Patterns of drought tolerance in major European temperate forest trees: climatic drivers and variability

Supporting Information

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Table S1: Location and elevation for all sampling sites, and characteristics of tree-ring chronologies for the sampled species: mean segment length (MSL), expressed population signal (EPS), mean interseries correlation (Rbar), mean sensitivity (MS), and mean basal area increment (MBAI).

#	Site	Lat [°N]	Lon [°E]	Alt [m a.s.l.]	Species	MSL [a]	EPS	Rbar	MS	MBAI [mm^2]
1	QGHT	49.17	9.10	230	*P. abies*	76	0.89	0.45	0.29	2375
2					*A. alba*	80	0.96	0.70	0.31	1769
3					*F. sylvatica*	79	0.99	0.88	0.25	1883
4	HSBB	50.13	9.72	250	*F. sylvatica*	74	0.97	0.78	0.22	1208
5	HSKM	50.14	9.72	250	*F. sylvatica*	87	0.99	0.88	0.24	1833
6	ASHE	49.96	9.74	260	*F. sylvatica*	110	0.98	0.66	0.26	1002
7	HSLF	50.15	9.72	260	*P. abies*	99	0.87	0.40	0.26	1418
8					*F. sylvatica*	93	0.97	0.79	0.26	732
9	QGHK	49.19	9.33	285	*P. abies*	73	0.95	0.68	0.36	1146
10	QGHB	49.18	9.37	305	*P. abies*	76	0.94	0.62	0.29	1488
11					*A. alba*	78	0.95	0.68	0.33	1710
12					*F. sylvatica*	114	0.96	0.68	0.35	1333
13	QGHI	49.03	9.27	310	*P. abies*	45	0.86	0.43	0.30	1930
14					*A. alba*	65	0.95	0.66	0.29	2883
15					*F. sylvatica*	58	0.97	0.80	0.32	2518
16	RTAV	49.45	10.96	360	*P. abies*	97	0.94	0.61	0.33	1466
17					*A. alba*	91	0.94	0.60	0.30	1571
18					*F. sylvatica*	117	0.90	0.47	0.28	1074
19	BBOB	50.24	9.93	400	*P. abies*	65	0.89	0.48	0.28	1584
20					*A. alba*	88	0.95	0.68	0.26	915
21					*F. sylvatica*	75	0.99	0.92	0.23	912
22	RXHS	49.49	11.56	420	*P. abies*	67	0.97	0.76	0.28	3211
23					*A. alba*	95	0.91	0.51	0.27	1283
24	KNJB	49.73	10.27	430	*F. sylvatica*	123	0.91	0.51	0.28	2116
25	RTSL	49.31	10.37	440	*P. abies*	77	0.95	0.67	0.33	1597
26					*A. alba*	98	0.91	0.51	0.33	1417
27					*F. sylvatica*	87	0.98	0.81	0.27	1014
28	SNBS	49.57	12.05	440	*P. abies*	106	0.98	0.84	0.20	348
29	SNHS	49.57	12.05	440	*P. abies*	75	0.94	0.60	0.25	1771
30					*A. alba*	100	0.98	0.86	0.29	977
31	SNMG	49.63	11.59	440	*P. abies*	60	0.94	0.65	0.26	2289
32					*F. sylvatica*	89	0.97	0.79	0.21	1348
33	ALWB	49.14	11.04	460	*P. abies*	75	0.94	0.61	0.25	1742
34					*A. alba*	142	0.97	0.77	0.32	978
35					*F. sylvatica*	144	0.97	0.79	0.26	495
36	BTHK	49.94	11.32	460	*P. abies*	91	0.92	0.54	0.23	1847
37					*A. alba*	100	0.96	0.71	0.27	1294
38					*F. sylvatica*	101	0.99	0.90	0.20	704
39	KHKF	48.84	11.91	470	*P. abies*	68	0.95	0.65	0.26	1269
40					*F. sylvatica*	78	0.97	0.74	0.27	1145
41	KHKT	48.84	11.91	470	*P. abies*	67	0.95	0.67	0.27	731
42	KHLF	48.84	11.91	470	*F. sylvatica*	111	0.98	0.86	0.23	622
43	KHLW	48.84	11.91	470	*P. abies*	82	0.86	0.33	0.25	1528
44					*F. sylvatica*	111	0.94	0.62	0.25	768
45	LLSN	48.45	11.27	470	*P. abies*	102	0.95	0.67	0.23	1404
46					*A. alba*	109	0.90	0.46	0.26	1216
47	LLSR	48.45	11.25	470	*P. abies*	85	0.96	0.69	0.22	1795
48					*A. alba*	89	0.95	0.64	0.26	1253
49					*F. sylvatica*	82	0.98	0.81	0.19	2304
50	LLSS	48.45	11.26	470	*P. abies*	93	0.92	0.54	0.24	2269

