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Trees do not always act their age: size-deterministic tree ring standardization for long-term trend estimation in shade-tolerant trees

Rachel Dietrich and Madhur Anand

Correspondence to: Madhur Anand (manand@uoguelph.ca)

Supplement S1 – SORTIE-ND simulation parameters

For the sugar maple simulation, initial stand densities were estimated from an intensively sampled maple dominated stand in Northern Ontario (Toobee Lake, Table 1). Standard model parameters were used (Pacala 1996, Pacala 1993) with one exception, annual adult stochastic mortality was raised to 0.015 (from 0.010) as it has been suggested that old-growth maple stands exhibit higher adult mortality than suggested by the SORTIE model (Lorimer et al. 2001). The model was run for 1000 years, ensuring a stable age distribution was achieved. This suggested minimal net change in biomass across the stand and ensured no underlying long-term growth-trend was present in the raw tree-ring data. For the white pine simulation, the stand was 100% white pine, standard model parameters were used, and the simulation was run for 1000 years. All living trees (>5 cm dbh), (n=3657 sugar maple), (n=7362, white pine) in the final year of the model run were used for further analysis.

References :

Lorimer, C. G., Dahir, S. E., & Nordheim, E. V. (2001). Tree mortality rates and longevity in mature and old-growth hemlock-hardwood forests. *Journal of Ecology*, *89*(6), 960-971.

Pacala, S. W., Canham, C. D., Saponara, J., Silander, J. A., Kobe, R. K., & Ribbens, E. (1996). Forest models defined by field measurements: estimation, error analysis and dynamics. *Ecological Monographs*, *66*(1), 1-43.

Pacala, S. W., Canham, C. D., & Silander Jr, J. A. (1993). Forest models defined by field measurements: I. The design of a northeastern forest simulator. *Canadian Journal of Forest Research*, *23*(10), 1980-1988.

Supplement S2 –Evaluation of linear trend reconstruction by tree ring standardization models in simulated and real tree ring data

S2.1 Parameters for linear increasing and decreasing trends

(1) $$RWt_{yi} = RWr_{yi} * m$$

Where m=1.00552564 for increasing trend and m=-1.004524382 for decreasing trend.

S2.2 Results in simulated tree ring data

Table S1: Average spearman's rho correlation between imposed linear trends and chronologies produced by five standardization methods (Model) applied to SORTIE simulated sugar maple data across various minimum size thresholds.

Trend	Model	Minimum size threshold (DBH)				**Average**
		All	>10 cm	> 30cm	> 50cm	
(+) linear	BAI	0.806	0.850	0.902	0.974	0.883
	CM	0.640	0.690	0.716	0.725	0.693
	COMB	0.990	0.989	0.988	0.984	0.988

	RCS	0.895	0.898	0.907	0.908	0.902
	SDS	0.987	0.986	0.985	0.979	0.984
	CD	NA	0.557	0.536	0.678	0.590
(-) linear	BAI	0.764	0.723	0.719	0.735	0.735
	CM	0.160	0.219	0.242	0.360	0.245
	COMB	0.986	0.986	0.981	0.964	0.979
	RCS	0.874	0.863	0.833	0.701	0.818
	SDS	0.978	0.979	0.972	0.947	0.969
	CD	NA	-0.526	-0.512	-0.605	-0.548

Table S2: Tukey's honest significant differences among average Spearman's rank correlation coefficients presented in Table S3.1

Trend	**Model**	BAI	CM	COMB	RCS	SDS	CD
(+) linear	BAI	-	-	-	-	-	-
	CM	***	-	-	-	-	-
	COMB	***	***	-	-	-	-
	RCS	n.s.	***	***	-	-	-
	SDS	***	***	n.s.	***	-	-
	CD	***	***	***	***	***	-
(-) linear	BAI	-	-	-	-	-	-
	CM	***	-	-	-	-	-
	COMB	***	n.s.	-	-	-	-
	RCS	**	***	***	-	-	-
	SDS	***	***	***	***	-	-
	CD	***	***	***	***	***	-

(***) p<0.01, (**) p<0.05, (*) p<0.10, (n.s.) not significant

Table S3: Average spearman's rho correlation between imposed linear trends and chronologies produced by five standardization methods (Model) applied to SORTIE simulated white pine data across various minimum size thresholds.

