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Supplementary Materials for

Drivers of woody dominance across global drylands

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This PDF file includes:

Appendix 1. Supporting information.

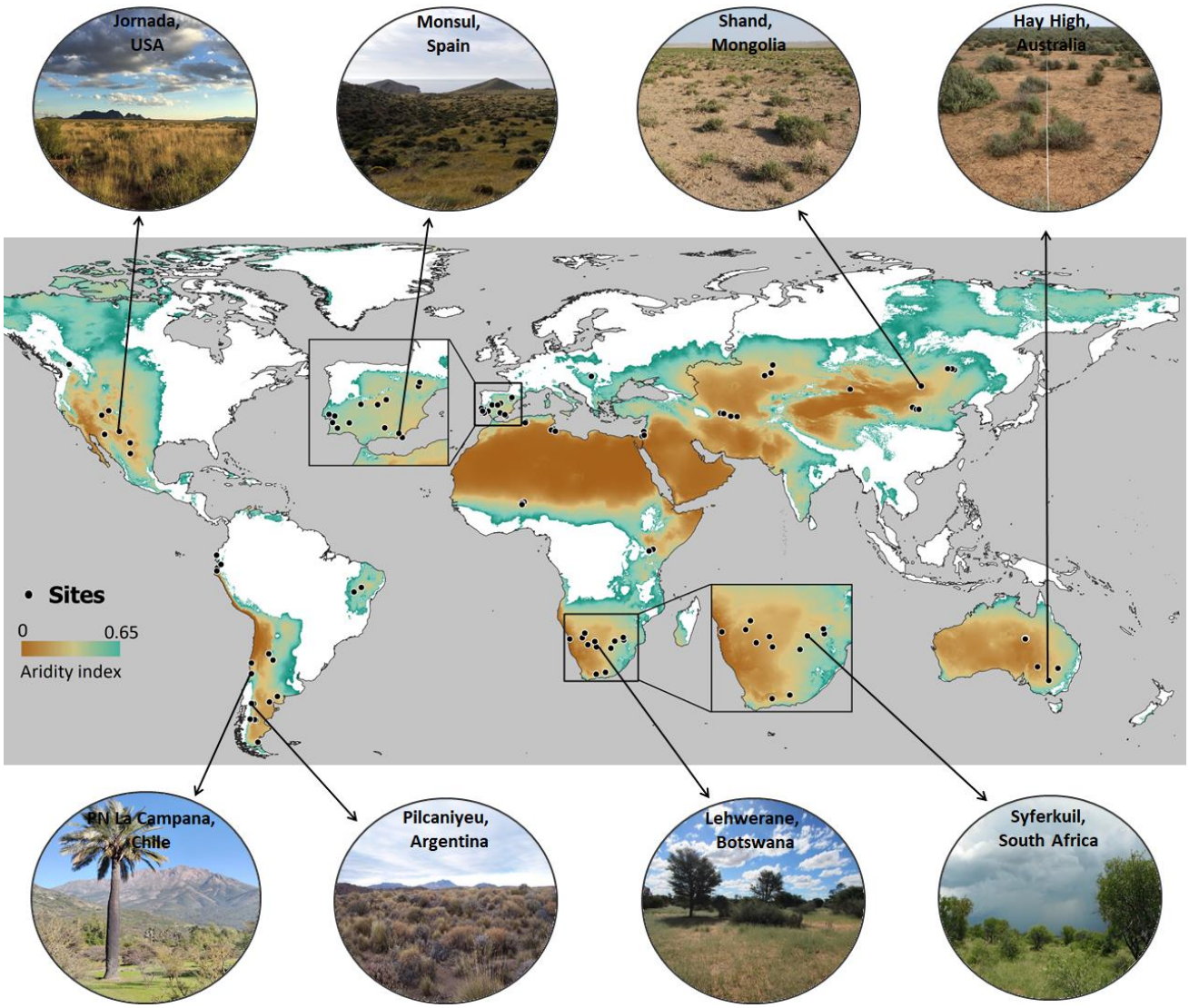

Figure S1. **Location of the 304 plots at the 92 experimental sites surveyed**. Background colors represent aridity index for drylands (areas with an aridity index (mean annual precipitation/potential evapotranspiration) lower than 0.65). Pictures illustrate the structural and compositional diversity of vegetation captured by our survey.

