

A Taccoen *et al.* – Electronic Supplementary Material

Electronic Supplementary Material, Panel 1. Additional materials and methods

a) Study sites and database description.

Plot data were collected yearly based on a systematic 10 km x 10 km sampling grid. One tenth of this grid was sampled on a spatially systematic sub-grid, with one plot every 20 km² (1). For each plot, an ecological inventory was carried out in a 700-m² area, and a tree inventory was implemented using three nested circles of 9, 12, and 15 m of radius. The minimum tree diameter threshold for NFI measurements was 7.5 cm at 1.3 m height (diameter at breast height, dbh). All trees were inventoried regardless of their health status. A tree was considered to be dead when it did not show any living element over 1.3 m height from the ground and was presumed to have died within the last 5 years prior to the inventory. No information was available for dead trees harvested before the plot inventory, either recorded in harvested trees (< 5 years) or absent trees (> 5 years). The soil was surveyed in each plot with a 40-cm-depth soil pit combined with an auger survey of 1 m depth maximum. Soil texture and the proportion of coarse fragments were evaluated empirically. Observations about past forest fires, storms, or important anthropogenic disturbances were systematically recorded. Plots with such observations were removed from the study. Plots including forest edges and small groves were also removed because the proximity of forest edges modifies light availability, increases wind-related disturbances, and induces different growth conditions from closed forest (2). When a plot was composed of less than 10% of trees exceeding the minimum diameter threshold of 7.5 cm, this information was recorded qualitatively in the field. These plots were discarded because it was impossible to calculate reliable synthetic indices such as basal area (BA). Finally, felled and broken individual trees were discarded.

b) Species under study

Among the most common species present in the NFI database, we discarded species for which massive and unpredictable damage events were documented in the area, i.e. *Castanea sativa* (3, 4), *Fraxinus excelsior* and *Fraxinus angustifolia* (5), *Ulmus campestris* (6), and *Alnus glutinosa* (7). Based on a previous sensitivity analysis of logistic regression to the minimum number of plots and individuals (8), we set a threshold of fifteen different plots with at least one dead individual per plot to keep the species in the study. The final number of species was 43, including 14 evergreen species and 29 deciduous species (Supplementary Information 1).

c) Effects of environmental conditions

Using field soil surveys and the textural description of soils, we computed Available Water Content (AWC, mm) with pedotransfer functions and textural coefficients (9). The pH, the carbon-to-nitrogen ratio (*C/N*), the temporary and permanent waterlogging indices (*PW* and *TW*) were calculated using indicator values (IVs) and the floristic surveys performed on each plot. IVs were elaborated using the EcoPlant database (10) that contains plots with exhaustive floristic surveys, waterlogging description in a soil pit, and soil analyses from a soil laboratory. Using modeling techniques, each species was attributed an optimum value for *pH* and *C/N* (10). For waterlogging, we calculated the association coefficient of fidelity between species occurrences for temporary and permanent waterlogging (11). We then used the floristic surveys carried out on each plot to estimate *pH*, *C/N*, *TW*, and *PW* by averaging their indicator values.

The surface water runoff (Topo) was estimated from the site topography qualitatively measured in the field. Mean climatic conditions represented the average temperature and rainfall values at the plot location in the absence of climate change. The years 1961 to 1987 were considered as the climate reference period, and 1987 was considered as a change point for climate conditions in Europe (12). To characterize mean climate conditions, monthly values of mean temperature (*T*[°]) and total rainfall (RF) were calculated on the reference period with a climate model (13). We averaged temperature values and

summed rainfall values per season. We studied the effects of mean spring (March to May), summer (June to August), autumn (September to November) and winter (December to February) T° on tree mortality ($Tm_{spr}6187$, $Tm_{sum}6187$, $Tm_{aut}6187$, and $Tm_{win}6187$, respectively). We considered spring and summer values for RF ($RF_{spr}6187$ and $RF_{sum}6187$, respectively) because water stress mainly occurs during the vegetation period (14).

d) Climate change variables calculation

We used 274 historic homogenized climate series supplied by Météo France and spanning the 1961-2015 period (21) for temperature, and 1119 for rainfall to obtain the six variables describing climate change intensity ($Tm_{win}Evo$, $Tm_{spr}Evo$, $Tm_{sum}Evo$, $Tm_{aut}Evo$, $RF_{spr}Evo$ and $RF_{sum}Evo$). We interpolated each mean monthly climate anomaly of the fifteen-year periods obtained with ordinary kriging. We averaged mean temperature anomalies values and summed mean rainfall anomalies for the different seasons. Each plot was then associated with the climate change variables corresponding to the fifteen years preceding its date of survey.

e) Details on statistical indicators used

The drop contribution value (17) is the difference in explained deviance when the variable is dropped from the multivariate model:

$$DropContribution_{vi} = ResidualDeviance_{without_vi} - ResidualDeviance_{with_vi}$$

vi = variable i in the model

We calculated the ratio of the drop contribution of the variable over the sum of the drop contributions of all the variables in the multivariate model for each variable, representing the relative importance of the variable in the model (RI):

$$RelativeImportance_{vi} = \frac{DropContribution_{vi}}{\sum_{j=1}^n DropContribution_{vj}}$$

n = number of variables in the model

Electronic Supplementary Material, Panel 2. Details about the calculation of mean excess probability of mortality per species. To calculate the mean excess probability of mortality value associated with each species, we calculated the difference for each tree between the predicted probability of mortality from the complete model and the predicted probability of mortality in a model where the target climate change effect had been set to 0. We then calculated the average delta value of all the trees of the target species.