Trend	Model	Minimum size threshold (DBH)				**Average**
		All	>10 cm	> 30cm	> 50cm	
(+) linear	BAI	0.595	0.910	0.991	0.998	0.874
	CM	0.946	0.965	0.959	0.970	0.960
	COMB	0.961	0.967	0.974	0.966	0.967

	RCS	0.921	0.956	0.965	0.937	0.945
	SDS	0.973	0.982	0.990	0.988	0.983
	CD	NA	0.694	0.740	0.808	0.747
(-) linear	BAI	0.693	0.527	0.826	0.936	0.745
	CM	0.492	0.550	0.751	0.869	0.666
	COMB	0.901	0.883	0.881	0.910	0.894
	RCS	0.820	0.623	0.619	0.760	0.706
	SDS	0.951	0.936	0.954	0.976	0.954
	CD	NA	-0.555	-0.562	-0.706	-0.608

Table S4: Tukey's honest significant differences among average Spearman's rank correlation coefficients presented in Table S3.2

Trend	**Model**	BAI	CM	COMB	RCS	SDS	CD
(+) linear	BAI	-	-	-	-	-	-
	CM	***	-	-	-	-	-
	COMB	***	n.s.	-	-	-	-
	RCS	***	**	**	-	-	-
	SDS	***	n.s.	n.s.	***	-	-
	CD	***	***	***	***	***	-
(-) linear	BAI	-	-	-	-	-	-
	CM	***	-	-	-	-	-
	COMB	***	***	-	-	-	-
	RCS	n.s.	***	***	-	-	-
	SDS	***	***	n.s.	***	-	-
	CD	***	***	***	***	***	-

