Drought tolerance of western Canadian forests tree species inferred from dendrochronology

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(Abstract with figures and tables. For more information contact Benjamin Panes)

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Abstract: Western Canadian forests have been subject to periods of drought stress over the last three decades, resulting in growth reductions, dieback, and increased wildfires in the context of climate change. To contribute to adaptive forest management, this study compares drought vulnerabilities of eight common western Canadian tree species based on 392 tree-ring chronologies. Chronologies were grouped into clusters with similar climatologies and assessed for drought resistance, resilience and recovery. The results show that the most severe drought impacts occurred in dry boreal mixedwood ecosystems, east of the Rocky Mountains. The dominant species in these ecosystems (white spruce and jack pine) were most vulnerable in the north, rather than at the southern fringe of the boreal forest, suggesting lack of adaptive traits to cope with drought conditions in northern populations. The same pattern emerges for sub-boreal ecosystems further west. For example, interior Douglas-fir was most vulnerable to drought at the northern edge of its distribution. In moister montane ecosystems, Douglas-fir and limber pine showed the least drought resistance, but all species recovered well from drought events. The results have implications for forest management in western Canada: interior Douglas-fir should not be planted beyond its northern range limitations despite significant regional warming trends. Across large sections of western boreal forests, not just the southern boreal fringe, the most common species such as white spruce and jack pine appear vulnerable in the long term, while submontane forest ecosystems of British Columbia and Alberta may serve as regional climate change refugia.

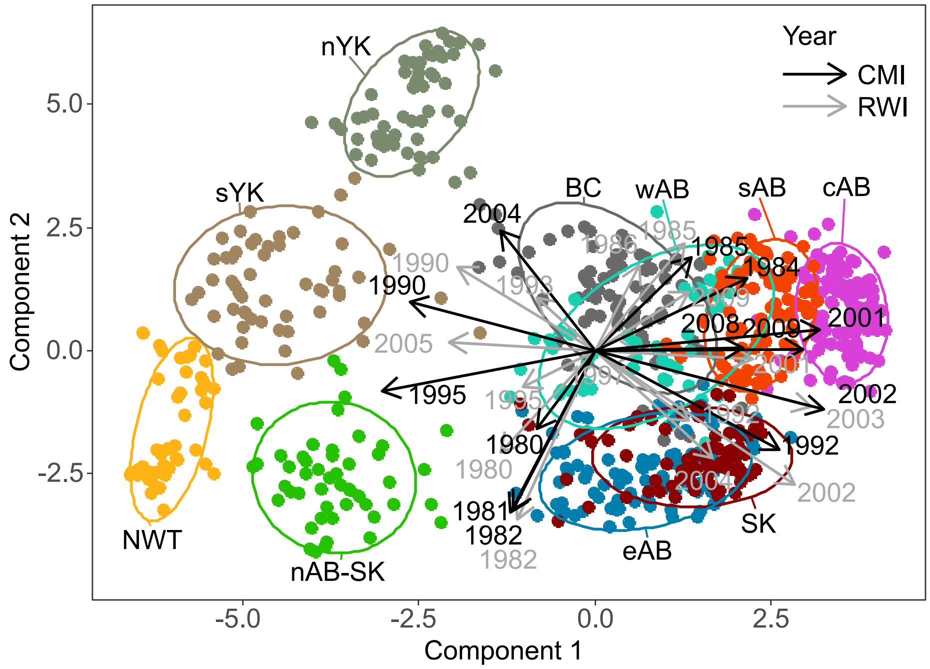

Figure 1. Principal component ordination of k-means clusters for chronologies, based on similarities in timing of drought events and growth responses. Variables included a scaled and negated climate moisture index (CMI, black vectors) and a detrended and negated ring width index (RWI grey vectors). Vectors point towards groups of chronologies that most severely experienced drought events and growth reductions in these years.

