Supplementary material for the manuscript

CO_2 fertilization plays a minor role in long-term carbon accumulation patterns in temperate pine forests in the southwestern Pyrenees

Yueh-Hsin Lo[1], Juan A. Blanco[1], Ester González de Andrés[1], J. Bosco Imbert[1], Federico J. Castillo[1]

[1]Institute for Multidisciplinary Research in Applied biology, Universidad Pública de Navarra,
Campus de Arrosadía, Pamplona, Navarra, 31006, Spain

Contact author:
Dr. Juan A. Blanco
Dep. Ciencias, Universidad Pública de Navarra
Campus de Arrosadía, Pamplona, Navarra, 31006, Spain
E-mail: juan.blanco@unavarra.es
Tel: +34 948 16 98 59
Fax: +34 948 16 89 30

Part of the special issue "Modelling Forest Ecosystems"

1. RESEARCH SITES USED FOR MODEL CALIBRATION

Research plots are located in the higher Ebro Basin, in northern-central Spain, in the southwestern Pyrenees. Nine research plots are placed at two different sites with distinct geo-climatic features, providing a climatic gradient representative of most Mediterranean mountains. The first site (near the village of Aspurz) has cool Mediterranean climate, 680 m altitude, 10% average slope, average annual temperature (Tm) of 12.0 ºC and annual precipitation (P) of 900 mm. The second site (near the village of Garde) is a cool continental site at 1380 m altitude, 45% slope, Tm 8.2ºC and P 1300 mm (Figure 1 in main text). At both sites, Scots pine is the dominant species, with a presence of beech trees in the lower canopy and understory layers (Table S1).

Table S1. Site features both sites (mean ± standard error).

Variable	**Cold wet Mediterranean site**[1]	**Cold wet continental site**[1]
Name of nearest town	Aspurz	Garde
Latitude N	42º42′31′′	42º48′50′′
Longitude W	1º08′40′′	0º52′30′′
Altitude a.s.l. (m)	625	1,335
Mean slope (%)	7	40
Aspect	N	NE
Mean annual precipitation (mm)[2]	895	1802
Mean temperature (ºC) [2]	11.9	9.3
Soil type (FAO)	Haplic Alisol	Dystric Cambisol
Texture (FAO)	Sandy loam	Clay loam
Maximum root depth	45 cm	35 cm
Saturated water content	42.6%	51.3%
Organic C (mg g^{-1})[3]	53.12 ± 2.75	52.62 ± 2.36
Organic N (mg g^{-1})[3]	2.62 ± 0.12	2.39 ± 0.08
Available P (mg g^{-1})[3]	0.018 ± 0.001	0.025 ± 0.002
C/N	20.68 ± 0.51	22.43 ± 1.13
N/P	196.9 ± 13.9	139.3 ± 22.4

[1] According to Papadakis classification.

[2] Variables calculated for the period 1985-2014.

3 Surface mineral horizon: organic C (Walkley-Black method, USDA, 1972), organic N (Kjeldahl), available P (Olsen, Kuo, 1996).

2. MODELLING APPROACH

2.1. FORECAST Climate development

FORECAST Climate was developed from FORECAST (Kimmins *et al.*, 1999) which is a managed-oriented, deterministic, non-spatial, stand-level forest growth and ecosystem dynamics simulator. FORECAST was designed to accommodate a wide variety of harvesting and silvicultural systems in order to compare and contrast their effect upon forest productivity, stand dynamics and a series of biophysical indicators of non- timber stand values. The model has been used in a wide variety of applications and has been evaluated against field data for growth, yield, ecophysiological and soil variables (e.g. Bi *et al.*, 2007; Blanco *et al.*, 2007; Seely *et al.*, 2008). The model uses a hybrid approach to vegetation growth modelling, as it merges the use of empirical data modified by the simulation of the most important ecological processes (Kimmins *et al*., 1999; Landsberg, 2003). Projection of stand growth and ecosystem dynamics is based on a representation of the rates of key ecological processes regulating the availability of, and competition for, light and nutrient resources (Fig. S1A). FORECAST assumes that climate for the simulated site quality is similar to the climate during the time when empirical data were recorded. However, the rising trends in greenhouse gas emissions and their associated impacts on future temperature and precipitation patterns (IPCC, 2013) triggered the development of an explicit representation in the model of moisture and temperature on ecosystem processes.

Hydrological processes are simulated by the forest hydrology model ForWaDy, in which water flows through a layered forest ecosystem (Fig. S1B). ForWaDy´s general data requirements are shown in Table S2. FORECAST and ForWaDy are dynamically linked to create FORECAST Climate, as the respective functions from each model are continuously updated in response to the iterative sharing of information encoded within a series of feedback loops.

