ***	-1.7337 ***	1281	8307.9	0.3794
	Pinus uncinata	0.95	13.332 ***	-2.0183 ***	930	539.7	0.4171
		0.99	12.197 ***	-1.6159 ***	1092	572.0	0.4470
Broadleaf	*Fagus sylvatica*	0.95	13.283 ***	-2.0057 ***	922	1435.9	0.5188
		0.99	13.030 ***	-1.8756 ***	1089	1774.1	0.4990
	Quercus faginea	0.95	12.307 ***	-1.8437 ***	585	1902.5	0.2057
		0.99	12.224 ***	-1.6850 ***	898	2129.0	0.1389
	Quercus ilex	0.95	12.483 ***	-2.1209 ***	286	7723.4	0.5099
		0.99	12.439 ***	-2.0294 ***	367	8503.5	0.4919
	Quercus petraea	0.95	12.077 ***	-1.6479 ***	874	387.8	0.3990
		0.99	12.974 ***	-1.8351 ***	1173	479.4	0.3702
	Quercus pyrenaica	0.95	12.291 ***	-1.7838 ***	699	4565.1	0.2974
		0.99	12.182 ***	-1.6603 ***	932	4848.3	0.3151
	Quercus robur	0.95	12.241 ***	-1.7466 ***	749	965.7	0.4265
		0.99	12.066 ***	-1.6576 ***	837	1101.9	0.4214
	Quercus suber	0.95	12.530 ***	-1.9372 ***	542	1272.9	0.4834
		0.99	12.319 ***	-1.8162 ***	647	1424.5	0.4731

****p<0.001; **p<0.01; *p<0.05*

Supplementary Table 4.1: Climate-dependent MSDR models for ***Pinus canariensis*** fitted at the 97.5th quantile arranged by AIC

model	α_0	α_1	β_0	β_1	AIC	pseudo-R^2
T	107.072 ***	-16.757 ***	-1.6999 ***	-	2524.8	0.3642
T1	76.138 ***	-11.314 ***	-1.6712 ***	-	2554.2	0.3560
T2	81.878 ***	-12.343 ***	-1.6815 ***	-	2547.8	0.3578
T3	126.032 ***	-20.086 ***	-1.7406 ***	-	2502.1	0.3704
T4	206.414 ***	-34.143 ***	-1.8183 ***	-	2447.6	0.3850
MNT	96.203 ***	-14.857 ***	-1.7213 ***	-	2546.1	0.3583
MNT1	79.203 ***	-11.873 ***	-1.6778 ***	-	2559.4	0.3546
MNT2	68.779 ***	-10.070 ***	-1.6443 ***	-	2575.4	0.3501
MNT3	12.204 ***	-	3.2524 ***	-0.0175 ***	2542.7	0.3592
MNT4	159.366 ***	-25.941 ***	-1.7586 ***	-	2473.7	0.3781
MXT	111.833 ***	-17.545 ***	-1.7230 ***	-	2513.5	0.3673
MXT1	83.453 ***	-12.568 ***	-1.6919 ***	-	2555.3	0.3558
MXT2	96.515 ***	-14.864 ***	-1.7412 ***	-	2524.3	0.3643
MXT3	137.266 ***	-21.979 ***	-1.8149 ***	-	2478.6	0.3767
MXT4	192.808 ***	-31.680 ***	-1.8256 ***	-	2482.7	0.3756
MXTWM	231.904 ***	-38.519 ***	-1.8596 ***	-	2466.4	0.3800
MNTCM	261.436 **	-44.206 *	-12.8800 *	0.0398 *	2582.9	0.3486
TAR	-552.597 *	99.707 *	28.9155 *	-0.1061 *	2600.4	0.3436
P	13.161 ***	-	-2.6082 ***	0.0015 ***	2364.4	0.4067
P1	3.639 ***	2.448 ***	-2.0891 ***	-	2320.8	0.4178
P2	12.989 ***	-	-2.3961 ***	0.0075 ***	2420.9	0.3921
P3	12.954 ***	-	-2.2695 ***	0.0217 ***	2447.3	0.3851
P4	11.513 ***	0.739 ***	-1.8848 ***	-	2528.0	0.3633
PWM	4.176 ***	2.059 ***	-1.9567 ***	-	2347.4	0.4111
PDM	13.025 ***	0.071 **	-1.8108 ***	-0.1100 ***	2555.4	0.3563
M	10.028 ***	0.940 ***	-1.8486 ***	-	2435.8	0.3882
M1	11.738 ***	1.061 ***	-1.8500 ***	-	2431.5	0.3893
M2	12.005 ***	0.544 ***	-1.8100 ***	-	2488.1	0.3742
M3	12.646 ***	-	-2.0458 ***	0.3009 ***	2452.8	0.3836
M4	13.555 ***	0.576 ***	-1.8333 ***	-	2509.1	0.3685
PET	37.144 ***	-3.559 ***	-1.8398 ***	-	2488.2	0.3741
PET1	22.219 ***	-2.401 ***	-1.7990 ***	-	2496.4	0.3719
PET2	20.601 ***	-2.013 ***	-1.7907 ***	-	2499.1	0.3712
PET3	27.754 ***	-3.298 ***	-1.8447 ***	-	2504.4	0.3698
PET4	50.420 ***	-7.841 ***	-2.0254 ***	-	2479.2	0.3766

****p<0.001; **p<0.01; *p<0.05*

Supplementary Table 4.2: Climate-dependent MSDR models for ***Pinus halepensis*** fitted at the 97.5th quantile arranged by AIC