51					*A. alba*	104	0.87	0.40	0.32	1174
52	ANOS	49.33	10.23	475	*P. abies*	89	0.86	0.38	0.28	1919
53					*A. alba*	97	0.88	0.43	0.27	1617
54					*F. sylvatica*	100	0.96	0.76	0.24	1157
55	FSSC	48.41	11.71	475	*P. abies*	35	0.97	0.76	0.26	484
56	WHWG	48.33	10.26	520	*A. alba*	55	0.95	0.67	0.25	4344
57	MWSE	47.79	13.55	527	*P. abies*	179	0.89	0.45	0.22	536
58					*F. sylvatica*	180	0.97	0.76	0.18	344
59	WHBK	48.29	10.30	530	*P. abies*	105	0.97	0.75	0.27	951
60	WHSB	48.32	10.25	530	*P. abies*	75	0.91	0.49	0.24	2292
61					*A. alba*	82	0.95	0.67	0.29	2015
62					*F. sylvatica*	90	0.90	0.47	0.22	1667
63	WHSG	48.32	10.25	530	*F. sylvatica*	55	0.96	0.74	0.23	3235
64	WSEF	48.09	11.87	560	*P. abies*	83	0.93	0.56	0.23	1731
65	WSEM	48.09	11.87	560	*P. abies*	80	0.90	0.46	0.23	1977
66	MCFP	48.07	11.48	570	*P. abies*	57	0.96	0.74	0.27	3388
67	SNFB	49.47	12.02	580	*P. abies*	57	0.97	0.80	0.24	2245
68					*A. alba*	70	0.96	0.73	0.29	1724
69					*F. sylvatica*	109	0.94	0.60	0.25	1066
70	WSHK	48.02	11.79	590	*P. abies*	77	0.95	0.68	0.20	1192
71					*A. alba*	68	0.94	0.60	0.23	2145
72					*F. sylvatica*	84	0.92	0.53	0.27	1642
73	NGML	47.58	12.99	680	*P. abies*	104	0.94	0.62	0.22	1022
74					*F. sylvatica*	108	0.94	0.61	0.24	827
75	TSSW	47.59	13.00	690	*P. abies*	68	0.98	0.82	0.23	2291
76					*A. alba*	122	0.93	0.58	0.20	590
77					*F. sylvatica*	89	0.89	0.45	0.23	1398
78	SAGB	47.53	12.74	700	*P. abies*	115	0.75	0.23	0.14	1278
79					*F. sylvatica*	102	0.85	0.36	0.18	1076
80	ATTI	47.30	9.68	700	*P. abies*	71	0.87	0.50	0.18	1941
81					*A. alba*	83	0.94	0.70	0.22	1111
82	SMTN	47.84	11.77	730	*P. abies*	100	0.90	0.48	0.23	1579
83					*A. alba*	105	0.90	0.49	0.22	1650
84					*F. sylvatica*	104	0.95	0.75	0.22	979
85	SMTS	47.83	11.77	730	*P. abies*	104	0.89	0.46	0.20	1944
86					*A. alba*	105	0.91	0.50	0.22	1702
87	MXUB	47.75	11.51	740	*P. abies*	74	0.96	0.71	0.20	2181
88					*A. alba*	77	0.96	0.70	0.18	2298
89					*F. sylvatica*	82	0.86	0.37	0.24	1562
90	BGBS	47.67	13.02	760	*P. abies*	134	0.89	0.45	0.19	669
91					*A. alba*	119	0.92	0.52	0.19	811
92					*F. sylvatica*	143	0.89	0.45	0.21	613
93	BGOB	47.65	13.02	770	*P. abies*	126	0.86	0.39	0.19	866
94					*A. alba*	138	0.83	0.32	0.18	689
95	MWSD	47.80	13.59	791	*P. abies*	225	0.87	0.40	0.22	166
96					*A. alba*	232	0.84	0.34	0.18	166
97					*F. sylvatica*	237	0.94	0.61	0.24	156
98	OGLD	47.48	11.03	838	*P. abies*	154	0.83	0.33	0.14	444
99					*A. alba*	183	0.89	0.46	0.18	281
100					*F. sylvatica*	171	0.92	0.54	0.20	261
101	NKZS	47.84	14.44	876	*P. abies*	217	0.92	0.52	0.20	710
102					*F. sylvatica*	207	0.92	0.53	0.25	274
103	NKZP	47.84	14.45	894	*P. abies*	94	0.96	0.69	0.16	1231
104					*F. sylvatica*	93	0.97	0.79	0.22	982
105	NKZN	47.84	14.44	901	*P. abies*	130	0.69	0.18	0.18	1089