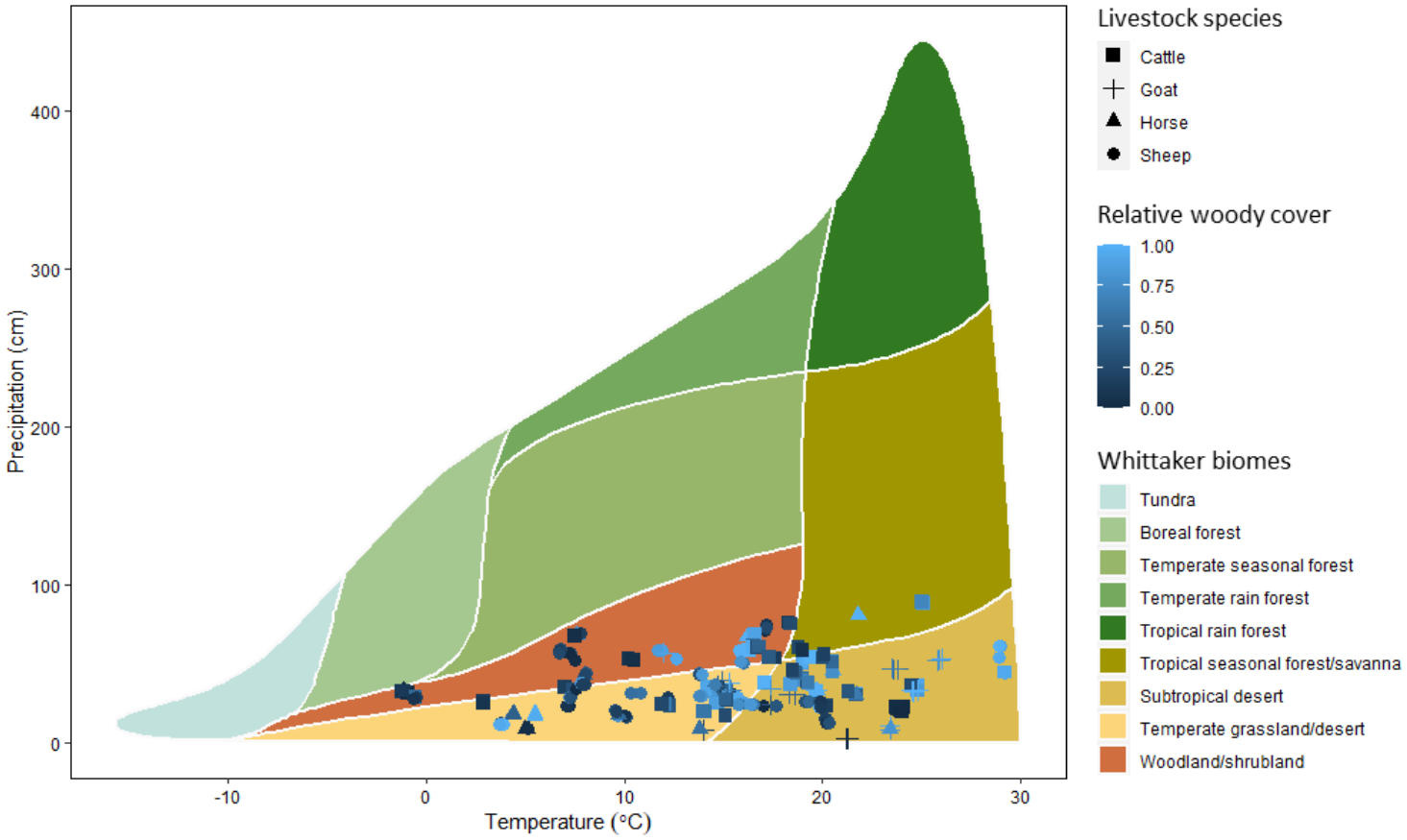

Figure S2. Whittaker biomes plot showing the different biomes surveyed in this study. The color of the symbols indicates values of relative woody cover across the plots and biomes surveyed. Different types of symbols indicate the livestock species dominant at each plot: cattle (squares), goat (crosses), horse (triangles) and sheep (circles).