model	α_0	α_1	β_0	β_1	AIC	pseudo-R^2
T	262.676 **	-44.319 **	-14.2340 *	0.0435 *	12539.9	0.3435
T1	234.196 **	-39.372 **	-13.7142 **	0.0423 **	12598.1	0.3403
T2	236.144 **	-39.788 **	-13.6817 **	0.0426 **	12588.7	0.3408
T3	378.851 ***	-64.788 ***	-19.9687 ***	0.0632 ***	12491.2	0.3461
T4	367.474 ***	-62.531 ***	-18.0298 **	0.0552 **	12431.1	0.3493
MNT	223.305 ***	-37.485 ***	-13.5951 ***	0.0421 ***	12605.5	0.3399
MNT1	124.575 **	-20.006 *	-8.0578 **	0.0226 *	12617.0	0.3393
MNT2	-	-	-	-	-	-
MNT3	210.862 ***	-35.261 ***	-13.0329 ***	0.0400 **	12606.1	0.3399
MNT4	406.012 ***	-69.505 ***	-22.6423 ***	0.0720 ***	12525.2	0.3442
MXT	96.070 ***	-14.848 ***	-1.7000 ***	-	12406.5	0.3505
MXT1	49.417 ***	-6.642 ***	-1.7142 ***	-	12572.9	0.3416
MXT2	78.396 ***	-11.777 ***	-1.6945 ***	-	12448.3	0.3483
MXT3	96.948 ***	-14.977 ***	-1.7045 ***	-	12368.1	0.3526
MXT4	105.595 ***	-16.445 ***	-1.7171 ***	-	12383.7	0.3517
MXTWM	100.504 ***	-15.542 ***	-1.7134 ***	-	12394.4	0.3512
MNTCM	-	-	-	-	-	-
TAR	31.561 ***	-3.436 ***	-1.7624 ***	-	12562.0	0.3421
P	10.155 ***	0.280 ***	-1.7468 ***	-	12412.3	0.3502
P1	11.330 ***	0.155 ***	-1.7620 ***	-	12518.5	0.3445
P2	11.966 ***	-	-1.8124 ***	0.0010 ***	12530.6	0.3438
P3	10.919 ***	0.231 ***	-1.7162 ***	-	12497.5	0.3456
P4	12.249 ***	-0.117 *	-1.8022 ***	0.0022 **	12527.8	0.3441
PWM	8.722 ***	0.784 ***	-1.6057 ***	-0.0026 *	12401.9	0.3509
PDM	12.074 ***	-0.108 ***	-1.7813 ***	0.0043 ***	12510.0	0.3451
M	9.241 ***	0.886 ***	-1.5559 ***	-0.0095 **	12325.5	0.3549
M1	11.764 ***	0.216 ***	-1.7732 ***	-	12459.3	0.3477
M2	11.871 ***	0.157 ***	-1.7808 ***	-	12492.2	0.3459
M3	11.632 ***	0.227 ***	-1.7060 ***	-	12476.9	0.3467
M4	11.827 ***	-	-1.7531 ***	0.0295 ***	12533.5	0.3437
PET	28.421 ***	-2.389 *	-2.3564 ***	0.0006 *	12466.9	0.3474
PET1	13.155 ***	-0.378 ***	-1.6926 ***	-	12486.4	0.3462
PET2	13.676 ***	-0.505 ***	-1.6990 ***	-	12446.1	0.3484
PET3	24.672 ***	-2.670 **	-2.4245 ***	0.0056 *	12467.3	0.3474
PET4	25.074 ***	-2.671 ***	-2.5475 ***	0.0057 **	12498.1	0.3457

****p<0.001; **p<0.01; *p<0.05*

Supplementary Table 4.3: Climate-dependent MSDR models for ***Pinus nigra*** fitted at the 97.5th quantile arranged by AIC

model	α_0	α_1	β_0	β_1	AIC	pseudo-R^2
T	871.072 ***	-151.945 ***	-48.8820 ***	0.1657 ***	5074.5	0.3036
T1	-	-	-	-	-	-
T2	-	-	-	-	-	-
T3	815.154 ***	-141.912 ***	-44.8688 ***	0.1507 ***	5066.2	0.3048
T4	119.527 ***	-18.797 ***	-1.8521 ***	-	5063.2	0.3050
MNT	-	-	-	-		
MNT1	568.796 ***	-98.980 ***	-35.8929 ***	0.1237 ***	5087.6	0.3016
MNT2	12.811 ***	-	-3.8799 ***	0.0075 **	5104.9	0.2987
MNT3	512.297 *	-88.755 *	-31.7062 *	0.1074 *	5089.2	0.3014
MNT4	748.493 **	-129.947 **	-40.9041 **	0.1358 **	5083.3	0.3023
MXT	154.667 ***	-24.995 ***	-1.9154 ***	-	5028.5	0.3102
MXT1	573.278 **	-99.152 **	-32.7777 **	0.1085 *	5085.6	0.3019
MXT2	13.019 ***	-	5.7005 ***	-0.0268 ***	5046.7	0.3075
MXT3	140.953 ***	-22.536 ***	-1.9324 ***	-	5010.9	0.3128
MXT4	104.610 ***	-16.094 **	-1.9119 ***	-	5045.9	0.3076
MXTWM	93.760 ***	-14.174 **	-1.9164 ***	-	5057.3	0.3059
MNTCM	12.800 ***	-	-4.1847 ***	0.0087 **	5100.9	0.2993
TAR	53.820 **	-7.171 *	-1.8746 ***	-	5067.2	0.3044
P	-	-	-	-	-	-
P1	11.568 ***	0.347 ***	-1.9117 ***	-	5056.4	0.3060
P2	11.821 ***	0.290 ***	-1.8973 ***	-	5047.8	0.3073
P3	-	-	-	-	-	-
P4	-	-	-	-	-	-
PWM	12.803 ***	-	-1.9221 ***	0.0010 *	5096.1	0.3001
PDM	-	-	-	-	-	-
M	11.963 ***	0.268 **	-1.8700 ***	-	5072.0	0.3037
M1	12.447 ***	0.334 ***	-1.8756 ***	-	5048.1	0.3072
M2	12.575 ***	0.282 ***	-1.8877 ***	-	5050.5	0.3069
M3	12.807 ***	-	-1.9221 ***	0.0246 *	5085.0	0.3017
M4	-	-	-	-	-	-
PET	-	-	-	-	-	-
PET1	-	-	-	-	-	-
PET2	-	-	-	-	-	-
PET3	-	-	-	-	-	-
PET4	-	-	-	-	-	-