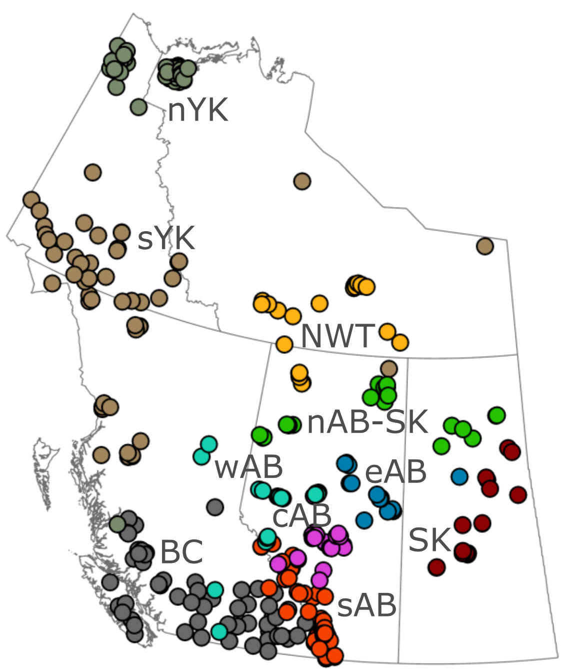

Figure 2. K-means clusters of chronology sites labeled according to their approximate geographic locations: northern Yukon (nYK), southern Yukon (sYK), British Columbia (BC), western Alberta (wAB), Northwest Territories (NWT), northern Alberta and Saskatchewan (nAB-SK), central Alberta (cAB), southern Alberta

