Supporting Information

Droughts preceding tree mortality events have increased in duration and intensity, especially in dry biomes

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Figures

Tables

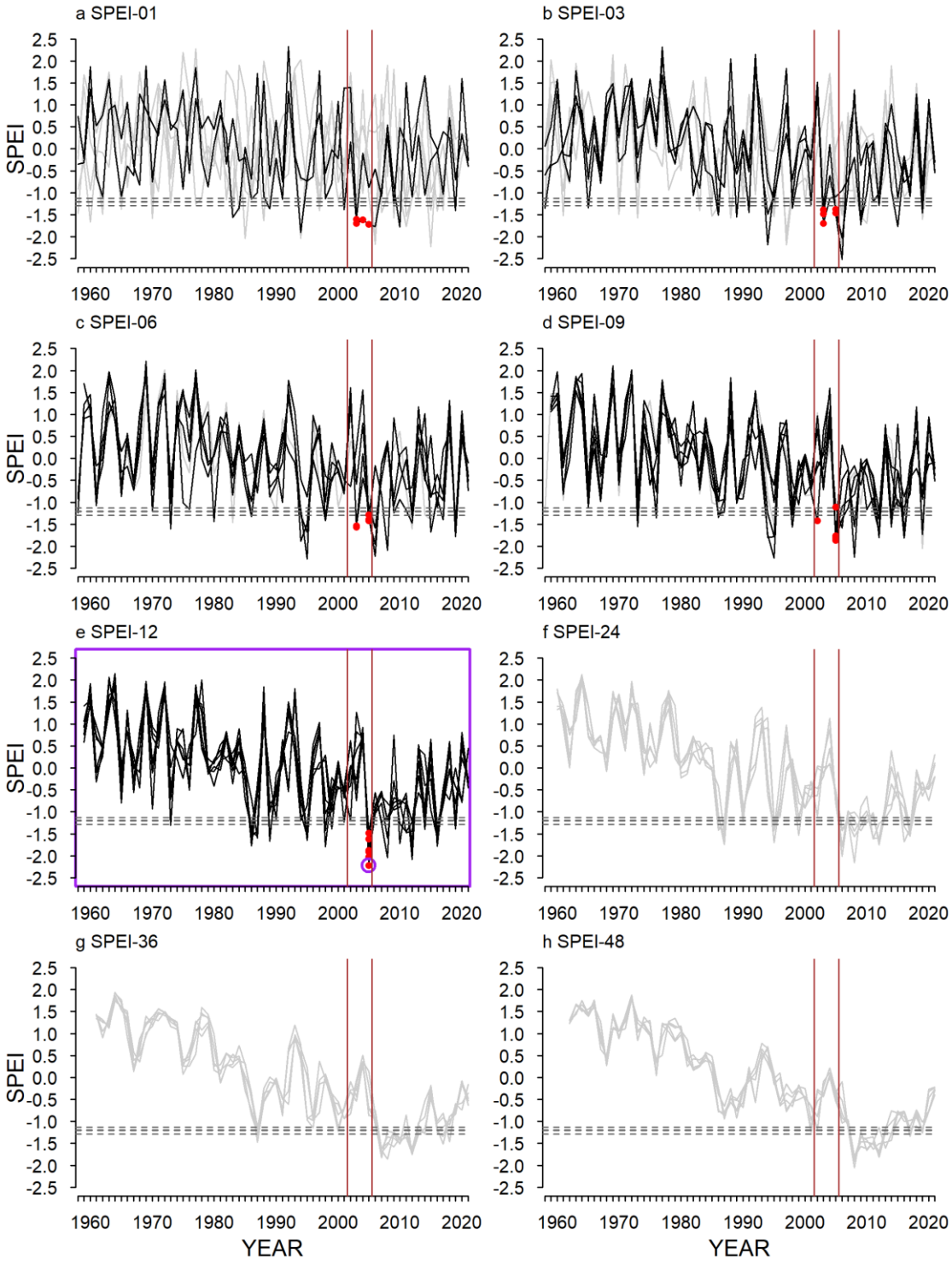

Figure S1. Graphical illustration of how the duration, intensity and completeness of extreme droughts preceding tree mortality was characterized. We classified extreme droughts preceding the onset of tree mortality based on the Standardized Evapotranspiration Precipitation Index (hereafter SPEI). For each temporal scale (i.e., 1, 3, 6, 9, 12, 24, 36, or 48 months – Panels "a" – "h") and month we defined as extreme drought events those that had an SPEI below or equal to the 10% lowest values (dashed grey horizontal lines in the figure) for the entire series

(1958–2021; grey and black lines in the figure) during the onset of tree mortality (red dots in the figure). In the selected example, Mortality occurred in the year 2005 (red lines delimit the period 2001-2005). SPEI values below or equal to the 10% lowest values were observed at the 1, 3, 6, 9 and 12 month scales. Note that these values only observed in some months (black lines in the figure) while in others (grey lines) values were above the selected threshold (dashed horizontal line). The minimum SPEI value (purple circle) among those selected (red circles) was observed at the 12-month scale which was also the longest scale (purple box). The completeness was calculated as the percentage of situations in which the SPEI was below the threshold (i.e. number of red dots) across months and scales.