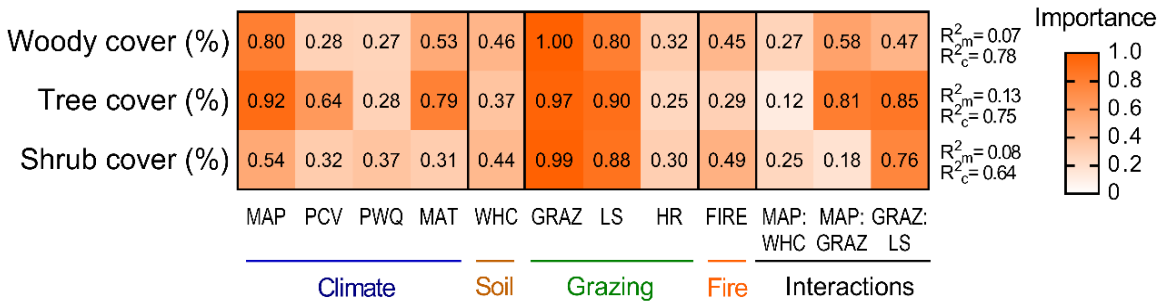

Figure S3. Importance of predictors of woody (tree + shrub), tree, and shrub absolute cover. Importance is based on the sum of Akaike weights of all models where each predictor is present using a multimodel inference approach. MAP = mean annual precipitation; PCV = precipitation seasonality, PWQ = % precipitation at warmest quarter, MAT = mean annual temperature, WHC soil water holding capacity, GRAZ = grazing pressure, LS = dominant livestock species, HR = herbivore richness, and FIRE = fire occurrence during the 2001-2019 period. Values of R^2_m= marginal R^2 and R^2_c = conditional R^2, correspond to the lowest AIC models for each response variable.

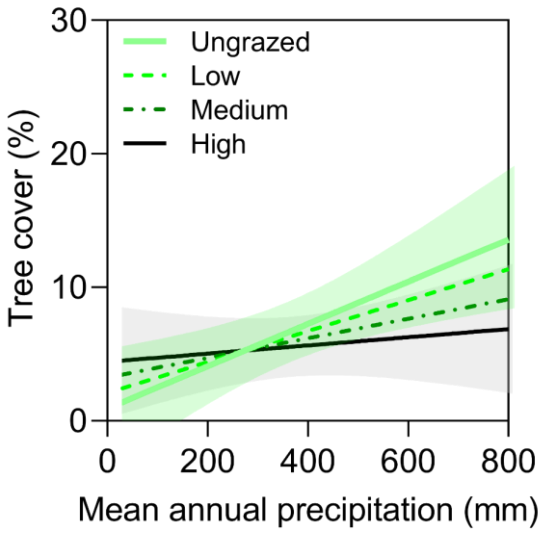

Figure S4. Predicted values of tree cover for the different grazing pressure levels evaluated along the precipitation gradient surveyed. Confidence intervals bands are shown only for Ungrazed and High grazing pressure to smooth visualization

Table S1. Explanatory variables for relative woody cover used in this study, range of values found in this study, rationale for including them and references.

