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Reconstructing burnt area during the Holocene: an Iberian case study

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This SI contains the following sections: (1) the Canonical Correlation Analysis (CCA) of modern pollen assemblages (2) information about the preparation of the Iberian pollen data, (3) information about the Iberian charcoal data, (4) the analyses used to select the final GLM, (5) Box-Cox transformation of palaeo burnt area fraction, (6) testing of the impact of using of micro and macro charcoal on the burnt area fraction reconstructions, and (7) comparisons of the fxTWA-PLS reconstructions with reconstructions based on alternative methods (WA-PLS, TWA-PLS).

This SI includes the following Figures and Tables:

Figure S1. Partial correlations test based on data sets for the Iberian Peninsula that include annual observations at 0.5° for the period between 2001 and 2016. The data are all transformed according to Table S5 prior to the test.

Figure S2. Partial residual plots of the final model (Table S6, last column). The plot includes (1) the expected value (blue line); (2) a confidence interval for the expected value (grey band); (3) partial residuals (dark grey dots).

Figure S3. Distribution of palaeo burnt area fraction before (Panel A) and after (Panel B) Box-Cox transform.

Figure S4. Composite plots for macroscopic and macroscopic charcoal separately of 16 charcoal sites with both macroscopic and microscopic entities using the locfit() function with half-width=300, number of bootstrap samples=1000. The locally estimated scatterplot smoothing is shown in blue; The upper and lower 95th-percentile confidence intervals are shown in grey.

Figure S5. The fitted plots and residual plots of WA-PLS and TWA-PLS methods, with and without fx correction.

Figure S6. Composite curves of reconstructed burnt area using WAPLS and TWAPLS, with and without fx correction, using the locfit() function with half-width=300, number of bootstrap samples=1000. The locally estimated scatterplot smoothing is shown in blue; The upper and lower 95th-percentile confidence intervals are shown in grey.

Table S1. Canonical Correlation Analysis (CCA) of pollen data

Table S2. Information on the pollen records. Latitude: degrees decimal where +ve is N and –ve is S. Longitude: degrees decimal where +ve is E and –ve is W. Elevation: in metres above sea level. Source: EPD = European Pollen Database (www.europeanpollendatabase.net); PANGAEA = www.pangaea.de/.

Table S3. Pollen taxa in the Iberian dataset (205 taxa). Pollen taxa using in deriving the fire-vegetation relationship and fire reconstructions are shown in bold (140 taxa).

Table S4. Information on the charcoal records. Latitude: degrees decimal where +ve is N and –ve is S. Longitude: degrees decimal where +ve is E and –ve is W. Elevation: in metres above sea level.

Table S5. Environmental variables and transformation methods

Table S6. The process of the model selection. Regression coefficients (t value) and pseudo-R^2 of each model are shown. The final model is shown in bold.

Table S7. Results of fxTWAPLS using different values of λ.

Table S8. Leave-out cross-validation fitness of WA-PLS and TWA-PLS methods, with and without fx correction, showing

S1. Canonical Correspondence Analysis (CCA) of the environmental controls on pollen assemblages

The central premise of our approach is that fire is *one* of the factors that modify vegetation assemblages, and therefore that differences in vegetation assemblages can be used to reconstruct fire. We used Canonical Correspondence Analysis (CCA) to investigate how much of the variation in modern pollen assemblages could be explained by burnt area alone, as compared to how much could be explained by burnt area combined with other environmental factors. We used the eight environmental factors considered in our generalised linear model (GLM) for this second analysis, specifically diurnal temperature range, dry days per month, wind speed, gross primary production, non-tree cover, cropland, grazing land, and urban population density. The CCA (Table S1) shows that *ca* 18% of the observed variability in the pollen assemblages is explained by the combination of these environmental variables and burnt area, and that burnt area alone explains *ca* 1% of the variability. Thus, the pollen assemblages contain specific information needed to reconstruct burnt area, even though other environmental influences have larger effects.

Table S1. Canonical Correspondence Analysis (CCA) of pollen data

CCA (a) – burnt area and other environmental variables		
	Inertia	Proportion explained
Total	6.129	1.0000
Constrained	1.113	0.1815
Unconstrained	5.016	0.8185
CCA (b) – burnt area only		
	Inertia	Proportion explained
Total	6.129	1.0000
Constrained	0.054	0.0088
Unconstrained	6.075	0.9912

S2. Preparation of the Iberian pollen data

Table S2 provides information about the Iberian pollen sites:

Table S2. Information on the pollen records. Latitude: degrees decimal where +ve is N and –ve is S. Longitude: degrees decimal where +ve is E and –ve is W. Elevation: in metres above sea level. Source: EPD = European Pollen Database (www.europeanpollendatabase.net); PANGAEA = www.pangaea.de/.

Site name	Entity	Source	Latitude	Longitude	Elevation	Reference
Almenara de Adaja	ADAJA	EPD	41.19	-4.67	784	(López Merino et al., 2009)
Alsa	ALSA	EPD	43.12	-4.02	560	(Mariscal, 1993)
Alvor Estuary Ribeira do Farelo Ribeira da Torre	Abi 05/07	author	37.15	-8.59	0.6	(Schneider et al., 2010, 2016)
Antas	ANTAS	EPD	37.21	-1.82	0	(Cano Villanueva, 1997; Pantaléon-Cano et al., 2003; Yll et al., 1995)
Arbarrain Mire	ARBARRAIN	author	43.21	-2.17	1004	(Pérez-Díaz et al., 2018)
Armacao de Pera Ribeira de Alcantarilha	ADP 01/06	author	37.11	-8.34	2.4	(Schneider et al., 2010, 2016)
Armena	Armena	author	42.51	0.34	2238	(Leunda et al., 2019)
Arroyo de Aguas Frias	AGUASFRIAS	author	40.27	-5.12	1120	(Julio Camarero et al., 2019)
Arroyo de las Cárcavas	CARCAVAS	EPD	40.84	-4.03	1300	(Morales-Molino et al., 2017a)
Arroyo de Navalacarreta	NAVALACA	EPD	40.85	-4.03	1250	(Morales-Molino et al., 2017a)
Arroyo de Valdeconejos	VALDECON	EPD	40.86	-4.06	1380	(Morales-Molino et al., 2017a)
Atxuri	ATXURI01	EPD	43.25	-1.55	500	(Penalba, 1994; Penalba and Garmendia, 1989)
Ayoó de Vidriales	AYOO	EPD	42.13	-6.07	780	(Morales-Molino and García-Antón, 2014)
Basa de la Mora	BSM08	author	42.55	0.33	1906	(Pérez-Sanz et al., 2013)
Bassa Nera	BSN6	author	42.64	0.92	1891	(Garces-Pastor et al., 2017)
Bermu Mire	BERMU	author	39.43	-4.15	783	(Luelmo-Lautenschlaeger et al., 2018c)
Borreguil de la Caldera	BdlC-01	author	37.05	-3.32	2992	(Ramos-Román et al., 2016)