****p<0.001; **p<0.01; *p<0.05*

Supplementary Table 4.4: Climate-dependent MSDR models for ***Pinus pinaster*** fitted at the 97.5th quantile arranged by AIC

model	α_0	α_1	β_0	β_1	AIC	pseudo-R^2
T	13.283 ***	-	3.6017 ***	-0.0195 ***	10357.7	0.2909
T1	70.461 ***	-10.167 ***	-1.9061 ***	-	10445.6	0.2838
T2	346.791 *	-59.217 *	-17.0639 *	0.0541 *	10449.5	0.2836
T3	13.324 ***	-	3.9110 ***	-0.0206 ***	10296.4	0.2958
T4	13.362 ***	-	2.8886 ***	-0.0167 ***	10360.4	0.2906
MNT	-	-	-	-		
MNT1	329.208 ***	-56.126 **	-16.9772 **	0.0539 **	10523.2	0.2777
MNT2	333.907 ***	-57.140 ***	-17.7443 ***	0.0577 **	10522.1	0.2777
MNT3	74.361 ***	-10.863 ***	-1.9146 ***	-	10458.3	0.2828
MNT4	-435.827 **	79.282 **	26.8313 ***	-0.0998 ***	10430.3	0.2852
MXT	13.446 ***	-	4.1770 ***	-0.0213 ***	10229.0	0.3011
MXT1	99.279 ***	-15.226 ***	-1.9214 ***	-	10335.1	0.2927
MXT2	13.389 ***	-	3.3318 ***	-0.0187 ***	10317.1	0.2941
MXT3	13.365 ***	-	3.5759 ***	-0.0190 ***	10241.6	0.3001
MXT4	13.462 ***	-	2.6955 ***	-0.0159 ***	10307.5	0.2949
MXTWM	13.492 ***	-	2.3540 ***	-0.0147 ***	10329.3	0.2931
MNTCM	341.604 ***	-58.565 ***	-18.3189 ***	0.0601 ***	10531.9	0.2769
TAR	-440.516 ***	79.590 ***	23.5515 ***	-0.0852 ***	10489.8	0.2804
P	-	-	-	-	-	-
P1	-	-	-	-	-	-
P2	-	-	-	-	-	-
P3	8.636 ***	1.167 ***	-1.6924 ***	-0.0048 ***	10517.0	0.2782
P4	11.446 ***	0.556 ***	-1.8094 ***	-0.0048 ***	10492.2	0.2802
PWM	-	-	-	-	-	-
PDM	13.124 ***	0.106 ***	-2.0045 ***	-	10513.0	0.2783
M	11.641 ***	0.489 **	-1.8491 ***	-0.0035 **	10542.3	0.2761
M1	-	-	-	-	-	-
M2	-	-	-	-	-	-
M3	-	-	-	-	-	-
M4	12.712 ***	0.866 **	-1.8330 ***	-0.0752 **	10483.1	0.2809
PET	13.329 ***	0.461 ***	-1.8409 ***	-0.1135 ***	10475.7	0.2815
PET1	13.246 ***	-	-1.8523 ***	-0.0001 *	10569.4	0.2737
PET2	13.306 ***	-	-1.7219 ***	-0.0062 ***	10432.2	0.2849
PET3	13.340 ***	-	-1.7265 ***	-0.0061 ***	10430.2	0.2850
PET4	-27.039 ***	8.433 ***	0.7719 *	-0.0228 ***	10403.1	0.2874

****p<0.001; **p<0.01; *p<0.05*

Supplementary Table 4.5: Climate-dependent MSDR models for ***Pinus pinea*** fitted at the 97.5th quantile arranged by AIC

model	α_0	α_1	β_0	β_1	AIC	pseudo-R^2
T	-	-	-	-	-	-
T1	-	-	-	-	-	-
T2	13.505 ***	-	-4.4234 ***	0.0080 *	3257.7	0.3921
T3	-	-	-	-	-	-
T4	-	-	-	-	-	-
MNT	-	-	-	-		
MNT1	13.650 ***	-	-4.5010 ***	0.0082 *	3250.2	0.3938
MNT2	13.763 ***	-	-4.7594 ***	0.0091 ***	3235.8	0.3970
MNT3	13.565 ***	-	-5.1013 ***	0.0103 **	3245.7	0.3948
MNT4	-	-	-	-	-	-
MXT	-	-	-	-	-	-
MXT1	-	-	-	-	-	-
MXT2	-	-	-	-	-	-
MXT3	-	-	-	-	-	-
MXT4	-	-	-	-	-	-
MXTWM	-	-	-	-	-	-
MNTCM	-29.493 *	7.684 **	-2.2089 ***	-	3228.5	0.3986
TAR	77.368 **	-11.127 *	-2.2790 ***	-	3213.2	0.4020
P	13.213 ***	-	-2.2271 ***	0.0003 **	3210.7	0.4026
P1	-	-	-	-	-	-
P2	-	-	-	-	-	-
P3	13.465 ***	-	-2.4048 ***	0.0063 ***	3226.9	0.3990
P4	15.072 ***	-0.460 *	-2.4379 ***	0.0093 ***	3139.5	0.4185
PWM	-	-	-	-	-	-
PDM	14.023 ***	-	-2.3647 ***	0.0039 *	3228.1	0.3987
M	13.304 ***	-	-2.2518 ***	0.0077 *	3216.7	0.4013
M1	-	-	-	-	-	-
M2	-	-	-	-	-	-
M3	13.649 ***	-	-2.3483 ***	0.0875 *	3249.1	0.3940
M4	13.531 ***	-0.467 **	-2.4556 ***	0.2919 ***	3144.0	0.4176
PET	20.341 ***	-0.887 *	-2.3588 ***	-	3232.4	0.3978
PET1	-	-	-	-	-	-
PET2	-	-	-	-	-	-
PET3	14.074 ***	-	-2.0350 ***	-0.0024 *	3238.5	0.3964
PET4	17.595 ***	-0.713 **	-2.3301 ***	-	3226.0	0.3992

****p<0.001; **p<0.01; *p<0.05*

Supplementary Table 4.6: Climate-dependent MSDR models for ***Pinus radiata*** fitted at the 97.5th quantile arranged by AIC

model	α_0	α_1	β_0	β_1	AIC	pseudo-R^2
T	-	-	-	-	-	-
T1	-	-	-	-	-	-
T2	-	-	-	-	-	-
T3	-	-	-	-	-	-
T4	-	-	-	-	-	-
MNT	-	-	-	-	-	-
MNT1	-	-	-	-	-	-
MNT2	-	-	-	-	-	-
MNT3	-	-	-	-	-	-
MNT4	-	-	-	-	-	-
MXT	-	-	-	-	-	-
MXT1	-	-	-	-	-	-
MXT2	-	-	-	-	-	-
MXT3	-	-	-	-	-	-
MXT4	-	-	-	-	-	-
MXTWM	-	-	-	-	-	-
MNTCM	-	-	-	-	-	-
TAR	-	-	-	-	-	-
P	-	-	-	-	-	-
P1	-	-	-	-	-	-
P2	-	-	-	-	-	-
P3	-	-	-	-	-	-
P4	-	-	-	-	-	-
PWM	-	-	-	-	-	-
PDM	-	-	-	-	-	-
M	-	-	-	-	-	-
M1	-	-	-	-	-	-
M2	-	-	-	-	-	-
M3	-	-	-	-	-	-
M4	-	-	-	-	-	-
PET	-	-	-	-	-	-
PET1	6.920 **	1.675 *	-1.3894 ***	-0.0119 **	1421.2	0.3778
PET2	-	-	-	-	-	-
PET3	110.968 ***	-21.507 ***	-8.0490 ***	0.0652 ***	1402.4	0.3845
PET4	88.959 ***	-16.269 **	-6.5496 ***	0.0441 **	1409.2	0.3821