106					*F. sylvatica*	201	0.91	0.51	0.24	384
107	OGHP	47.80	11.02	910	*P. abies*	101	0.91	0.49	0.23	1392
108					*A. alba*	107	0.96	0.72	0.26	1012
109	SSHU	47.63	12.00	920	*P. abies*	190	0.79	0.27	0.15	411
110					*A. alba*	165	0.89	0.44	0.17	142
111					*F. sylvatica*	173	0.94	0.59	0.22	75
112	NKRB	47.76	14.34	950	*P. abies*	176	0.79	0.27	0.20	794
113					*A. alba*	221	0.80	0.28	0.17	180
114					*F. sylvatica*	175	0.94	0.60	0.23	317
115	NGEW	47.57	12.80	960	*P. abies*	137	0.96	0.73	0.16	831
116					*A. alba*	146	0.78	0.26	0.15	1055
117					*F. sylvatica*	145	0.87	0.39	0.22	890
118	MWSC	47.80	13.59	978	*P. abies*	230	0.82	0.32	0.19	455
119					*A. alba*	222	0.89	0.45	0.20	352
120					*F. sylvatica*	250	0.86	0.39	0.27	162
121	ATVB	47.30	9.68	1000	*P. abies*	125	0.68	0.17	0.18	1824
122					*A. alba*	131	0.90	0.44	0.22	1585
123	BGOA	47.66	13.02	1020	*P. abies*	132	0.84	0.34	0.17	1148
124					*A. alba*	133	0.75	0.23	0.18	483
125					*F. sylvatica*	133	0.91	0.51	0.22	757
126	OGLC	47.49	11.03	1020	*P. abies*	178	0.73	0.21	0.16	350
127					*A. alba*	184	0.63	0.15	0.18	541
128					*F. sylvatica*	188	0.93	0.58	0.22	148
129	BGGP	47.63	12.85	1040	*P. abies*	121	0.90	0.47	0.18	1122
130					*A. alba*	159	0.53	0.10	0.17	1051
131					*F. sylvatica*	175	0.80	0.29	0.25	357
132	SAMA	47.51	12.78	1080	*P. abies*	115	0.76	0.24	0.18	1286
133					*A. alba*	139	0.67	0.17	0.15	842
134					*F. sylvatica*	166	0.86	0.38	0.20	433
135	SSHO	47.04	11.26	1110	*P. abies*	184	0.84	0.34	0.18	258
136					*A. alba*	180	0.99	0.91	0.16	235
137					*F. sylvatica*	171	0.92	0.52	0.18	138
138	NKSK	47.75	14.44	1150	*P. abies*	194	0.87	0.41	0.21	582
139					*A. alba*	211	0.88	0.41	0.19	421
140					*F. sylvatica*	220	0.90	0.48	0.29	254
141	MWSB	47.81	13.59	1209	*P. abies*	227	0.91	0.51	0.17	812
142					*A. alba*	231	0.94	0.62	0.15	578
143					*F. sylvatica*	233	0.93	0.56	0.28	237
144	NGLS	47.51	13.02	1220	*P. abies*	182	0.87	0.40	0.18	963
145					*F. sylvatica*	189	0.90	0.48	0.36	621
146	OGLB	47.49	11.03	1220	*P. abies*	195	0.90	0.48	0.17	385
147					*A. alba*	178	0.87	0.41	0.18	536
148					*F. sylvatica*	195	0.95	0.65	0.31	206
149	SAMG	47.51	12.78	1250	*P. abies*	141	0.90	0.49	0.15	826
150					*A. alba*	171	0.61	0.13	0.16	950
151					*F. sylvatica*	181	0.91	0.50	0.31	196
152	SSAK	47.64	11.97	1270	*P. abies*	77	0.87	0.41	0.16	964
153					*A. alba*	195	0.80	0.29	0.17	427
154					*F. sylvatica*	155	0.77	0.25	0.20	151
155	OGWB	47.50	11.14	1280	*P. abies*	201	0.79	0.28	0.15	259
156	ATBL	47.28	9.78	1300	*P. abies*	132	0.92	0.52	0.17	1967
157					*A. alba*	158	0.77	0.25	0.16	2124
158	NGMW	47.56	12.80	1310	*P. abies*	198	0.90	0.46	0.15	463
159					*A. alba*	156	0.79	0.27	0.15	1325
160					*F. sylvatica*	159	0.93	0.57	0.31	353