Bosc dels Estanyons	BOSCESTA	EPD	42.48	1.63	2180	(De Beaulieu et al., 2005; Miras et al., 2007)
Botija Bog	BOTIJA	author	39.60	-4.70	755	(Luelmo-Lautenschlaeger et al., 2018b)
Campo Lameiro	PRD4	EPD	42.53	-8.52	260	(Kaal et al., 2011; López-Merino et al., 2012; Kaal et al., 2013)
Cañada de la Cruz	CANCRUZ	EPD	38.07	-2.69	1595	(Carrión et al., 2001)
Canada del Gitano_Sierra de Baza	SBAZA	EPD	37.23	-2.70	1900	(Carrión et al., 2007)
Canaleja	CANALEJA	EPD	40.90	-2.45	1029	(Cerrillo Cuenca et al., 2007; Cerrillo Cuenca and González Cordero, 2011)
Castello Lagoon	Castello Lagoon core EM	author	42.28	3.10	2.4	(Ejarque et al., 2016)
Cha das Lameiras	LAMEIRAS	author	40.94	-7.68	950	(López-Sáez et al., 2017)
Charco da Candieira	CANDIEIR	EPD	40.34	-7.58	1409	(van der Knaap and van Leeuwen, 1984, 1995, 1997)
Creixell	CreixellT	EPD	41.16	1.43	1	(Burjachs and Expósito, 2015)
Cucú cueva	CUCU	EPD	37.64	-2.26	1600	(González-Ramón et al., 2012)
Cueto de la Avellanosa	CUETOAV	EPD	43.12	-4.36	1320	(Mariscal Alvarez, 1983)
Culazón	CULAZON	EPD	43.23	-4.49	592	(López-Sáez et al., 2013)
Elx	ELX	EPD	38.17	-0.75	1	(Burjachs et al., 1997; Burjachs and Expósito, 2015)
El Brezosa	BREZOSA	author	39.35	-4.36	733	(Morales-Molino et al., 2018)
El Carrizal	CARRIZAL	EPD	41.32	-4.15	860	(Franco-Múgica et al., 2005)
El Maíllo mire	MAI	EPD	40.55	-6.21	1100	(Morales-Molino et al., 2013)
El Payo	ELPAYO	EPD	40.25	-6.77	1000	(Abel-Schaad et al., 2009b; Silva-Sánchez et al., 2016)
El Perro mire	ELPERRO	author	39.05	-4.76	690	(Luelmo-Lautenschlaeger et al., 2019a, 2019b)
El Portalet	PORTALET	author	42.80	-0.40	1802	(González-Sampériz et al., 2006)
El Redondo	REDONDO	author	40.22	-5.66	1765	(López-Sáez et al., 2016b)
El Sabinar	SABINAR	EPD	38.20	-2.12	1117	(Carrión et al., 2004)
El Tiemblo	TIEMBLO	author	40.36	-4.53	1250	(López-Sáez et al., 2018b)

Enol	ENOL	author	43.27	-4.99	1075	(Moreno et al., 2011)
Espinosa de Cerrato	CERRATO	author	41.96	-3.94	885	(Morales-Molino et al., 2017b; Múgica et al., 2001)
Estanilles	ESTANILLES	EPD	42.63	1.30	2247	(Pérez-Obiol et al., 2012)
Estanya	Estanya Catena	author	42.03	0.53	677	(González-Sampériz et al., 2017; Morellón et al., 2011)
Fuente de la Leche	LECHE	author	40.35	-5.06	1382	(Robles-López et al., 2018)
Fuente del Pino Blanco	PINOBLANCO	author	40.24	-4.98	1343	(Robles-López et al., 2018)
Hinojos Marsh	HINOJOS	author	36.96	-6.39	1.5	(López-Sáez et al., 2018a)
Hoya del Castillo	N-CAS	EPD	41.48	-0.16	258	(Davis and Stevenson, 2007)
La Cruz	LACRUZ	EPD	39.99	-1.87	1024	(Burjachs et al., 1997)
La Molina mire	MOLINAES	author	43.38	-6.33	650	(López-Merino et al., 2011)
Labradillos Mire	LABRADILLOS	author	40.34	-4.57	1460	(Robles-López et al., 2017)
Lago de Ajo	LAGOAJO	EPD	43.05	-6.15	1570	(Allen et al., 1996; McKeever, 1984)
Lagoa Comprida 2	LAGOA_CO	EPD	40.36	-7.64	1650	(Van Den Brink and Janssen, 1985; Janssen and Woldringh, 1981; Moe and Van Der Knaap, 1990)
Laguna de la Mosca	LdlMo composite	author	37.06	-3.31	2889	(Manzano et al., 2019)
Laguna de la Mula	LdlM 10-02	author	37.06	-3.42	2497	(Jiménez-Moreno et al., 2013)
Laguna de la Roya	LAROYA	PANGAEA	42.22	-6.77	1608	(Allen et al., 1996)
Laguna de Rio Seco	Laguna de Rio Seco core 1	author	37.05	-3.35	3020	(Anderson et al., 2011)
Laguna Guallar	N-GUA	EPD	41.41	-0.23	336	(Davis and Stevenson, 2007)
Laguna Mesagosa	LAGMESAG	EPD	41.97	-2.81	1600	(Engelbrechten, 1999)
Laguna Negra	LAGNEGRA	EPD	42.00	-2.85	1760	(Engelbrechten, 1999)
Laguna Salada Chiprana	N-SAL	EPD	41.23	-0.17	150	(Valero-Garcés et al., 2000)
Lake Banyoles	Banyoles SB2	EPD	42.13	2.75	174	(Revelles et al., 2015)
Lake Banyoles	BANYOLES_1	EPD	42.13	2.75	174	(Pèrez-Obiol and Julià, 1994)
Lake Saloio	SALOIO	EPD	39.61	-9.02	70	(Gomes, 2011)
Lanzahíta	LANZBOG	author	40.22	-4.94	558	(López-Sáez et al., 1999, 2010)

Las Animas Mire	ANIMAS	author	36.69	-5.03	1403	(Alba-Sánchez et al., 2019)
Las Lanchas	LANCHAS	author	39.59	-4.89	800	(Luelmo-Lautenschlaeger et al., 2018a)
Las Pardillas	LASPARDI	EPD	42.03	-3.03	1850	(Sanchez Goñi and Hannon, 1999)
Las Vinuelas	VINUELAS	author	39.37	-4.49	761	(Morales‐Molino et al., 2019)
Les Palanques	PALANQUES	EPD	42.16	2.44	460	(Revelles et al., 2018)
Manaderos	Manaderos core	author	40.34	-4.69	1292	(Robles-López et al., 2020)
Marbore	Marbore composite	author	42.70	0.04	2612	(Leunda et al., 2017)
Monte Areo mire	AREO	EPD	43.53	-5.77	200	(López-Merino et al., 2010)
Montes do Buio Cuadramón	CUAII	EPD	43.47	-7.53	700	(González and Saa, 2000)
Navamuno	Navamuno_S3	author	40.32	-5.78	1505	(López-Sáez et al., 2020)
Navarrés	NAVA1	EPD	39.10	-0.68	225	(Carrión and Dupre, 1996)
Navarrés	NAVARRE3	EPD	39.10	-0.68	225	(Carrión and Van Geel, 1999)
Ojos del Tremendal	Ojos del Tremendal core 1	author	40.54	-2.05	1650	(Stevenson, 2000)
Patateros bog	PATATERO	EPD	39.60	-4.67	700	(Dorado-Valiño et al., 2014)
Pedrido	PEDRIDO	EPD	43.44	-7.07	770	(Stefanini, 2008)
Pena de Cadela	CADELA	EPD	42.83	-7.17	970	(Mighall et al., 2006)
Peña Negra	PENANEGR	EPD	40.33	-5.79	1000	(Abel-Schaad and López-Sáez, 2013)
Pico del Sertal	SERTAL	EPD	43.22	-4.44	940	(Mariscal Alvarez, 1986)
Pla de l'Estany	PLAESTANY	EPD	42.19	2.54	520	(Burjachs, 1994)
Planell de Perafita	PERAFITA	EPD	42.48	1.57	2240	(Miras et al., 2010)
Posidonia Lligat	LLIGAT	EPD	42.29	-3.29	-3	(López-Sáez et al., 2009)
Pozo de la Nieve	PozoN_2015 core	author	40.35	-4.55	1600	(Robles-López et al., 2017)
Praillos de Bossier Mire	BOSSIER	EPD	36.91	-4.07	1610	(Abel-Schaad et al., 2017)
Puerto de Belate	BELATE01	EPD	43.03	-2.05	847	(Penalba, 1994; Penalba and Garmendia, 1989)
Puerto de las Estaces de Trueba	ESTACAS	PANGAEA	43.12	-3.70	1160	(Mariscal, 1989)
Puerto de Los Tornos	TORNOS01	EPD	43.15	-3.43	920	(Penalba and Garmendia, 1989)

