Supplementary Online material

Climate and land use change impacts on plant distributions in Germany

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Table S1. 38 bioclimatic variables computed from average monthly values from 1961-1990 and 2051-2080 on the 10' resolution grid (Mitchell et al. 2004; Settele et al. 2005), spring: March-May, summer: June-August, autumn: September-November, winter: December-February.

Symbol	Description	Unit	Number
mta	mean annual temperature	°C	1
tmp	mean monthly temperature (Jan, Apr, Jul, Oct)	°C	4
dtr	diurnal temperature range (Jan, Apr, Jul, Oct)	°C	4
gdd	growing degree days above 5°C (annual; spring, summer, autumn, winter)	°C	5
tmn	mean temperature of the coldest month	°C	1
tmx	mean temperature of the warmest month	°C	1
ran	temperature range (annual; spring, summer, autumn, winter)	°C	5
eet	equilibrium evapotranspiration	mm	1
pre	precipitation (annual; spring, summer, autumn, winter)	mm	5
ioa	index of aridity (tmp July/annual pre)		1
wdf	water deficit (cf. Ohlemüller et al. 2006)	mm	1
iso	isothermality (dtr/(tmx-tmn); Jan, Apr, Jul, Oct)		4
ranpre	precipitation range (annual; spring, summer, autumn, winter)	mm	5

Table S2. Kendall rank correlation coefficients (τ, $p<0.05$) of loss, gain and turnover estimates per grid cell using SEDG, BAMBU and GRAS up to 2080, based on measures of 2995 grid cells and 845 selected plant species for GLM, GAM, RF in Germany. We computed losses (L), gains (G) and turnover (T=100 *(L+G)/(Species Richness+G)) as a percentage per grid cell between future and current distribution. To calculate L (G) within grid cell (2051-80), we summed up the number of species lost (or gained) and related the results to present potential species richness estimates (1961-90) (see Thuiller et al. 2005). For T and G we assumed that a species can reach a new suitable, modelled bioclimatic space without dispersal limitations.

	SEDG			**BAMBU**			**GRAS**		
				Loss					
	GLM	GAM	RF	GLM	GAM	RF	GLM	GAM	RF
GLM	1.0000			1.0000			1.0000		
GAM	0.6622	1.0000		0.6474	1.0000		0.7032	1.0000	
RF	0.5395	0.4477	1.0000	0.5671	0.4666	1.0000	0.6858	0.5604	1.0000
				Gain					
	GLM	GAM	RF	GLM	GAM	RF	GLM	GAM	RF
GLM	1.0000			1.0000			1.0000		
GAM	0.7378	1.0000		0.7144	1.0000		0.7234	1.0000	
RF	0.4950	0.4934	1.0000	0.5096	0.5273	1.0000	0.4277	0.4309	1.0000
				Turnover					
	GLM	GAM	RF	GLM	GAM	RF	GLM	GAM	RF
GLM	1.0000			1.0000			1.0000		
GAM	0.7064	1.0000		0.6257	1.0000		0.6400	1.0000	
RF	0.6303	0.5462	1.0000	0.5355	0.4554	1.0000	0.5206	0.4728	1.0000