2.2. Climate impacts on productivity, decomposition and mortality

Climate impact (temperature and moisture) on plant growth and decomposition processes is represented with species-specific curvilinear response functions simulated on a daily time step (Fig. S2). A net daily growth response index of species *i* and day *d* ($GRI_{Day\ i,d}$) and a daily decomposition response index of soil layer *l* and day *d* ($DRI_{Day\ l,d}$) are derived as the product of temperature and water stress components. Daily response indexes are then summed to calculate annual response indexes for growth ($GRI_{Year\ i,y}$) and decomposition ($DRI_{Year\ l,y}$). A calibration run is conducted with the reference climate data set from which t $GRI_{Year\ i,y}$ and $DRI_{Year\ l,y}$ are calculated. By averaging the annual values for the length of the reference climate period, a normalized growth and decomposition response indexes are derived for each species or soil layer that reflects ‘normal’ conditions in an average historical climate year. Annual climate response indexes are compared against normalized response indexes to obtain climate factors, which modify base growth and decomposition rates to achieve a climate- limited growth and decomposition (Eq. S1 and S2).

$$CRF_{i,y} = (GRI_{Year\ i,y} - NGRI_i) / NGRI_i \text{ and } CDF_{x,y} = (DRI_{Year\ l,y} - NDRI_l) / NDRI_l \qquad (S1)$$

$$CGR_{i,y} = BRG_{i,y} * CRF_{i,y} \text{ and } CDR_{x,y} = BRD_{x,y} * CDF_{x,y} \qquad (S2)$$

where, $CRF_{i,y}$ is the climate response factor for species *i* in year *y*; $CDF_{x,y}$ is the climate decomposition factor for litter type *x* in year *y*; $NGRI_i$ and $NDRI_l$ are normalized growth and decomposition rates, respectively, derived from the reference climate; $CGR_{i,y}$ is the climate-limited growth rate for species *i* in year *y* (Mg ha^{-1}); $CDR_{x,y}$ is the expected climate decomposition rate for litter type *x* and year *y* (Mg ha^{-1}); $BRG_{i,y}$ is base growth rate determined in FORECAST as the light and nutrient-limited growth rate ; and $BRD_{x,y}$ is the base decomposition rate for each litter type determined as a function of litter quality.

Drought-related mortality is also included in FORECAST Climate since long dry periods can cause plant individual loss, either directly or by increasing vulnerability to biotic disturbance agents (Allen *et al*., 2010). Water stress mortality is simulated through a user-defined graphical function of species-specific, two-year running average TDI (Fig. S3). For further details on impacts of increasing CO_2 on forest growth, linkage between FORECAST and ForWaDy and climate response factors of growth and soil related processes calculation see Seely *et al*. (2015).

Table S2. General data requirements for the ForWaDy model.

Climate data (daily)	Vegetation data	Forest floor and soil data
Mean, max and min air temperature (ºC)	Seasonal tree Leaf Area Index (LAI)	Fine litter mass (kg.ha^{-1})
Solar radiation (MJ. m^2).	Seasonal understory cover (%).	Humus layer depth (cm) and bulk density (g.cm^3)
Total precipitation (mm).	Rooting depth for trees (cm)	Depth of mineral soil layers (rooting depth) (cm)
Snow fraction.	Rooting depth for understory (cm)	Soil texture class of each soil layer
Atmospheric [CO_2].	Canopy resistance and albedo (by species)	Coarse fragment content (> 2 mm) in each soil layer

2.3. Model calibration and initialization

Published yield tables and biomass equations were used to build historical *P. sylvestris* growth patterns (age-biomass curves) (García and Tella, 1986; Puertas, 2003). Data on tree light and nitrogen requirements were derived from field data (Blanco *et al*., 2009; Primicia *et al*., 2014) and literature (Oliver and Larson, 1996; Terradas, 2001; Santa Regina and Tarazona, 2001; Dufrene *et al*., 2005; Balandier *et al*., 2010). Literature data were also used to calibrate shading (Pretzsch *et al*., 2015) and turnover rates (Mäkelä and Vanninen, 2000; Mainiero and Kazda, 2006; Finér *et al*., 2007). Litter production was derived from field data (Kimmins, 2004; Blanco *et al*., 2006a). Decomposition rates and soil data were derived from field data (Blanco *et al*., 2011; Fernández, 2013; Martínez, 2015) and literature (Blanco *et al*., 2006b). Empirical data showed the absence of N fixation in *P. sylvestris* stands (Blanco *et al*., 2016). Atmospheric deposition rates are based on García-Gómez *et al*. (2014) predictions, and mineral weathering rates are from literature (Kimmins, 2004; Fisher and Binkley, 2000). Understory growth patterns (limited in the simulation to *Rubus* spp., the main dominant understory species by biomass at both sites; Arias, 2014), nutrient concentration and litterfall decomposition rates were derived from literature (Mitchell *et al*., 2000; Imbert *et al*., 2008; García Del Barrio, 2000) and field data (Arias, 2014). Values of soil and tree-related parameters can be found in Table S3 and Table S4, respectively.

Seasonal changes in leaf area index (LAI) needed for ForWaDy model calibration were estimated with data from PEP725 Pan European Phenology Data (http://www.zamg.ac.at/pep725/) and literature (Gill *et al*., 1998; Vitasse *et al*., 2009), whereas seasonal understory cover was derived from field data. Literature data were used for rooting depth of trees and understory vegetation (Fotelli *et al*., 2001; Bonnemann, 1939 in Pretzsch *et al*., 2015), and canopy resistance and albedo (Otto *et al*., 2014). The climate response functions within FORECAST Climate were calibrated using historical daily climate data. Solar radiation was estimated from maximum and minimum air temperature, elevation, latitude, slope and aspect of study sites using published radiation models (Seely *et al*., 2015).