Predictor set	Variables	Range of values	Rationale	References
Climate	Mean annual precipitation (MAP)	29 - 891 (mm)	Higher mean annual precipitation favors relative woody cover as more water is available at deeper soil layers	(*4*, *13*, *53*)
	Mean annual temperature (MAT)	-1.21 - 29.2 (°C)	Higher mean annual temperature increases relative woody cover in drylands due to increasing soil water evaporation and lower water availability for grasses	(*4*, *53*)
	Precipitation at warmest quarter (PWQ)	0 – 82.6 (%)	Lower water availability during growth season increases relative woody cover, because there would be more water availability at deeper soil layers	(*91*, *92*)
	Precipitation seasonality (CV)	13.5 – 186.7 (%)	Higher variation in water availability during the year would favor woody species with deep roots not relying on top soil water	(*26–30*, *55*)
Soil	Water holding capacity (WHC)	10.7 – 48.7 (%)	Coarser textures would favor woody dominance as more water is available at deeper soil layers	(*17*, *19*, *21*)
Grazing	Grazing pressure (GRAZ)	Ungrazed, low, moderate, high	Higher grazing pressure increases relative woody cover, because livestock herbivory mainly feeds on grasses, favoring growth of woody species	(*4*, *49*)
	Livestock species (LS)	Cattle, horse, goat, sheep	Different livestock species have different dietary preferences, selectivity and behavior that could change woody:grass ratios. Browser species would decrease relative woody cover, while the opposite is expected for grazers.	(*42*, *43*, *93*)
	Herbivore richness (HR)	1 to 5	Complementarity in foraging/browsing/grazing behavior could affect grasses, increasing relative woody cover. In this study we included domesticated and wild mammalian herbivores	(*94*)
Fire	Fire occurrence (FIRE)	0 – 1	Fire reduces woody cover because of negative effects on establishment and size growth of trees and shrubs	(*4*, *29*, *33*)
Interactions	MAP:WHC	-	At lower precipitation sites, grass cover is predicted to be higher in coarser soils (less water retention and evaporation losses), while is predicted to be lower at finer soils, changing the relative woody cover. The opposite pattern is expected at higher precipitation sites.	(*20*, *65*, *66*)
	MAP:GRAZ	-	Increasing grazing pressure effects on relative woody cover at low precipitation sites may be lower than on mesic sites, as dry site vegetation has functional and structural traits adapted to both drought and grazing.	(*47*, *48*)
	GRAZ:LS	-	Grazing pressure effect could depend on herbivore type because of differential selectivity and preference	(*36*, *37*, *49*)

Table S2. Characteristics of the study sites surveyed. The values of perennial plant richness, Shannon diversity index and the weight of dung of all herbivores (proxy of grazing pressure) represent averages across all plots surveyed at each site. Livestock and mammalian wild herbivore species mentioned are based on the feces found across all the plots for each site (see Methods).

