Supplementary document :

How does radial growth of water-stressed populations of European beech (*Fagus sylvatica* L.) trees vary under multiple drought events?

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Table S1. The comparisons of micro and macronutrient concentrations in soils between dry and less-dry plots.

Equal numbers of plots were selected from the dry and less-dry areas of Badenweiler, Schwäbische Alb, and Klettgau (N_{dry} = 9, $N_{less\text{-}dry}$ = 9, total N = 18) for soil chemical analysis. The soil samples were collected from Ah and B horizons. The data followed a Gaussian distribution (Shapiro-Wilk values not significant at p = 0.05 level). None of these elements differed significantly (p value > 0.05) between dry and less-dry plots when Student's t-test compared the concentrations with 1000 iterations (*d.f.* = degree of freedom).

Soil profiles	Nutrients	Dry plots		Less-dry plots		Test statistics		
		Mean concentrations (mg/l)	Standard error	Mean concentrations (mg/l)	Standard error	*t*-value	*d.f.*	*p* value
Ah Horizon	K	0.3359	0.0189	0.3323	0.0328	0.0961	16	0.9246
	Mg	0.2579	0.0195	0.2711	0.0226	-0.4418	16	0.6645
	Mn	0.0874	0.0291	0.0656	0.0163	0.6529	16	0.5231
	Na	0.0396	0.0027	0.0417	0.0035	-0.4988	16	0.6247
	Al	1.6484	0.1303	1.1724	0.2268	1.8196	16	0.0876
	Ca	10.0279	1.8540	9.8833	1.0705	0.0675	16	0.9470
	Fe	0.4881	0.0367	0.3547	0.0561	1.9897	16	0.0640
	P	0.0363	0.0045	0.0375	0.0070	-0.1413	16	0.8894
B Horizon	K	0.1974	0.0153	0.1587	0.0116	2.0179	16	0.0607
	Mg	0.1241	0.0263	0.1017	0.0172	0.7148	16	0.4850
	Mn	0.0096	0.0032	0.0058	0.0013	1.0816	16	0.2955
	Na	0.0378	0.0053	0.0305	0.0019	1.2950	16	0.2137
	Al	1.0980	0.2404	0.5585	0.1624	1.8597	16	0.0814
	Ca	10.2072	1.3545	8.3163	1.0374	1.1083	16	0.2841

	Fe	0.3120	0.0624	0.1855	0.0383	1.7273	16	0.1034
	P	0.0238	0.0054	0.0153	0.0044	0.9988	16	0.3328

Table S2. Monthly climatic variables of the study sites calculated from the climatic data collected from German [29] and Swiss [30] weather services, separately shown for the two climatic periods (1947-1979 and 1980-2011) as the climate become more extreme after the 1980s (see citations in the article).

CV: climatic variables, T: average monthly temperature in °C, P: average monthly total precipitation in mm, PET: average monthly total potential evapotranspiration in mm, P-PET: average monthly total precipitation minus potential evapotranspiration, BAD: Badenweiler, KLET: Klettgau, SBA: Schwäbische Alb.

		1947-1979												1980-2011											
CV	Study sites	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
T	BAD	0,2	1,2	4,8	8,4	12,5	15,7	17,8	17,0	14,2	9,2	4,4	1,1	0,9	1,7	5,4	8,8	13,2	16,4	18,5	18,2	14,2	9,8	4,7	2,1
	KLET	-1,8	-0,4	3,4	7,4	11,8	15,1	16,8	15,9	12,9	7,6	2,7	-0,7	-1,7	-0,4	3,8	7,8	12,3	15,4	17,3	16,9	12,9	8,1	2,4	-0,5
	SBA	-3,6	-2,6	0,8	4,6	8,9	12,1	13,9	13,1	10,2	5,3	0,7	-2,7	-3,1	-2,2	1,3	4,9	9,5	12,6	14,6	14,2	10,3	6,0	0,8	-2,0
P	BAD	66	65	64	85	100	112	92	115	76	61	87	68	62	57	67	77	105	101	97	96	91	94	76	85
	KLET	73	76	57	63	70	90	81	103	62	50	84	81	94	78	79	72	92	95	99	86	74	90	75	108
	SBA	50	51	49	63	86	110	87	95	57	46	61	48	44	42	55	65	102	97	103	80	64	69	53	62
PET	BAD	22	33	51	94	150	175	185	159	111	63	25	12	16	19	54	98	154	178	189	165	111	66	26	14
	KLET	11	18	40	86	144	171	181	154	106	56	18	6	24	10	43	90	149	173	183	159	106	59	18	6
	SBA	52	51	42	60	119	151	163	138	91	42	11	13	22	18	27	63	125	154	168	145	92	46	13	18
P-PET	BAD	44	31	13	-9	-50	-63	-93	-44	-35	-2	62	56	46	38	13	-21	-49	-77	-91	-68	-21	28	50	71
	KLET	61	58	17	-23	-74	-81	-100	-51	-44	-7	66	75	70	68	37	-18	-57	-78	-84	-73	-32	32	57	102
	SBA	-2	0	7	2	-33	-41	-76	-43	-34	4	50	35	22	23	28	1	-23	-57	-65	-65	-27	23	40	44

A1: Climatic parameters and drought indices

Climate data collection

The nearest climate stations were selected for the three locations (i.e., location 1: Badenweiler (stand-Innerberg); location 2: Schwäbische Alb (stand-Schönberg); and location 3: Klettgau (three stands-Kätzler, Steimüri, and Steinbruch). The weather stations were selected using the following criteria:

1) Weather station located within a 20 km radius of a stand,
2) Temperature data collected from the stations with the elevation closest to that of the study site, and
3) Precipitation data collected according to the orographic location (windward or leeward side) of the sites.