To establish initial site conditions we carried-out a modified version of the typical spin-up process used to let the model reach a stable state (Hashimoto *et al*., 2011; Shi *et al*., 2013). Initial conditions were created by running the model for ten 150-year cycles ending with a clear-cutting and harvest of 90% of logs and allowed for a new cohort of trees to grow (Blanco *et al*., 2007, Blanco and González, 2010). Simulated stands were pine-beech mixtures. These runs allowed the model to accumulate soil organic matter (SOM) until reaching a stable value (378.1 and 506.3 Mg ha^{-1} for the high and low elevations sites, respectively). The final products of these runs were used as the starting conditions for the simulations.

Table S3. Values used to calibrate FORECAST parameters related to soil and geochemical cycles.

Parameter	**Mediterranean site**	**Continental site**
N concentration in slow / fast humus (%)	2.50 / 1.20	2.50 / 1.20
Decomposition rate slow / fast humus (% year^{-1})	0.25 / 1.30	0.25 / 1.20
CEC soil (CEC humus) / AEC [a] (kg N.ha^{-1} · year^{-1})	85.0 (0.1) / 2.0	50.0 (0.1) / 1.0
Atmospheric deposition / seepage (kg N · ha^{-1} ·year^{-1})	10.5 / 0.35	6.5 / 0.0
Initial SOM [b] (humus + litter) (Mg · year^{-1})	506.27	378.08

[a] CEC: cation exchange capacity; AEC: anion exchange capacity
[b] SOM: soil organic matter

Table S4. Values used to calibrate FORECAST parameters related to *Pinus sylvestris*.

Tree parameter	**Mediterranean site**	**Subalpine site**
Nitrogen concentration in leaves young/old/dead Nitrogen (%)	1.40/1.35/0.64	1.10/1.06/0.68
Nitrogen concentration in stem sapwood/heartwood (%)	0.11 / 0.09	0.10 / 0.04
Nitrogen concentration in bark live/dead (%)	0.38 / 0.33	0.25 / 0.19
Nitrogen concentration in branches live/dead (%)	0.53 / 0.31	0.36 / 0.11
Nitrogen concentration in root sapwood/heartwood (%)	0.53 / 0.31	0.25 / 0.23
Nitrogen concentration in fine roots live/dead (%)	0.96 / 0.62	0.86 / 0.57
Shading by maximum foliage biomass (% of full light)	0.15	0.25
Soil volume occupied at maximum fine root biomass (%)	0.97	0.97
Efficiency of N root capture (%)	1	1
Retention time for young/old foliage/dead branches (years)	1 / 3 / 10	1 / 4 / 22
Fine roots turnover (years^{-1})	0.65	0.95
Maximum foliage biomass (kg · tree^{-1})	30	17