Site	Biome	Ecoregion	Perennial plant richness	Shannon diversity index	Livestock species across plots	Wild species based on feces found	Dung of all herbivores (kg ha^{-1})
Alikhani	Temperate Broadleaf & Mixed Forests	Caspian Hyrcanian mixed forests	13	0.98	Sheep	NA	NA
Andalgala	Montane Grasslands & Shrublands	High Monte	4	0.17	Goat, Cattle, Horse	NA	54.11
Baharkish	Deserts & Xeric Shrublands	Central Persian desert basins	41	2.51	Sheep	NA	108.38
Bani	Tropical & Subtropical Grasslands, Savannas & Shrublands	West Sudanian savanna	5	0.29	Sheep, Cattle	NA	26.67
Baño nuevo	Temperate Grasslands, Savannas & Shrublands	Patagonian steppe	15	1.24	Sheep, Cattle, Horse	Hare, Rhea	78.68
Barra	Tropical & Subtropical Grasslands, Savannas & Shrublands	Cerrado	28	2.42	Cattle	NA	49.83
Beit Nir	Mediterranean Forests, Woodlands & Scrub	Eastern Mediterranean conifer-broadleaf forests	9	1.48	Cattle	Gazelle	83.48
Big Bend Ranch State Park	Deserts & Xeric Shrublands	Chihuahuan desert	23	2.06	Cattle	Rabbit	23.49
Boyenga	Tropical & Subtropical Grasslands, Savannas & Shrublands	West Sudanian savanna	6	0.34	Sheep	NA	13.87
Casa Nova	Tropical & Subtropical Dry Broadleaf Forests	Caatinga	17	1.76	Goat	NA	184.52
Castro Verde	Mediterranean Forests, Woodlands & Scrub	Iberian sclerophyllous and semi-deciduous forests	3	0.49	Cattle	NA	302.97
CEMB	Deserts & Xeric Shrublands	Simpson desert	18	1.10	Cattle	Camel	0.56
Central	Temperate Grasslands, Savannas & Shrublands	Patagonian steppe	15	1.15	Sheep, Horse	Rabbit, Guanaco	55.85
CHA	Temperate Grasslands, Savannas & Shrublands	Mongolian-Manchurian grassland	37	2.04	Sheep, Cattle, Horse	NA	111.43
CHB	Temperate Grasslands, Savannas & Shrublands	Mongolian-Manchurian grassland	34	2.14	Cattle	NA	415.53
CHC	Temperate Grasslands, Savannas & Shrublands	Daurian forest steppe	40	2.20	Cattle, Sheep	NA	128.03
Ciempozuelos	Mediterranean Forests, Woodlands & Scrub	Iberian sclerophyllous and semi-deciduous forests	18	1.96	Goat	Rabbit	35.00
Claro	Tropical & Subtropical Dry Broadleaf Forests	Tumbes-Piura dry forests	13	1.12	Goat, Horse	NA	122.61
CNAB	Deserts & Xeric Shrublands	Simpson desert	11	0.27	Cattle	NA	0.07
Companhia das Lezirias	Mediterranean Forests, Woodlands & Scrub	Southwest Iberian Mediterranean sclerophyllous and mixed forests	5	0.34	Cattle	NA	140.59

Contenda	Mediterranean Forests, Woodlands & Scrub	Iberian sclerophyllous and semi-deciduous forests	2	0.13	Sheep	Deer	67.61
Crucita	Mangroves	South American Pacific mangroves	18	1.89	Cattle	NA	NA
CSBB	Deserts & Xeric Shrublands	Simpson desert	10	0.23	Cattle	Kangaroo	0.09
Darkesh	Temperate Conifer Forests	Elburz Range forest steppe	42	2.31	Sheep	NA	65.33
Ebenhaezer	Deserts & Xeric Shrublands	Kalahari xeric savanna	21	1.34	Sheep	Springbok, Steenbok	123.88
El Ouassria	Mediterranean Forests, Woodlands & Scrub	Mediterranean dry woodlands and steppe	18	1.40	Sheep	NA	60.84
Eriopoda	Deserts & Xeric Shrublands	Chihuahuan desert	19	2.03	Cattle	Rabbit, Deer, Rabbit	12.87
Etuoke	Montane Grasslands & Shrublands	Ordos Plateau steppe	11	1.34	Sheep	NA	109.08
Fowlers	Deserts & Xeric Shrublands	Tirari-Sturt stony desert	15	1.70	Sheep	Kangaroo	30.00
Freixo	Mediterranean Forests, Woodlands & Scrub	Southwest Iberian Mediterranean sclerophyllous and mixed forests	4	0.88	Horse	NA	29.02
Galed	Mediterranean Forests, Woodlands & Scrub	Eastern Mediterranean conifer-broadleaf forests	4	0.64	Cattle	NA	251.98
Grandola	Mediterranean Forests, Woodlands & Scrub	Southwest Iberian Mediterranean sclerophyllous and mixed forests	6	0.98	Cattle	NA	166.99
Guelb Fguira	Deserts & Xeric Shrublands	North Saharan Xeric Steppe and Woodland	8	1.11	Sheep	Camel	25.21
Hassi Bahbah	Mediterranean Forests, Woodlands & Scrub	Mediterranean dry woodlands and steppe	11	0.79	Sheep	NA	98.58
Hay	Temperate Grasslands, Savannas & Shrublands	Southeast Australia temperate savanna	12	0.97	Sheep, Cattle	Kangaroo, Rabbit	36.85
IBP	Deserts & Xeric Shrublands	Sonoran desert	20	2.13	Cattle	Rabbit, Deer	31.72
Jornada LTER	Deserts & Xeric Shrublands	Chihuahuan desert	16	1.84	Cattle	Rabbit	445.58
Kalama	Tropical & Subtropical Grasslands, Savannas & Shrublands	Northern Acacia-Commiphora bushlands and thickets	21	1.91	Goat	Zebra, Camel	27.08
Khabul	Deserts & Xeric Shrublands	Eastern Gobi desert steppe	10	1.20	Sheep	Rabbit, Camel	48.51
Khage	Montane Grasslands & Shrublands	Kopet Dag woodlands and forest steppe	15	1.18	Sheep	NA	522.70
Korgalzhin	Temperate Grasslands, Savannas & Shrublands	Kazakh steppe	36	1.21	Cattle	Suslilks	29.64
la Campana	Mediterranean Forests, Woodlands and Scrubs	Chilean Matorral	13	1.23	Cattle	Rabbit	730.53
La Flor	Deserts & Xeric Shrublands	Chihuahuan desert	4	0.63	Cattle	Rabbit	65.83
Lac du Bois	Temperate Conifer Forests	Okanogan dry forests	29	2.42	Cattle	Deer	161.67