161	NGMK	47.58	12.89	1330	*P. abies*	147	0.91	0.50	0.15	973
162					*F. sylvatica*	173	0.95	0.67	0.38	553
163	MWSA	47.81	13.59	1337	*P. abies*	206	0.82	0.31	0.17	243
164	NKGU	47.76	14.42	1350	*P. abies*	138	0.81	0.29	0.16	1327
165					*F. sylvatica*	158	0.94	0.59	0.31	415
166	OGLA	47.50	11.03	1400	*P. abies*	197	0.88	0.42	0.15	333
167					*A. alba*	162	0.90	0.48	0.15	814
168					*F. sylvatica*	180	0.93	0.57	0.33	228
169	SSMS	47.64	11.98	1450	*P. abies*	135	0.91	0.49	0.20	612
170	NKGO	47.76	14.42	1460	*P. abies*	158	0.83	0.32	0.16	797
171					*F. sylvatica*	143	0.93	0.57	0.28	491
172	SAKK	47.54	12.82	1530	*P. abies*	153	0.88	0.43	0.16	690
173	NGMA	47.55	12.81	1560	*P. abies*	122	0.89	0.46	0.15	1495
174	NGSB	47.57	12.82	1600	*P. abies*	293	0.83	0.32	0.16	217
175	NGHS	47.56	12.82	1620	*P. abies*	148	0.93	0.57	0.15	781
176	NGKS	47.52	13.01	1670	*P. abies*	167	0.93	0.57	0.17	1009

Supporting Methods M1

Checking interpolated climate data against station data and the HISTALP data set

Since the spatial resolution of the CRU TS 3.2 data set is rather crude, with a 0.5° x 0.5° grid cell covering ca. 2700 km^2, we checked the quality of the interpolation from the CRU data against station data from the German Weather Service (Deutscher Wetterdienst, DWD), and the HISTALP (Auer et al. 2007) data set. To this end, all sites for which nearby weather stations could be identified (mainly the lowland sites, 45 sites in total), station data from climate and precipitation stations was acquired and interpolated to the site using inverse distance weighting. For the alpine sites (39 sites in total), interpolated control series were obtained by inverse distance weighting on the four nearest grid cells from the HISTALP data set.

Agreement between interpolated CRU TS 3.2 data was assessed using Pearson's correlation coefficient for the monthly resolved climate series on a common time span from 1950 to 2007. Agreement was found to be generally high, with a mean correlation between CRU TS 3.2 temperature data and local station data of 0.98 ± 0.03, a mean correlation between CRU TS 3.2 precipitation data and local station data of 0.86 ± 0.07, a mean correlation between CRU TS 3.2 temperature data and HISTALP temperature data of 0.99 ± 0.002, and a mean correlation between CRU TS 3.2 precipitation data and HISTALP precipitation data of 0.93 ± 0.07.

Note that this is not a valid test for the general quality of the data, since the station and HISTALP data used is not independent from the data the CRU TS 3.2 is constructed from. We rather use this approach for checking the quality of the interpolation based on the 0.5° CRU grid.

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Supporting Methods M2

Verification of drought conditions on the sampled sites

To verify that all sites experienced drought in the selected years, we compared the Standardized Precipitation and Evapotranspiration Index (SPEI, Vicente-Serrano *et al.*, 2010a) for these sites, both from interpolated gridded data resulting from the same grid space used for the climatic data (Vicente-Serrano *et al.*, 2010b), as well as calculated for the local station data (lowland) and interpolated HISTALP data set (Auer *et al.* 2007) using *R* package *SPEI* (Beguería & Vicente-Serrano, 2013).