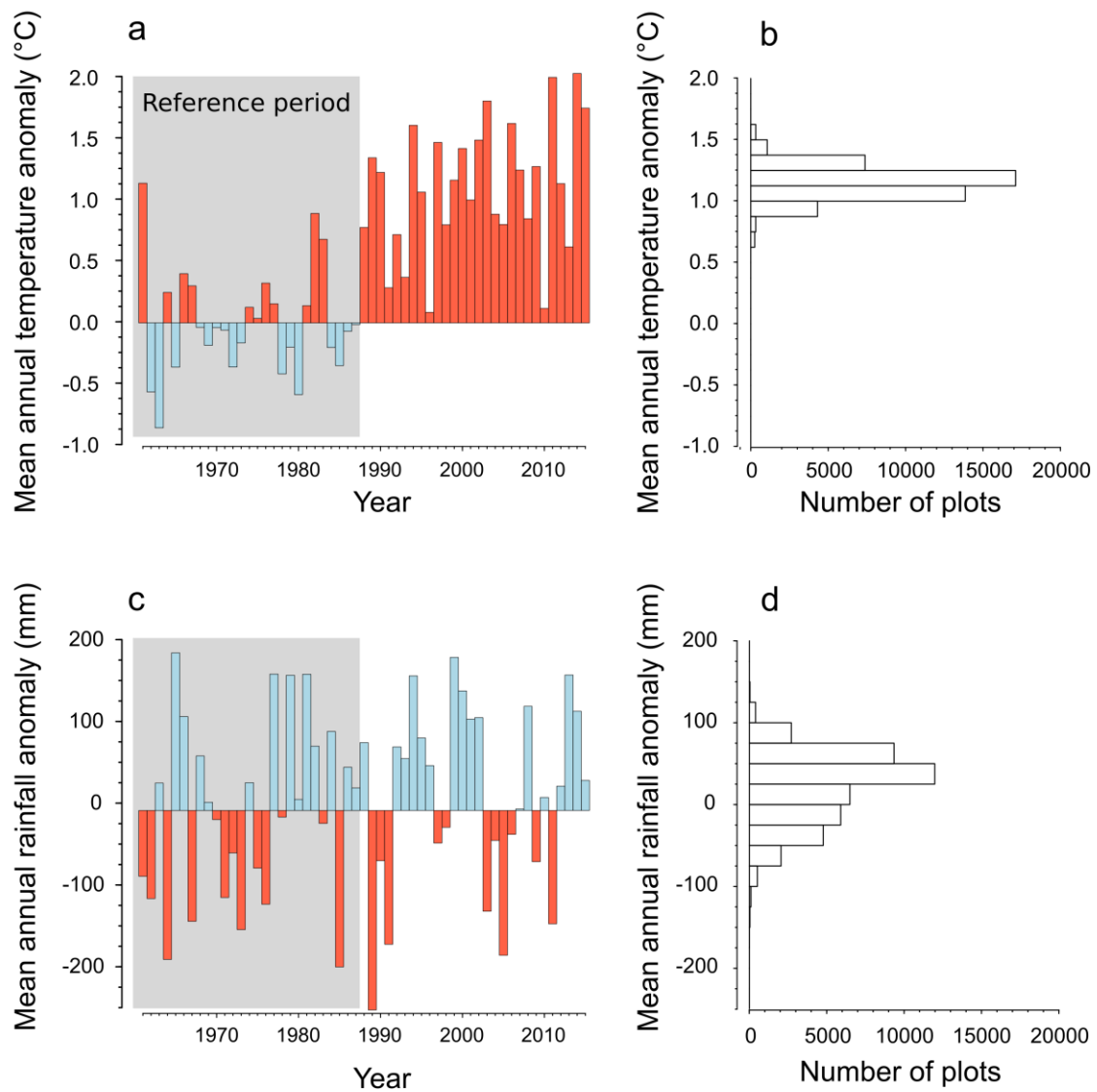
Electronic Supplementary Material, Panel 3. Details about the calculation of harvest intensity.

The proportion of cut trees after 5 years was estimated from re-measurements made on previously surveyed plots that started in 2013. As of July 2018, only three years of data were available for the re-measurement of plots. We calculated the number of trees harvested between the two survey dates and related it to the total number of trees that were actually re-measured. We related this value to a value per hectare. We then separated the species in two groups, each composed of an equal number of species: those with a high harvest intensity and those with a low harvest intensity. The threshold value between the two groups was a harvest intensity rate of 4.5% of trees per ha cut in 5 years.

