Supplementary Information for the manuscript

Soil C/N ratios cause opposing effects on decomposition rates and stabilization factors in southern European forests compared to grasslands

Juan A. Blanco[1], María Durán[2], Josu Luquin[1], Leticia San Emeterio[2], Antonio Yeste[1], Rosa M. Canals[2]

[1]Institute for Multidisciplinary Applied Biology (IMAB), Departamento de Ciencias, Universidad Pública de Navarra (UPNA), 31006 Pamplona, Spain;

[2]Institute of Innovation and Sustainable Food Chain (IS-FOOD), Departamento de Agronomía, Biotecnología y Alimentación, Universidad Pública de Navarra (UPNA), 31006 Pamplona, Spain;

Corresponding author:

Juan A. Blanco

Address: Institute for Multidisciplinary Applied Biology (IMAB), Departamento de Ciencias, Universidad Pública de Navarra (UPNA), 31006 Pamplona, Spain;

E-mail: juan.blanco@unavarra.es

Phone: +34 948 16 9859

S1. Additional sites info

Detailed characterization of each ecosystem type in each site was carried out following the protocol defined by Keuskamp et al. (2013). Details on the classification used are listed in Table S2. The values in that Table are later used to characterize each site in Tables S2 to S9.

Table S1. Classification systems used to characterize the sites and ecosystem types in the study (Adapted from Teatime4science; http://www.teatime4science.org/).

Meteorological information	Meteonavarra (2022) http://meteo.navarra.es
Aridity index	Thronthwaite (1948)
Canopy tree cover	Spanish Ministry for Ecological Transition and Demographic Challenge (2022). https://www.miteco.gob.es
Floristic description	Geoportal de Navarra (2022) https://idena.navarra.es
Environmental features	
Shade	Low: all day exposed to direct sun radiation
	Medium: half day exposed to direct sun radiation
	High: all day shaded
Management	Low: low intensity grazing, ploughing or mowing
	Moderate: intermediate intensity of grazing, ploughing or mowing
	High: intense activity of grazing, ploughing or mowing
Topography	Data estimated in the field
Edaphic features	Data estimated in the lab with soil samples (see main text section 2. Material and Methods)

Table S2. Detailed edaphic, botanical and meteorological data for spring 2017 for the site "Valtierra".

Meteorological station	Bardenas (El Plano)	Aridity index (Thornthwaite)	30
Coordinates	X:622213 Y:4683826	Altitude (m.a.s.l.)	431

Ecosystem	**Grassland**		
Coordinates	X:618950 Y:4680330	Altitude (m.a.s.l.)	397
Main floristic description	*Genista scorpius, Thymus vulgaris, Rosmarinus officinales, Brachypodium retusum*		
Phytosociology	*Rhamno lyciodis-Querco coccifera S.*		

Environmental features	Shade	Management	Soil depth (cm)	Roots depth (cm)	Slope (%)	Facing
	Low	Low	5-15	5-15	5	Southeast

Edaphic features	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture (USDA)	
	6.1	21.7	32.2	40.0	Clay loam	
	pH (1:2.5)	Conductivity (µS/cm)	Organic matter (%)	Organic carbon (%)	N-Kjeldhal (%)	C:N
	8.66	149.00	2.43	1.41	0.21	6.71

Ecosystem	**Forest** (Canopy tree cover: 70%)		
Coordinates	X:618971 Y:4680346	Altitude (m.a.s.l.)	392
Main floristic description	*Pinus halepensis, Quercus coccifera, Pistacia lentiscus, Brachypodium retusum*		
Phytosociology	*Rhamno lyciodis-Querco coccifera S.*		

Environmental features	Shade	Management	Soil depth (cm)	Roots depth (cm)	Slope (%)	Facing
	Low	Low	5-15	5-15	5	Southeast

Edaphic features	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture (USDA)	
	9.2	37.4	16.1	37.3	Sandy clay	
	pH (1:2.5)	Conductivity (µS/cm)	Organic matter (%)	Organic carbon (%)	N-Kjeldhal (%)	C:N
	8.14	457.00	9.09	5.27	0.46	11.46

Table S3. Detailed edaphic, botanical and meteorological data for spring 2017 for the site "Tafalla".