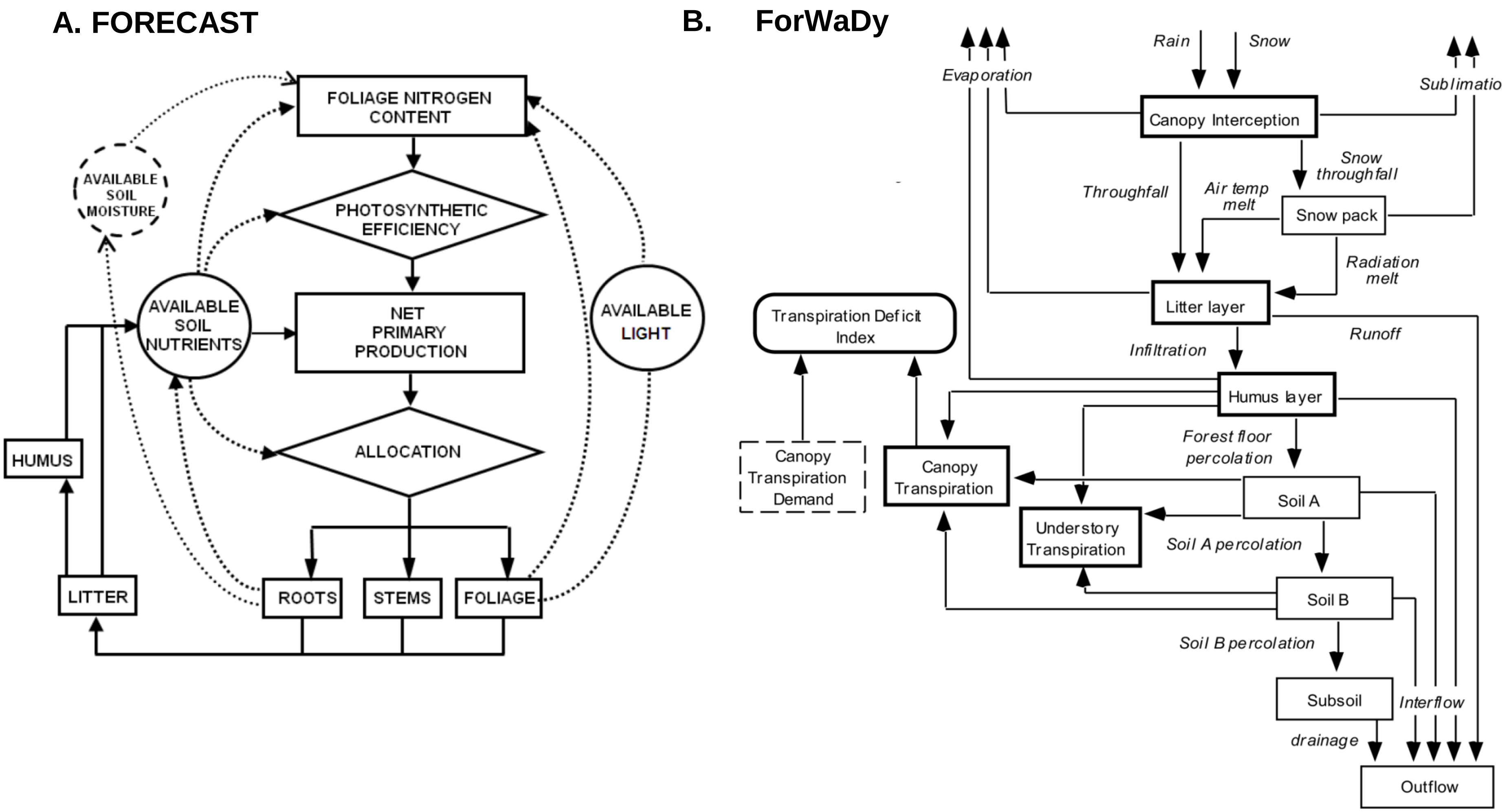

Figure S1. Schematic representation of: (A) key ecosystem processes and interactions (black dotted lines), and mass flows between ecosystem pools (black solid lines) represented in FORECAST model (after Blanco, 2012); and (B) the forest hydrology model ForWaDy indicating water flow pathways and storage compartments in the model (after Seely *et al*., 1997), used to estimate the available soil moisture in FORECAST.

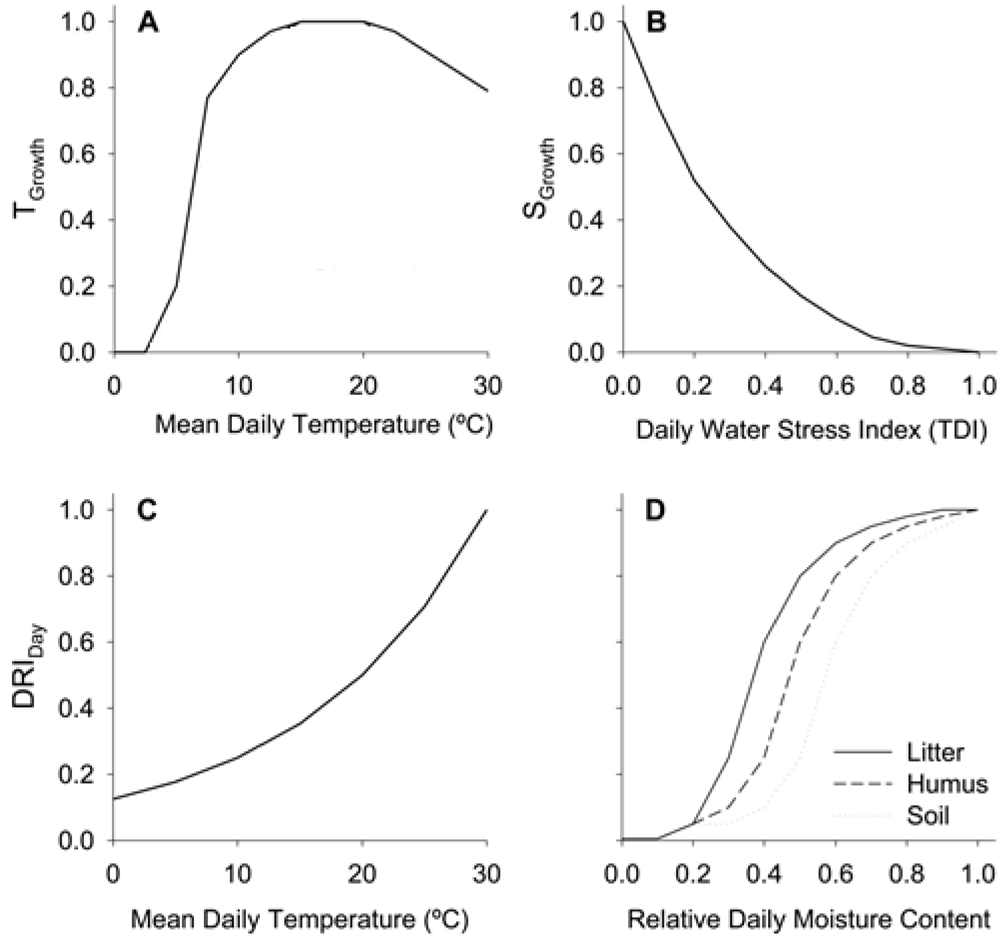

Figure S2. Climate response function showing the effect of temperature and water stress on growth (A, B) and decomposition (C, D). Relationships between mean daily temperature and a temperature growth modifier for both tree species (A), and daily water stress and moisture growth modifier (B). Daily decomposition index in relation to daily air temperature (C), based upon a Q_{10} function where $Q_{10} = 2$, and relative daily moisture content shown for litter, humus and mineral soil (D).