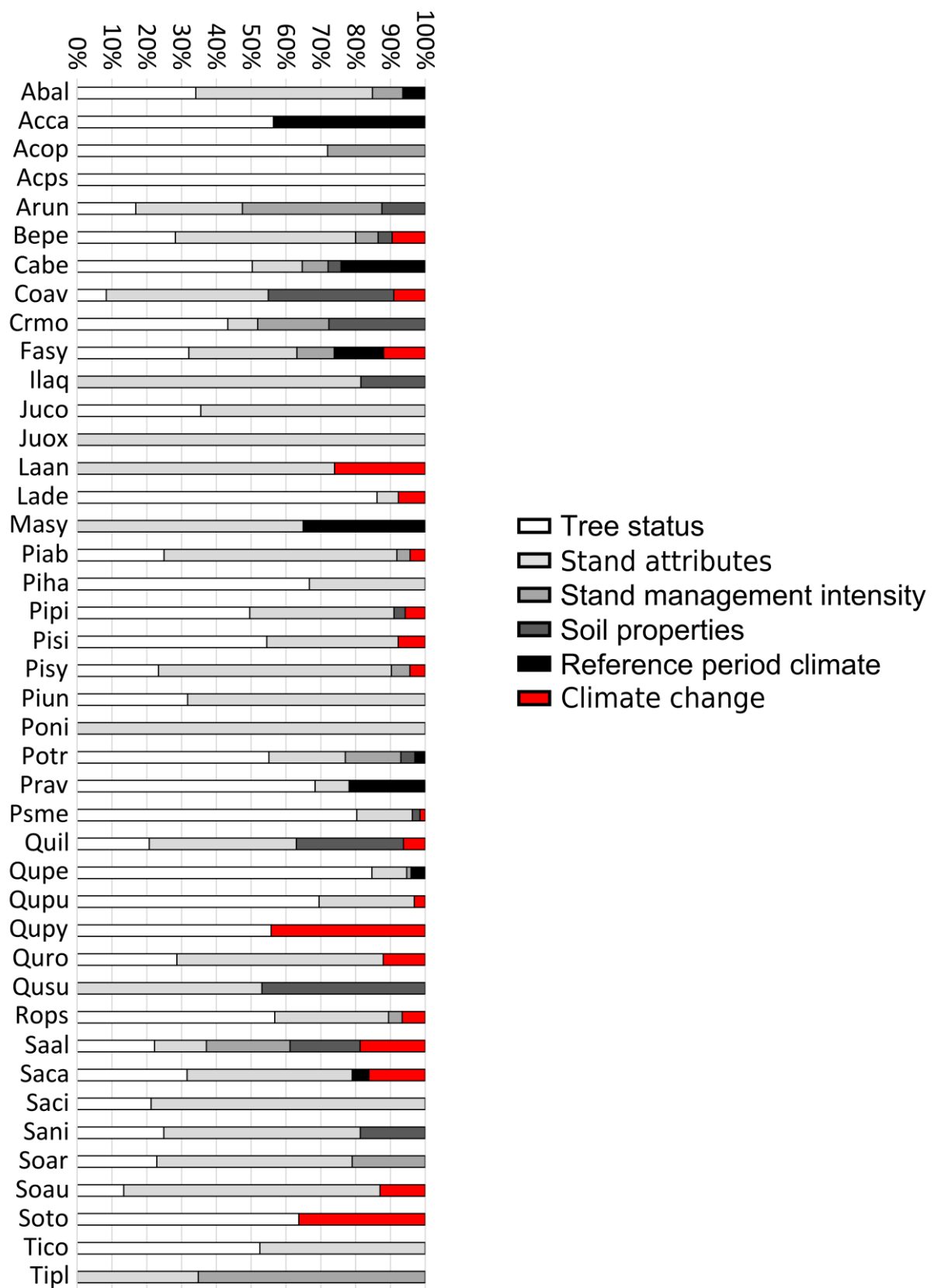
Electronic Supplementary Material, Panel 4. Additional information about the calculation of the indicator values used for computing the pH, the carbon-to-nitrogen ratio, and permanent and temporary waterlogging indices in the plots. The pH, the carbon-to-nitrogen ratio (C/N), the temporary and permanent waterlogging indices (PW and TW) were calculated using indicator values (IVs). IVs were elaborated using the EcoPlant database (10) that contains plots with exhaustive floristic surveys, waterlogging description in a soil pit, and soil analyses from a soil laboratory. Using modeling

techniques, each species was attributed an optimum value for pH and C/N (10). For waterlogging, we calculated the association coefficient of fidelity between species occurrences for temporary and permanent waterlogging (11). We then used the floristic surveys carried out on each plot to estimate pH , C/N , TW , and PW by averaging their indicator values.