Meteorological station	Tafalla	Aridity index (Thornthwaite)	30
Coordinates	X:607987 Y:4708448	Altitude (m.a.s.l.)	430

Ecosystem	**Grassland**		
Coordinates	X:606700 Y:4705962	Altitude (m.a.s.l.)	469
Main floristic description	*Brachypodium rupestre*		
Phytosociology	*Querco rotundifoliae S.*		

Environmental features	Shade	Management	Soil depth (cm)	Roots depth (cm)	Slope (%)	Facing
	Low	High	5-15	5-15	0	Flat

Edaphic features	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture (USDA)	
	24.8	20.7	30.6	23.9	Loam	
	pH (1:2.5)	Conductivity (µS/cm)	Organic matter (%)	Organic carbon (%)	N-Kjeldhal (%)	C:N
	8.25	186.00	6.12	3.55	0.28	13.15

Ecosystem	**Forest** (Canopy tree cover: 55%)		
Coordinates	X:606735 Y:4706063	Altitude (m.a.s.l.)	470
Main floristic description	*Quercus rotundifolia*		
Phytosociology	*Querco rotundifoliae S.*		

Environmental features	Shade	Management	Soil depth (cm)	Roots depth (cm)	Slope (%)	Facing
	Medium	High	5-15	5-15	0	Flat

Edaphic features	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture (USDA)	
	18.0	25.9	30.6	25.5	Clay loam	
	pH (1:2.5)	Conductivity (µS/cm)	Organic matter (%)	Organic carbon (%)	N-Kjeldhal (%)	C:N
	8.26	231.00	6.67	3.87	0.52	7.44

Table S4. Detailed edaphic, botanical and meteorological data for spring 2017 for the site "Yesa".

Meteorological station	Leyre	Aridity index (Thornthwaite)	20
Coordinates	X:649876 Y:4721878	Altitude (m.a.s.l.)	759

Ecosystem	**Grassland**		
Coordinates	X:650466 Y:4721985	Altitude (m.a.s.l.)	750

Main floristic description	*Genista hispanica, Helianthenum oelandicum, Aphillantes monspeliensis, Brachypodium retusum*					
Phytosociology	*Spiraeo obovatae-Querco fagineae S.*					
Environmental features	Shade	Management	Soil depth (cm)	Roots depth (cm)	Slope (%)	Facing
	Low	Low	>15	>15	5	Southeast
Edaphic features	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture (USDA)	
	4.6	20.0	46.6	28.8	Loam	
	pH (1:2.5)	Conductivity (µS/cm)	Organic matter (%)	Organic carbon (%)	N-Kjeldhal (%)	C:N
	8.16	167.00	5.67	3.29	0.28	11.75

Ecosystem	**Forest** (Canopy tree cover: 90%)		
Coordinates	X:650527 Y:4722031	Altitude (m.a.s.l.)	745

Main floristic description	*Quercus faginea, Ligustrum vulgare, Viburnum lantana*					
Phytosociology	*Spiraeo obovatae-Querco fagineae S.*					
Environmental features	Shade	Management	Soil depth (cm)	Roots depth (cm)	Slope (%)	Facing
	High	Sligh	>15	>15	5	South
Edaphic features	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture (USDA)	
	5.3	32.2	25.7	36.8	Clay loam	
	pH (1:2.5)	Conductivity (µS/cm)	Organic matter (%)	Organic carbon (%)	N-Kjeldhal (%)	C:N
	6.61	161.00	7.59	4.40	0.25	17.60

Table S5. Detailed edaphic, botanical and meteorological data for spring 2017 for the site "Garde".

Meteorological station	Erremendia (Salazar)	Aridity index (Thornthwaite)	0
Coordinates	X:64225 Y:474880	Altitude (m.a.s.l.)	1047

Ecosystem	**Grassland**		
Coordinates	X:673255 Y:4741156	Altitude (m.a.s.l.)	1420
Main floristic description	*Cynosurus cristatus*		
Phytosociology	*Veronico officinalis-Pino sylvestris S.*		

Environmental features						
	Shade	Management	Soil depth (cm)	Roots depth (cm)	Slope (%)	Facing
	Low	Low	>15	5-15	5	Northeast

Edaphic features						
	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture (USDA)	
	1.7	32.6	48.2	17.5	Loam	
	pH (1:2.5)	Conductivity (µS/cm)	Organic matter (%)	Organic carbon (%)	N-Kjeldhal (%)	C:N
	5.68	291.00	5.80	3.37	0.33	10.22