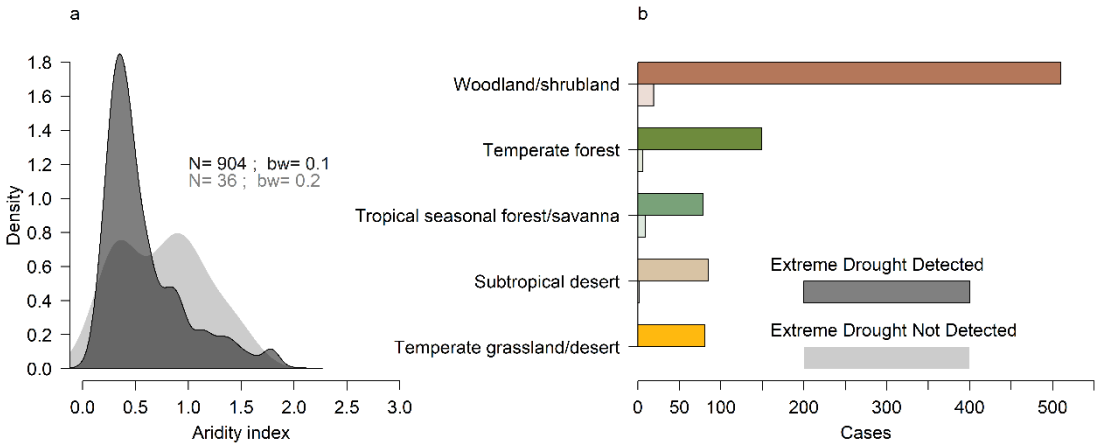

Figure S2. Drought-induced tree mortality events studied and their distribution along the aridity gradient and across biomes. Extreme droughts preceding mortality episodes were detected in 904 out of the 940 sites considered. Overall, sites in which extreme droughts were not detected (36; grey shading in Panels a) were: i) less arid (Panel "a") although differences were not significant; ii) sparsely distributed across biomes (Panel "b") but more prevalent in tropical seasonal forest / savanna. Different colors are used for each biome in panel "b". In panel "a", the number of cases (N) in which drought events were detected (black) and no detected (grey) are shown together with the bandwidth (bw) for the kernel estimation. In panel b, darker bars indicate sites in which extreme droughts and mortality events were detected.

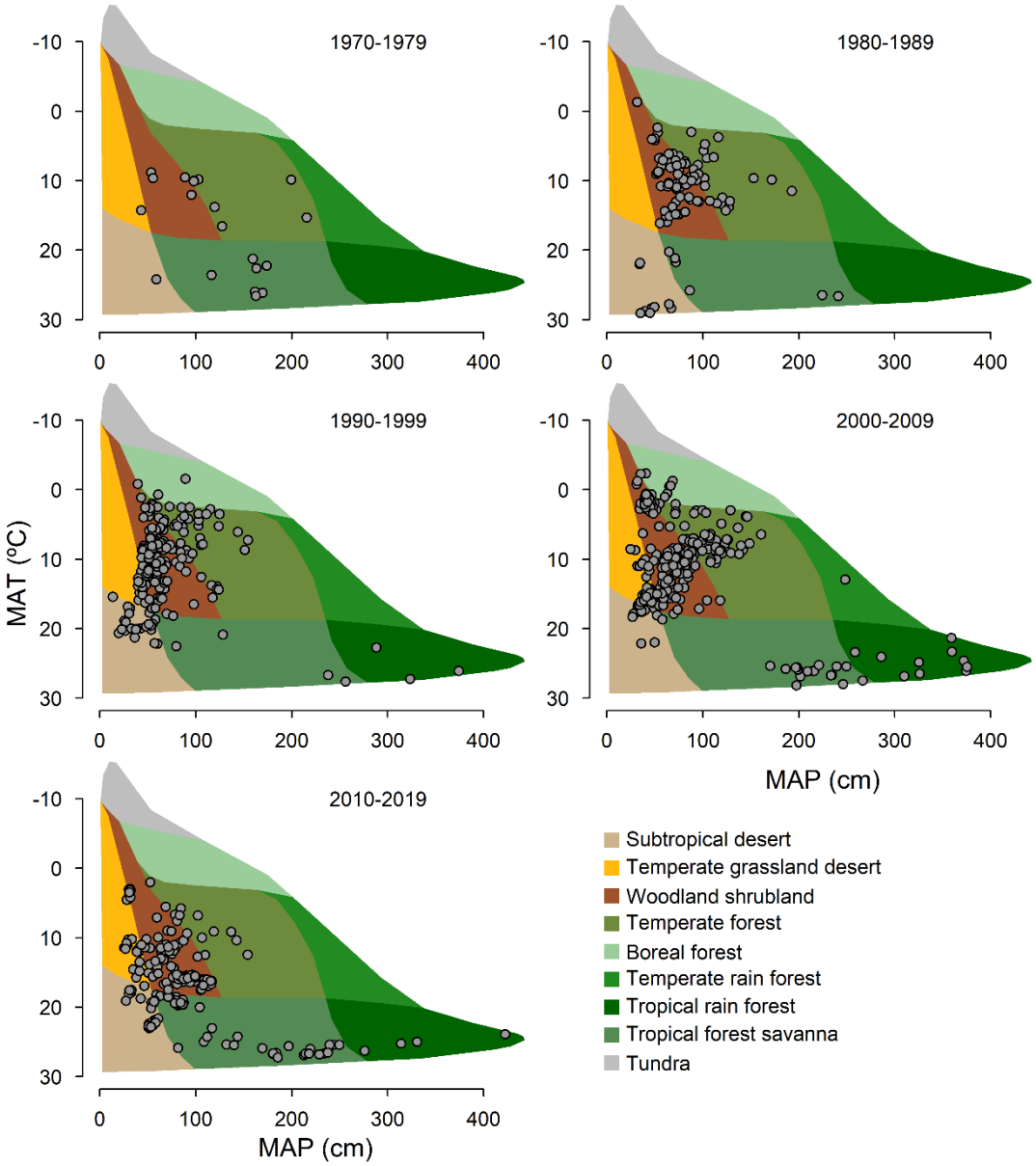

Figure S3. Distribution of drought-induced tree mortality events across biomes and along decades. Each point represents a study site classified depending on the biome type (color of polygons) and on the decade they belong to (graph).