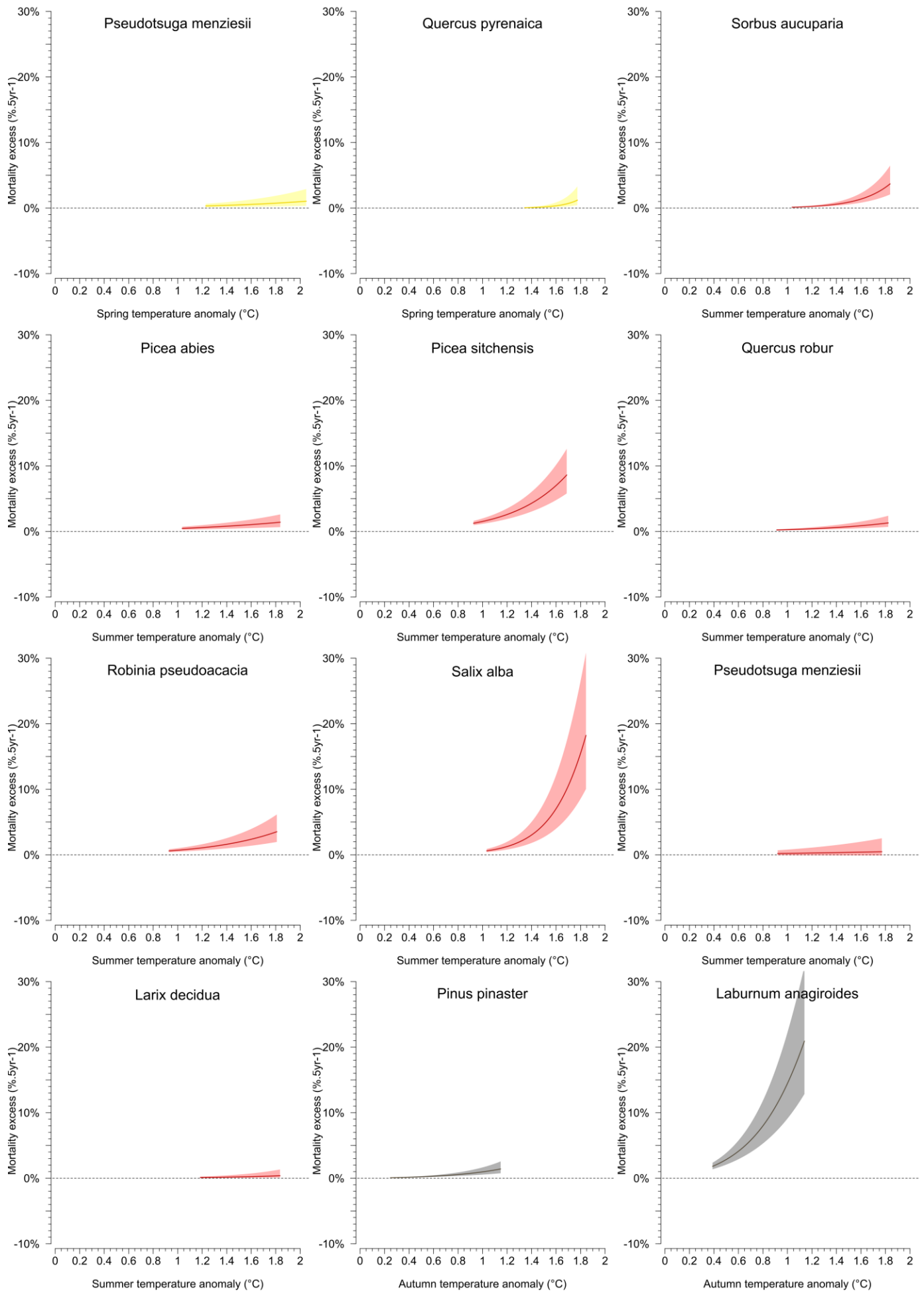
Electronic Supplementary Material, Figure 1. Mean annual temperature and rainfall anomalies in France between 1961 and 2015, and distribution of plots along climate anomaly gradients. a and c, mean annual temperature and rainfall anomalies compared to the averaged values of the reference period (1961-1987). Annual temperature and rainfall values were extracted from raster layers at 1-km resolution for the 34,097 plots and averaged for each year. b and d, distribution of the plots along the temperature and rainfall anomaly gradients. Anomalies were calculated as the difference between the contemporary climate of the date of survey and the 1961-1987 reference period. The contemporary climate of the date of survey was calculated by averaging the temperature and rainfall values over the 15 years preceding the date of the survey (e.g., the contemporary climate of a plot measured in 2014 was the climate over the 1999-2014 period, see Methods section).