Ecosystem	**Forest** (Canopy tree cover: 90%)		
Coordinates	X:673302 Y:441161	Altitude (m.a.s.l.)	1405
Main floristic description	*Pinus sylvestris, Juniperus communis, Deschampsia flexuosa*		
Phytosociology	*Veronico officinalis-Pino sylvestris S.*		

Environmental features						
	Shade	Management	Soil depth (cm)	Roots depth (cm)	Slope (%)	Facing
	High	Low	>15	>15	5	North

Edaphic features						
	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture (USDA)	
	2.3	43.5	30.9	23.3	Loam	
	pH (1:2.5)	Conductivity (µS/cm)	Organic matter (%)	Organic carbon (%)	N-Kjeldhal (%)	C:N
	5.48	105.00	8.60	5.01	0.33	15.18

Table S6. Detailed edaphic, botanical and meteorological data for spring 2017 for the site "Orbaizeta".

Meteorological station	Irabia	Aridity index (Thornthwaite)	0
Coordinates	X:650091 Y:4760774	Altitude (m.a.s.l.)	822

Ecosystem	**Grassland**		
Coordinates	X:648163 Y:4762980	Altitude (m.a.s.l.)	1094
Main floristic description	*Danthonia decumbens, Potentilla erecta*		
Phytosociology	*Saxifrago hirsutae-Fago sylvaticae S.*		

Environmental features						
	Shade	Management	Soil depth (cm)	Roots depth (cm)	Slope (%)	Facing
	Low	Low	>15	>15	30	North

Edaphic features						
	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture (USDA)	
	1.5	40.8	38.6	19.1	Loam	
	pH (1:2.5)	Conductivity (µS/cm)	Organic matter (%)	Organic carbon (%)	N-Kjeldhal (%)	C:N
	4.96	231.00	8.29	4.81	0.37	13.00

Ecosystem	**Forest** (Canopy tree cover: 90%)		
Coordinates	X:648448 Y:4762957	Altitude (m.a.s.l.)	1075
Main floristic description	*Fagus sylvatica*		
Phytosociology	*Saxifrago hirsutae-Fago sylvaticae S.*		

Environmental features						
	Shade	Management	Soil depth (cm)	Roots depth (cm)	Slope (%)	Facing
	Shade	Low	>15	>15	30	Northeast

Edaphic features						
	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture (USDA)	
	1.4	37.7	37.0	23.9	Loam	
	pH (1:2.5)	Conductivity (µS/cm)	Organic matter (%)	Organic carbon (%)	N-Kjeldhal (%)	C:N
	3.97	272.00	10.33	5.99	0.65	9.22

Table S7. Detailed edaphic, botanical and meteorological data for spring 2017 for the site "Valcarlos".

Meteorological station	Aurizberri-Espinal	Aridity index (Thornthwaite)	0
Coordinates	X:633116 Y:4759793	Altitude (m.a.s.l.)	871

Ecosystem	**Grassland**					
Coordinates	X:637039 Y:4764323	Altitude (m.a.s.l.)	1100			
Main floristic description	*Danthonia decumbens, Potentilla erecta*					
Phytosociology	*Saxifrago hirsutae-Fago sylvaticae S.*					
Environmental features	Shade	Management	Soil depth (cm)	Roots depth (cm)	Slope (%)	Facing
	Low	Low	>15	>15	30	West
Edaphic features	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture (USDA)	
	15,9	16,8	43,4	23,9	Loam	
	pH (1:2.5)	Conductivity (µS/cm)	Organic matter (%)	Organic carbon (%)	N-Kjeldhal (%)	C:N
	5,39	54,00	3,53	2,05	0,17	12,06

Location	Ibañeta					
Ecosystem	**Forest (Canopy tree cover: 90%)**					
Coordinates	X:636990 Y:4764310	Altitude (m.a.s.l.)	1075			
Main floristic description	*Fagus sylvatica*					
Phytosociology	*Saxifrago hirsutae-Fago sylvaticae S.*					
Environmental features	Shade	Management	Soil depth (cm)	Roots depth (cm)	Slope (%)	Facing
	High	Low	>15	>15	30	West
Edaphic features	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture (USDA)	
	3,7	56,3	27,3	12,7	Clay loam	
	pH (1:2.5)	Conductivity (µS/cm)	Organic matter (%)	Organic carbon (%)	N-Kjeldhal (%)	C:N
	3,69	412,00	11,96	6,94	0,48	14,46

Table S8. Detailed edaphic, botanical and meteorological data for spring 2017 for the site "Bertizarana".