****p<0.001; **p<0.01; *p<0.05*

Supplementary Table 4.7: Climate-dependent MSDR models for ***Pinus sylvestris*** fitted at the 97.5th quantile arranged by AIC

model	α_0	α_1	β_0	β_1	AIC	pseudo-R^2
T	-	-	-	-	-	-
T1	-	-	-	-	-	-
T2	-	-	-	-	-	-
T3	-	-	-	-	-	-
T4	55.518 **	-7.547 *	-1.7711 ***	-	7697.6	0.3698
MNT	-	-	-	-		
MNT1	-	-	-	-	-	-
MNT2	322.444 *	-55.329 *	-21.8988 *	0.0746 *	7673.7	0.3718
MNT3	-	-	-	-	-	-
MNT4	-	-	-	-	-	-
MXT	65.896 ***	-9.391 ***	-1.7774 ***	-	7664.1	0.3724
MXT1	54.869 ***	-7.463 ***	-1.7703 ***	-	7679.3	0.3712
MXT2	41.879 **	-5.164 *	-1.7745 ***	-	7696.3	0.3699
MXT3	58.945 ***	-8.154 ***	-1.7767 ***	-	7653.0	0.3732
MXT4	71.686 ***	-10.376 ***	-1.7699 ***	-	7643.9	0.3739
MXTWM	74.540 ***	-10.872 ***	-1.7675 ***	-	7637.6	0.3744
MNTCM	617.791 ***	-108.147 ***	-40.0934 ***	0.1425 ***	7630.1	0.3751
TAR	66.470 ***	-9.442 ***	-1.7478 ***	-	7594.7	0.3777
P	-	-	-	-	-	-
P1	-	-	-	-	-	-
P2	12.110 ***	0.107 **	-1.7104 ***	-	7675.6	0.3715
P3	-	-	-	-	-	-
P4	-	-	-	-	-	-
PWM	-	-	-	-	-	-
PDM	-	-	-	-	-	-
M	12.579 ***	-	-1.7462 ***	0.0007 *	7704.4	0.3693
M1	12.390 ***	0.107 **	-1.7119 ***	-	7684.3	0.3708
M2	12.375 ***	0.115 ***	-1.7107 ***	-	7670.7	0.3719
M3	-	-	-	-	-	-
M4	-	-	-	-	-	-
PET	-	-	-	-	-	-
PET1	12.675 ***	-	-1.6454 ***	-0.0031 *	7709.1	0.3689
PET2	-	-	-	-	-	-
PET3	-	-	-	-	-	-
PET4	-	-	-	-	-	-

****p<0.001; **p<0.01; *p<0.05*

Supplementary Table 4.8: Climate-dependent MSDR models for ***Pinus uncinata*** fitted at the 97.5th quantile arranged by AIC

model	α_0	α_1	β_0	β_1	AIC	pseudo-R^2
T	65.799 ***	-9.413 **	-1.8310 ***	-	541.6	0.4536
T1	72.583 **	-10.637 *	-1.8259 ***	-	542.5	0.4530
T2	62.186 **	-8.808 *	-1.8206 ***	-	550.6	0.4472
T3	-	-	-	-	-	-
T4	-	-	-	-	-	-
MNT	-	-	-	-	-	-
MNT1	-	-	-	-	-	-
MNT2	-	-	-	-	-	-
MNT3	65.683 **	-9.395 *	-1.8730 ***	-	544.1	0.4518
MNT4	73.860 **	-10.813 *	-1.8292 ***	-	548.7	0.4486
MXT	-	-	-	-	-	-
MXT1	74.959 ***	-11.002 **	-1.9032 ***	-	539.0	0.4555
MXT2	55.316 **	-7.575 *	-1.7969 ***	-	542.7	0.4528
MXT3	52.975 ***	-7.087 **	-1.8875 ***	-	540.9	0.4541
MXT4	60.606 ***	-8.384 ***	-1.9346 ***	-	539.5	0.4551
MXTWM	56.182 **	-7.606 *	-1.9176 ***	-	540.0	0.4547
MNTCM	-	-	-	-	-	-
TAR	57.065 **	-7.756 *	-1.8802 ***	-	546.6	0.4500
P	9.699 ***	0.451 *	-1.8620 ***	-	542.5	0.4530
P1	11.168 ***	0.363 *	-1.8635 ***	-	540.0	0.4548
P2	11.386 ***	0.364 ***	-1.9112 ***	-	538.1	0.4561
P3	-	-	-	-	-	-
P4	-	-	-	-	-	-
PWM	-	-	-	-	-	-
PDM	-	-	-	-	-	-
M	11.993 ***	0.228 *	-1.8876 ***	-	541.0	0.4541
M1	12.856 ***	-	-1.9196 ***	0.0077 **	539.0	0.4555
M2	12.364 ***	0.203 **	-1.8344 ***	-	540.6	0.4543
M3	-	-	-	-	-	-
M4	-	-	-	-	-	-
PET	12.899 ***	-	-1.6288 ***	-0.0004 **	535.6	0.4578
PET1	12.896 ***	-	-1.6636 ***	-0.0082 *	538.6	0.4558
PET2	12.908 ***	-	-1.6784 ***	-0.0077 **	536.7	0.4571
PET3	12.918 ***	-	-1.6378 ***	-0.0031 **	534.6	0.4586
PET4	16.777 ***	-0.838 ***	-1.8979 ***	-	535.5	0.4580