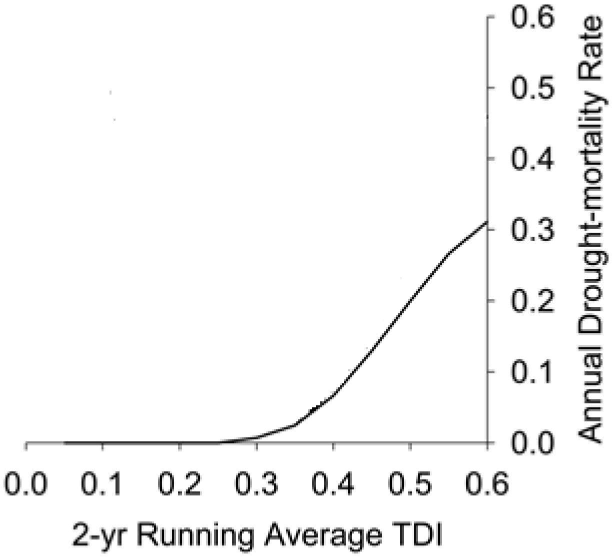

Figure S3. The drought-related mortality rate as a function of the 2-year running average water stress index

3. CLIMATE CHANGE SCENARIOS

Six different well-established general circulation models (GCMs) included as part of the Intergovernmental Panel on Climate Change AR5 analysis (IPCC 2013; Table S5) were used to generate climate change scenarios. Two emissions pathways based on a representative CO_2 concentration pathways that generates radiative forcing of 4.5 Wm^{-2} (RCP 4.5) and 8.5 Wm^{-2} (RCP 8.5) (Meinshausen *et al.*, 2011) were selected (Fig. S4).While the latter presents a high radiative forcing and greenhouses gases concentration, the former is an intermediate pathway that predicts stabilization in 2100-2150 and it is reflected in a large number of publications. GCMs were regional downscaled using the Statistical Downscaling Method (SDSM), a regression-based downscaling method that has been broadly applied to produce high-resolution climate change scenarios around the world (Wilby and Dawson, 2013). Empirical relationships were established between data from weather stations for the period 1961-1990 and GCMs predictions interpolated into a 2.5° re-analysis grid NCEP/NCAR (Serrano *et al.*, 2014). Maximum and minimum temperatures were predicted using unconditional models and minimum sum of absolute errors regression for parameter estimation: the variance of the series is increased by adding a random-residual factor to the deterministic component. Precipitation projections were made with conditional models by following the procedure specified by Kilsby *et al*. (1998) and the least square method. In this case, an additional stochastic process is included to determine whether a particular day precipitation occurred or not by comparing the probability obtained from the regression model and a pseudo-random number extracted from a uniform distribution with values between 0 and 1. Models were validated with observed data from the period 1991-2000 (Serrano *et al.*, 2014). The projections from five near to study sites weather stations were averaged and subtracted or divided by temperature and precipitation, respectively, from climate series for the reference period 1975-2004 from each study site. The resulting data set spanned a 100-year period (2015–2114). Changes in growing season mean temperature and total precipitation are shown in Fig. S5.

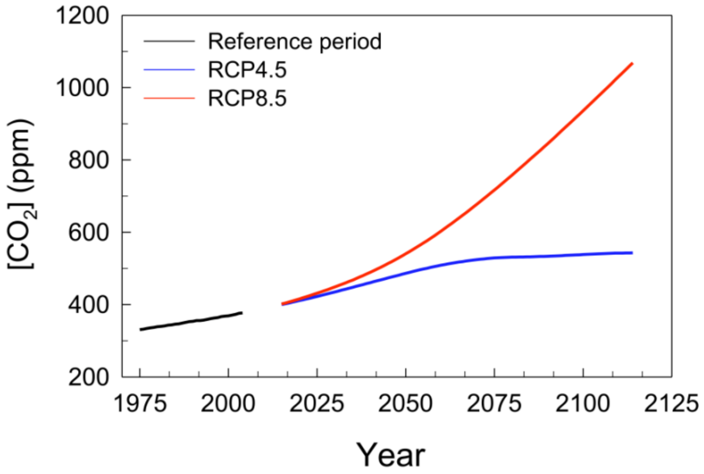

Figure S4. Atmospheric CO_2 concentration ($[CO_2]$) for the historical period 1975-2004 (black line) and projected increase for the RCP 4.5 (blue line) and RCP 8.5 emissions scenarios (red line).

Table S5. General Circulation Models (GCMs) used for climate change scenarios projections.

Name	Institution (Country)	References
BNU-ESM	Beijing Normal University (China)	Merrifield *et al.* (2013) , von Salzen *et al.* (2013)
CanESM2	Canadian Center for Climate Modelling and Analysis (Canada)	Arora *et al.* (2011), von Salzen *et al.* (2013)
CMCC-CM	Centro Euro-Mediterraneo per I Cambiamenti Climatici (Italy)	Fogli *et al.* (2009), Scoccimarro *et al.* (2011),
IPSL-CM5B-LR	Institut Pierre Simon Laplace (France)	Dufresne *et al.* (2012),
MIROC-ESM	University of Tokyo, National Institute for Environmental Studies, and Japan Agency for Marine-Earth Science and Technology (Japan)	Watanabe *et al.* (2011)
MPI-ESM-MR	Max Planck Institute for Meteorology (Germany)	Stevens *et al.* (2012), Reick *et al.* (2013)

References

Arias, M. 2014. Influencia a largo plazo de las claras forestales en el sotobosque de bosques de pino del Pirineo navarro: observaciones tras 13 años. BSc thesis (in Spanish). Universidad Pública de Navarra, Pamplona.