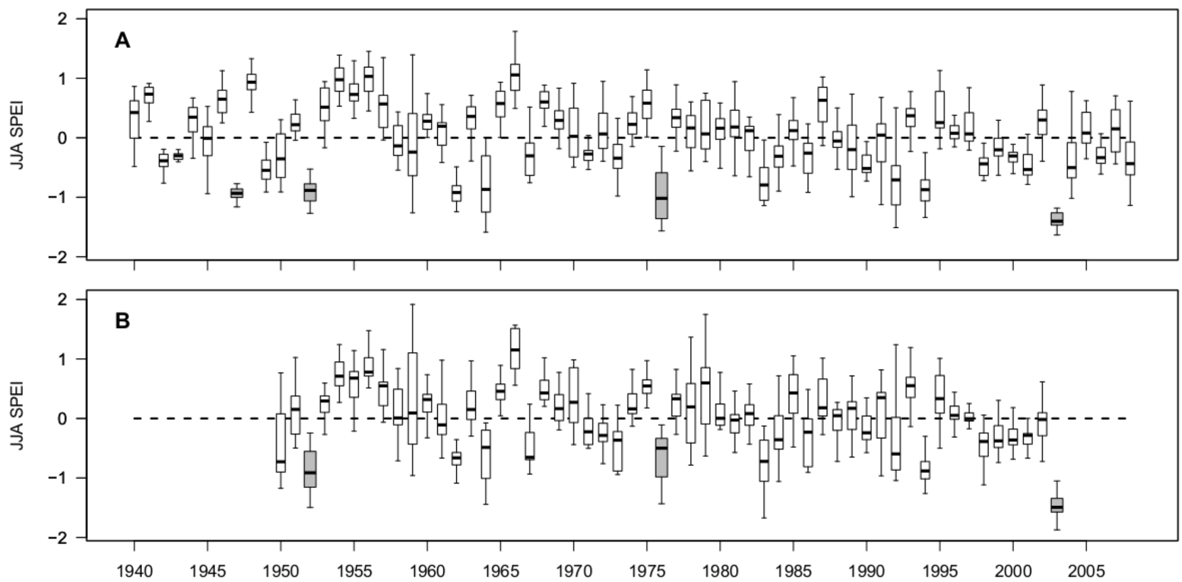

Fig. S1: SPEI values for all sites, calculated from A) gridded SPEI data, and B) from local station data and the HISTALP data set.

For the gridded data set, each site displays SPEI values for 2003 and 1947 that are in the lowest quartile of the data, confirming severe drought conditions for these years (Fig. S1A). The comparably dry year of 1952 was omitted from the analysis because of temporal proximity to 1947. For the SPEI calculated from station and HISTALP data, all sites are in the lowest quartile for 2003, and 64% of the sites are in the lowest quartile for 1976, with the rest located in the second quartile (figure S1B). The relative conditions for 1947 could not be assessed for station data, as reliable climatic information for all sites could only be obtained for the years 1950 and later.

Consequently, both approaches confirm the selected drought years of 1947, 1976 and 2003 to represent absolute (values below 0 in all cases) and relative drought conditions (positions in the distribution for each site).

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Figur S2: Response to drought characterized by growth in the periods before the drought event (PreDr), during (Dr), and after the drought event (PostDr) (modified after Lloret *et al.*, 2011). Indices for resistance (Rt = Dr/PreDr), recovery (Rc = PostDr/Dr), and resilience (Rs = PostDr/PreDr) are used to quantify the patterns in drought response.

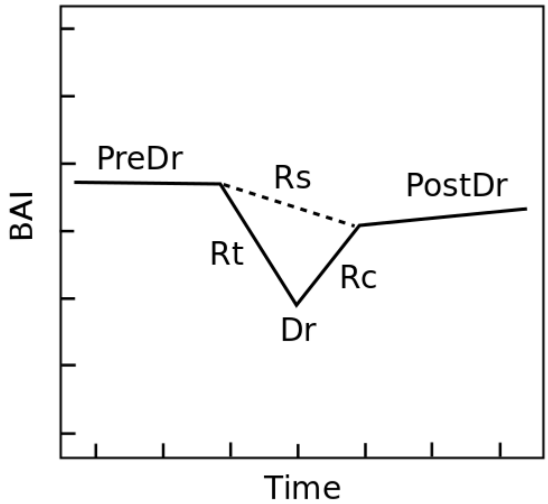

Figure S3: Testing for ontogenetic effects on variability in tolerance indices. For spruce (a), fir (b), and beech (c), the tolerance indices resistance (Rt), recovery (Rc), and resilience (Rs) have been computed separately for the drought years 1947, 1976, and 2003. Depicted are the changes in variability for the respective drought years compared to the background variability.