Meteorological station	Bertiz	Aridity index (Thornthwaite)	0
Coordinates	X:612961 Y:4777420	Altitude (m.a.s.l.)	172

Ecosystem	**Grassland**					
Coordinates	X:612633 Y:4779120	Altitude (m.a.s.l.)	172			
Main floristic description	*Agrostis capillaris, Cynosurus cristatus, Dactylis glomerata, Pteridium aquilinum*					
Phytosociology	*Saxifrago hirsutae-Fago sylvaticae S.*					
Environmental features	Shade	Management	Soil depth (cm)	Roots depth (cm)	Slope (%)	Facing
	Medium	High	>15	>15	0	Flat
Edaphic features	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture (USDA)	
	21.1	16.4	46.6	15.9	Loam	
	pH (1:2.5)	Conductivity (µS/cm)	Organic matter (%)	Organic carbon (%)	N-Kjeldhal (%)	C:N
	4.30	106.00	8.79	5.10	0.43	11.86

Ecosystem	**Forest** (Canopy tree cover: 90%)					
Coordinates	X:612633 Y:479454	Altitude (m.a.s.l.)	250			
Main floristic description	*Fagus sylvatica, Luzula sylvatica, Anemone nemorosa*					
Phytosociology	*Saxifrago hirsutae-Fago sylvaticae S.*					
Environmental features	Shade	Management	Soil depth (cm)	Roots depth (cm)	Slope (%)	Facing
	High	Low	>15	>15	5	Southeast
Edaphic features	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture (USDA)	
	10.1	22.6	43.4	23.9	Loam	
	pH (1:2.5)	Conductivity (µS/cm)	Organic matter (%)	Organic carbon (%)	N-Kjeldhal (%)	C:N
	5.59	106.00	10.83	6.28	0.45	13.96

Table S9. Detailed edaphic, botanical and meteorological data for spring 2017 for the site "Bera".

Meteorological station	Bera	Aridity index (Thornthwaite)	0
Coordinates	X:607332 Y:4792708	Altitude (m.a.s.l.)	50

Ecosystem	**Grassland**		
Coordinates	X:605339 Y:479300	Altitude (m.a.s.l.)	80
Main floristic description	*Anthoxanthum odoratu, Prunella vulgaris, Aquillea millefolium*		
Phytosociology	*Hyperico pulchri-Querco roboris S.*		

Environmental features	Shade	Management	Soil depth (cm)	Roots depth (cm)	Slope (%)	Facing
	Low	High	>15	>15	5	East

Edaphic features	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture (USDA)	
	18.7	21.7	40.2	19.1	Loam	
	pH (1:2.5)	Conductivity (µS/cm)	Organic matter (%)	Organic carbon (%)	N-Kjeldhal (%)	C:N
	6.23	74.00	3.81	2.21	0.21	10.52

Ecosystem	**Forest** (Canopy tree cover: 90%)		
Coordinates	X:605320 Y:479291	Altitude (m.a.s.l.)	100
Main floristic description	*Castanea sativa, Corylus avellana, Rubus sp., Blechnum spicant, Pteridium aquilinum*		
Phytosociology	*Hyperico pulchri-Querco roboris S.*		

Environmental features	Shade	Management	Soil depth (cm)	Roots depth (cm)	Slope (%)	Facing
	High	High	>15	>15	5	East

Edaphic features	Coarse sand (%)	Fine sand (%)	Silt (%)	Clay (%)	Texture (USDA)	
	24.4	16.3	33.8	25.5	Clay loam	
	pH (1:2.5)	Conductivity (µS/cm)	Organic matter (%)	Organic carbon (%)	N-Kjeldhal (%)	C:N
	4.59	216.00	9.03	5.24	0.36	14.56

S2. Additional results

S2.1. Interactions with additional environmental variables in *S* and *k* models

There were no significant interactions between ecosystem type and other environmental variables such as soil pH and soil N (Figure S1).

S2.1. *S/k* ratio models

The model for *S/k* was the simplest of the three LMMs constructed (Table S1). It did not included any of the soil variables, being selected only daily P_{mean} and average of daily T_{max}, as well as their interactions with the ecosystem type. There was a negative correlation between the *S/k* ratio and mean daily precipitation and, in this case, it happened on both grasslands and forests but was more marked on grasslands. The effect of temperature was a negative correlation between average of daily T_{max} and *S/k* ratio on grasslands, while it did not produce a significant on forests (Figure S2).