Arora VK, Scinocca JF, Boer GJ, Christian JR, Denman KL, Flato GM, Kharin VV, Lee WG, Merryfield WJ. 2011. Carbon emission limits required to satisfy future representative concentration pathways of greenhouse gases. *Geophysical Research Letters* **38**: L05805. DOI: 10.1029/2010GL046270.

Balandier P, Marquier A, Perret S, Collet C, Courbeau B. 2010. Comment estimer la lumière dans le sous-bois forestier à partir des caractéristiques dendrométriques des peuplements. Rendez-Vous Techniques ONF, .27-28, 52-58.

Bi J, Blanco JA, Kimmins JP, Ding Y, Seely B, Welham C. 2007. Yield decline in Chinese Fir plantations: A simulation investigation with implications for model complexity. *Canadian Journal of Forest Research* **37**: 1615–1630. DOI: 10.1139/X07-018.

Blanco JA, González E. 2010. Exploring the sustainability of current management prescriptions for *Pinus caribaea* plantations in Cuba: a modelling approach. *Journal of Tropical Forest Science* **22**: 139–54.

Blanco JA, Imbert JB, Castillo FJ. 2006a. Influence of site characteristics and thinning intensity on litterfall production in two Pinus sylvestris L. forests in the Western Pyrenees. *Forest Ecology and Management* **237**: 342–352. DOI: 10.1016/j.foreco.2006.09.057.

Blanco JA, Imbert JB, Castillo FJ. 2006b. Effects of thinning on nutrient pools in two contrasting Pinus sylvestris L. forests in the western Pyrenees. *Scandinavian Journal of Forest Research* **21**: 143–150. DOI: 10.1080/02827580600559726.

Blanco JA, Seely B, Welham C, Kimmins JP, Seebacher TM. 2007. Testing the performance of FORECAST, a forest ecosystem model, against 29 years of field data in a Pseudotsuga menziesii plantation. *Canadian Journal of Forest Research* **37**: 1808–1820. DOI: 10.1139/X07-041.

Blanco JA, Imbert JB, Castillo FJ. 2009. Thinning affects nutrient resorption and nutrient-use efficiency in two Pinus sylvestris stands in the Pyrenees. *Ecological Applications* **19**: 682-698. DOI: 10.1890/1051-0761-19.3.682.

Blanco JA, Imbert JB, Castillo FJ. 2011. Thinning affects Pinus sylvestris needle decomposition rates and chemistry differently depending on site conditions. *Biogeochemistry* **106**: 397–414. DOI: 10.1007/s10533-010-9518-2.

Blanco JA, San Emeterio L, González de Andrés E, Imbert JB, Larrainzar E, Castanera R, Peralta J, Lo YH, Castillo FJ, AG Pisabarro. 2016. Scots pine forests in the Western Pyrenees depend on external N sources to keep their productivity. Proceedings of ECOSUMMIT2016, Montpellier, France August 28th – September 1st.

Dufrêne E, Davi H, François C, le Maire G, Le DantecV, Granier A. 2005. Modelling carbon and water cycles in a beech forest: Part I: Model description and uncertainty analysis on modelled NEE. *Ecological Modelling* **185**: 407-436. DOI: 10.1016/j.ecolmodel.2005.01.004.

Dufresne JL, *et al.*, 2012. Climate change projections using the IPSL-CM5 Earth System Model: From CMIP3 to CMIP5. *Climate Dynamics* **40**: 2123-2165. DOI:10.1007/s00382-012-1636-1.

Fernández M. (MSc thesis). 2013. Effect of the tree species and forest management on the soil capacity for water interception. University of the Basque Country, Leioa (in Spanish).

Fisher RF, Binkley D. 2000. *Ecology and Management of Forest Soils.* Wiley: New York.

Finér L, Helmisaari HS, Lõhmus K, Majdi H, Brunner I, Børja I, Eldhuset T, Godbold D, Grebenc T, Konôpka B, Kraigher H, Möttönen MR, Ohashi M, Oleksyn J, Ostonen I, Uri V, Vanguelova E. 2007. *Plant Biosystems* **141**: 394-405. DOI: 10.1080/11263500701625897.

Fogli PG, Manzini E, Vichi M, Alessandri A, Patara L, Gualdi S, Scoccimarro E, Masina S, Navarra A. 2009. INGV-CMCC Carbon (ICC): A Carbon Cycle Earth System Model. *CMCC Res. Papers*. Euro-Mediterranean Center on Climate Change: Bologna, Italy.

Fotelli MN, Geßler A, Peuke AD, Rennenberg H. 2001. Drought affects the competitive interactions between Fagus sylvatica seedlings and an early successional species, Rubus fruticosus: responses of growth, water status and $\delta^{13}C$ composition. *New Phytologist* **151**: 427-435. DOI: 10.1046/j.1469-8137.2001.00186.x.