Puerto de Serranillos	SERRANIL	EPD	40.31	-4.93	1700	(López-Merino et al., 2009)
Quintanar de la Sierra	QUINTA02	EPD	42.03	-3.02	1470	(Penalba, 1994; Penalba and Garmendia, 1989)
Roquetas de Mar	ROQUETAS	EPD	36.79	-2.59	0	(Cano Villanueva, 1997; Obiol and Roure, 1994; Pantaléon-Cano et al., 2003; Yll et al., 1995)
Salada Pequeña	N-PEQ	EPD	41.03	-0.22	357	(Davis, 2010)
Saldropo	SALDROPO	EPD	43.05	-2.72	625	(Penalba, 1994; Penalba and Garmendia, 1989)
Salines playa-lake	SALINES	EPD	38.50	-0.89	475	(Burjachs et al., 2017)
San Rafael	SANRAFA	EPD	36.77	-2.60	0	(Cano Villanueva, 1997; Pantaléon-Cano et al., 2003; Yll et al., 1995)
Sanabria Marsh	SANABRIA	EPD	42.10	-6.73	1050	(Allen et al., 1996; Hannon, 1985; Turner and Hannon, 1988)
Serra Mitjana Fen	MITJANA	EPD	42.47	1.58	2406	(Miras et al., 2015)
Serrania de las Villuercas	VILLUERCAS	author	39.48	-5.4	1000	(Gil-Romera et al., 2008)
Sierra de Gádor	GADOR	EPD	36.90	-2.92	1530	(Carrión et al., 2003)
Siles Lake	SILES	EPD	38.40	-2.50	1320	(Carrión, 2002)
Tubilla del Lago	TUB	EPD	41.81	-3.57	900	(Morales-Molino et al., 2017b)
Turbera de La Panera Cabras	PANERA	EPD	40.17	-5.76	1648	(Abel-Schaad et al., 2009a)
Valdeyernos bog	VALDEYER	EPD	39.44	-4.10	850	(Dorado-Valiño et al., 2014)
Valle do Lobo Ribeira de Carcavai	VdL PB2	author	37.06	-8.07	2.3	(Schneider et al., 2010, 2016)
Verdeospesoa mire	VERDEOSPESOA	author	43.06	-2.86	1015	(Pérez-Díaz and López-Sáez, 2017, 2019)
Vilamora Ribeira de Quarteira	Vilamora P01-5	author	37.09	-8.14	3.5	(Schneider et al., 2010, 2016)
Villarquemado		author	40.49	-1.29	985	(González-Sampériz et al., 2020; Valero-Garcés et al., 2019)
Villaverde	VILLAVERDE	EPD	38.80	-2.37	870	(Carrión et al., 2001b)
Xan de Llamas	XL	EPD	42.30	-6.32	1500	(Morales-Molino et al., 2011)
Zoñar	ZONARcombined	author	37.48	-4.69	300	(Martín-Puertas et al., 2008)

Non-pollen palynomorphs (e.g. fungi, algae), introduced species, and fire-insensitive plants (e.g. obligate aquatics) were removed before analysis on the assumption that these were not diagnostic of changing fire regimes. Some pollen taxa are not identified consistently by palynologists or occur at very few sites, so some pollen types were amalgamated to higher taxonomic groups (genera for trees, families for herbaceous taxa) for consistency across the records (Table S3).

Table S3. Pollen taxa in the Iberian dataset (205 taxa). Pollen taxa using in deriving the fire-vegetation relationship and fire reconstructions are shown in bold (140 taxa).

Taxon:			
Abies	**Acer**	**Aconitum**	**Adonis**
Aesculus	Aizoaceae	**Alnus**	**Amaranthaceae**
Amaryllidaceae	Anacardiaceae	**Apiaceae**	Aquilegia
Araliaceae	**Arbutus**	Arctostaphylos	**Aristolochiaceae**
Artemisia	**Asparagaceae**	**Asphodelaceae**	**Asteraceae**
Asteraceae Liguliflorae	**Asteroideae**	**Astragalus**	**Berberidaceae**
Berberis	**Betula**	**Boraginaceae**	**Brassicaceae**
Buxus	Calicotome	**Calluna**	**Campanulaceae**
Caprifoliaceae	**Carduoideae**	**Carpinus betulus**	Carpinus orientalis Ostrya
Caryophyllaceae	**Castanea**	**Cedrus**	**Celastraceae**
Celtis	Ceratonia	Chamaerops	**Cichorioideae**
Cistaceae	**Cistus**	Clematis	**Colchicaceae**
Convolvulaceae	Coriaria	Cornus	**Corylus**
Crassulaceae	**Crataegus**	Cucurbitaceae	**Cupressaceae**
Cyperaceae	Cytinaceae	**Daphne**	Delphinium
Dennstaedtiaceae	Dryas	Elaeagnus	**Empetrum**
Ephedra	Ephedraceae	**Equisetum**	**Erica**
Ericaceae	Eriocaulaceae	**Euphorbiaceae**	**Fabaceae**
Fabaceae herbs	**Fagus**	**Frangula**	**Fraxinus**
Genisteae	**Gentianaceae**	**Geraniaceae**	Grossulariaceae
Halimium	Haloragaceae	**Hedera**	**Helianthemum**
Helleborus	Hippophae	**Huperzia**	Hymenophyllaceae
Hypericaceae	**Ilex**	**Iridaceae**	Jasminum
Juglans	**Juncaceae**	Juncaginaceae	Koenigia
Lamiaceae	Larix	**Lavandula**	Ledum
Ligustrum	**Liliaceae**	**Linaceae**	Linnaea
Linum	**Lonicera**	Loranthaceae	**Lycopodium**
Lysimachia	**Lythraceae**	**Malvaceae**	Maytenus

Melanthiaceae	Mercurialis	Montiaceae	**Moraceae**
Myrica	**Myrtaceae**	**Nartheciaceae**	Nerium
Nigella	**Olea**	**Oleaceae**	**Onagraceae**
Ononis	**Ophioglossaceae**	Orchidaceae	**Orobanchaceae**
Osmundaceae	Oxalidaceae	**Oxyria Rumex**	**Paeonia**
Papaveraceae	Parrotia	Periploca	**Phillyrea**
Picea	**Pinus**	**Pinus diploxylon**	Pinus haploxylon
Pistacia	**Plantaginaceae**	Platanus	**Plumbaginaceae**
Poaceae	**Polemoniaceae**	**Polygalaceae**	**Polygonaceae**
Polygonum	**Polypodiales**	**Populus**	Portulacaceae
Potentilla	**Primulaceae**	**Prunus**	**Pteridaceae**
Pterocarya	**Quercus deciduous**	**Quercus evergreen**	**Quercus intermediate**
Ranunculaceae	**Ranunculus**	**Resedaceae**	Retama
Rhamnaceae	**Rhamnus**	Rhododendron	Rhus
Ribes	**Rosaceae**	Rosmarinus	**Rubiaceae**
Rubus	Rutaceae	**Salix**	**Sambucus**
Sanguisorba group	Santalaceae	Sapotaceae	**Saxifragaceae**
Sciadopityaceae	**Scrophulariaceae**	Smilax	**Solanaceae**
Sorbus	**Tamarix**	Taxaceae	**Taxus**
Teucrium	**Thalictrum**	**Thymelaeaceae**	**Tilia**
Trollius	**Ulmus**	Ulmus Zelkova	**Urticaceae**
Vaccinium	**Valerianaceae**	Verbenaceae	**Viburnum**
Violaceae	Viscum	Vitex	**Ziziphus**
Zygophyllaceae			

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S3. Information about the Iberian charcoal data

Table S4. Information on the charcoal records. Latitude: degrees decimal where +ve is N and –ve is S. Longitude: degrees decimal where +ve is E and –ve is W. Elevation: in metres above sea level.