Based on these criteria, we chose three stations for Badenweiler (i.e., Müllheim, Malsburg-Marzell-Friedrichheim, and Eschbach), two stations for the Schwäbische Alb (i.e., Hechingen and Trochtelfingen), and two stations for Klettgau (i.e., Hallau and Schaffhausen) to collect all climatic parameters.

Temperature correction

For Badenweiler, the longest segment of temperature data was from the Müllheim climate station. Gaps were filled for Malsburg-Marzell-Friedrichheim and Eschbach climate station data using linear regression equations [*Temperature of Müllheim = 2.566 + 1.035 * Malsburg-Marzell-Friedrichheim* (R_2 = 0.94, $p < 0.001$) and *Temperature of Müllheim = (-0.331) + 0.991 * Eschbach* (R_2 = 0.98, $p < 0.001$)].

For the Schwäbische Alb, the longest segment of temperature data was from the Hechingen climate station. Gaps were filled for Trochtelfingen climate station data using a regression equation [*Temperature of Hechingen = 2.353 + 0.994 * Trochtelfingen* (R_2 = 0.97, $p < 0.001$)].

For Klettgau, the longest segment of temperature data was from the Hallau climate station. Gaps were filled for Schaffhausen climate station data using a regression equation [*Hallau = 0.066 + 0.999 * Schaffhausen* (R_2 = 0.99, $p < 0.001$)].

It was feasible to have a weather station at the identical elevation of the study sites. Therefore, to capture the real temperature values for the exact elevation point of a respective stand, we first developed a correction factor based on our data collected from different weather stations, which was then used to calculate the temperature for that stand. The calculations are presented in the following section.

Correction factors for different study locations

Location: Badenweiler

The Innerberg stand elevation was 517 m a.s.l.

Yearly temperature mean of Müllheim: 10.11 °C; yearly temperature mean of Malsburg-Marzell-Friedrichheim: 7.08 °C; difference: (10.11-7.08) = 3.03 °C.

Elevation of Müllheim: 409 m a.s.l.; elevation of Malsburg-Marzell-Friedrichheim: 852 m a.s.l.; difference: (852-409) = 443 m

Correction factor/meter: 3.03/443 = 0.00684

Elevation difference between the Müllheim weather station and the Innerberg stand: (517-409) = 108 m

Correction factor for Müllheim temperature values: (0.00684*108) = 0.739 (this value must be subtracted because Müllheim was at a lower elevation than Innerberg).

Elevation difference between Malsburg-Marzell-Friedrichheim and Innerberg: (852-517) = 335 m

Correction factor for Malsburg-Marzell-Friedrichheim temperature values: (0.00684*335) = 2.29 (this value required addition because Malsburg-Marzell-Friedrichheim was located at a higher elevation than Innerberg).

Elevation difference between Eschbach and Innerberg: (517-222.5) = 291.5 m

Correction factor for Müllheim temperature values: (0.00684*291.5) = 1.99 (with this value subtracted because Eschbach is located at a lower elevation than Innerberg).

Location: Schwäbische Alb

Elevation of Schönberg study area was 743 m a.s.l.

Yearly temperature mean of Hechingen: 8.465 °C; yearly temperature mean of Trochtelfingen: 5.91 °C; difference: (8.465-5.91) = 2.56 °C.

Elevation of Hechingen: 517 m a.s.l.; elevation of Trochtelfingen: 700 m a.s.l.; difference: (700-517) = 183 m

Correction factor/meter: 2.56/183 = 0.014

Elevation difference between Hechingen and Schönberg: (743-517) = 226 m

Correction factor for Hechingen temperature values: (0.014*226) = 3.164 (this value required subtraction because Hechingen is located at a lower elevation than Schönberg).

Elevation difference between Trochtelfingen and Schönberg: (743-700) = 43 m

Correction factor for Trochtelfingen temperature values: (0.014*43) = 0.602 (this value must be subtracted because Hechingen is located at a lower elevation than Schönberg).

Location: Klettgau (Kätzler, Steimüri and Steinbruch)

Elevation for Kätzler was 558 m a.s.l., for Steimüri, 570 m a.s.l., and for Steinbruch, 633 m a.s.l.

Yearly temperature mean of Hallau: 9.123 °C; yearly temperature mean of Scahffhausen: 8.939 °C; difference: (9.123-8.939) = 0.184 °C.