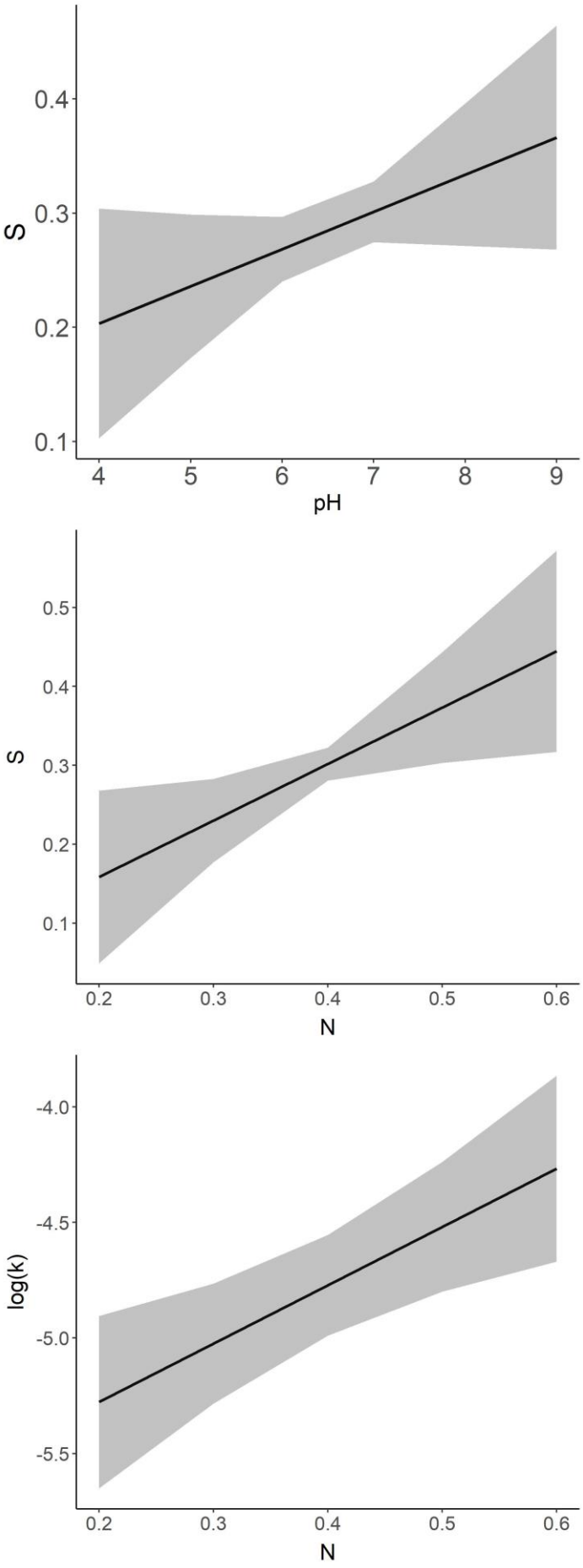

Figure S1. Ecosystem-independent partial effects of N and pH on the on the stabilization factor *S* (top and central panels) and of N on the decomposition rate *k* (bottom panel). Error bars indicate 95% confidence interval.

Table S10. Results of GLMM analysis for the ratio *S/k*. LRT: Likelihood ratio test. Best fitting model for log(*k*): Ecosystem type + P_{mean} + T_{max} + Ecosystem type:P_{mean} + Ecosystemm type:T_{max}

Model Term	LRT	*p*
Ecosystem type:T_{max}	7.7	0.005
Ecosystem type:P_{mean}	18.7	<0.001