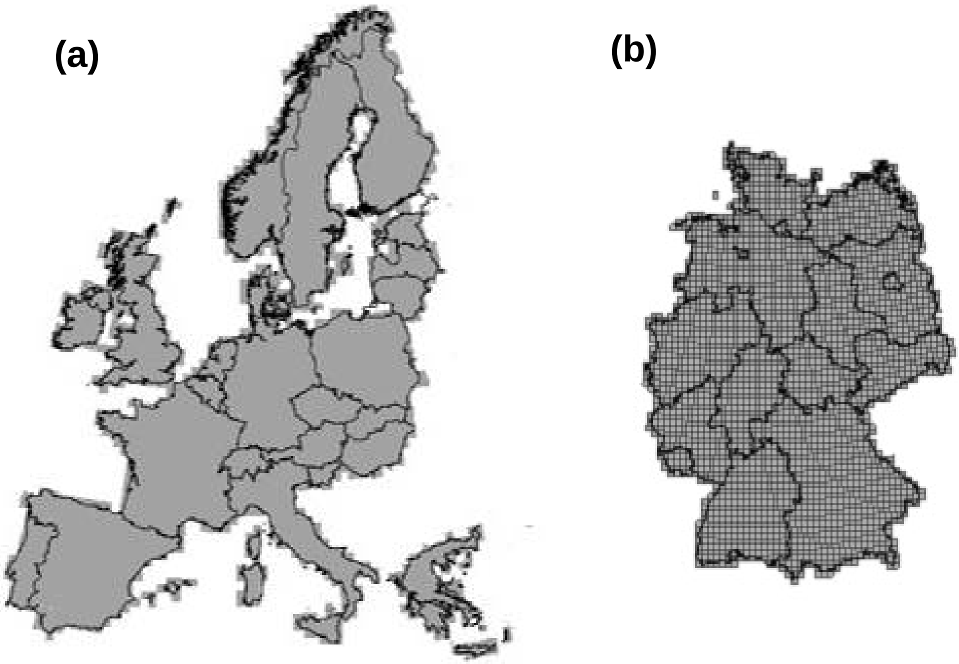

Figure S1. (a) Overlaying spatial extent of selected 2141 grid cells of the AFE grid (50×50 km² grid cells, Jalas & Suominen 1972-2004) after combining climatic, land use, soil data for model calibration on the European level, (b) 6'×10' resolution grid (ca. 11×12 km², 2995 grid cells) in Germany. Spatial resolution is based on the national plant distribution database FLORKART (www.floraweb.de) and was used for projection at the finer resolution for recent past, 1961-90, and the scenarios from 2051-80. Graphical operations were done with ArcGis 9.1 software.

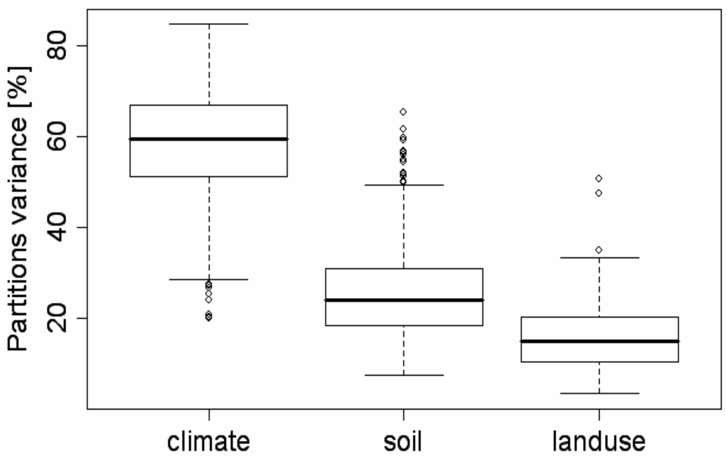

Figure S2. Result from hierarchical partitioning for the regression model (GLM) based on the European range of selected 845 plant species, boxplot with contribution of each parameter by total variance: climate 59±12% (mean ± standard deviation), soil 25±10% and land use 16±7%. Climate comprised six PCA axes (as predictors after principal component analyses of 38 bioclimatic variables, see Table S1); soil comprised six CA axes (as predictors after correspondence analyses of eleven soil characteristics, namely parent material, texture of the surface, base saturation, available water capacity, cation exchange capacity, depth to gleyed horizon, depth to rock, organic carbon content, slope); land use comprised of four categories with forest, grassland, cropland and urban areas. Calculations and graphical presentation were done in R software environment (R Development Core Team 2004).

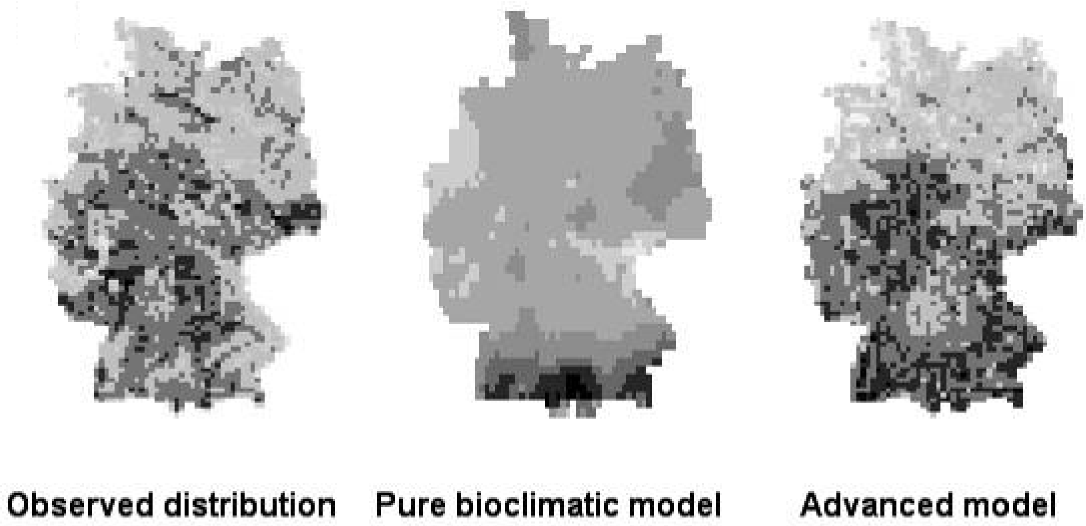

Figure S3. Current species richness (six classes, dark: high, light: low): observed species richness in Germany based on FLORKART (6'×10', www.floraweb.de), modelled species richness from a pure bioclimatic model based on Thuiller et al. 2005 (10'×10') related to seven bioclimatic variables, advanced model framework (GLM, 6'×10') related to bioclimatic, land use and soil predictors.