****p<0.001; **p<0.01; *p<0.05*

Supplementary Table 4.9: Climate-dependent MSDR models for ***Fagus sylvatica*** fitted at the 97.5th quantile arranged by AIC

model	α_0	α_1	β_0	β_1	AIC	pseudo-R^2
T	84.978 ***	-12.783 ***	-1.8450 ***	-	1520.2	0.5264
T1	69.028 ***	-9.970 **	-1.8495 ***	-	1528.6	0.5246
T2	71.240 ***	-10.382 **	-1.8500 ***	-	1524.0	0.5255
T3	12.813 ***	-	2.0872 *	-0.0138 ***	1510.2	0.5285
T4	12.771 ***	-	3.2512 ***	-0.0176 ***	1521.3	0.5261
MNT	72.193 ***	-10.536 ***	-1.8614 ***	-	1533.1	0.5236
MNT1	61.002 ***	-8.555 ***	-1.8669 ***	-	1537.9	0.5226
MNT2	60.650 ***	-8.525 **	-1.8516 ***	-	1542.0	0.5217
MNT3	76.863 ***	-11.370 ***	-1.8514 ***	-	1531.2	0.5240
MNT4	100.456 ***	-15.481 **	-1.8687 ***	-	1529.6	0.5244
MXT	84.592 ***	-12.675 ***	-1.8615 ***	-	1515.0	0.5275
MXT1	70.247 ***	-10.155 ***	-1.8648 ***	-	1523.2	0.5257
MXT2	75.624 ***	-11.138 ***	-1.8360 ***	-	1512.2	0.5281
MXT3	12.870 ***	-	2.0880 ***	-0.0137 ***	1507.5	0.5290
MXT4	12.966 ***	-	1.9497 ***	-0.0131 ***	1523.2	0.5257
MXTWM	12.952 ***	-	2.4228 ***	-0.0147 ***	1528.7	0.5245
MNTCM	49.285 **	-6.485 *	-1.8831 ***	-	1551.5	0.5197
TAR	-	-	-	-	-	-
P	-	-	-	-	-	-
P1	13.387 ***	-	-2.1378 ***	0.0012 ***	1564.8	0.5168
P2	-	-	-	-	-	-
P3	-	-	-	-	-	-
P4	-	-	-	-	-	-
PWM	11.163 ***	0.469 ***	-2.0059 ***	-	1563.5	0.5171
PDM	-	-	-	-	-	-
M	13.279 ***	-	-2.1438 ***	0.0031 ***	1529.2	0.5244
M1	12.133 ***	0.671 ***	-2.0013 ***	-	1514.9	0.5275
M2	12.406 ***	0.450 ***	-1.9686 ***	-	1528.0	0.5247
M3	13.290 ***	-	-2.1362 ***	0.0326 **	1539.8	0.5222
M4	13.488 ***	-	-2.1392 ***	0.0421 *	1563.7	0.5171
PET	13.036 ***	-	-1.5861 ***	-0.0004 ***	1533.2	0.5236
PET1	12.911 ***	-	-1.5935 ***	-0.0085 ***	1514.5	0.5276
PET2	12.851 ***	-	-1.6180 ***	-0.0068 **	1517.0	0.5270
PET3	13.018 ***	-	-1.6126 ***	-0.0029 ***	1545.1	0.5210
PET4	-	-	-	-	-	-

****p<0.001; **p<0.01; *p<0.05*

Supplementary Table 4.10: Climate-dependent MSDR models for ***Quercus faginea*** fitted at the 97.5th quantile arranged by AIC

model	α_0	α_1	β_0	β_1	AIC	pseudo-R^2
T	12.436 ***	-	8.7757 *	-0.0374 **	1970.3	0.2019
T1	-	-	-	-	-	-
T2	-	-	-	-	-	-
T3	233.156 ***	-38.984 **	-1.9505 ***	-	1960.8	0.2073
T4	271.627 ***	-45.750 ***	-1.6856 ***	-	1910.6	0.2359
MNT	-	-	-	-	-	-
MNT1	-1047.998 **	188.507 **	63.4382 **	-0.2352 **	1991.1	0.1908
MNT2	-	-	-	-	-	-
MNT3	-	-	-	-	-	-
MNT4	275.616 ***	-46.563 ***	-1.7134 ***	-	1934.1	0.2227
MXT	204.087 **	-33.789 **	-1.9014 ***	-	1944.0	0.2170
MXT3	12.416 ***	-	7.8794 *	-0.0340 *	1977.7	0.1975
MXT4	190.412 **	-31.459 **	-1.9219 ***	-	1968.4	0.2029
MXTWM	202.428 **	-33.429 **	-1.9483 ***	-	1934.4	0.2225
MNTCM	254.074 ***	-42.519 ***	-1.7485 ***	-	1899.6	0.2420
TAR	247.037 ***	-41.233 ***	-1.7874 ***	-	1883.7	0.2508
P	-	-	-	-	-	-
P1	12.606 ***	-	12.9044 ***	-0.0495 ***	1886.9	0.249
P2	7.655 ***	0.703 ***	-1.7754 ***	-	1933.3	0.2231
P3	9.939 ***	0.568 **	-1.8101 ***	-	1959.9	0.2079
P4	9.747 ***	0.686 ***	-1.8566 ***	-	1940.6	0.2190
PWM	8.949 ***	0.800 ***	-1.7900 ***	-	1930.8	0.2245
PDM	10.242 ***	0.542 ***	-1.7612 ***	-	1952.0	0.2124
M	8.663 ***	0.813 ***	-1.7536 ***	-	1960.1	0.2078
M1	13.080 ***	-0.249 *	-2.0875 ***	0.0095 ***	1928.2	0.2271
M2	9.667 ***	0.812 ***	-1.8657 ***	-	1915.9	0.2329
M3	11.463 ***	0.645 *	-1.8078 ***	-	1948.8	0.2142
M4	11.662 ***	0.691 ***	-1.8910 ***	-	1922.7	0.2291
PET	11.375 ***	0.838 ***	-1.7905 ***	-	1919.0	0.2312
PET1	12.083 ***	0.516 ***	-1.7726 ***	-	1943.5	0.2173
PET2	12.066 ***	-	-0.8581 ***	-0.0009 ***	1944.3	0.2169
PET3	20.420 ***	-2.270 ***	-1.8082 ***	-	1957.5	0.2093
PET4	20.828 ***	-2.343 ***	-1.8209 ***	-	1949.2	0.2140