Site name	Entity name	Latitude	Longitude	Elevation	Reference
Alvor Estuary Ribeira do Farelo Ribeira da Torre	Abi 05_07_100minus	37.15	-8.59	0.6	(Schneider et al., 2010, 2016)
Alvor Estuary Ribeira do Farelo Ribeira da Torre	Abi 05_07_100plus	37.15	-8.59	0.6	(Schneider et al., 2010, 2016)
Arbarrain Mire	Arbarrain Mire core	43.21	-2.17	1004	(Pérez-Díaz et al., 2018)
Armacao de Pera Ribeira de Alcantarilha	ADP 01/06_100minus	37.11	-8.34	2.4	(Schneider et al., 2010, 2016)
Armacao de Pera Ribeira de Alcantarilha	ADP 01/06_100plus	37.11	-8.34	2.4	(Schneider et al., 2010, 2016)
Arroyo de Aguas Frias	Aguas Frias core	40.27	-5.12	1120	(Julio Camarero et al., 2019)
Arroyo de las Carcavas	Arroyo de las Carcavas core	40.84	-4.03	1300	(Morales-Molino et al., 2017a)
Arroyo de Valdeconejos	VALDECON	40.86	-4.06	1380	(Morales-Molino et al., 2017a)
Basa de la Mora	BSM08	42.55	0.33	1906	(Pérez-Sanz et al., 2013)
Bermu Mire	Bermu Mire core_large	39.43	-4.15	783	(Luelmo-Lautenschlaeger et al., 2018c)
Bermu Mire	Bermu Mire core_small	39.43	-4.15	783	(Luelmo-Lautenschlaeger et al., 2018c)
Borreguil de la Caldera	BdlC-01	37.05	-3.32	2992	(Ramos-Román et al., 2016)
Campo Lameiro	PRD4	42.53	-8.52	260	(Kaal et al., 2008)
Canada de la Cruz	Canada de la Cruz core	38.07	-2.69	1595	(Carrión et al., 2001a)
Canada del Gitano_Sierra de Baza	Baza section	37.23	-2.70	1900	(Carrión et al., 2007)
Castello Lagoon	Castello Lagoon core EM	42.28	3.10	2.4	(Ejarque et al., 2016)
Cha das Lameiras	Cha das Lameiras soil profile_macro	40.94	-7.68	950	(López-Sáez et al., 2017)

Cha das Lameiras	Cha das Lameiras soil profile_micro	40.94	-7.68	950	(López-Sáez et al., 2017)
Charco da Candieira	Candieira (Charco da Candieira) core	40.34	-7.58	1409	(Connor et al., 2012; van der Knaap and van Leeuwen, 1995, 1997)
Cubelles	Cubelles core	41.20	-1.67	2	(Riera-Mora and Esteban-Amat, 1994)
El Brezosa	El Brezosa core_macro	39.35	-4.36	733	(Morales-Molino et al., 2018)
El Brezosa	El Brezosa core_micro	39.35	-4.36	733	(Morales-Molino et al., 2018)
El Carrizal	El Carrizal core	41.32	-4.15	860	(Franco-Múgica et al., 2005)
El Perro mire	El Perro mire core	39.05	-4.76	690	(Luelmo-Lautenschlaeger et al., 2019a, 2019b)
El Portalet	PORTALET_macro	42.80	-0.40	1802	(González-Sampériz et al., 2006)
El Portalet	PORTALET_micro	42.80	-0.40	1802	(González-Sampériz et al., 2006)
El Redondo	El Redondo core o125	40.22	-5.66	1765	(López-Sáez et al., 2016b)
El Redondo	El Redondo core u125	40.22	-5.66	1765	(López-Sáez et al., 2016b)
El Tiemblo	El Tiemblo core	40.36	-4.53	1250	(López-Sáez et al., 2018b)
Espinosa de Cerrato	Espinosa de Cerrato core	41.96	-3.94	885	(Morales-Molino et al., 2017b)
Fuente de la Leche	Fuente de la Leche core	40.35	-5.06	1382	(Robles-López et al., 2018)
Fuente del Pino Blanco	FPB core	40.24	-4.98	1343	(Robles-López et al., 2018)
Hinojos Marsh	Hinojos Marsh_core S1_macro	36.96	-6.39	1.5	(López-Sáez et al., 2018a)
Hinojos Marsh	Hinojos Marsh_core S1_micro	36.96	-6.39	1.5	(López-Sáez et al., 2018a)
Hoya del Castillo	Hoya del Castillo N-CAS	41.48	-0.16	258	(Davis and Stevenson, 2007)
Hoya del Castillo	Hoya del Castillo N-CAS macro	41.48	-0.16	258	(Davis and Stevenson, 2007)
Laguna de la Mosca	LdlMo composite	37.06	-3.31	2889	(Manzano et al., 2019)

Laguna de la Mula	LdlM 10-02	37.06	-3.42	2497	(Jiménez-Moreno et al., 2013)
Laguna de Rio Seco	Laguna de Rio Seco core	37.05	-3.35	3020	(Anderson et al., 2011)
Laguna Guallar	N-GUA_macro	41.41	-0.23	336	(Davis and Stevenson, 2007)
Laguna Guallar	N-GUA_micro	41.41	-0.23	336	(Davis and Stevenson, 2007)
Lake Banyoles	Banyoles SB2	42.13	2.75	174	(Revelles et al., 2015)
Lanzahita	Lanzahita core	40.22	-4.94	588	(López-Sáez et al., 2018b)
Las Animas Mire	Las Animas Mire core_macro	36.69	-5.03	1403	(Alba-Sánchez et al., 2019)
Las Animas Mire	Las Animas Mire core_micro	36.69	-5.03	1403	(Alba-Sánchez et al., 2019)
Las Pardillas	Las Pardillas core	42.03	-3.03	1850	(Sanchez Goñi and Hannon, 1999)
Las Vinuelas	Las Vinuelas core_macro	39.37	-4.49	761	(Morales‐Molino et al., 2019)
Las Vinuelas	Las Vinuelas core_micro	39.37	-4.49	761	(Morales‐Molino et al., 2019)
Manaderos	Manaderos core	40.34	-4.69	1292	(Robles-López et al., 2020)
Marbore	Marbore composite	42.70	0.04	2612	(Leunda et al., 2017)
Navamuno	Navamuno_S3	40.32	-5.78	1505	(Turu et al., 2018; López-Sáez et al., 2020)
Navarres	NAVARRE3	39.10	-0.68	225	(Carrión and Van Geel, 1999)
Ojos del Tremendal	Ojos del Tremendal core	40.54	-2.05	1650	(Stevenson, 2000)
Pena da Cadela	Pena da Cadela core	42.83	-7.17	970	(Martínez Cortizas et al., 2002)
Pena Negra	Pena Negra core	40.33	-5.79	1000	(Abel-Schaad and López-Sáez, 2013)
Pozo de la Nieve	PozoN_2015 core	40.35	-4.55	1600	(Robles-López et al., 2017)
Puerto de Serranillos	Serranillos_macro	40.31	-4.93	1700	(López-Sáez et al., 2018b)
Puerto de Serranillos	Serranillos_micro	40.31	-4.93	1700	(López-Sáez et al., 2018b)

Puerto del Pico	Puerto del Pico core_macro	40.32	-5.01	1395	(López-Sáez et al., 2016a)
Puerto del Pico	Puerto del Pico core_micro	40.32	-5.01	1395	(López-Sáez et al., 2016a)
Sierra de Gador	Gador core	36.90	-2.92	1530	(Carrión et al., 2003)
Siles Lake	Siles Lake core	38.40	-2.50	1320	(Carrión, 2002)
Tubilla del Lago	Tubilla del Lago core	41.81	-3.57	900	(Morales-Molino et al., 2017b)
Valle do Lobo Ribeira de Carcavai	VdL PB2_100minus	37.06	-8.07	2.3	(Schneider et al., 2010, 2016)
Valle do Lobo Ribeira de Carcavai	VdL PB2_100plus	37.06	-8.07	2.3	(Schneider et al., 2010, 2016)
Verdeospesoa	Verdeospesoa core	43.06	-2.86	1015	(Pérez-Díaz and López-Sáez, 2017, 2019)
Vilamora Ribeira de Quarteira	Vilamora P01-5_100minus	37.09	-8.14	3.5	(Schneider et al., 2010, 2016)
Vilamora Ribeira de Quarteira	Vilamora P01-5_100plus	37.09	-8.14	3.5	(Schneider et al., 2010, 2016)
Villaverde	Villaverde core	38.80	-2.37	870	(Carrión et al., 2001b)

S4. Selection of the final GLM

We initially examined 13 variables that have been shown in global analyses to influence burnt area. Table S5 provides information on the source of each of the data sets, their original resolution, and the transformation used prior to analysis.