The geographical pattern of species richness estimates are more similar to observed species numbers in Germany than to the patterns resulting from the pure bioclimatic model. Between the downscaled modelled distribution and the observed distribution of the selected 845 species at a 6'x10' resolution we found significant positive correlations averaged over all species for GLM (τ=0.30), GAM (τ=0.32) and RF (τ=0.38) (Kendall rank correlation, all $p<0.05$). Modelled species richness estimates accounted for high agreement among all models (GLM, GAM, RF) at the fine resolution (Kendall rank correlation, τ=0.68±0.1 (mean ± standard deviation), $p<0.05$).

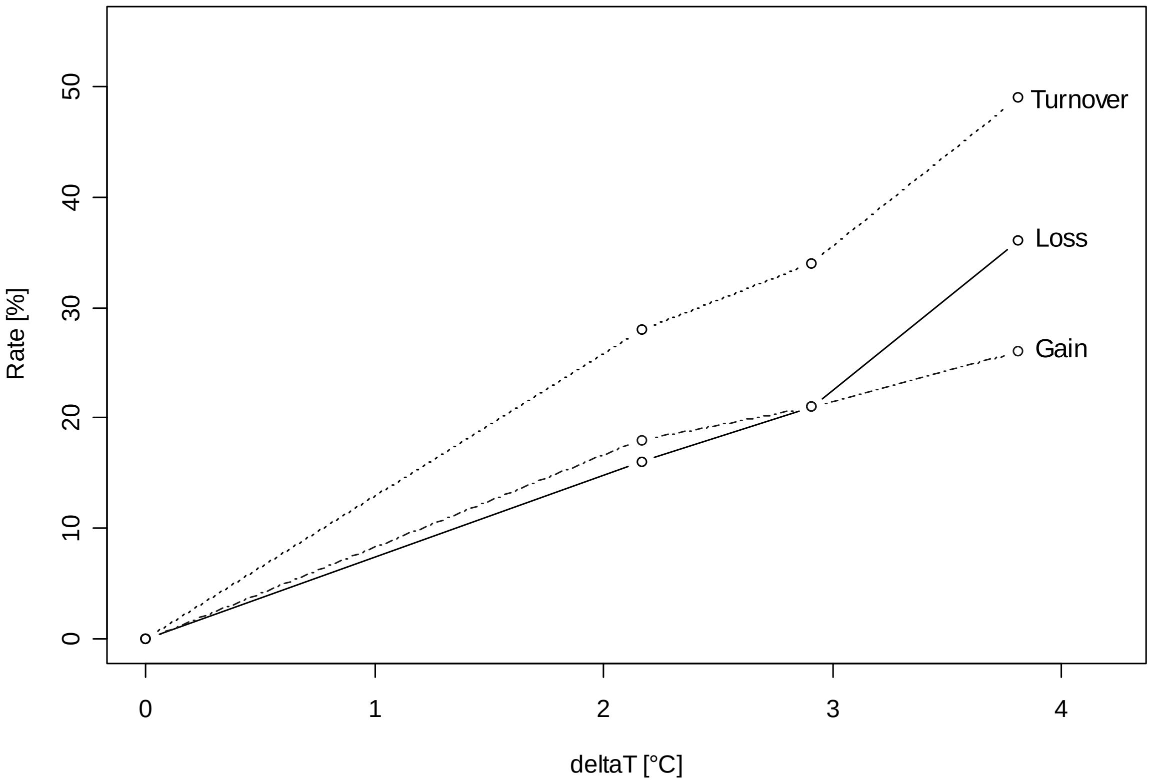

Figure 4. The rate of loss, turnover and gain [%] per degree of temperature change increased from SEDG to BAMBU to GRAS (see averages in table 1); corresponding average increase in annual mean temperature between reference (1961-90) and scenario period (2051-80) was 2.2, 2.9 and 3.8 °C for SEGD, BAMBU and GRAS, respectively.