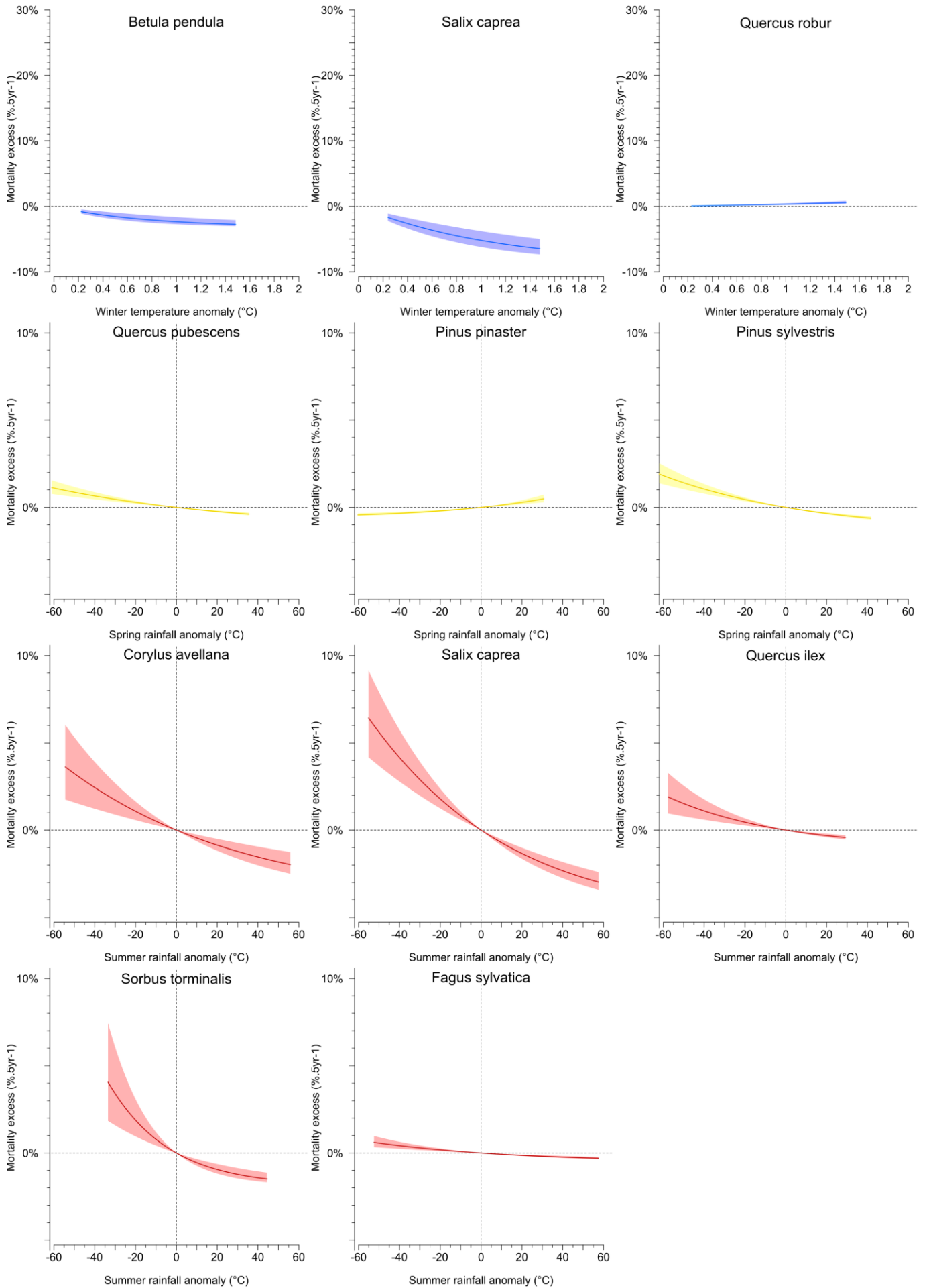


Electronic Supplementary Material, Figure 2. Relative importance of the different categories of factors explaining tree mortality in the models for each of the 43 tree species.