Table S5. Environmental variables and transformation methods.

Environmental variables	Data source	Resolution	Transformation	Reference
Dry days per month	CRUNCEP V7	0.5° × 0.5°	Logarithmic	Viovy, 2018
Diurnal temperature range (K)	CRUNCEP V7	0.5° × 0.5°	Logarithmic	Viovy, 2018
Maximum temperature (K)	CRUNCEP V7	0.5° × 0.5°	Logarithmic	Viovy, 2018
Wind speed (m/s)	CRUNCEP V7	0.5° × 0.5°	Logarithmic	Viovy, 2018
Gross primary production (gC m^{-2} day^{-1})	FLUXCOM	0.5° × 0.5°	Logarithmic	Jung et al., 2020
Tree cover (%)	VCF	0.05° × 0.05°	Cell fraction	Hansen and Song, 2018
Non-tree cover (%)	VCF	0.05° × 0.05°	Cell fraction	Hansen and Song, 2018
Cropland (km^2)	HYDE 3.2	0.083° × 0.083°	Cell fraction	Klein Goldewijk et al., 2017
Total rainfed other crops (no rice) (km^2)	HYDE 3.3	0.083° × 0.083°	Cell fraction	Klein Goldewijk et al., 2017
Grazing land (km^2)	HYDE 3.2	0.083° × 0.083°	Cell fraction	Klein Goldewijk et al., 2017
Total population density (inhabitants km^{-2})	HYDE 3.2	0.083° × 0.083°	Square root	Klein Goldewijk et al., 2017
Urban population density (inhabitants km^{-2})	HYDE 3.2	0.083° × 0.083°	Square root	Klein Goldewijk et al., 2017
Rural population density (inhabitants km^{-2})	HYDE 3.2	0.083° × 0.083°	Square root	Klein Goldewijk et al., 2017

The process of final model selection: The partial correlation test (Fig. S1) shows that tree cover is highly correlated with both GPP (0.63) and non-tree cover (0.69), and rainfed cropland is highly correlated with total cropland (0.62). The three population variables are also strongly correlated with one another (> 0.80). There are moderate correlations between maximum temperature of the warmest month, maximum diurnal temperature range, and maximum dry days per month (> 0.40). We tested the impact of including or removing highly and moderately correlated variables before selecting the final model. Tree cover was not included in any GLM model because of its high correlation with both GPP and non-tree cover. The GLM model including cropland has a higher pseudo-R^2 than the model including total rainfed cropland (Table S6: first 2 columns), so only total cropland was retained. Comparison of the GLM models using total, urban and rural population density (Table S6: 2-4 columns) shows that only urban population density is statistically significant and the model with urban population density has the best fit (pseudo-R^2=0.20). All the variables in this model, except for maximum temperature, are statistically significant ($P < 0.1$). Given the lack of statistical significance of maximum temperature and the moderate correlations between maximum

temperature and both diurnal temperature range and dry days per month (Fig. S1), we constructed three models leaving out one variable in turn. We obtained pseudo-R^2 values of 0.20, 0.17 and 0.20 respectively for these three models (Table S6: the last 3 columns). The model which does not include maximum temperature has the best fit (pseudo-R^2= 0.20). The final model was constructed using eight variables (Table S6: the last column).

Figure S1. Partial correlations test based on data sets for the Iberian Peninsula that include annual observations at 0.5° for the period between 2001 and 2016. The data are all transformed according to Table S5 prior to the test.

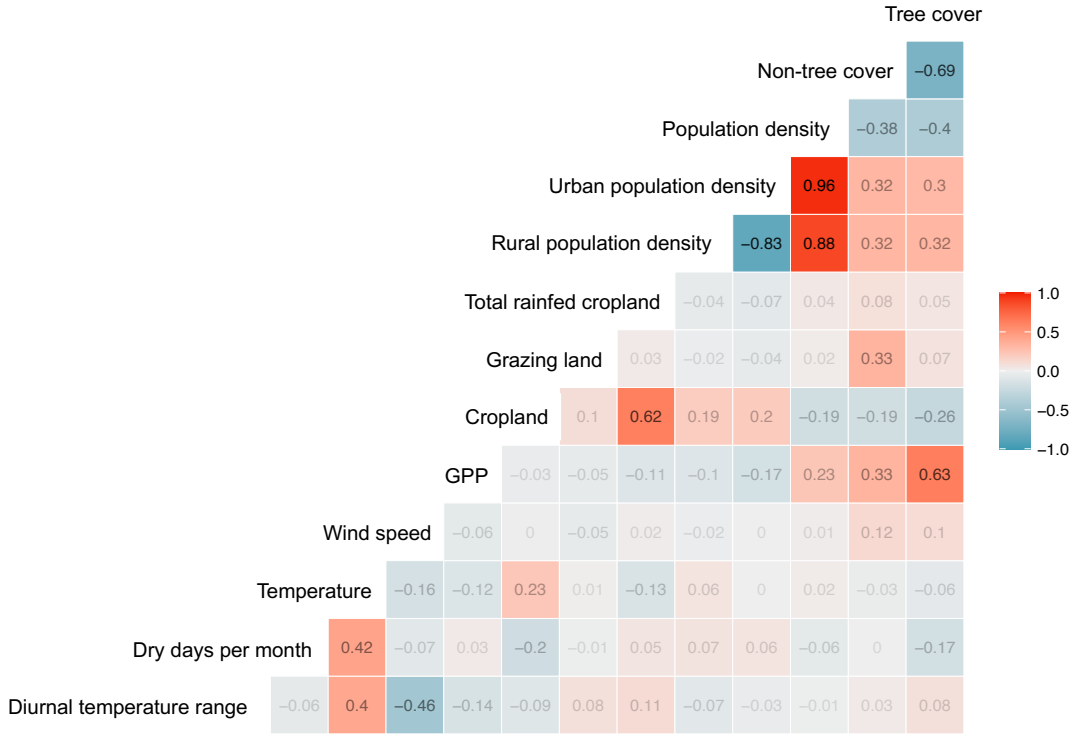


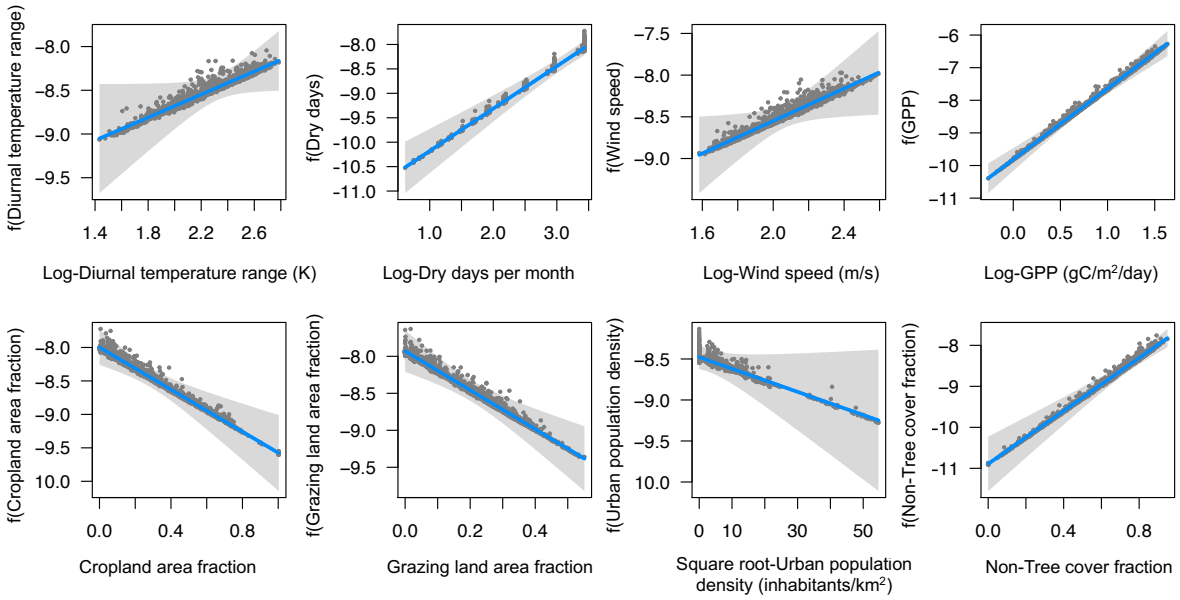
Table S6. The process of the model selection. Regression coefficients (t value) and pseudo-R^2 of each model are shown. The final model is shown in bold.