****p<0.001; **p<0.01; *p<0.05*

Supplementary Table 4.11: Climate-dependent MSDR models for ***Quercus ilex*** fitted at the 97.5th quantile arranged by AIC

model	α_0	α_1	β_0	β_1	AIC	pseudo-R^2
T	11.966 ***	-	5.4244 ***	-0.0256 ***	7614.5	0.5350
T1	11.99 ***	-	4.3763 ***	-0.0223 ***	7761.6	0.5254
T2	11.959 ***	-	4.5974 ***	-0.0232 ***	7718.4	0.5283
T3	-203.752 **	38.076 **	18.6551 ***	-0.0713 ***	7548.9	0.5393
T4	12.000 ***	-	5.1724 ***	-0.0241 ***	7517.9	0.5412
MNT	12.059 ***	-	4.3424 ***	-0.0224 ***	7785.8	0.5238
MNT1	12.064 ***	-	3.5385 ***	-0.0197 ***	7880.2	0.5176
MNT2	12.221 ***	-	2.3123 ***	-0.0158 ***	7950.2	0.5129
MNT3	-183.104 *	34.619 *	15.2413 **	-0.0612 ***	7786.2	0.5239
MNT4	-171.905 **	32.405 **	16.2231 ***	-0.0624 ***	7576.3	0.5376
MXT	11.882 ***	-	5.3381 ***	-0.0248 ***	7523.0	0.5409
MXT1	11.963 ***	-	4.5508 ***	-0.0225 ***	7671.1	0.5313
MXT2	127.035 ***	-20.350 ***	-1.8931 ***	-	7568.2	0.5380
MXT3	11.899 ***	-	5.0064 ***	-0.0234 ***	7474.1	0.5440
MXT4	11.963 ***	-	5.0802 ***	-0.0234 ***	7491.1	0.5429
MXTWM	11.969 ***	-	4.7651 ***	-0.0223 ***	7484.2	0.5433
MNTCM	59.321 ***	-8.377 ***	-2.0487 ***	-	8017.5	0.5083
TAR	12.342 ***	-	2.9730 ***	-0.0166 ***	7749.4	0.5262
P	12.474 ***	-	-2.2131 ***	0.0002 ***	7877.8	0.5177
P1	-	-	-	-	-	-
P2	-	-	-	-	-	-
P3	10.088 ***	0.559 ***	-2.0213 ***	-	7640.1	0.5333
P4	11.433 ***	0.220 ***	-1.9687 ***	-	7634.6	0.5337
PWM	-	-	-	-	-	-
PDM	12.004 ***	-	-1.9947 ***	0.0037 ***	7635.8	0.5336
M	12.379 ***	-	-2.1959 ***	0.0054 ***	7747.0	0.5264
M1	12.342 ***	0.267 ***	-2.1479 ***	-	8013.3	0.5086
M2	12.387 ***	0.220 ***	-2.1347 ***	-	7997.2	0.5097
M3	11.702 ***	0.541 ***	-1.9684 ***	-	7549.0	0.5392
M4	12.139 ***	0.215 ***	-1.9555 ***	-	7588.7	0.5367
PET	11.773 ***	-	-1.4050 ***	-0.0004 ***	7449.7	0.5455
PET1	11.881 ***	-	-1.5566 ***	-0.0078 ***	7564.1	0.5382
PET2	11.865 ***	-	-1.5025 ***	-0.0087 ***	7491.1	0.5429
PET3	11.777 ***	-	-1.3094 ***	-0.0044 ***	7398.6	0.5487
PET4	11.909 ***	-	-1.5462 ***	-0.0024 ***	7510.4	0.5417

****p<0.001; **p<0.01; *p<0.05*

Supplementary Table 4.12: Climate-dependent MSDR models for ***Quercus petraea*** fitted at the 97.5th quantile arranged by AIC

model	α_0	α_1	β_0	β_1	AIC	pseudo-R^2
T	12.404 ***	-	11.6926 ***	-0.0475 ***	369.3	0.4779
T1	12.335 ***	-	12.6721 ***	-0.0513 ***	378.7	0.4656
T2	12.338 ***	-	10.9878 ***	-0.0458 ***	380.4	0.4633
T3	12.429 ***	-	9.9918 ***	-0.0414 ***	364.9	0.4836
T4	12.674 ***	-	11.0925 ***	-0.0446 ***	361.6	0.4878
MNT	-1169.241 ***	209.898 ***	82.0857 ***	-0.3009 ***	385.4	0.4593
MNT1	12.140 ***	-	12.0032 **	-0.0493 **	397.8	0.4396
MNT2	12.380 ***	-	11.4710 ***	-0.0484 ***	411.1	0.4207
MNT3	12.308 ***	-	10.6062 ***	-0.0441 ***	388.8	0.4519
MNT4	12.689 ***	-	13.1134 ***	-0.0523 ***	371.1	0.4756
MXT	-489.861 ***	88.759 ***	36.5003 ***	-0.1334 ***	357.6	0.4954
MXT1	12.623 ***	-	10.8801 **	-0.0447 ***	369.6	0.4775
MXT2	-348.430 *	63.966 *	28.0916 ***	-0.1058 ***	363.2	0.4883
MXT3	12.615 ***	-	7.5139 ***	-0.0323 ***	360.0	0.4899
MXT4	12.593 ***	-	9.0312 ***	-0.0370 ***	358.5	0.4917
MXTWM	12.382 ***	-	8.8624 ***	-0.0360 ***	360.8	0.4889
MNTCM	12.602 ***	-	10.6650 ***	-0.0459 ***	429.1	0.3942
TAR	157.524 **	-25.493 **	-1.7459 ***	-	381.0	0.4625
P	-	-	-	-	-	-
P1	-	-	-	-	-	-
P2	4.285 *	1.879 ***	-1.2898 ***	-0.0054 ***	419.1	0.4120
P3	-	-	-	-	-	-
P4	12.565 ***	-	-1.3686 ***	-0.0075 ***	398.0	0.4392
PWM	32.910 ***	-4.432 **	-2.9490 ***	0.0119 **	419.5	0.4114
PDM	12.808 ***	-	-1.4380 ***	-0.0088 ***	415.9	0.4137
M	-	-	-	-	-	-
M1	10.500 ***	0.818 ***	-1.5610 ***	-	416.1	0.4135
M2	10.786 ***	0.818 **	-1.6339 ***	-	410.9	0.4209
M3	23.887 ***	-8.481 ***	-4.2699 ***	0.6577 ***	398.5	0.4414
M4	12.167 ***	-	-1.3617 ***	-0.1387 ***	427.3	0.3969
PET	12.289 ***	-	-0.8605 *	-0.0009 *	421.7	0.4053
PET1	12.013 ***	-	-0.4393 *	-0.0345 ***	401.2	0.4349
PET2	12.283 ***	-	-0.6573 **	-0.0298 ***	385.2	0.4568
PET3	22.509 ***	-2.189 *	-1.7088 ***	-	421.0	0.4062
PET4	11.831 ***	-	-2.1149 ***	0.0049 **	431.4	0.3907