Lehwerane	Deserts & Xeric Shrublands	Kalahari xeric savanna	18	1.35	Cattle, Horse	Steenbok, Common Duiker, Red hartebeest, Hartebeest, Springbok, Spring hare, Gemsbok	79.90
Lichtenburg	Montane Grasslands & Shrublands	Highveld grasslands	37	2.17	Cattle	Springbok	NA
Lohondor	Temperate Broadleaf & Mixed Forests	Caspian Hyrcanian mixed forests	33	2.07	Sheep	NA	NA
London Farm	Tropical & Subtropical Grasslands, Savannas & Shrublands	Central bushveld	43	2.25	Cattle	Eland, Rabbit	NA
Los Pozos	Temperate Grasslands, Savannas & Shrublands	Patagonian steppe	37	2.20	Sheep	NA	56.30
Mara Experimental Farm	Tropical & Subtropical Grasslands, Savannas & Shrublands	Central bushveld	36	2.40	Cattle	NA	NA
Mata	Temperate Broadleaf & Mixed Forests	Pannonian mixed forests	23	1.42	Cattle	NA	104.15
Mhijra	Deserts & Xeric Shrublands	North Saharan Xeric Steppe and Woodland	13	1.16	Sheep	Camel	38.76
Monfrague	Mediterranean Forests, Woodlands & Scrub	Iberian sclerophyllous and semi-deciduous forests	7	1.17	Sheep	Red deer	312.50
Monsul	Mediterranean Forests, Woodlands & Scrub	Southeast Iberian shrubs and woodlands	22	1.58	Sheep, Goat	NA	31.73
Mostaza	Tropical & Subtropical Moist Broadleaf Forests	Eastern Cordillera Real montane forests	3	0.64	Cattle, Horse	NA	39.74
Muri	Deserts & Xeric Shrublands	Junggar Basin semi-desert	6	0.74	Sheep, Horse	NA	147.56
Nagyivan	Temperate Broadleaf & Mixed Forests	Pannonian mixed forests	19	1.12	Cattle	NA	52.74
Natab	Deserts & Xeric Shrublands	Namib Desert	1	0.00	Goat	Springbok	7.42
Needles	Deserts & Xeric Shrublands	Colorado Plateau shrublands	24	2.31	Cattle	Rabbit	17.48
Nyngan	Temperate Grasslands, Savannas & Shrublands	Southeast Australia temperate savanna	12	0.74	Cattle, Sheep	Kangaroo	57.20
Occidental	Temperate Grasslands, Savannas & Shrublands	Patagonian steppe	12	1.75	Sheep	Rabbit	85.18
Page	Deserts & Xeric Shrublands	Colorado Plateau shrublands	16	1.70	Cattle	Rabbit	178.49
Palestine	Mediterranean Forests, Woodlands & Scrub	Eastern Mediterranean conifer-broadleaf forests	17	0.95	Goat	NA	80.23
Parker	Deserts & Xeric Shrublands	Chihuahuan desert	11	1.20	Cattle	Rabbit, Deer	64.23
Pilcaniyeu	Temperate Grasslands, Savannas & Shrublands	Patagonian steppe	23	2.12	Horse, Sheep	Rabbit	87.58
Puerto de las Coberteras	Mediterranean Forests, Woodlands & Scrub	Iberian conifer forests	23	1.24	Sheep, Goat	NA	NA
Quebrada de Talca	Deserts & Xeric Shrublands	Chilean Matorral	10	1.25	Goat, Horse	Rabbit	302.40
Qysylschar	Deserts & Xeric Shrublands	Kazakh semi-desert	27	1.56	Horse	Suslilks	36.54