	1 Include total rainfed cropland	2 Include total population density	3 Include rural population density	4 Include urban population density	5 Remove diurnal temperature range	6 Remove dry days per month	7 **Remove maximum temperature**
Diurnal temperature range	1.95$^{\cdot}$	1.86$^{\cdot}$	2.38*	1.77$^{\cdot}$		1.19	**1.90**$^{\cdot}$
Dry days per month	7.81***	7.66***	7.56***	7.66***	-1.01***		**8.46*****
Maximum temperature	-0.50	0.01	-0.19	0.07	7.60	4.07***	
Wind speed	2.00*	2.04*	2.05*	2.07*	0.69	1.89$^{\cdot}$	**2.11***
GPP	9.54***	9.76***	9.49***	9.85***	1.43***	9.41***	**10.10*****
Non-tree cover	7.11***	7.27***	7.19***	7.33***	7.44***	9.50***	**7.34*****
Cropland		-3.95***	-4.08***	-3.95***	9.76***	-4.86***	**-4.04*****
Total rainfed cropland	-3.62***						
Grazing land	-4.64***	-4.29***	-4.19***	-4.36***	-4.17***	-4.96***	**-4.36*****
Total population density	-1.55	-1.07					
Rural population density			0.06				
Urban population density				-1.68$^{\cdot}$	-2.32*	-1.38	**-1.69**$^{\cdot}$
Pseudo-R^2	0.2008	0.2031	0.2013	0.2020	0.2012	0.1654	**0.2031**

Notes: $^{\cdot}p < 0.1$; $^{*}p < 0.05$; $^{**}p < 0.01$; $^{***}p < 0.001$.

Figure S2 shows the partial residuals obtained for the final model.

Figure S2. Partial residual plots of the final model (Table S6, last column). The plot includes (1) the expected value (blue line); (2) a confidence interval for the expected value (grey band); (3) partial residuals (dark grey dots)



S5. Box-Cox transformation of palaeo burnt area fraction

The standard Box-Cox transformation is:

$$Y_i^{(\lambda)} = \begin{cases} \dfrac{Y_i^{(\lambda)} - 1}{\lambda} & (\lambda \neq 0) \\ \log(Y_i) & (\lambda = 0) \end{cases}$$

The inverse Box-Cox transformation is:

$$Y_i = \begin{cases} \exp\left(\dfrac{\log(1 + \lambda Y_i^{(\lambda)})}{\lambda}\right) & (\lambda \neq 0) \\ \exp\left(Y_i^{(\lambda)}\right) & (\lambda = 0) \end{cases}$$

After deriving palaeo burnt area fraction from charcoal by applying conversion factors, we applied the Box-Cox transformation to the palaeo burnt area fraction to reduce the skewness of the data. The parameter λ was set as 0.25 after trials of a range of values (Figure S3, Table S7). This value has the highest predictive power ($R^2 = 0.436$) and less local compression ($b_1 = 0.526$) compared to using other values of λ. Figure S3 shows the change in the distribution of palaeo burnt area fraction before and

after Box-Cox transformation. The predicted values of palaeo burnt area fraction from fxTWAPLS were then obtained via the inverse Box-Cox transformation.

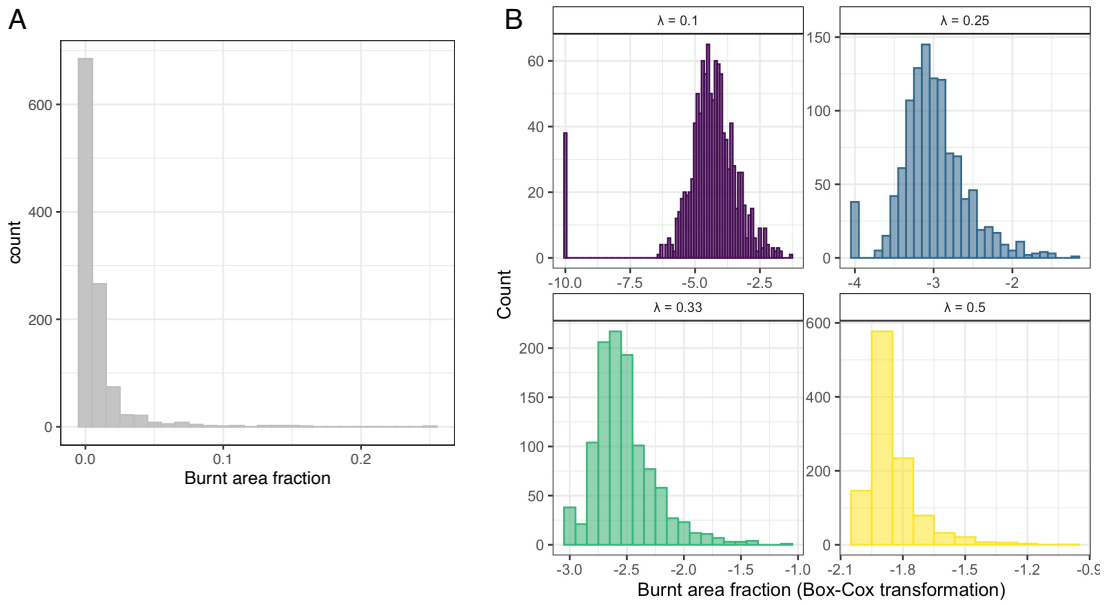


Figure S3. Distribution of palaeo burnt area fraction before (Panel A) and after (Panel B) Box-Cox transformation.

Table S7. Results of fxTWAPLS using different values of λ.

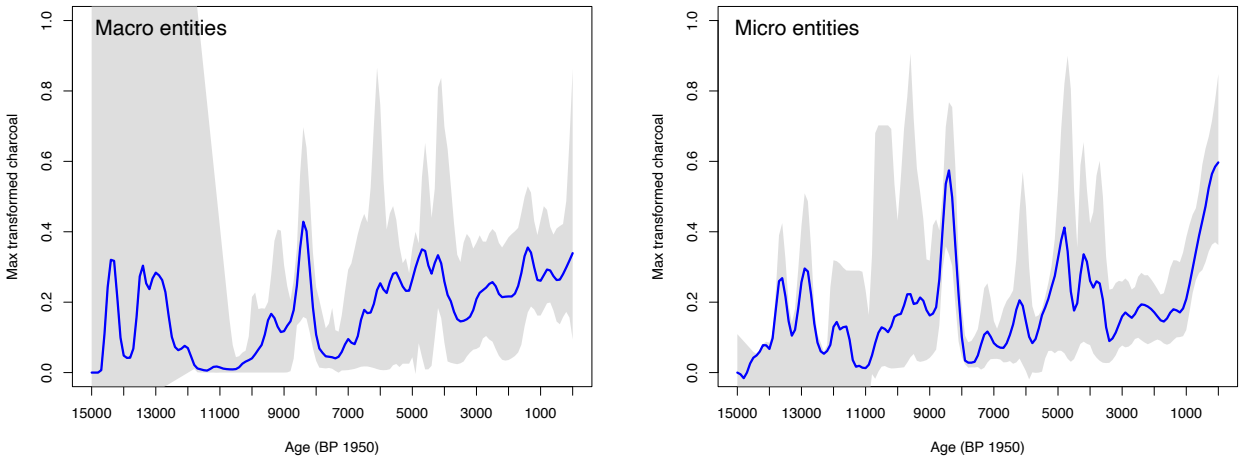
method	ncomp	R^2	RMSEP	ΔRMSEP	p	b_0	b_1	b_0.se	b_1.se
λ = 0.1	1	0.227	1.184	-9.799	0.001	-3.453	0.175	0.045	0.010
	2	0.289	1.135	-4.126	0.001	-3.283	0.220	0.048	0.010
	3	0.380	1.042	-8.182	0.001	-2.669	0.371	0.066	0.014
	4	0.399	1.026	-1.531	0.010	-2.460	0.420	0.072	0.016
	5	0.416	1.011	-1.490	0.002	-2.452	0.421	0.070	0.015
	6	**0.425**	**1.002**	**-0.882**	**0.002**	**-2.456**	**0.423**	**0.069**	**0.015**
	7	0.429	1.004	0.161	0.560	-2.531	0.400	0.064	0.014
	8	0.427	1.007	0.327	0.761	-2.529	0.398	0.064	0.014
λ = 0.25	1	0.249	0.366	-11.172	0.001	-2.083	0.280	0.044	0.015
	2	0.333	0.340	-7.027	0.001	-1.822	0.380	0.049	0.016
	3	0.404	0.326	-4.332	0.005	-1.467	0.502	0.056	0.018
	4	**0.436**	**0.316**	**-2.988**	**0.012**	**-1.390**	**0.526**	**0.054**	**0.018**
	5	0.439	0.316	-0.006	0.483	-1.381	0.526	0.054	0.018
	6	0.443	0.313	-0.857	0.230	-1.402	0.520	0.053	0.018
	7	0.461	0.308	-1.584	0.010	-1.343	0.541	0.053	0.018
	8	0.474	0.305	-0.909	0.081	-1.282	0.561	0.054	0.018