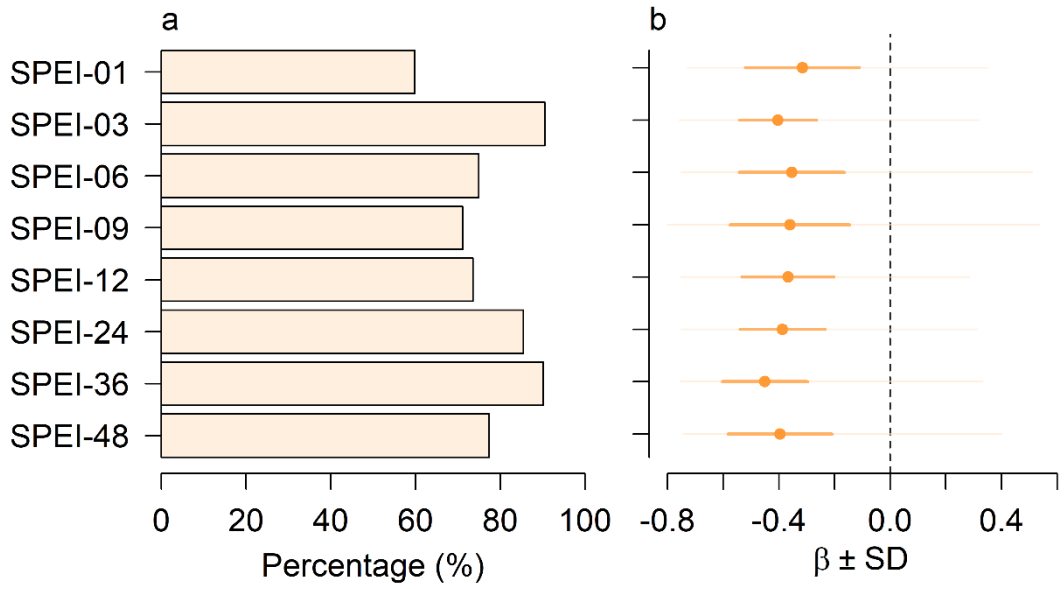

Figure S4. Relationship between SPEI at varying temporal scales and growing-season vapor pressure deficit (VPD). For each site, a linear regression between the SPEI at varying temporal scales (1, 3, 6, 9, 12, 24, 36, and 48 months) and the VPD of the growing season for the period 1958-2021 was done. The percentage of sites showing a significant negative relationship (i.e. low SPEI and high VPD) is shown (Panel "a"), along with the average regression slope (dot) ± its standard deviation (dark segment) and the minimum and maximum values observed (Panel "b"). Negative relationships between SPEI and VPD were significant ($P < 0.05$) in more than 75% of the sites on average indicating a prevalence of hotter droughts.

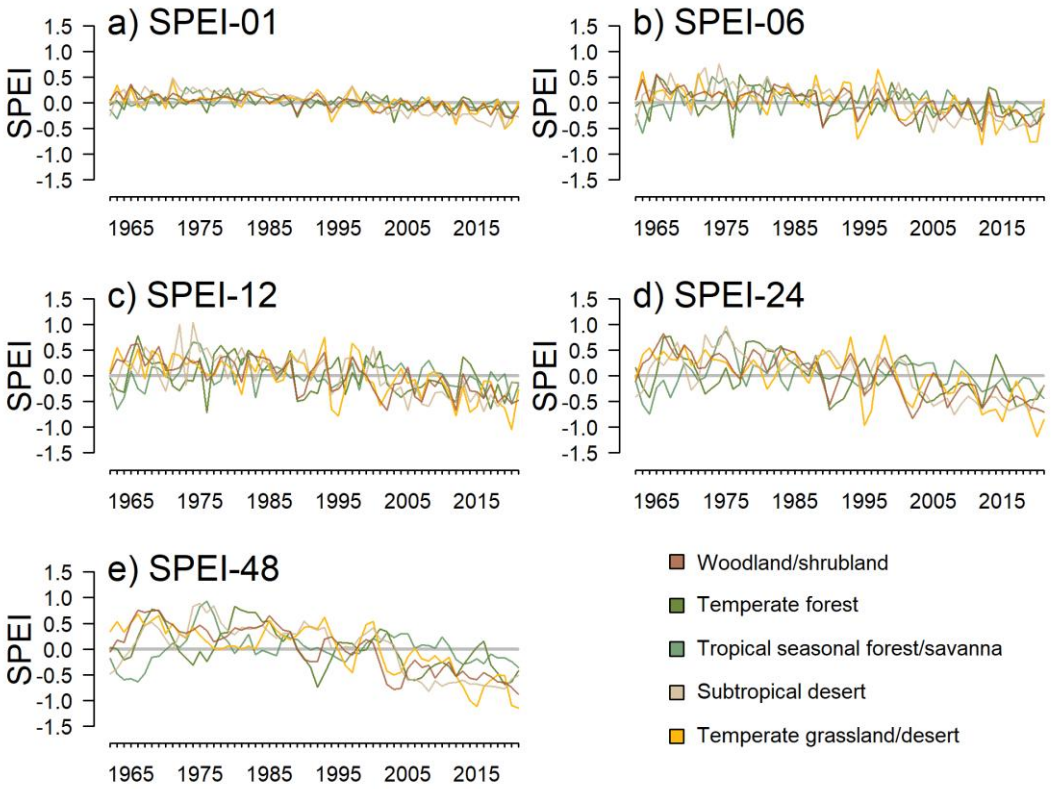

Figure S5. Variation in the SPEI across temporal scales, years and biomes. The mean for the average SPEI of the year is shown across SPEI temporal scales: a) 1 month, b) 6 months, c) 12 months, d) 24 months and e) 48 months. Different colors are used for each biome.