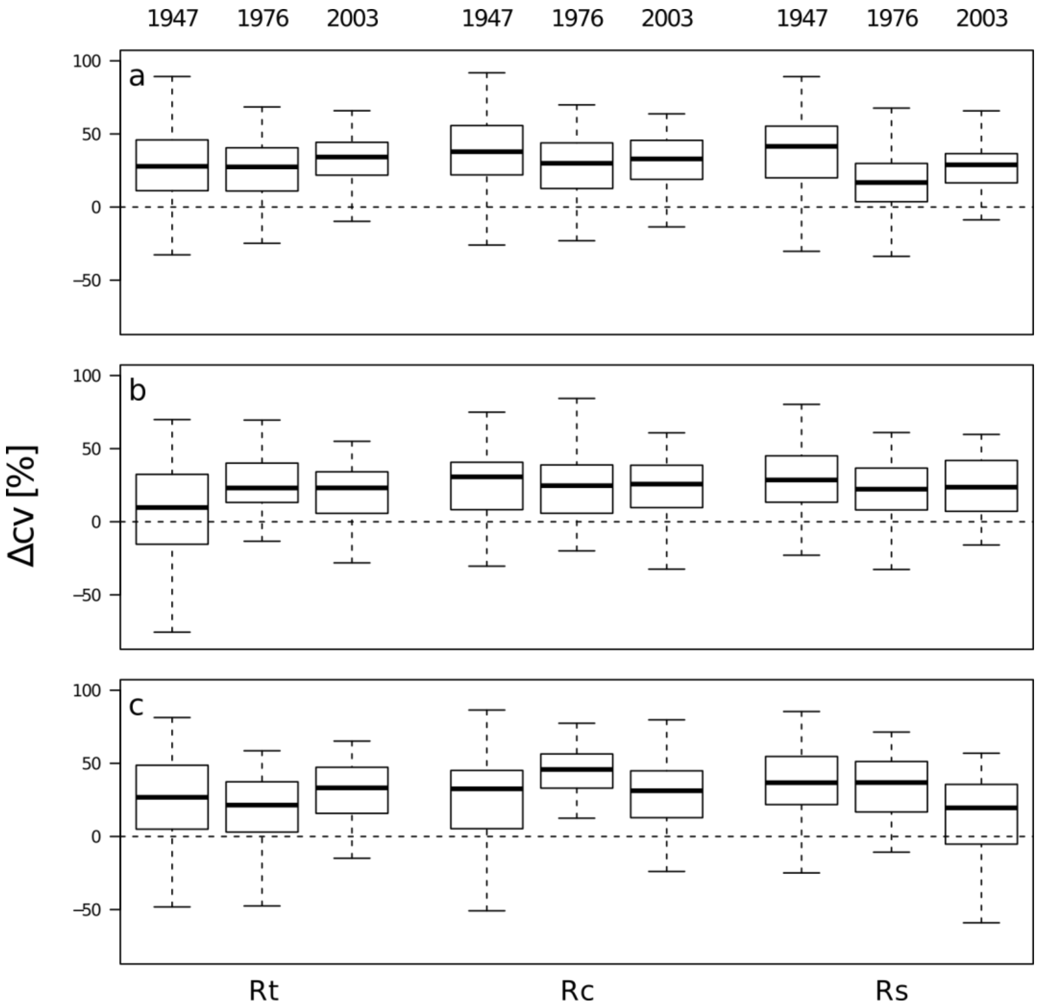

Figure S4: Exemplary distance-CV-relation for the mean geographic distance of 10 randomly selected trees and the CV for a tolerance index. Here, CV for resistance (Rt) of spruce is shown. The correlation is significant due to the high number of replicates (n = 1000), but the amount of explained variance is low (< 1%).