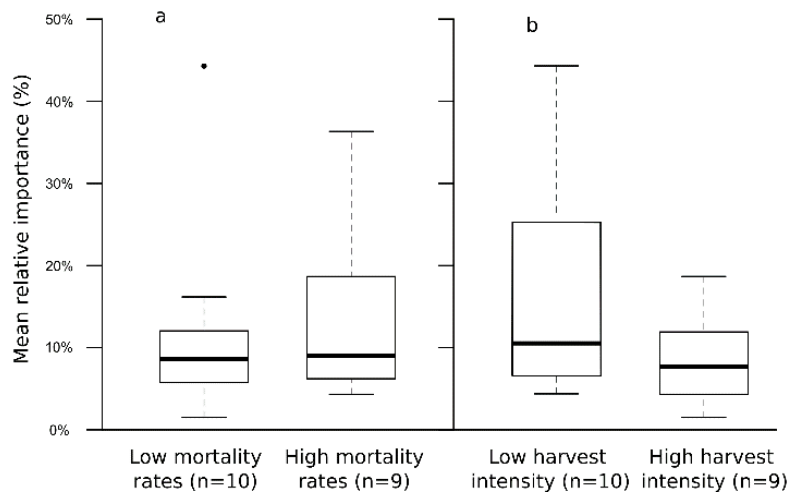


Electronic Supplementary Material, Figure 3. Excess probability of mortality along temperature and rainfall anomaly gradients for the species with significant climate change effects with 95% confidence interval. For each species sensitive to climate change, we calculated the response curve corresponding to the climate change variable involved. To estimate the excess probability of mortality along each significant gradient of climate change variable, we calculated the difference between the response curve and the value corresponding to the mean predicted probability of mortality, with the target climate change effect fixed to 0. For species with several selected climate change variables, one curve *per* variable was plotted. We represented the four seasons in four different colors. For the correspondence table between the species names and the abbreviations, see Figure 1.





Electronic Supplementary Material, Figure 4. Relationships between base mortality rates (a), management intensity (b), and the relative importance of climate change effects for species whose models presented significant climate-change-related effects. We ordered and separated the species with significant climate change effects in two sets based on (a) mean observed mortality rates, and (b and Electronic Supplementary Material, Panel 3 for harvest intensity calculation) harvest intensity estimated from the proportion of cut trees after 5 years. We then calculated the mean relative importance of the climate change effects for each set of species. *n*: number of species in each set of species.



Electronic Supplementary Material, Table 1. Performance of the mortality models for the 42 species in terms of AUC and TSS. Prevalence indicates the proportion of dead individuals as compared to the total number of trees of a given species. Calibration dataset: n = 298,379 trees; validation dataset: n = 74,595 trees. No AUC and TSS values could be calculated for *Pyrus communis* because no variables were significant (LRT P-value > 0.01).

Species	Number of trees	Prevalence	Calibration dataset		Validation dataset	
			AUC	TSS	AUC	TSS
<i>Abies alba</i>	21,796	1,1%	0.81	0.52	0.78	0.46
<i>Acer campestre</i>	5,525	1,0%	0.8	0.48	0.85	0.52
<i>Acer opalus</i>	1,241	1,4%	0.8	0.53	0.75	0.42
<i>Acer pseudoplatanus</i>	4,949	0,4%	0.8	0.61	0.76	0.44
<i>Arbutus unedo</i>	1,812	4,4%	0.82	0.46	0.76	0.37
<i>Betula pendula</i>	11,238	2,1%	0.8	0.47	0.78	0.43
<i>Carpinus betulus</i>	36,629	0,7%	0.84	0.54	0.75	0.42
<i>Corylus avellana</i>	6,773	5,1%	0.67	0.25	0.67	0.23
<i>Crataegus monogyna</i>	2,679	4,1%	0.74	0.37	0.71	0.33
<i>Fagus sylvatica</i>	40,135	0,9%	0.84	0.56	0.84	0.57
<i>Ilex aquifolium</i>	1,020	1,2%	0.89	0.68	0.83	0.58
<i>Juniperus communis</i>	422	13,5%	0.65	0.21	0.64	0.22
<i>Juniperus oxycedrus</i>	395	4,8%	0.83	0.59	0.81	0.56
<i>Laburnum anagyroides</i>	191	16,6%	0.82	0.49	0.91	0.57
<i>Larix decidua</i>	3,340	1,7%	0.89	0.64	0.82	0.58
<i>Malus sylvestris</i>	364	3,7%	0.8	0.52	0.78	0.42
<i>Picea abies</i>	21,246	2,2%	0.83	0.54	0.8	0.44
<i>Picea sitchensis</i>	1,131	4,1%	0.87	0.59	0.83	0.56
<i>Pinus halepensis</i>	2,974	1,7%	0.83	0.61	0.83	0.53
<i>Pinus pinaster</i>	15,240	1,7%	0.88	0.63	0.83	0.57
<i>Pinus sylvestris</i>	23,778	2,9%	0.8	0.47	0.8	0.46
<i>Pinus uncinata</i>	2,160	3,8%	0.78	0.46	0.72	0.33
<i>Populus nigra</i>	463	2,9%	0.7	0.35	0.67	0.29
<i>Populus tremula</i>	5,049	4,4%	0.84	0.54	0.83	0.57
<i>Prunus avium</i>	4,065	2,9%	0.77	0.41	0.76	0.39
<i>Pseudotsuga menziesii</i>	10,492	2,2%	0.89	0.65	0.91	0.69
<i>Pyrus communis</i>	233	4,9%	/	/	/	/
<i>Quercus ilex</i>	14,352	1,5%	0.74	0.36	0.71	0.32
<i>Quercus petraea</i>	38,271	1,4%	0.9	0.69	0.86	0.62
<i>Quercus pubescens</i>	27,733	2,4%	0.79	0.47	0.73	0.34
<i>Quercus pyrenaica</i>	1,264	1,3%	0.82	0.6	0.76	0.47
<i>Quercus robur</i>	36,829	1,9%	0.83	0.57	0.88	0.64
<i>Quercus suber</i>	915	2,3%	0.85	0.55	0.83	0.5
<i>Robinia pseudoacacia</i>	58,62	4,5%	0.78	0.44	0.76	0.42
<i>Salix alba</i>	438	3,9%	0.86	0.59	0.82	0.55
<i>Salix caprea</i>	4,038	6,2%	0.79	0.44	0.81	0.5
<i>Salix cinerea</i>	1,026	7,0%	0.79	0.47	0.8	0.52
<i>Sambucus nigra</i>	416	7,3%	0.78	0.44	0.83	0.58
<i>Sorbus aria</i>	2,442	3,2%	0.76	0.42	0.73	0.4
<i>Sorbus aucuparia</i>	1,058	6,3%	0.79	0.47	0.76	0.44
<i>Sorbus torminalis</i>	2,113	1,8%	0.69	0.33	0.67	0.16
<i>Tilia cordata</i>	1,999	0,8%	0.84	0.6	0.79	0.59
<i>Tilia platyphyllos</i>	1,566	0,8%	0.85	0.66	0.8	0.5