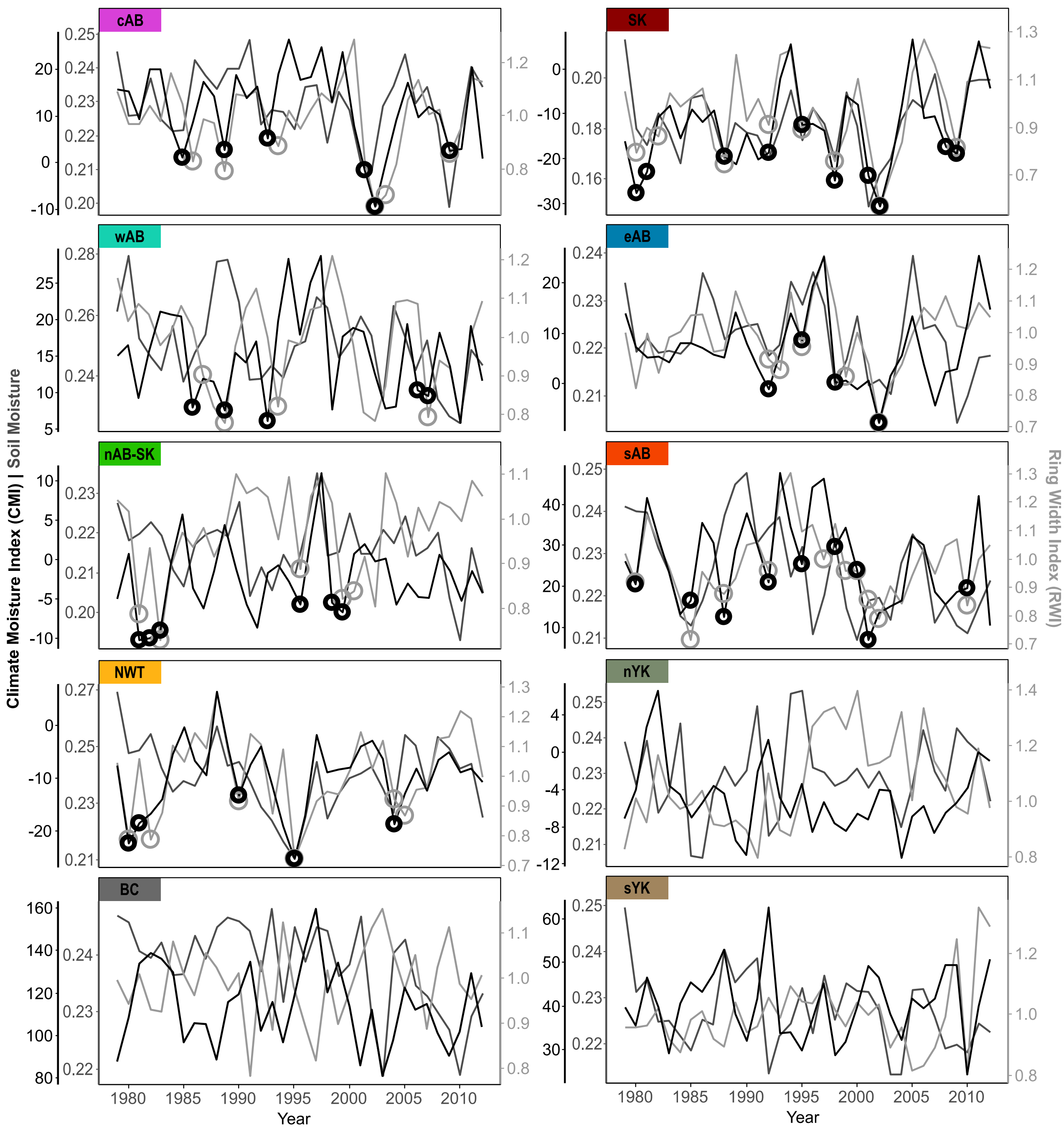

Figure 3. Time series of climate moisture index (mm, black lines), remotely sensed soil moisture ($cm^3\ cm^{-3}$, dark gray), and detrended ring width index (light gray), for each cluster (colors and cluster abbreviations as in Fig. 2). Drought events that caused a significant growth reduction (defined as a ring width index <0.8 in at least 50% of chronologies of at least one species in a cluster), with growth responses in the same or subsequent year are highlighted with circles.

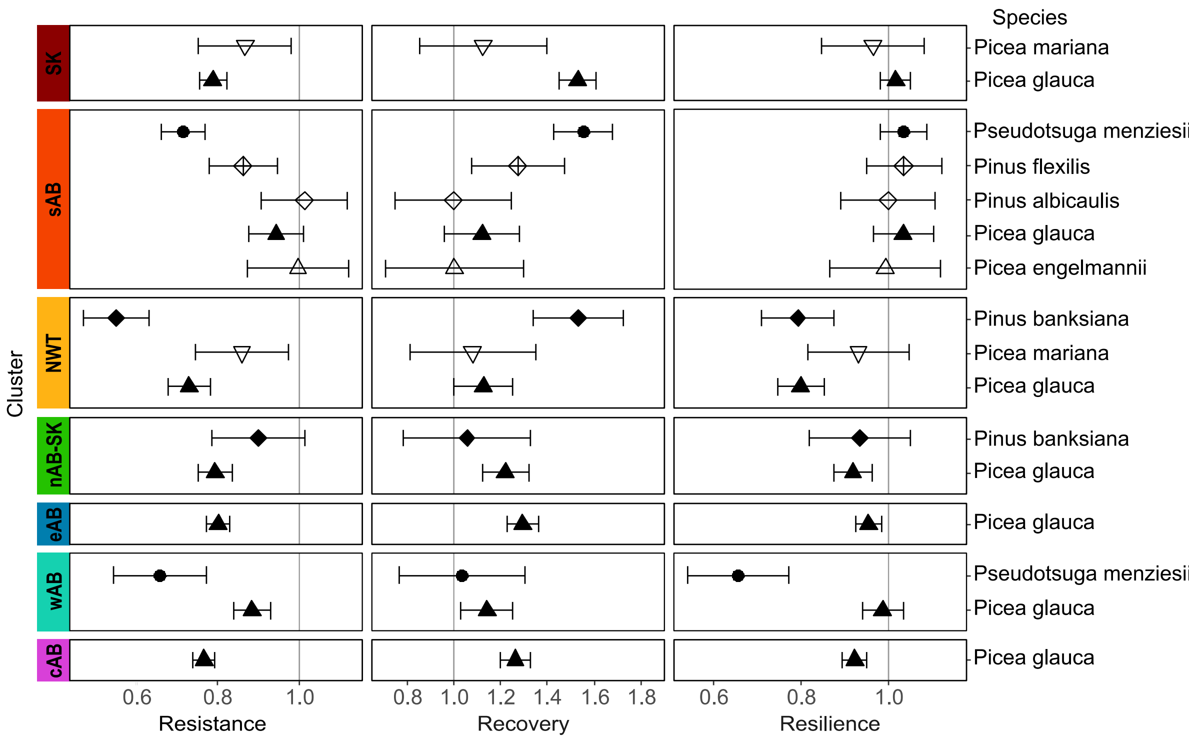

Figure 4. Drought resistance, recovery, and resilience metrics according to Loiret et al. (2011) for each species and cluster. Clusters where growth was not primarily limited by water availability were omitted (BC, nYK and sYK), as were species with an insufficient number of sample locations (<5 sites within a cluster). Error bars represent a 95% confidence interval, and therefore indicate statistically significant deviations from the reference values, indicating no impact on growth for a resistance value of 1, no post-drought improvement for a recovery value of 1, and recovery to pre-drought growth values for a resilience value of 1 (gray lines).