(***) $p<0.01$, (**) $p<0.05$, (*) $p<0.10$, (n.s.) not significant

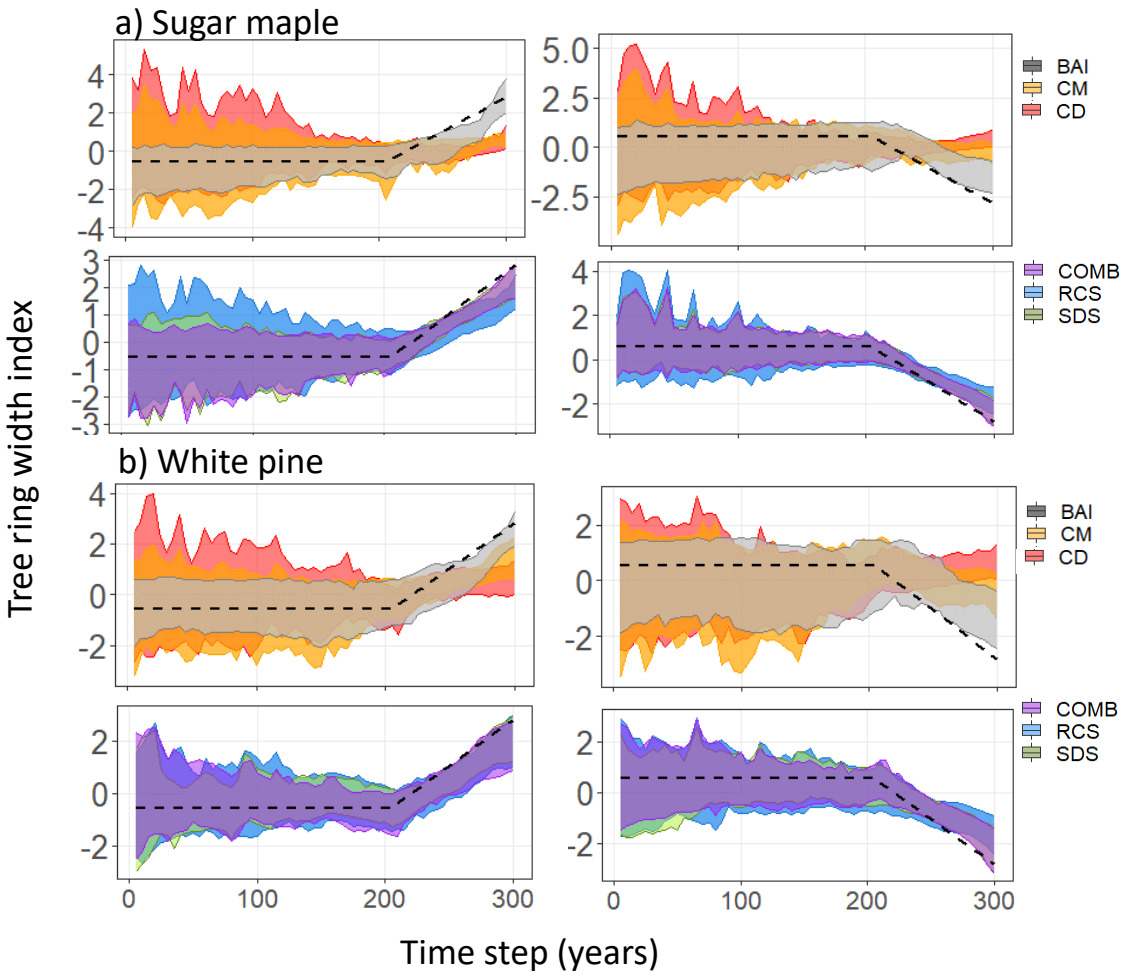

Figure S1: 95% confidence intervals for standardized chronologies produced by each standardization method (legend right side) applied SORTIE simulated sugar maple and white pine tree ring data. Confidence intervals obtained via bootstrap resampling (rep=100) of 60 trees (>10 cm DBH) from the SORTIE simulated populations. Dotted lines indicate the standardized increasing (left side) or decreasing (right side) linear trend that was added to the raw tree ring data.