García JL, Tella G. 1986. Tablas de producción de densidad variable para Pinus sylvestris L. en el sistema pirenaico. *Comunicaciones INIA. Serie Recursos Naturales*, 43, Madrid.

García Del Barrio JM. 2000. Compartimentos y flujos de biomasa y nutrientes en un pinar de Pinus sylvestris L. en el monte de Valsaín. Monografias INIA, Serie Forestal 2, Madrid.

García-Gómez H, Garrido JL,Vivanco MG, Lassaletta L, Rábago I, Ávila A, Tsyro S, Sánches G, González Ortiz A, González-Fernández I, Alonso R. 2014. Nitrogen deposition in Spain: Modeled patterns and threatened habitats within the Natura 2000 network. *Science of the Total Environment* **485-486**. 450-460. DOI: 10.1016/j.scitotenv.2014.03.112.

Gill DS, Amthor JS, Bormann FH. 1998. Leaf phenology, photosynthesis, and the persistence of saplings and shrubs in a mature northern hardwood forest. *Tree Physiology* **18**: 281-289. DOI: 10.1093/treephys/18.5.281.

Hashimoto, S., Wattenbach, M., Smith, P. 2011. A new scheme for initializing process-based ecosystem models by scaling soil carbon pools. *Ecological Modelling* **222**: 3598-3602.

Imbert JB, Blanco JA, Castillo FJ. 2008. Gestión forestal y ciclo de nutrientes en el marco del cambio global. In: Valladares, F. (ed.). *Ecología del bosque mediterráneo en un mundo cambiante*. Ministerio de Medio Ambiente/EGRAF S.A.: Madrid.

IPCC. 2013. Summary for Policymakers. In: Stocker TF, Qin D, Plattner G-K, Tignor M, Allen SK, Boschung J, Nauels A, Xia Y, Bex V, Midgley PM (eds.). *Climate Change 2013: The Physical Science Basis Contribution of Working Group I to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge University Press: New York. DOI: 10.1017/CBO9781107415324.004.

Kilsby CG. 1998. Predicting rainfall statistics in England and Wales using atmospheric circulation variables. *International Journal of Climatology* **18**: 523-539. DOI: 10.1002/(SICI)1097-0088(199804)18:5<523::AID-JOC268>3.0.CO;2-X.

Kimmins JP. 2004. *Forest Ecology. A Foundation for Sustainable Management and Environmental Ethics in Forestry*. Prentice Hall: New Jersey.

Kimmins JP, Mailly D, Seely B. 1999. Modelling forest ecosystem net primary production: the hybrid simulation approach used in FORECAST. *Ecological Modelling* **122**: 195–224. DOI: 10.1016/S0304-3800(99)00138-6.

Kuo S. 1996. Phosphorus. In: Sparks D.L. (Ed.) Methods of Soil Analysis: Part 3- Chemical and Microbiological Properties. (pp. 869-919), American Society of Agronomy, Madison, Wisconsin.

Landsberg J. 2003. Modelling forest ecosystems: state of the art, challenges, and future directions. *Canadian Journal of Forest Research* **33**: 385–397. DOI: 10.1139/x02-129.

Mainiero R, Kazda M. 2006. Depth-related fine root dynamics of Fagus sylvaticaduring exceptional drought. *Forest Ecology and Management* **237**: 135-142. DOI: 10.1016/j.foreco.2006.09.034.

Mäkelä A, Vanninen P. 2000. Estimation of fine root mortality and growth from simple measurements: a method based on system dynamics. *Trees* **14**: 316-323. DOI: 10.1007/s004680050224.

Martínez C. (MSc thesis). 2015. Thinning influence on coarse woody debris production in pine forests in the Navarrean Pyrenees. Public University of Navarre, Pamplona (in Spanish).

Meinshausen M, Smith SJ, Calvin KV, Daniel JS, Kainuma JF, Lamarque M, Matsumoto K, Montzka SA, Raper SCB, Riahi K, Thomsom A, Velders GJM, van Vuuren DPP. 2011. The RCP greenhouse gas concentrations and their extension from 1765 to 2300. *Climate Change* **109**: 213–241. DOI: 10.1007/s10584-011-0156-z.

Merryfield MA, Maltrud ME. 2011: Regional sea level trends due to a Pacific trade wind intensification. *Geophysical Research Letters* **38**: L21605.DOI: 10.1029/2011GL049576.

Mitchell RJ, Auld MHD, Hughes JM, Marrs RH. 2000. Estimates of nutrient removal during heathland restoration of successional sites in Dorset, southern England. *Biological Conservation* **95**: 233–246. DOI: 10.1016/S0006-3207(00)00046-X.

Oliver, C.D., Larson, B.C., 1996. *Forest Stand Dynamics: Update Edition*. Wiley: New York.

Otto J, Berveiller D, Bréon FM, Delpierre N, Geppert G, Granier A, Jans W, Knohl A, Kuusk A, Longdoz B, Moors E, Mund M, Pinty B, Schelhaas J, Luyssaert S. 2014. Forest summer albedo is sensitive to species and thinning: how should we account for this in Earth system models? *Biogeosciences* **11**: 2411-2427. DOI: 10.5194/bg-11-2411-2014.