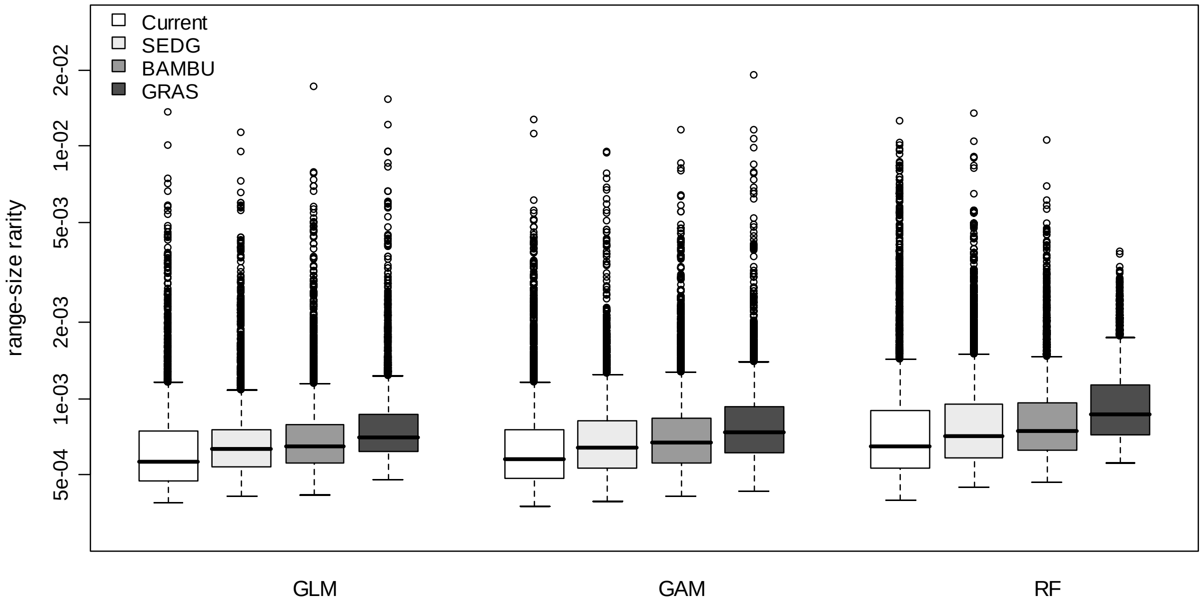

Figure S5. Range-size rarity index (Kier & Barthlott 2001, log transformed) for the modelled current distribution (1961-90) and per scenario: SEDG, BAMBU, GRAS (2051-80). Range-size rarity was calculated as a sum of inverse range size by each species for each grid cell. Rarity scores were divided by the modelled species numbers (SR) per grid cell (under the assumption that each species could reach a new suitable bioclimatic space). Paired Wilcoxon tests showed a significant increase of range size rarity scores under all scenarios and models ($p<0.05$, GLM, GAM, RF).

Supplementary references

Jalas, J. & Suominen, J. 1972-2004 Atlas Florae Europaeae, Helsinki: The Committee for Mapping the Flora of Europe and Societas Biologica Fennica Vanamo.

Kier, G. & Barthlott, W. 2001 Measuring and mapping endemism and species richness: a new methodological approach and its application on the flora of Africa. *Biodiv. Con.* **10**, 1513-1529.

Mitchell, T.D., Carter, T.R., Jones, P.D., Hulme, M. & New, M. 2004 A comprehensive set of high-resolution grids of monthly climate for Europe and the globe: the observed record (1901-2000) and 16 scenarios (2001-2100). Working Paper 55. Tyne Centre for Climate Change Research, University of East Anglia, Norwich, UK.

Ohlemüller, R., Gritti, E.S., Sykes, M.T. & Thomas, C.D. 2006 Towards European climate risk surfaces: the extent and distribution of analogous and non-analogous climates 1931–2100. *Glob. Ecol Biogeogr.* **15**, 395–405.

R Development Core Team 2004 R: A language and environment for statistical computing. R–Foundation for Statistical Computing. Vienna, Austria.

Settele, J., Hammen, V., Hulme, P.E., Karlson, U., Klotz, S., Kotarac, M., Kunin, W.E., Marion, G., O'Connor, M., Petanidou, T. et al. 2005 ALARM: Assesing LArge scale environmental Risks for biodiversity with tested Methods. *GAIA* **14**, 96-72.

Thuiller, W., Lavorel, S., Araújo, M.B., Sykes, M.T. & Prentice, C. 2005 Climate change threats to plant diversity in Europe. *PNAS* **102**, 8245-8250.