Rio Colorado	Temperate Grasslands, Savannas & Shrublands	Espinal	29	2.20	Cattle	Cavy, Rabbit	250.98
Rumuruti	Tropical & Subtropical Grasslands, Savannas & Shrublands	Northern Acacia-Commiphora bushlands and thickets	52	2.31	Sheep	Rabbit	2.42
Sair	Deserts & Xeric Shrublands	Eastern Gobi desert steppe	6	0.55	Sheep	Rabbit, Camel	34.62
San Martin	Mediterranean Forests, Woodlands & Scrub	Iberian sclerophyllous and semi-deciduous forests	10	1.22	Goat	Roe Deer, Red deer, Rabbit	80.12
San Nicolas	Tropical & Subtropical Grasslands, Savannas & Shrublands	Dry Chaco	33	2.61	Cattle, Horse	NA	14.83
San Ramon	Temperate Grasslands, Savannas & Shrublands	Patagonian steppe	22	1.33	Horse, Sheep, Cattle	Guanaco	938.35
Sandveld	Deserts & Xeric Shrublands	Kalahari xeric savanna	48	2.67	Cattle	Common Duiker, Warthog, Greater kudu, Spring hare	4.09
Sayeret Shaked	Deserts & Xeric Shrublands	Mesopotamian shrub desert	6	0.80	Sheep	NA	21.00
Shand	Deserts & Xeric Shrublands	Eastern Gobi desert steppe	12	1.02	Sheep	Camel, Rabbit	34.35
Subandine	Temperate Grasslands, Savannas & Shrublands	Patagonian steppe	30	1.51	Sheep	Rabbit	145.28
Syferkuil	Tropical & Subtropical Grasslands, Savannas & Shrublands	Central bushveld	47	2.43	Cattle	NA	NA
Talap	Deserts & Xeric Shrublands	Kazakh semi-desert	12	0.85	Horse	Suslilks	40.55
Tamou	Tropical & Subtropical Grasslands, Savannas & Shrublands	West Sudanian savanna	5	0.59	Sheep	Camel	30.27
Tierberg	Deserts & Xeric Shrublands	Nama Karoo shrublands	27	2.14	Sheep	Common Duiker	242.00
Valcheta	Temperate Grasslands, Savannas & Shrublands	Low Monte	20	1.99	Cattle	Rabbit	219.97
Verdelecho	Mediterranean Forests, Woodlands & Scrub	Iberian sclerophyllous and semi-deciduous forests	9	1.22	Goat, Sheep	Rabbit	27.99
Viljoenskroon	Deserts & Xeric Shrublands	Kalahari xeric savanna	10	1.35	Sheep	Lepus saxatilis, Pedetes capensis, Hystrix africaeaustralis	78.47
Wheatlands	Deserts & Xeric Shrublands	Nama Karoo shrublands	39	2.51	Goat	Common Duiker	211.08
Wuxing	Montane Grasslands & Shrublands	Ordos Plateau steppe	10	1.65	Sheep	NA	181.56
Xasape	Deserts & Xeric Shrublands	Kalahari xeric savanna	28	1.99	Cattle	Hartebeest, Common duiker, Spring hare, Steenbok, Red hartebeest	21.24
Yuyang	Montane Grasslands & Shrublands	Ordos Plateau steppe	7	0.80	Sheep	NA	88.21
Zapotillo	Tropical & Subtropical Dry Broadleaf Forests	Tumbes-Piura dry forests	8	0.70	Goat	NA	346.60