λ = 0.33	1	0.240	0.240	-10.025	0.001	-1.708	0.304	0.041	0.016
	2	0.326	0.223	-7.049	0.001	-1.492	0.399	0.044	0.017
	3	0.400	0.213	-4.610	0.005	-1.209	0.514	0.048	0.019
	4	**0.431**	**0.208**	**-2.541**	**0.039**	**-1.143**	**0.537**	**0.047**	**0.019**
	5	0.421	0.212	2.251	0.952	-1.109	0.548	0.049	0.019
	6	0.436	0.207	-2.263	0.001	-1.113	0.548	0.048	0.019
	7	0.447	0.206	-0.641	0.193	-1.054	0.574	0.049	0.019
	8	0.451	0.205	-0.736	0.176	-1.073	0.564	0.048	0.019
λ = 0.5	**1**	**0.209**	**0.120**	**-0.030**	**0.500**	**-1.285**	**0.279**	**0.030**	**0.016**
	2	0.293	0.109	-8.666	0.001	-1.177	0.343	0.030	0.016
	3	0.361	0.103	-6.261	0.001	-0.953	0.470	0.035	0.019
	4	0.384	0.102	-0.892	0.242	-0.917	0.488	0.035	0.019
	5	0.375	0.103	1.681	0.954	-0.868	0.515	0.037	0.020
	6	0.396	0.101	-2.624	0.001	-0.856	0.522	0.036	0.019
	7	0.396	0.100	-0.312	0.341	-0.824	0.542	0.037	0.020
	8	0.401	0.100	-0.644	0.241	-0.826	0.541	0.037	0.020

S6. Impact of using of micro and macro charcoal on the burnt area fraction reconstructions

The charcoal data used in these analyses was generated in several different ways and includes counts of both microcharcoal and macrocharcoal. Some sites had only macroscopic charcoal, some only microscopic charcoal, and a small number of sites included both. Macrocharcoal is often thought to be associated with local fires, and microcharcoal to represent regional fires. In order to test whether size had any impact of the composite reconstructions, we compared the 16 charcoal sites with both macroscopic and microscopic records (Fig. S4). Since this analysis suggests there is no difference in the curves obtained, we used both types of record in our analyses, though preferring macrocharcoal at those sites with both kinds of records.

Figure S4. Composite plots for macroscopic and macroscopic charcoal separately of 16 charcoal sites with both macroscopic and microscopic entities using the locfit() function with half-width=300, number of bootstrap samples=1000. The locally estimated scatterplot smoothing is shown in blue; The upper and lower 95th-percentile confidence intervals are shown in grey.



S7. Comparisons of WA-PLS and TWA-PLS reconstructions with and without fx correction

Weighted Averaging Partial Least-Squares (WA-PLS) regression (ter Braak et al., 1993; ter Braak and Juggins, 1993; Salonen et al., 2012) is widely used for climate reconstructions, but there is a known tendency for the reconstructed values to be compressed towards the middle of the range of the climate variable as expressed in the training data set. Tolerance-weighted Weighted Averaging Partial Least-Squares with a sampling frequency correction (fxTWA-PLS: Liu et al., 2020) is a modification of WA-PLS, designed to reduce the compression of reconstructions towards the centre of the climatic range sampled by the training dataset by accounting for the climatic tolerances of individual pollen taxa and the frequency (fx) of the sampled climate variable in the training dataset. Since fxTWA-PLS has not previously been used to reconstruct burnt area fractions, we tested whether this approach reduced compression in the burnt area fraction reconstructions when compared to WA-PLS. We also tested the impact of using the sampling frequency correction (fx) separately for both WA-PLS and TWA-PLS. Cross-validation fitness assessment (Table S8) and visual comparison of the fitted plots and residuals (Fig. S5) indicate that fxTWA-PLS reduces the compression bias more than other methods and also has higher predictive power. The composite curves produced using each approach are shown in Fig. S6.

Table S8. Leave-out cross-validation fitness of WA-PLS and TWA-PLS methods, with and without fx correction, showing results for all the components. The last significant number of components are shown in bold.

method	ncomp	R^2	RMSEP	ΔRMSEP	p	b0	b1	b0.se	b1.se
WA-PLS	1	0.260	0.355	-13.870	0.001	-2.190	0.274	0.042	0.014
	2	0.341	0.336	-5.487	0.001	-1.906	0.370	0.047	0.015
	3	0.390	0.322	-3.936	0.001	-1.785	0.409	0.047	0.015
	4	**0.405**	**0.318**	**-1.196**	**0.003**	**-1.738**	**0.424**	**0.047**	**0.015**
	5	0.418	0.315	-0.961	0.163	-1.659	0.451	0.048	0.016
	6	0.425	0.314	-0.576	0.226	-1.629	0.461	0.049	0.016
	7	0.427	0.313	-0.239	0.391	-1.623	0.462	0.049	0.016
	8	0.432	0.312	-0.210	0.400	-1.584	0.476	0.050	0.016
TWA-PLS	1	0.249	0.357	-13.313	0.001	-2.285	0.239	0.038	0.013
	2	0.334	0.337	-5.624	0.001	-1.950	0.355	0.046	0.015
	3	0.403	0.319	-5.349	0.001	-1.732	0.427	0.047	0.016
	4	0.434	0.311	-2.658	0.001	-1.637	0.459	0.048	0.016
	5	**0.450**	**0.306**	**-1.476**	**0.019**	**-1.589**	**0.474**	**0.048**	**0.016**
	6	0.462	0.303	-1.034	0.074	-1.557	0.484	0.048	0.016
	7	0.465	0.302	-0.207	0.380	-1.532	0.493	0.048	0.016
	8	0.473	0.300	-0.771	0.120	-1.494	0.505	0.049	0.016
WA-PLS with fx correction	1	0.260	0.363	-12.037	0.001	-2.038	0.297	0.046	0.015
	2	**0.339**	**0.343**	**-5.337**	**0.001**	**-1.660**	**0.438**	**0.056**	**0.018**
	3	0.373	0.333	-3.100	0.099	-1.612	0.450	0.053	0.018
	4	0.392	0.329	-1.028	0.120	-1.506	0.486	0.055	0.018
	5	0.410	0.326	-1.077	0.151	-1.424	0.513	0.056	0.019
	6	0.416	0.323	-0.822	0.256	-1.421	0.515	0.056	0.018
	7	0.399	0.329	1.972	0.937	-1.453	0.501	0.056	0.018
	8	0.405	0.327	-0.553	0.005	-1.438	0.506	0.056	0.018
TWA-PLS with fx correction	1	0.249	0.366	-11.172	0.001	-2.083	0.280	0.044	0.015
	2	0.333	0.340	-7.027	0.001	-1.822	0.380	0.049	0.016
	3	0.404	0.326	-4.332	0.005	-1.467	0.502	0.056	0.018
	4	**0.436**	**0.316**	**-2.988**	**0.012**	**-1.390**	**0.526**	**0.054**	**0.018**
	5	0.439	0.316	-0.006	0.483	-1.381	0.526	0.054	0.018
	6	0.443	0.313	-0.857	0.230	-1.402	0.520	0.053	0.018
	7	0.461	0.308	-1.584	0.010	-1.343	0.541	0.053	0.018
	8	0.474	0.305	-0.909	0.081	-1.282	0.561	0.054	0.018

Figure S5. The fitted plots and residual plots of WA-PLS and TWA-PLS methods, with and without fx correction.