Table 1. Species and chronology statistics included in the study. Number of site chronologies for each species, as well as mean inter-series correlations (R-bar), expressed population signal (EPS) and mean sample depth (S-Depth) are listed as averages across site chronologies.

Common Name	Scientific Name	Sites	R-bar	EPS	S-Depth
White spruce	*Picea glauca* (Moench) Voss	206	0.40	0.91	23.3
Engelmann spruce	*Picea engelmanii* Parry ex Engelm.	60	0.37	0.95	22.9
Black spruce	*Picea mariana* (Mill.) Britton	24	0.33	0.93	38.2
Jack pine	*Pinus banksiana* Lamb.	24	0.38	0.94	22.7
Whitebark pine	*Pinus albicaulis* Engelm.	15	0.33	0.96	29.9
Limber pine	*Pinus flexilis* E. James	15	0.44	0.97	22.3
Douglas-fir	*Pseudotsuga menziesii* (Mirbel) Franco	48	0.54	0.97	25.2

Table 2. Drought events ordered chronologically, and clusters (as in Fig. 2) affected by each drought period. Response years refer to years with a low detrended ring width index value. Drought severity was measured as absolute water deficits of a 15-month CMI value (mm), and the relative drought severity is the same CMI value expressed in standard deviations from chronology means of zero for the study period, averaged across all chronologies within the affected clusters.

Drought years	Response years	Relative drought severity (stdev)	Absolute drought severity (mm)	Regional clusters affected by the drought						
1980-82	1980-82	-1.28, -1.18, -1.15	-12.5, -21.4, -11.3	sAB	SK				nAB-SK	NWT
1984-85	1985-86	-1.19, -0.90	1.5, 15.2	sAB		cAB	wAB			
1988	1988	-0.99	1.0	sAB	SK	cAB	wAB			
1990	1990	-0.46	-16.6							NWT
1992	1992-93	-0.8	3.1	sAB	SK	cAB	wAB	eAB		
1995	1995-97	-0.44	-2.3	sAB	SK			eAB	nAB-SK	NWT
1998-99	1998-99	-0.58, -0.72	-0.2, -8.5	sAB	SK			eAB	nAB-SK	
2001-02	2001-03	-1.42, -2.08	-7.7, -19.9	sAB	SK	cAB		eAB		
2004	2004-05	-1.23	-23.3							NWT
2006-07	2007	-0.58, -0.78	12.8, 11.9				wAB			
2008-09	2009	-0.43, -0.81	-21.8, -10.1		SK	cAB				
2010	2010	-0.66	24.5	sAB						

Table 3. Long-term climate normal conditions for regional clusters as shown in Fig 2. Regional clusters are ordered from left to right based on their water balance according to Hogg's (1999) climate moisture index, where a value near zero is calibrated for the boreal forest to grassland transition zone in western Canada (last row).

Climate normals (1978-2010)	SK	NWT	nAB-SK	nYK	eAB	cAB	wAB	sAB	sYK	BC
Mean annual temperature (°C)	1.7	-2.4	0.0	-7.8	1.4	2.7	2.7	1.4	-1.6	2.1
Mean coldest month temp. (°C)	-17.8	-23.9	-19.5	-27.8	-17.0	-13.4	-12.5	-12.5	-17.1	-8.8
Mean warmest month temp. (°C)	17.7	16.3	15.6	14.1	15.9	15.6	14.9	13.3	11.8	12.7
Mean annual precipitation (mm)	424	358	435	260	490	555	585	671	693	1456
Climate moisture index (mm/yr)	-6.1	0.0	3.4	3.8	6.4	8.6	15.3	27.8	42.0	112.0