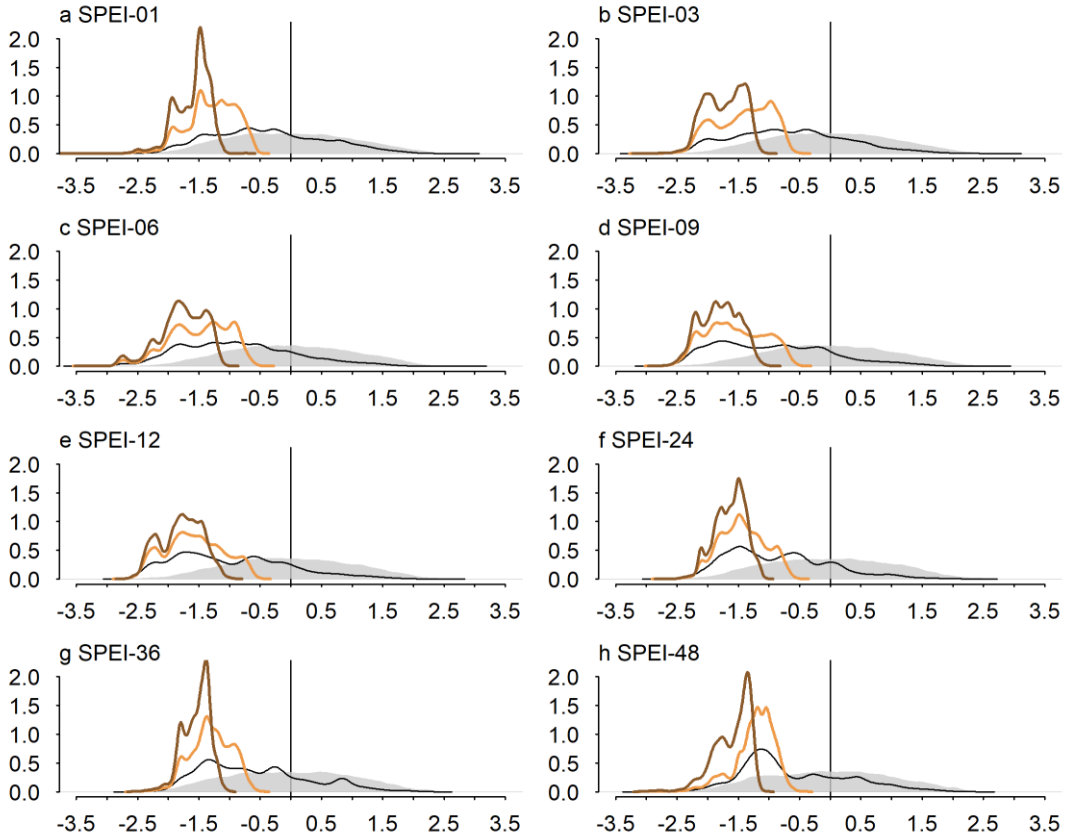

Figure S6. The SPEI in each site across years (grey area), in the year when mortality events started (black line), and in those sites in which it was selected as an extreme value (10 and 25 % percentile light brown and dark brown lines, respectively) is shown across different temporal scales: a) 1 month, b) 3 months, c) 6 months, d) 9 months, e) 12 months, f) 24 months, g) 36 months, h) 48 months. A vertical line indicates the zero SPEI value.

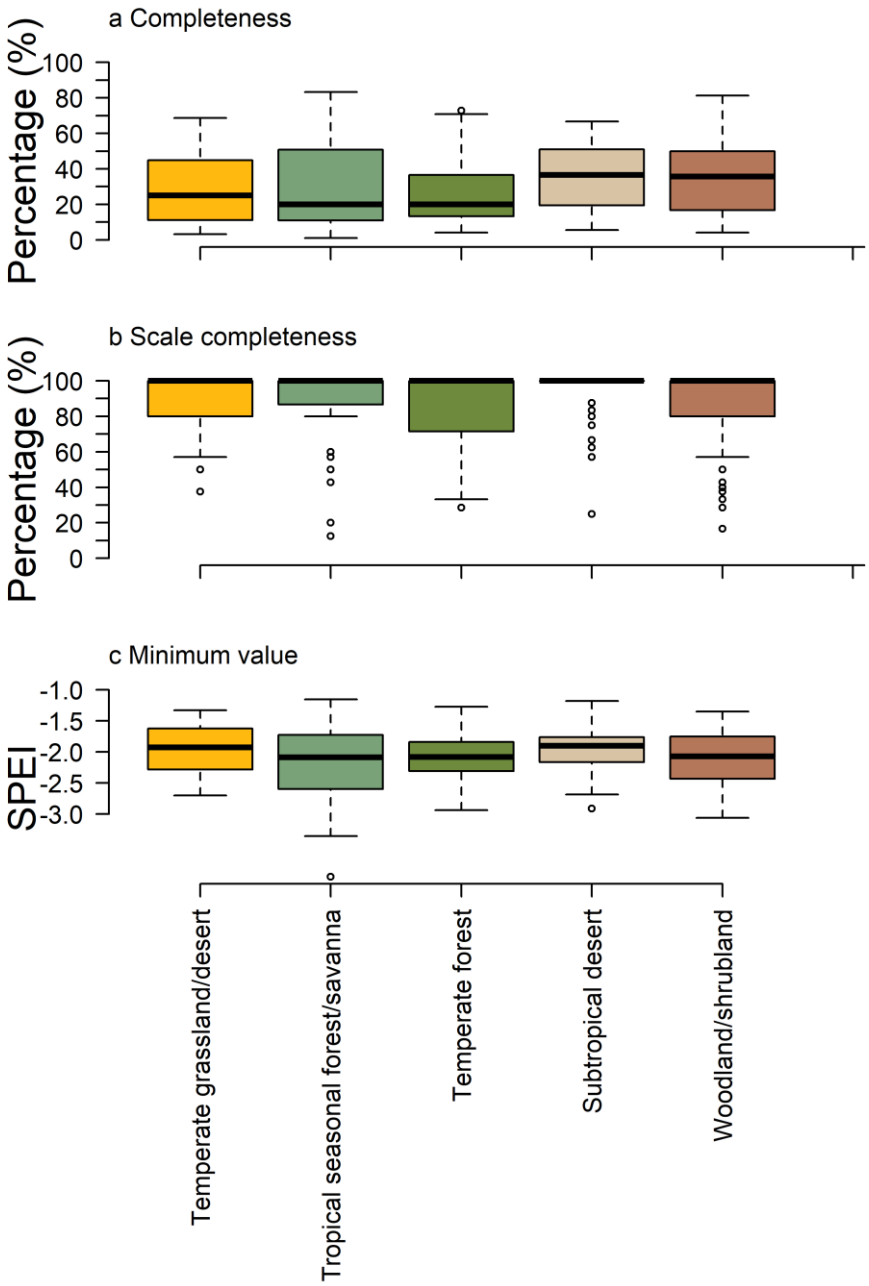

Figure S7. Variation in drought characteristics across biomes. In Panel "a" the differences in the number of months within the growing season of the drought showing extraordinarily low values (completeness) and temporal scales (Panel "b"; scale completeness) are shown in the box plots as well as the variation in the minimum SPEI value observed in the four years before the mortality event (Panel "c"). Different colors are used for each biome. Boxplots represents the distance between the 1st and the 3rd quartile, the solid line represents the Median, the whiskers indicate 1.5 interquartile range (IQR) and points represents values outside of the 1.5 IQR.