Elevation of Hallau: 419 m a.s.l; elevation of Schaffhausen: 438 m a.s.l.; difference: (438-419) = 19 m

Correction factor/meter: 0.184/19 = 0.01

Elevation difference between Hallau and Kätzler: (558-419) = 139 m

Correction factor for Hallau temperature values: (0.01*139) = 1.39 (this value must be subtracted because Hallau is at a lower elevation than Kätzler).

Elevation difference between Hallau and Steimüri: (570-419) = 151 m

Correction factor for Hallau temperature values: (0.01*151) = 1.51 (this value must be subtracted because Hallau is at a lower elevation than Steimüri).

Elevation difference between Hallau and Steinbruch: (633-419) = 214 m

Correction factor for Hallau temperature values: (0.01*214) = 2.14 (this value must be subtracted because Hallau is at a lower elevation than Steinbruch).

Table A1.1: Regression equations developed using a quadratic function for different climatic parameters, including mean temperature, total precipitation, total potential evapotranspiration (PET), and climatic drought index for the three study locations for annual and growing season periods (May-September) for 1947-2011. Significant relations are marked in bold letters under *p*-value.

Parameter	**Location**	**Equation**	R^2	***p*-value**
Annual temperature	Badenweiler	$y = 9.092 - 0.023x + 0.001x^2$	0.3	**0.000**
	Klettgau	$y = 7.924 - 0.042x + 0.001x^2$	0.3	**0.000**
	Schwäbische Alb	$y = 5.520 - 0.048x + 0.001x^2$	0.3	**0.000**
Growing season temperature	Badenweiler	$y = 15.659 - 0.021x + 0.001x^2$	0.1	**0.012**
	Klettgau	$y = 15.061 - 0.054x + 0.001x^2$	0.2	**0.001**
	Schwäbische Alb	$y = 12.296 - 0.062x + 0.001x^2$	0.3	**0.000**
Annual precipitation	Badenweiler	$y = 916.727 + 6.591x - 0.093x^2$	0.02	0.47
	Klettgau	$y = 678.783 + 16.998x - 0.190x^2$	0.3	**0.000**
	Schwäbische Alb	$y = 742.321 + 4.825x - 0.057x^2$	0.1	0.212
Growing season precipitation	Badenweiler	$y = 490.942 + 0.509x - 0.011x^2$	0.002	0.941
	Klettgau	$y = 348.770 + 4.172x - 0.042x^2$	0.10	**0.036**
	Schwäbische Alb	$y = 419.148 + 0.862x - 0.005x^2$	0.01	0.666
Annual PET	Badenweiler	$y = 1116.781 - 3.041x + 0.048x^2$	0.1	0.164
	Klettgau	$y = 1009.6 - 1.363x + 0.029x^2$	0.03	0.455
	Schwäbische Alb	$y = 995.71 - 5.025x - 0.057x^2$	0.03	0.371
Growing season PET	Badenweiler	$y = 784.56 - 0.527x + 0.015x^2$	0.2	**0.005**
	Klettgau	$y = 768.96 - 1.245x + 0.025x^2$	0.2	**0.001**
	Schwäbische Alb	$y = 685.3 - 2.202x + 0.041x^2$	0.3	**0.000**
Annual drought index (P-PET)	Badenweiler	$y = - 200.040 + 9.630x - 0.141x^2$	0.1	0.23
	Klettgau	$y = - 330.806 + 18.361x - 0.219x^2$	0.2	**0.001**
	Schwäbische Alb	$y = -253.386 + 9.850x - 0.114x^2$	0.1	0.12

Growing season drought index (P-PET)	Badenweiler	$y = -293.454 + 1.019x - 0.025x^2$	0.01	0.66
	Klettgau	$y = -420.190 + 5.418x - 0.066x^2$	0.1	0.08
	Schwäbische Alb	$y = -266.152 + 3.064x - 0.046x^2$	0.02	0.53

Table S3. The year-wise tabulation of heterogeneity (Q values) in short- and mid-term resistance, recovery, and resilience measured for the cumulative effect sizes.

A significant heterogeneity indicates a high variation of resistance, recovery, and resilience in trees within (i.e., dry vs. less-dry plots) and between the study sites. The statistical steps for the heterogeneity calculation (Q-statistics) were described in Saha *et al.* (2012) [52] (see citation in the article). Single * denoted $p < 0.1$, and ** denoted $p < 0.05$.

Year of drought	Short-term			Mid-term		
	Resistance	Recovery	Resilience	Resistance	Recovery	Resilience
1976	1.5535	2.0776	2.3377	1.4131	3.0758	5.4288*
1984	15.8910**	8.6481**	6.2167**	10.2291**	5.001*	11.1391**
1989	0.7081	0.8759	0.2896	1.7495	2.2155	0.2508
1992	5.3892*	0.5297	6.2353**	6.8541**	0.763	6.6596**
1998	1.009	0.7157	1.1255	2.9202	0.4944	3.4423
2003	2.5172	2.7243	5.9394**	0.0767	4.9718*	6.6694**