Electronic Supplementary Material, Table 2. Logistic regression coefficients for the mortality models of the 43 species. For qualitative variables (Dist, Trails, Cut, and Topo), the coefficients associated with each factor are displayed in different lines (e.g. Dist coeff 1, Dist coeff2...). For the correspondence table between the species names and the species codes, see Table 1.

Species codes	Abal	Acca	Acop	Acps	Arun	Bepe	Cabe	Coav	Crmo	Fasy	Ilaq	Juco	Juox	Laan	Lade
Intercept	-9.78	-11.07	1.35	-2.36	0.25	-2.24	-16.39	-3.67	15.92	-9.18	-54.46	-1.81	-3.09	-7.43	-3.22
Circ	-0.08					-0.02	0.03			-0.03					
Circ ²															
RelCirc	-3.68	-5.05	-4.94	-3.67	-2.98	-4.85	-7.82	-4.03	-2.98	-3.53		-1.71			-5.75
RelCirc ²	0.57	1.01				0.99		1.63		0.44					0.66
BA	0.04				-0.09								-0.10		0.02
BA ²															
NB														0.01	
NB ²															
CC						0.02		0.02							
CC ²															
QMD	2.01							-1.42			54.11		7.71		
QMD ²	-0.23							0.37			-36.26		-3.50		
Gini	13.58				15.70	17.89				24.88					
Gini ²	31.08				-35.13	-31.79				-52.50					
PropBA	5.37				-1.10	-6.93	0.91			4.19			-9.08	-15.29	
PropBA ²	-4.14					5.96				-3.31					
Nb_sp									0.18		11.89	0.36			
Nb_sp ²											-1.25				
Dist coeff 1					-0.51		0.12								
Dist coeff 2					-0.94		0.59		0.29						
Dist coeff 3					-1.40		0.83		1.57						
Dist coeff 4					-1.40		2.57		1.35						
Trails coeff 1					-0.75	0.38				-0.13					
Trails coeff 2					0.67	-0.40				0.29					
Trails coeff 3					2.03	-11.95				0.67					
Cut coeff 1															
Cut coeff 2			-1.97												
AWC															
AWC ²															
PW								-17.54	19.66						
PW ²															
TW															
TW ²															
pH							0.35	-0.74	-6.17						
pH ²								0.12	0.51						
CN					-0.09	-0.03		0.15			0.19				
CN ²															
Topo coeff 1															
Topo coeff 2															
Tm _{win} Ref															
Tm _{spr} Ref															
Tm _{sum} Ref		0.38					0.66								
Tm _{aut} Ref	0.24									0.61					
RF _{spr} Ref		0.01								-0.37					
RF _{sum} Ref															
Tm _{win} Evo						-1.35									
Tm _{spr} Evo															
Tm _{sum} Evo															
Tm _{aut} Evo															
RF _{spr} Evo															
RF _{sum} Evo									-0.01						
Tm _{win} Ref * Tm _{win} evo															
Tm _{spr} Ref * Tm _{spr} evo															
Tm _{sum} Ref* Tm _{sum} evo															0.15
Tm _{aut} Ref * Tm _{aut} evo														0.32	
RF _{spr} evo / RF _{spr} Ref															
RF _{sum} evo / RF _{sum} Ref										-3.30					