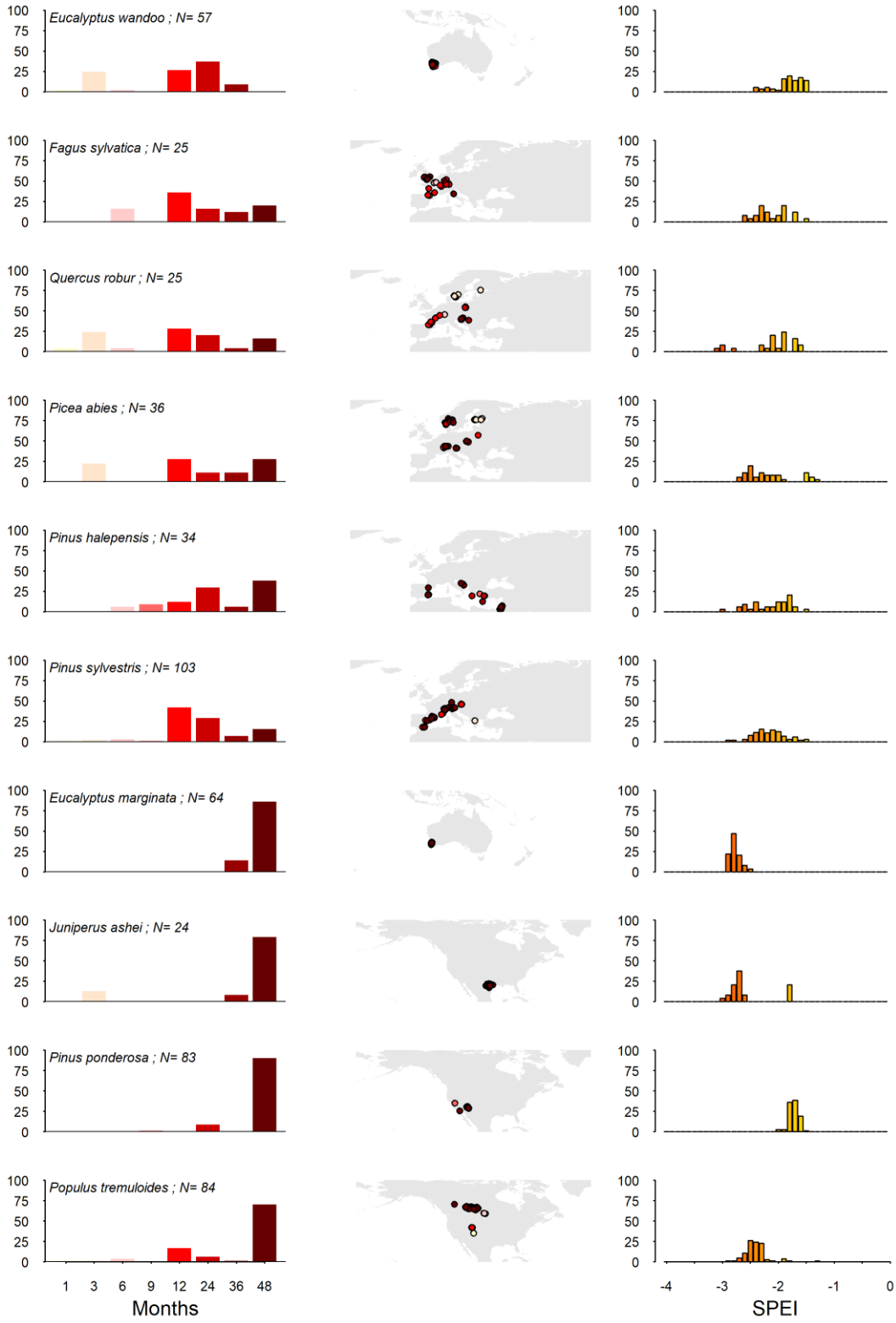

Figure S8. Variation in drought duration and intensity across tree species. For the 10 most represented tree species in the mortality database, the first histogram shows the longest SPEI scale within the 10% decile in the four years before mortality (-1 to -4). The map shows the sites in which mortality events were found and the second column of histograms shows the minimum SPEI values found in each site.