Zaragoza Arido	Mediterranean Forests, Woodlands & Scrub	Iberian sclerophyllous and semi-deciduous forests	23	2.42	Sheep	Rabbit	46.78
Zaragoza semiarido	Mediterranean Forests, Woodlands & Scrub	Iberian sclerophyllous and semi-deciduous forests	26	2.49	Sheep	NA	17.83

Table S3. Sites surveyed that experienced fire during the 2000-2019 period. Latitude and Longitude values correspond to the WGS84 Datum.

Site	Grazing	Latitude	Longitude
CSBB	Low	-23.65176	138.41831
CSBB	Ungrazed	-23.68172	138.43543
Lehwerane	Low	-25.60113	22.26667
Lehwerane	Ungrazed	-25.55868	22.24379
Xasape	High	-24.25235	21.86032
Xasape	Medium	-24.264	21.86169
Xasape	Low	-24.29197	21.85908
Xasape	Ungrazed	-24.35892	21.86228
Qysylschar	Medium	48.41341	69.57324
Qysylschar	Low	48.42521	69.58788
Rumuruti	Medium	0.21658	36.58256
Rumuruti	Low	0.21792	36.58769
Tsamsvlei	Low	-24.32231	15.75855
Syferkuil	Ungrazed	-23.82898	29.68705
Lichtenburg	High	-26.08351	26.21385
Lichtenburg	Medium	-26.08095	26.21334
Lichtenburg	Low	-26.07894	26.21026
Lichtenburg	Ungrazed	-26.07565	26.20792
Mara Experimental Farm	High	-23.14474	29.56172
Mara Experimental Farm	Medium	-23.14224	29.56416
Mara Experimental Farm	Low	-23.13721	29.56275
Mara Experimental Farm	Ungrazed	-23.14033	29.61382
Parker	High	31.7861	-110.82958
Parker	Medium	31.78614	-110.82741
Parker	Ungrazed	31.78635	-110.82431

Table S4. Models for significant quantitative predictors in linear mixed models of relative woody, tree, and shrub cover. MAP: mean annual precipitation (mm); PCV: precipitation seasonality estimated with intra annual coefficient of variation (% CV); MAT: mean annual temperature (°C); WHC: water holding capacity. Levels of WHC represent mean (26.93 %), low (-1 unit of standard deviation from mean, 18.76%) and high (+1 unit of standard deviation from mean, 35.11%) values.

Response variable	Predictor 1	Predictor 2 (interactions)	Equation
Relative woody cover	**MAP**	Low WHC	RWC = 0.34 + 0.0006 * MAP (mm)
		Mean WHC	RWC = 0.52 + 0.00012 * MAP (mm)
		High WHC	RWC = 0.7 - 0.00037 * MAP (mm)
	PCV	RWC = 0.37 + 0.002 * PCV (% CV)	
Relative tree cover	**MAP**	RTC = 0.05 + 0.00041 * MAP (mm)	
	MAT	RTC = -0.18 + 0.05 * MAT (°C) - 0.002 * MAT (°C)^2	
	PCV	RTC = 0.04 + 0.0021 * PCV (% CV)	
Relative shrub cover	**MAP**	Low WHC	RSC = 0.25 + 0.00029 * MAP (mm)
		Mean WHC	RSC = 0.46 - 0.00027 * MAP (mm)
		High WHC	RSC = 0.67 - 0.00083 * MAP (mm)
	Longitude	RSC = 0.35 - 0.09 * cos(Longitude)	

Table S5. Parameter estimates for the standard deviation of the random effects.

Model	Parameter	Estimate	Lower CI	Upper CI
Relative woody cover	sd(Intercept)	0.25	0.21	0.3
Relative tree cover		0.13	0.12	0.15
Relative shrub cover		0.19	0.17	0.21

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