Species codes	Masy	Piab	Pisi	Piha	Pipi	Pisy	Piun	Poni	Potr	Prav	Psme	Pyco	Quil	Qupe	Qupu
Intercept	-28.71	-1.63	-8.61	-0.34	-1.32	-1.66	0.53	-2.21	-10.60	4.05	-5.97		-41.08	-12.62	-1.69
Circ		-0.02				-0.05									-0.06
Circ ²															
RelCirc		-4.52	-7.14	-3.99	-4.19	-3.02	-2.82		-4.93	-2.34	-7.08		-1.72	-5.78	
RelCirc ²		0.67	1.60	0.59	0.55	0.57	0.65		0.80		1.12			0.67	
BA		0.01				0.03					0.02				0.04
BA ²															
NB															
NB ²															
CC						-0.04			0.02					0.02	0.01
CC ²															
QMD						1.96									0.56
QMD ²						-0.19									
Gini	106.55	21.94	49.31	5.14	21.80				18.58		21.94		-3.55	17.05	
Gini ²	-202.49	-42.41	-96.38		-44.33				-36.05		-43.00			-28.40	
PropBA		3.70	8.09	-2.87	-4.10	-2.70	-2.57	-2.66	-5.77		9.33		-1.75	5.56	-1.17
PropBA ²		-5.10	-7.57						5.12		-7.51			-5.00	
Nb_sp		-1.06	-1.32			-0.50				0.21					-0.14
Nb_sp ²		0.10	0.22			0.06									
Dist coeff 1									-0.14					0.12	
Dist coeff 2									-0.49					0.26	
Dist coeff 3									0.57					0.72	
Dist coeff 4									3.31					-12.58	
Trails coeff 1						-0.32									
Trails coeff 2						0.03									
Trails coeff 3						0.56									
Cut coeff 1		-2.11													
Cut coeff 2		-1.96													
AWC					0.05									-0.03	
AWC ²															
PW															
PW ²															
TW															
TW ²															
pH									0.36				10.73		
pH ²													-0.72		
CN															
CN ²															
Topo coeff 1															
Topo coeff 2															
Tm _{win} Ref															
Tm _{spr} Ref															
Tm _{sum} Ref	0.70								0.24	-0.38				0.41	
Tm _{aut} Ref															
RF _{spr} Ref															
RF _{sum} Ref															
Tm _{win} Evo															
Tm _{spr} Evo															
Tm _{sum} Evo															
Tm _{aut} Evo															
RF _{spr} Evo															-0.01
RF _{sum} Evo															
Tm _{win} Ref * Tm _{win} Evo															
Tm _{spr} Ref * Tm _{spr} Evo											0.03				
Tm _{sum} Ref * Tm _{sum} Evo		0.07	0.16								0.16				
Tm _{aut} Ref * Tm _{aut} Evo					0.19										
RF _{spr} Evo / RF _{spr} Ref					4.22	-3.42									
RF _{sum} Evo / RF _{sum} Ref														-2.24	

Species codes	Qupy	Quro	Qusu	Rops	Saal	Saca	Saci	Sani	Soar	Soau	Soto	Tico	Tipl
Intercept	-13.63	-6.33	-20.15	-19.40	-15.91	-3.42	-3.27	3.54	-13.82	-8.28	-1.73	-5.13	-11.53
Circ		-0.07			-0.02		-0.03					-0.06	
Circ ²													
RelCirc	-3.01	-3.72		-4.48	-1.52	-3.58		-6.57	-1.91	-2.37	-2.92		
RelCirc ²		0.46		0.97	0.14	0.51		2.90					
BA		0.17				0.03		-0.08		-0.18		0.06	
BA ²													
NB													
NB ²													
CC						0.01	0.04			0.05			
CC ²													
QMD				0.40								1.20	18.22
QMD ²													-11.86
Gini		9.65	37.22	19.56									
Gini ²		-16.93	-	-37.55									
PropBA		3.33	-2.19	-1.31		-1.81	-2.65	-4.24	-4.92	-6.21			
PropBA ²		-3.47								7.04			
Nb_sp				0.11					-0.98				
Nb_sp ²									0.10				
Dist coeff 1													-15.93
Dist coeff 2													0.78
Dist coeff 3													0.93
Dist coeff 4													2.81
Trails coeff 1					1.74								
Trails coeff 2					0.69								
Trails coeff 3					-16.71								
Cut coeff 1				10.69					-0.45				
Cut coeff 2				11.55					14.58				
AWC								-0.01					
AWC ²													
PW													
PW ²													
TW													
TW ²													
pH													
pH ²													
CN					0.59								
CN ²													
Topo coeff 1			16.41										
Topo coeff 2			14.62										
Tm _{win} Ref													
Tm _{spr} Ref													
Tm _{sum} Ref						0.13							
Tm _{aut} Ref													
RF _{spr} Ref													
RF _{sum} Ref													
Tm _{win} Evo						-0.98							
Tm _{spr} Evo													
Tm _{sum} Evo										4.26			
Tm _{aut} Evo													
RF _{spr} Evo													
RF _{sum} Evo						-0.02							
Tm _{win} Ref * Tm _{win} evo		0.16											
Tm _{spr} Ref * Tm _{spr} evo	0.68												
Tm _{sum} Ref * Tm _{sum} evo		0.10		0.10	0.25								
Tm _{aut} Ref * Tm _{aut} evo													
RF _{spr} evo / RF _{spr} Ref													
RF _{sum} evo / RF _{sum} Ref												-6.13	

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