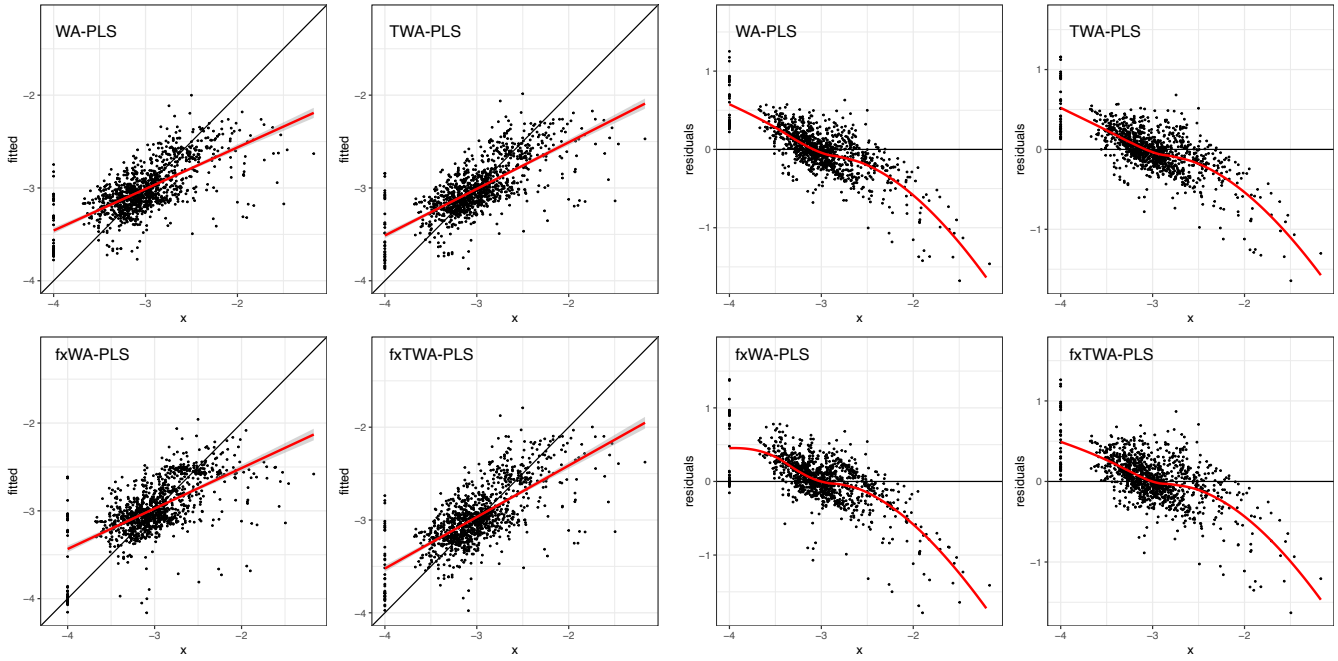
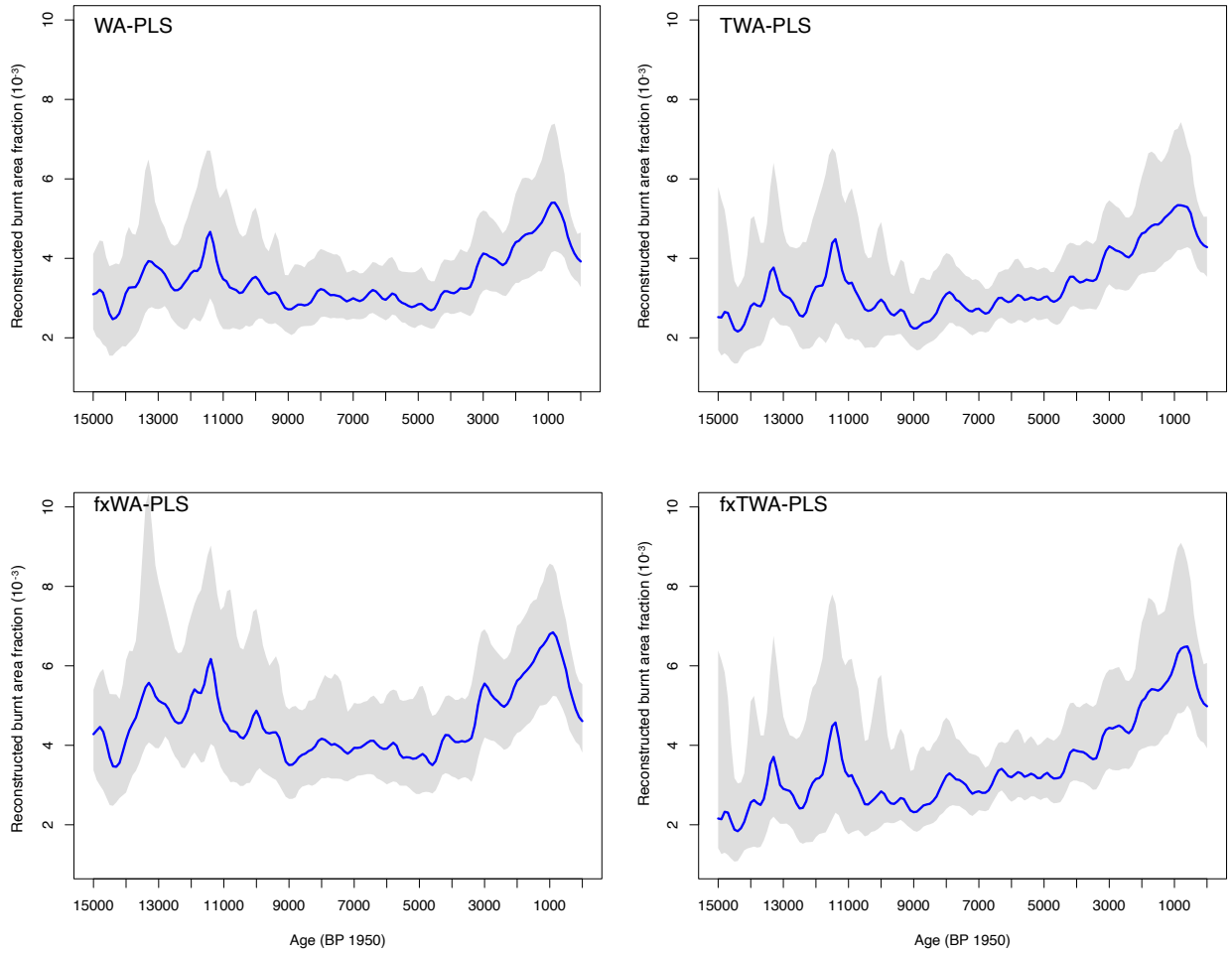


Figure S6. Composite curves of reconstructed burnt area using WA-PLS and TWA-PLS, with and without fx correction, using the locfit() function with half-width = 300, number of bootstrap samples = 1000. The locally estimated scatterplot smoothing is shown in blue; The upper and lower 95th-percentile confidence intervals are shown in grey.



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