Pretzsch H, del Río M, Ammer Ch, Avdagic A, Barbeito I, Bielak K, Brazaitis G, Coll L, Dirnberger G, Drössler L, Fabrika M, Forrester DI, Heym M, Hurt V, Kurylyak VML, Lombardi F, Mohren F, Motta R, den Ouden J, Pach M, Ponette Q, Schütze G, Schweig J, Skrzyszewski J, Sramek V, Sterba H, Stojanovic D, Svoboda M, Vanhellemont M, Verheyen K, Wellhausen K, Zlatanov T, Bravo-Oviedo A. 2015. Growth and yield of mixed versus pure stands of Scots pine (Pinus sylvestris L.) and European beech (Fagus sylvatica L.) along a gradient of productivity through Europe. *European Journal of Forest Research* **134**: 927-947. DOI: 10. 1007/s10342-015-0900-4.

Primicia I, Imbert JB, Traver MC, Castillo FJ. 2014. Inter-specific competition and management modify the morphology, nutrient content and resorption in Scots pine needles. *European Journal of Forest Research* **133**: 141-151. DOI: 10.1007/s10342-013-0753-7.

Puertas F. 2003. Scots pine in Navarre: economic importance and production. In: *Proceedings of the I.U.F.R.O. Meeting "Silviculture and sustainable Manage- ment in Mountain Forests in the Western Pyrenees"*, Navarre.

Reick CH, Raddatz T, Brovkin V, Gayler V. 2013. The representation of natural and anthropogenic land cover change in MPI-ESM. *Journal of Advances in Modeliing Earth Systems* **5**: 459-482. DOI:10.1002/jame.20022.

Scoccimarro E, Gualdi S, Belluci A,Sanna A,Flogi PG, Manzini E, Vichi M, Oddo P, Navarra A. 2011. Effects of tropical cyclones on ocean heat transport in a high resolution Coupled General Circulation Model. *Journal of Climate*, **24**: 4368–4384. DOI: 10.1175/2011JCLI4104.1.

Seely B, Hawkins C, Blanco JA, Welham C, Kimmins JP. 2008. Evaluation of a mechanistic approach to mixedwood modelling. *The Forestry Chronicle* **84**: 181–193. DOI: 10.5558/tfc84181-2.

Seely B, Welham C, Scoullar K. 2015. Application of a hybrid forest growth model to evaluate climate change impacts on productivity, nutrient cycling and mortality in a montane forest ecosystem. *PLoS ONE* **10**: e0135034. DOI: 10.1371/journal.pone.0135034.

Serrano AA, Morata A, Casado MJ, Martín JM, Petisco E, Ramos P, Rodríguez E. 2014. *Guía de los escenarios regionalizados de cambio climático sobre España a partir de los resultados del IPCC-AR4*. Ministerio de Agricultura, Alimentación y Medio Ambiente, Agencia Estatal de Meteorología: Madrid.

Shi M, Yang ZL, Lawrence D, Dickinson RE, Subin ZM. 2013. Spin-up processes in the Community Land Model version 4 with explicit carbon and nitrogen components. *Ecological Modelling* **263**: 308-325.

Stevens B, Giorgetta M, Esch M, Mauritsen T, Crueger T, Rast S, Salzmann M, Schmidt H, Bader J, Block K, Brokopf R, Fast I, Kinne S, Kornblueh L, Lohmann U, Pincus R, Reichler T, Roeckner E. 2012. The atmospheric component of the MPI-M Earth System Model: ECHAM6. *Journal of Advances in Modeliing Earth Systems* **5**: 146-172. DOI:10.1002/jame.20015.

Terradas J. 2001. *Ecología de la vegetación: De la ecofisiología de las plantas a la dinámica de comunidades y paisajes*. Ediciones Omega: Barcelona.

USDA – Soil Conseervation Service (1972). Investigación de suelos. Métodos de laboratorio y procedimientos para recoger muestra. Trillas, México D.F.

Vitasse Y, François C, Delpierre N, Dufrêne E, Kremer A, Chuine I, Delzon S. 2009. Assessing the effects of climate change on the phenology of European temperate trees. *Agricultural and Forest Meteorology* **151**: 969-980. DOI: 10.1016/j.agrformet.2011.03.003.

von Salzen K, Scinocca JF, McFarlane NA, Li J, Cole JNS, Plummer D, Verseghy D, Reader MC, Ma X, Lazare M, Solheim L. 2013: The Canadian Fourth Generation Atmospheric Global Climate Model (CanAM4). Part I: Representation of physical processes. *Atmosphere-Ocean* **51**: 104–125. DOI: 0.1080/07055900.2012.755610.

Watanabe M, Kug JS, Jin FF, Collins M, Ohba M, Wittenberg AT. 2012: Uncertainty in the ENSO amplitude change from the past to the future. *Geophysical Research Letters* **39**: L20703. DOI: 10.1029/2012GL053305.

Wilby RL, Dawson CW. 2013. The Statistical DownScaling Model: insights from one decade of application. *International Journal of Climatology* **33**: 1707-1719. DOI: 10.1002/joc.3544.