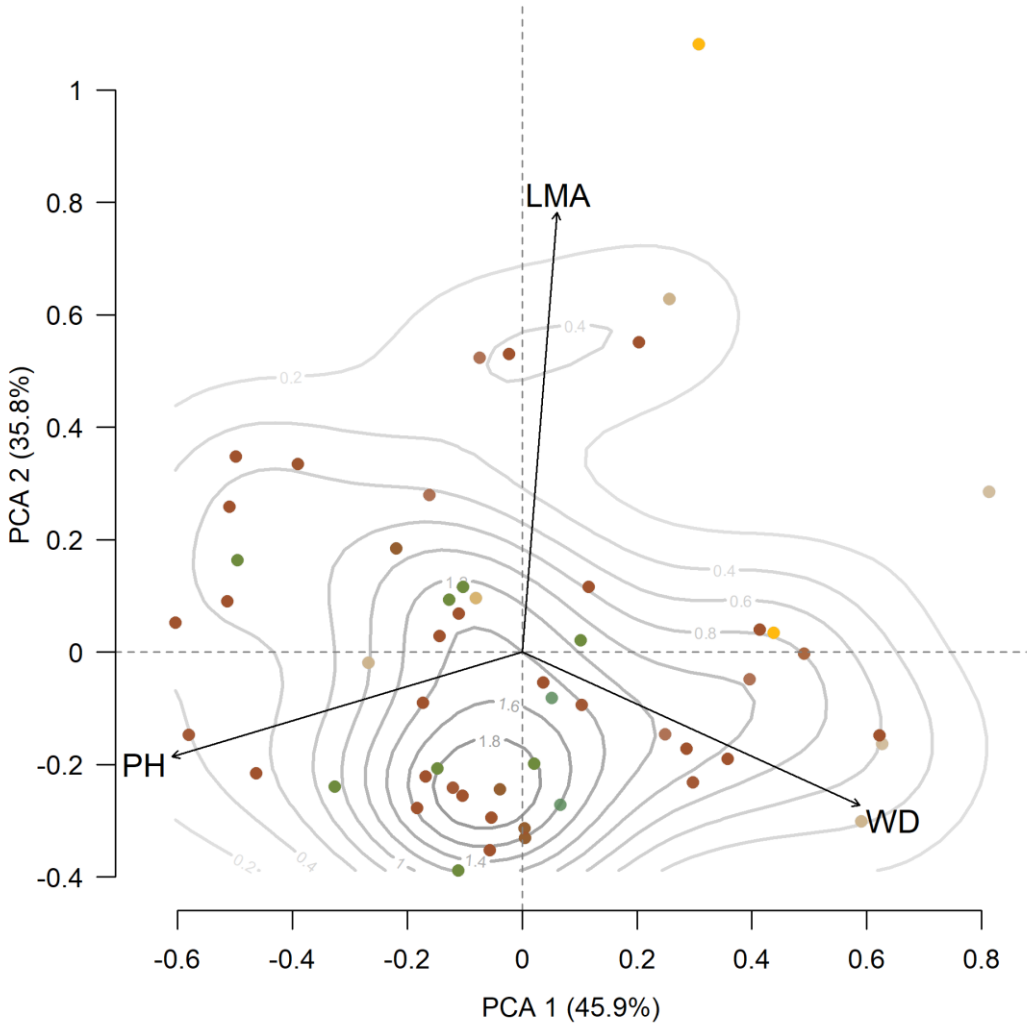

Figure S9. Ordination of sites according to the values of the functional traits of the tree species. The first two axes of the PCA (PCA 1 and PCA 2) represent the scores of mortality sites according to species' values of wood density (WD), leaf mass area (LMA) and maximum tree height (H). The percentage of variance explained by each axis is indicated.

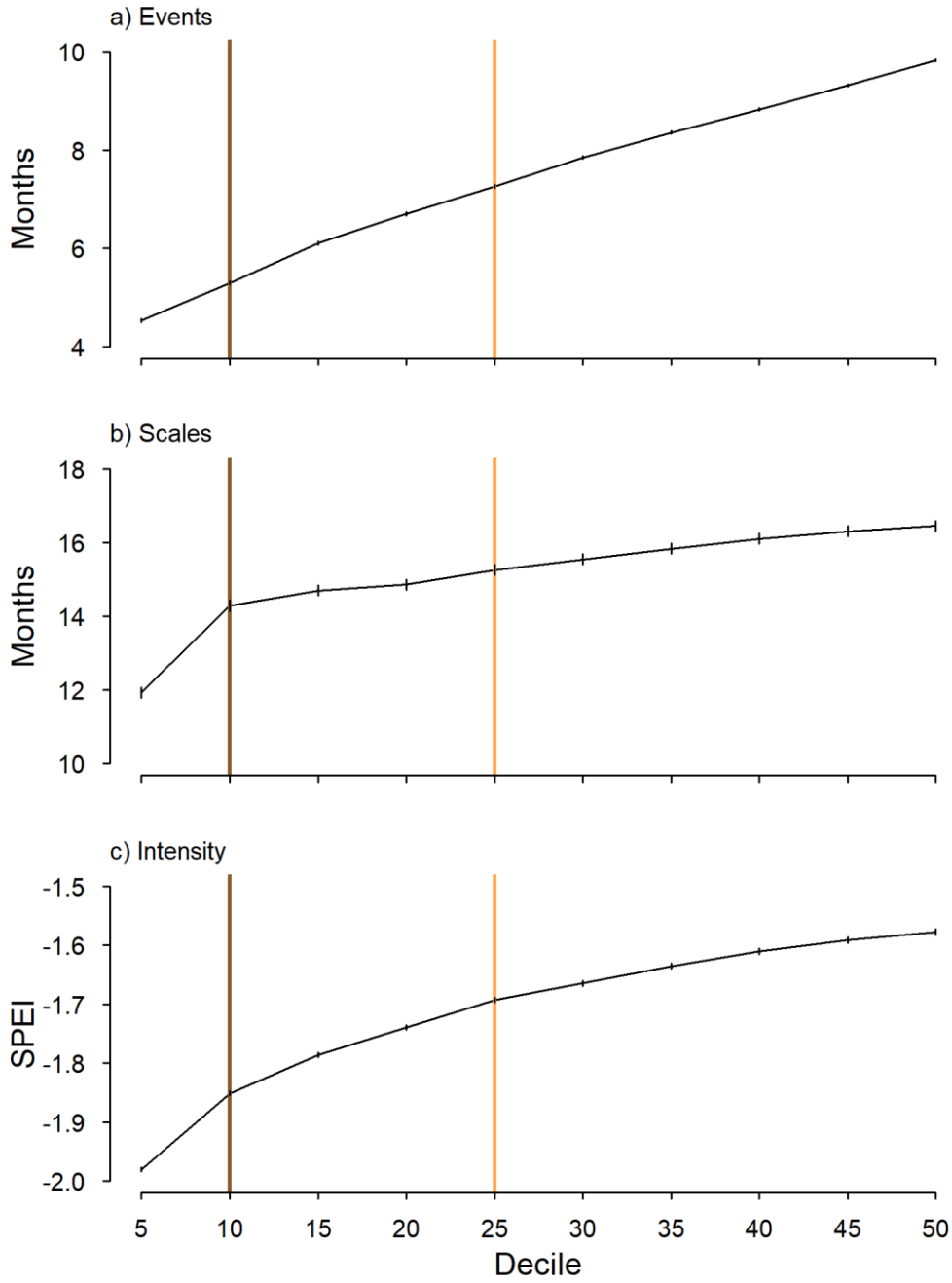

Figure S10. Variation in extreme events with the variation in the threshold, the number of extreme droughts considered (Panel "a"), the average duration in months (Panel "b") and the minimum value of the SPEI (Panel "c") changes as the value of the percentile chosen to define extreme droughts change. The vertical lines indicate the 10 and 25 percentiles, respectively. Lines represent the cases and the vertical segments the standard error for each percentile (from 5 to 50).