****p<0.001; **p<0.01; *p<0.05*

Supplementary Table 4.13: Climate-dependent MSDR models for ***Quercus pyrenaica*** fitted at the 97.5th quantile arranged by AIC

model	α_0	α_1	β_0	β_1	AIC	pseudo-R^2
T	-287.444 **	53.090 **	23.9132 ***	-0.0906 ***	4589.0	0.3207
T1	-320.175 **	58.994 ***	25.2750 ***	-0.0964 ***	4636.4	0.3121
T2	-	-	-	-		
T3	-296.017 **	54.575 **	24.1656 ***	-0.0912 ***	4593.5	0.3199
T4	-187.581 *	35.255 *	17.9460 ***	-0.0679 ***	4537.2	0.330
MNT	-328.016 **	60.450 ***	25.9570 ***	-0.0994 ***	4641.4	0.3112
MNT1	12.287 ***	-	3.0745 *	-0.0174 ***	4669.0	0.3057
MNT2	62.927 **	-9.041 *	-1.7177 ***	-	4702.2	0.2996
MNT3	12.300 ***	-	3.0244 *	-0.0171 ***	4676.4	0.3044
MNT4	12.312 ***	-	7.1163 ***	-0.0309 ***	4566.5	0.3244
MXT	-255.561 *	47.321 *	20.7678 **	-0.0783 **	4578.4	0.3226
MXT1	12.178 ***	-	3.1939 ***	-0.0172 ***	4640.7	0.3110
MXT2	12.309 ***	-	3.8858 ***	-0.0199 ***	4616.6	0.3154
MXT3	-310.973 *	57.023 *	24.1039 **	-0.0892 ***	4577.6	0.3228
MXT4	12.328 ***	-	5.5596 ***	-0.0248 ***	4578.1	0.3223
MXTWM	12.335 ***	-	5.6320 ***	-0.0250 ***	4570.0	0.3238
MNTCM	-	-	-	-	-	-
TAR	64.485 ***	-9.175 ***	-1.7080 ***	-	4679.1	0.3039
P	-	-	-	-	-	-
P1	-	-	-	-	-	-
P2	-	-	-	-	-	-
P3	10.821 ***	0.320 *	-1.6870 ***	-	4686.2	0.3026
P4	11.172 ***	0.297 ***	-1.7067 ***	-	4629.3	0.3130
PWM	-	-	-	-	-	-
PDM	11.570 ***	0.234 ***	-1.7462 ***	-	4608.1	0.3169
M	9.809 ***	0.677 **	-1.5369 ***	-0.0047 *	4697.6	0.3008
M1	-	-	-	-	-	-
M2	-	-	-	-	-	-
M3	11.766 ***	0.371 ***	-1.7009 ***	-	4647.6	0.3097
M4	12.156 ***	0.275 ***	-1.7087 ***	-	4617.2	0.3153
PET	12.270 ***	-	-1.2285 ***	-0.0005 ***	4584.9	0.3211
PET1	12.222 ***	-	-1.2564 ***	-0.0130 ***	4599.0	0.3186
PET2	12.364 ***	-	-1.3735 ***	-0.0105 ***	4593.1	0.3196
PET3	12.306 ***	-	-1.1779 ***	-0.0052 ***	4584.0	0.3213
PET4	12.269 ***	-	-1.2806 ***	-0.0034 ***	4596.3	0.3190

****p<0.001; **p<0.01; *p<0.05*

Supplementary Table 4.14: Climate-dependent MSDR models for ***Quercus robur*** fitted at the 97.5th quantile arranged by AIC

model	α_0	α_1	β_0	β_1	AIC	pseudo-R^2
T	-658.148 *	118.548 *	41.3317 *	-0.1508 *	1001.0	0.4497
T1	-602.202 ***	108.830 ***	37.3468 ***	-0.1381 ***	996.3	0.4520
T2	76.724 ***	-11.442 ***	-1.7353 ***	-	1002.7	0.4479
T3	92.442 ***	-14.184 ***	-1.7317 ***	-	1007.5	0.4455
T4	81.830 ***	-12.287 ***	-1.7053 ***	-	1011.0	0.4437
MNT	-820.659 ***	147.740 ***	51.1787 ***	-0.1885 ***	981.1	0.4594
MNT1	-624.820 **	113.080 **	39.0364 **	-0.1458 **	993.6	0.4533
MNT2	-605.574 ***	109.939 ***	37.8316 ***	-0.1435 ***	985.5	0.4572
MNT3	-795.789 ***	143.317 ***	49.1578 ***	-0.1812 ***	974.7	0.4624
MNT4	-1112.201 ***	198.611 ***	70.2864 ***	-0.2505 ***	989.2	0.4554
MXT	63.703 ***	-9.108 ***	-1.6903 ***	-	1011.8	0.4433
MXT1	74.444 ***	-11.004 ***	-1.7205 ***	-	1004.9	0.4468
MXT2	61.685 ***	-8.777 ***	-1.6824 ***	-	1011.1	0.4437
MXT3	-	-	-	-	-	-
MXT4	-	-	-	-	-	-
MXTWM	-	-	-	-	-	-
MNTCM	81.360 **	-12.334 *	-1.6887 ***	-	994.4	0.4519
TAR	-537.820 *	96.848 *	25.9075 *	-0.0944 *	1005.4	0.4475
P	-	-	-	-	-	-
P1	12.261 ***	-	-1.7063 ***	-0.0002 *	1015.6	0.4415
P2	-	-	-	-	-	-
P3	12.295 ***	-	-1.6408 ***	-0.0011 **	1009.6	0.4445
P4	12.181 ***	-	-1.5798 ***	-0.0022 **	1001.3	0.4485
PWM	-	-	-	-	-	-
PDM	9.142 ***	0.737 *	-1.3696 ***	-0.0059 **	1006.7	0.4468
M	-	-	-	-	-	-
M1	-	-	-	-	-	-
M2	-	-	-	-	-	-
M3	-	-	-	-	-	-
M4	12.233 ***	-	-1.5876 ***	-0.0623 **	1008.3	0.4451
PET	-	-	-	-	-	-
PET1	15.108 ***	-0.749 *	-1.7925 ***	-	1013.5	0.4425
PET2	-	-	-	-	-	-
PET3	-	-	-	-	-	-
PET4	11.979 ***	-	-1.7983 ***	0.0013 *	1011.8	0.4433