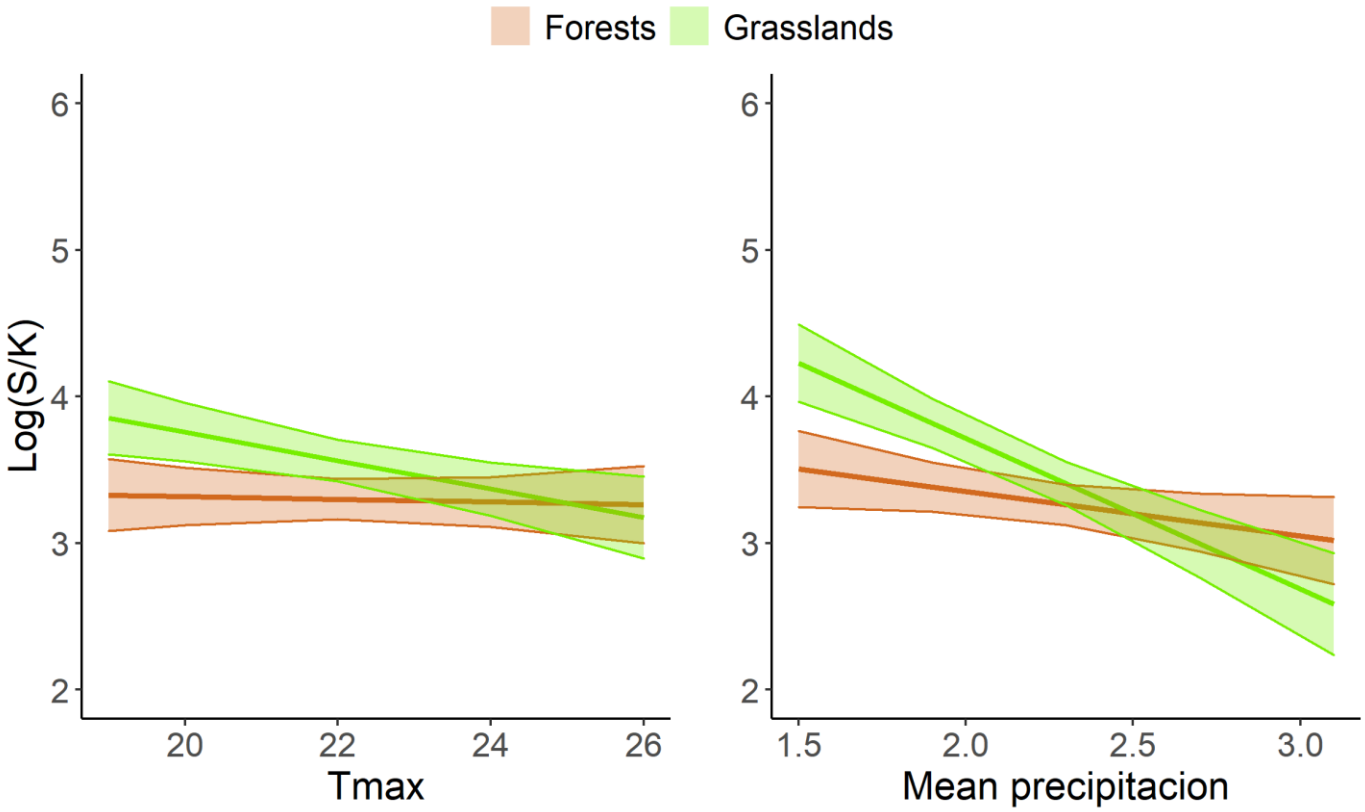

Figure S2. Ecosystem-dependent partial effects of daily maximum temperatures (left panel) and daily precipitation (mm day^{-1}) in spring 2017 (right panel) on the ratio *S/k*. Error bars indicate 95% confidence interval.

S3. References:

Keuskamp, J. A., Dingemans, B. J. J., Lehtinen, T., Sarneel, J. M., Hefting, M. M.,& Muller - Landau, H. (2013). Tea Bag Index: A novel approach to collect uniform decomposition data across ecosystems. Methods in Ecology and Evolution, 4, 1070 – 1075. https://doi.org/10.1111/2041 - 210X.12097.

Meteonavarra (2022) Meteorología y climatología de Navarra. Available at http://meteo.navarra.es/. Accessed on January 28th, 2022.

Spanish Ministry for Ecological Transition and Demographic Challenge (2022). Mapa forestal de España escala 1:50.000 (MFE50). https://www.miteco.gob.es/es/biodiversidad/temas/inventarios-nacionales/mapa-forestal-espana/mfe_50.aspx

Geoportal de Navarra (2022). Estructura de datos espaciales de Navarra. https://geoportal.navarra.es/es/idena

Thornthwaite, C.W. (1948) An Approach toward a Rational Classification of Climate. Geographical Review, 38, 55-94. http://dx.doi.org/10.2307/210739