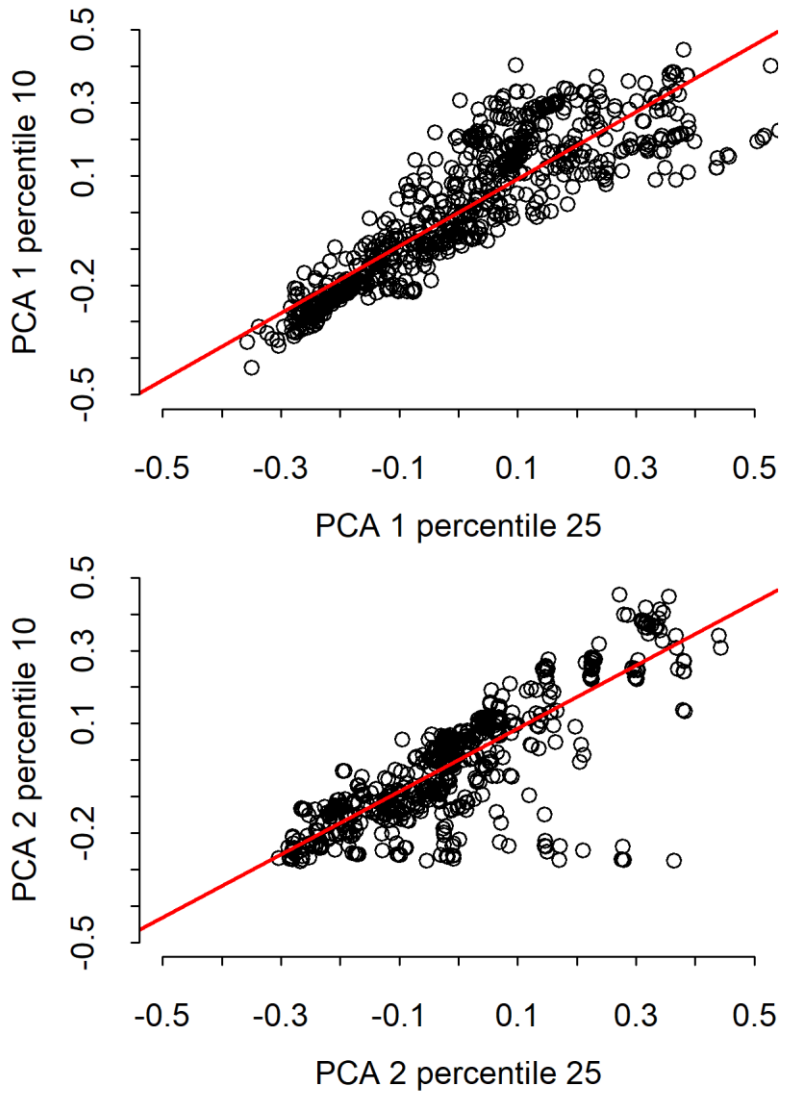

Figure S11. Influence of threshold on the ordination of drought characteristics. The relationship between the ordination of drought characteristics (duration, intensity, completeness, scale completeness and scale minimum value) is shown using the 10 and the 25% percentiles. The first (PCA 1) and the second (PCA 2) axes show a correlation of 0.877 (degrees of freedom = 730, P < 2.200*10-16) and 0.818 (degrees of freedom = 730, P < 2.200*10-16), respectively. Thus, general patterns are maintained.

Table S1. Differences in drought duration (longest scale), completeness (values which are considered in the 10% decile), SPEI minimum value, scale at which the minimum value is reached and scale completeness (scales which are considered in the 10% decile) across biomes according to the Dunnett's modified Tukey-Kramer Pairwise Multiple Comparison Test (two-sided test with *P-value* corrected for multiple comparisons). Lower and upper confidence intervals (CI) are also shown. Significant values (i.e. when the CI do not contain zero) are show in bold characters.

Comparison	Longest scale			Completeness		
	Diff	Lower CI	Upper CI	Diff	Lower CI	Upper CI
Temperate forest vs. Subtropical desert	-0.14	-0.28	0.00	**-0.10**	**-0.17**	**-0.04**
Temperate grassland/desert vs. Subtropical desert	-0.10	-0.25	0.05	-0.07	-0.15	0.01
Tropical seasonal forest/savanna vs. Subtropical desert	-0.18	-0.35	0.00	-0.06	-0.15	0.03
Woodland/shrubland vs. Subtropical desert	0.07	-0.04	0.18	-0.01	-0.07	0.05
Temperate grassland/desert vs. Temperate forest	0.04	-0.10	0.18	0.03	-0.04	0.10
Tropical seasonal forest/savanna vs. Temperate forest	-0.04	-0.20	0.13	0.04	-0.04	0.13
Woodland/shrubland vs. Temperate forest	**0.21**	**0.11**	**0.31**	**0.09**	**0.05**	**0.13**
Tropical seasonal forest/savanna vs. Temperate forest	-0.08	-0.26	0.09	0.01	-0.08	0.11
Woodland/shrubland vs. Temperate grassland/desert	**0.17**	**0.05**	**0.28**	**0.06**	**0.00**	**0.12**
Woodland/shrubland vs. Tropical seasonal forest/savanna	**0.25**	**0.10**	**0.39**	0.04	-0.03	0.12