****p<0.001; **p<0.01; *p<0.05*

Supplementary Table 4.15: Climate-dependent MSDR models for ***Quercus suber*** fitted at the 97.5th quantile arranged by AIC

model	α_0	α_1	β_0	β_1	AIC	pseudo-R^2
T	55.009 **	-7.508 *	-1.9023 ***	-	1337.2	0.4857
T1	-	-	-	-	-	-
T2	-	-	-	-	-	-
T3	101.496 **	-15.722 **	-1.8724 ***	-	1326.9	0.4896
T4	12.040 ***	-	6.6223 **	-0.0284 ***	1285.4	0.5047
MNT	-	-	-	-	-	-
MNT1	578.103 *	-100.247 *	-33.3097 **	0.1113 *	1326.3	0.4905
MNT2	557.855 ***	-96.901 ***	-32.6036 ***	0.1104 ***	1313.2	0.4954
MNT3	-	-	-	-	-	-
MNT4	12.231 ***	-	3.3563 *	-0.0178 ***	1318.1	0.4928
MXT	12.122 ***	-	4.2310 ***	-0.0206 ***	1301.1	0.4991
MXT1	473.409 *	-81.306 *	-25.7606 *	0.0823 *	1336.4	0.4868
MXT2	12.247 ***	-	3.0873 *	-0.0171 ***	1317.3	0.4931
MXT3	12.343 ***	-	9.4775 **	-0.0384 ***	1243.8	0.5195
MXT4	-670.091 **	119.608 **	43.6583 ***	-0.1515 ***	1239.5	0.5217
MXTWM	12.097 ***	-	9.7879 ***	-0.0385 ***	1235.9	0.5223
MNTCM	511.050 **	-88.657 **	-30.2000 ***	0.1022 ***	1302.8	0.4992
TAR	12.922 ***	-	2.2551 **	-0.0144 ***	1248.3	0.5179
P	24.550 ***	-1.802 *	-2.7602 ***	0.0011 **	1254.7	0.5164
P1	-	-	-	-	-	-
P2	17.454 ***	-1.033 **	-2.4402 ***	0.0048 **	1283.4	0.5062
P3	-	-	-	-	-	-
P4	-	-	-	-	-	-
PWM	27.431 ***	-3.154 ***	-3.0211 ***	0.0096 ***	1310.9	0.4962
PDM	-	-	-	-	-	-
M	13.048 ***	-	-2.2457 ***	0.0061 ***	1264.9	0.5121
M1	12.923 ***	0.347 ***	-2.1668 ***	-	1321.2	0.4917
M2	14.486 ***	-1.064 *	-2.4802 ***	0.1007 **	1295.3	0.5019
M3	-	-	-	-	-	-
M4	-	-	-	-	-	-
PET	11.606 ***	-	-1.1484 ***	-0.0005 ***	1269.5	0.5104
PET1	-	-	-	-	-	-
PET2	-	-	-	-	-	-
PET3	11.948 ***	-	-1.2349 ***	-0.0043 ***	1233.6	0.5231
PET4	11.846 ***	-	-1.3656 ***	-0.0025 ***	1239.2	0.5211

****p<0.001; **p<0.01; *p<0.05*

Supplementary Table 5: Functional traits and climatic requirements for the 15 species studied

Functional group	Species	ST	T (ºC)	MTWM (ºC)	MTCM (ºC)	DT	P (mm)	RSP (mm)
Coniferous	*Pinus canariensis*	1	13-17	18-25	7-14	Very tolerant	400-1000	No limit
	Pinus halepensis	1.35	12-16	21-26	3-8	4.97 (0.03)	300-700	20-132
	Pinus nigra	2.1 (0.43)	9-12	20-23	1-4	4.38 (0.47)	600-1200	60-130
	Pinus pinaster	1.89 (0.21)	12-16	18-27	1-7	3	400-1600	70-150
	Pinus pinea	1	11-18	21-16	3-11	High	430-800	15-125
	Pinus radiata	2.97 (0.03)	10-13	16-20	4-8	3	1000-2000	100-290
	Pinus sylvestris	1.67 (0.33)	6-12	15-20	0-3	4.34 (0.47)	600-1200	> 100
	Pinus uncinata	1.2	4	< 15	< 0	3.88	> 800	> 200
Broadleaf	*Fagus sylvatica*	4.56 (0.11)	7.3-10	18	0	2.4 (0.43)	600-900	150-200
	Quercus faginea	-	8-16	15-26	(-3)-5	-	350-1400	> 100
	Quercus ilex	3.02 (0.19)	10-18	14-28	(-3)-11	4.72	> 450	75-100
	Quercus petraea	2.73 (0.27)	5-15	15-25	(-3)-7	3.02 (0.15)	600	150
	Quercus pyrenaica	2.55 (0.11)	11-16	12-22	(-5)-7	4.29 (0.21)	600	> 125
	Quercus robur	2.45 (0.28)	10	14-25	-10	2.95 (0.31)	600	200
	Quercus suber	-	13-16	20-26	4-5	-	> 500	23-165

Note: ST - Shade Tolerance, T - Mean Annual Temperature (ºC), MTWM - Mean Temperature of the Warmest Month (ºC), MTCM - Mean Temperature of the Coldest Month (ºC), P - Mean Annual Precipitation (mm), and RSP - Required Summer Precipitacion (mm). Data obtained from Niinemets and Valladares (2006) and Serrada et al. (2008). Shade tolerance is ranked as proposed by Baker (1949): 1 = Very intolerant, 2 = intolerant, 3 = moderately tolerant, 4 = tolerant, 5 = very tolerant.