Comparison	SPEI Minimum value			Scale minimum value		
	Diff	Lower CI	Upper CI	Diff	Lower CI	Upper CI
Temperate forest vs. Subtropical desert	-0.12	-0.25	0.01	-0.03	-0.16	0.11
Temperate grassland/desert vs. Subtropical desert	-0.01	-0.16	0.15	-0.11	-0.26	0.04
Tropical seasonal forest/savanna vs. Subtropical desert	-0.20	-0.39	0.00	**-0.18**	**-0.32**	**-0.04**
Woodland/shrubland vs. Subtropical desert	**-0.16**	**-0.28**	**-0.04**	**0.10**	**0.00**	**0.20**
Temperate grassland/desert vs. Temperate forest	0.11	-0.03	0.26	-0.08	-0.23	0.07
Tropical seasonal forest/savanna vs. Temperate forest	-0.08	-0.26	0.11	**-0.15**	**-0.30**	**-0.01**
Woodland/shrubland vs. Temperate forest	-0.04	-0.14	0.06	**0.13**	**0.02**	**0.24**
Tropical seasonal forest/savanna vs. Temperate forest	-0.19	-0.39	0.01	-0.07	-0.23	0.09
Woodland/shrubland vs. Temperate grassland/desert	**-0.15**	**-0.28**	**-0.03**	**0.21**	**0.08**	**0.34**
Woodland/shrubland vs. Tropical seasonal forest/savanna	0.04	-0.14	0.21	**0.28**	**0.16**	**0.40**

Comparison	Scale completeness		
	Diff	Lower CI	Upper CI
Temperate forest vs. Subtropical desert	**-0.08**	**-0.14**	**-0.02**
Temperate grassland/desert vs. Subtropical desert	-0.04	-0.10	0.02
Tropical seasonal forest/savanna vs. Subtropical desert	-0.05	-0.13	0.03
Woodland/shrubland vs. Subtropical desert	**-0.08**	**-0.12**	**-0.03**
Temperate grassland/desert vs. Temperate forest	0.04	-0.03	0.10
Tropical seasonal forest/savanna vs. Temperate forest	0.03	-0.06	0.11
Woodland/shrubland vs. Temperate forest	0.00	-0.05	0.06
Tropical seasonal forest/savanna vs. Temperate forest	-0.01	-0.09	0.08
Woodland/shrubland vs. Temperate grassland/desert	-0.03	-0.09	0.02
Woodland/shrubland vs. Tropical seasonal forest/savanna	-0.03	-0.10	0.05

Table S2. Correlations (Pearson correlation test; two-sided) between the centroid of droughts and trait values (n = 53). Significant values are shown in bold. Abbreviations: WD, wood density; LMA, leaf mass per area. Drought characteristics are: the longest SPEI (longest SPEI retained as a 10% lower percentile); minimum SPEI (minimum SPEI value and the moment at which it was detected); SPEI minimum scale (the selected scale at which the minimum value was detected); completeness (potential events detected within the longest duration of the drought, up to 48 months) and scales (potential scales detected within the longest scale; up to 48 months).

Drought characteristics	Axis 1	*P*	Axis 2	*P*	WD	*P*	LMA	*P*	Plant height	*P*
Longest SPEI	0.185	0.184	0.190	0.172	0.077	0.584	0.191	0.170	-0.209	0.132
Minimum SPEI	-0.128	0.362	-0.170	0.225	-0.161	0.250	-0.240	0.084	0.030	0.831
SPEI minimum scale	-0.238	0.086	0.076	0.587	-0.104	0.459	0.121	0.388	**0.301**	0.028
Completeness	0.149	0.286	0.035	0.801	0.154	0.272	0.072	0.606	-0.088	0.529
Scales	0.122	0.386	-0.049	0.727	0.186	0.181	0.005	0.970	-0.018	0.897
PCA 1	-0.195	0.162	-0.087	0.537	-0.204	0.143	-0.143	0.307	0.108	0.443
PCA 2	-0.018	0.896	-0.173	0.216	0.020	0.887	-0.180	0.197	0.032	0.823

Table S3. Models (Generalized Least Square Models, GLS) of the relationships between drought conditions (Figure 5) and the trait values, aridity index (AI) and mortality year (mortality begin). The models accounted for 26% and 21% of the variation of the variation in the first (PCA 1) and second (PCA 2) PCA axes, without spatial structure and 68 % and 61 % of the variation in the first (PCA 1) and second (PCA 2) PCA axis with spatial structure. Bold values are significant ($P < 0.05$) regression coefficients according to the GLS

Axis 1	Factors	Value	Std. Error	*t*	*P*
No Spatial	Intercept	0.012	0.007	1.691	0.091
	AI	-0.006	0.007	-0.767	0.443
	mortality begin	**-0.106**	**0.007**	**-14.804**	**0.000**
	PCA 1	–	–	–	–
	PCA 2	**0.052**	**0.007**	**7.288**	**0.000**
	AI : mortality begin	**0.031**	**0.006**	**4.860**	**0.000**
Spatial	Intercept	0.012	0.020	0.637	0.524
	AI	0.005	0.012	0.432	0.666
	mortality begin	**-0.061**	**0.009**	**-7.221**	**0.000**
	PCA1	**0.024**	**0.009**	**2.648**	**0.008**
	PCA2	–	–	–	–
	AI : mortality begin	**0.015**	**0.007**	**2.165**	**0.031**
Axis 2					
No Spatial	Intercept	-0.010	0.006	-1.675	0.094
	AI	**0.015**	**0.007**	**2.323**	**0.020**
	mortality begin	**-0.027**	**0.006**	**-4.203**	**0.000**
	PCA 1	**0.066**	**0.006**	**10.342**	**0.000**
	PCA 2	**-0.018**	**0.006**	**-2.892**	**0.004**
	AI : mortality begin	**-0.022**	**0.006**	**-3.935**	**0.000**
Spatial	Intercept	**0.056**	**0.018**	**3.067**	**0.002**
	AI	–	–	–	–
	mortality begin	**-0.048**	**0.007**	**-6.907**	**0.000**
	PCA 1	0.011	0.008	1.488	0.137
	PCA 2	–	–	–	–
	AI : mortality begin	–	–	–	–