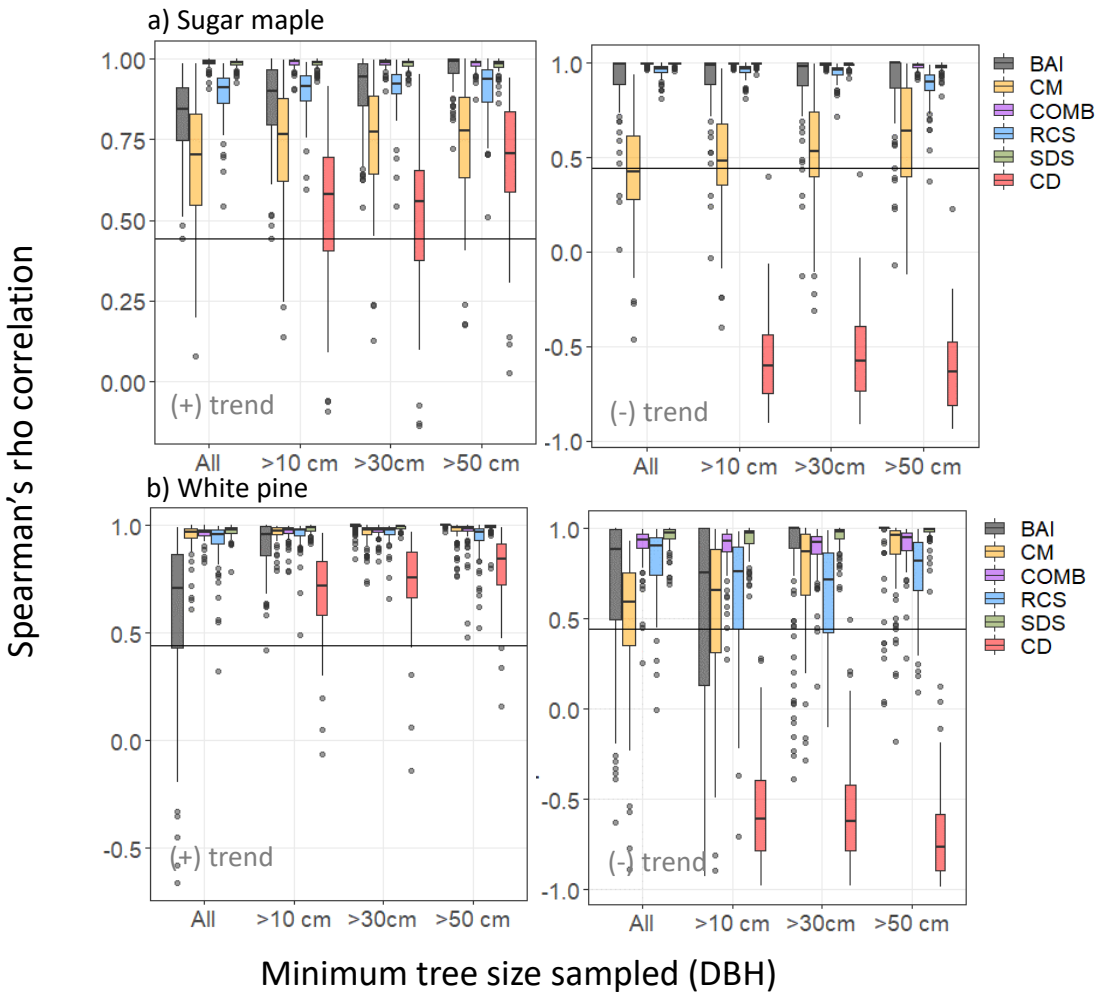

Figure S2: Spearman's correlation between chronologies produced by each of the five standardization methods and the imposed increasing (left column) or decreasing (right column) linear trend in SORTIE simulated (a) sugar maple and (b) white pine tree-ring data. Correlation distribution created by bootstrap resampling 60 trees (rep=100) from SORTIE simulated tree populations. Horizontal axis denotes minimum tree size (DBH) thresholds for sampling from the population. Horizontal lines indicate threshold for significant Spearman's rho (a=0.05) for correlation between chronologies and the imposed trend.

S2.3 Results in real tree ring data

Confidence intervals surrounding chronologies produced from each of the standardization methods applied to the tree ring series from six sugar maple stands are provided in Figure S3a for both increasing and decreasing linear trends. The corresponding distributions of Spearman's rank correlation coefficients are provided in Figure S4a). with significant differences ($p<0.05$)

being noted by letters. Chronologies and corresponding correlation coefficients for the identical analysis performed on 12 red spruce stands are provided in Figure S3a and S4b, respectively. Regardless of trend direction RCS, COMB and SDS chronologies exhibited comparable and consistent results across both species (Fig. S4). In general chronologies produced by all three methods exhibited conservative, but reliable, estimations of the imposed trends (Fig. S3). SDS produced chronologies with correlations as high or higher (Fig. S4b (negative trend)) than traditional RCS chronologies. Notably, the BAI and CM methods produced strong positive correlations between chronologies and the imposed trend only when the imposed trend was increasing (Fig. S3, S4). BAI and CM chronologies consistently failed to reproduce negative trends across both species (Fig. S3). Finally, across both species, CD chronologies exhibited low correlations with the imposed trend regardless of direction (Fig. S3, S4).

Table S5: Average spearman's rho correlation between imposed linear trends and chronologies produced by five standardization methods (Model) applied to sugar maple and red spruce tree ring data.

Trend	Model	Sugar maple	Red Spruce
(+) linear	BAI	0.933	0.984
	CM	0.769	0.923
	COMB	0.413	0.473
	RCS	0.348	0.687
	SDS	0.277	0.394
	CD	-0.002	0.105
(-) linear	BAI	-0.678	-0.960
	CM	-0.048	0.085
	COMB	0.654	0.326
	RCS	0.730	0.129
	SDS	0.789	0.744
	CD	0.116	0.140

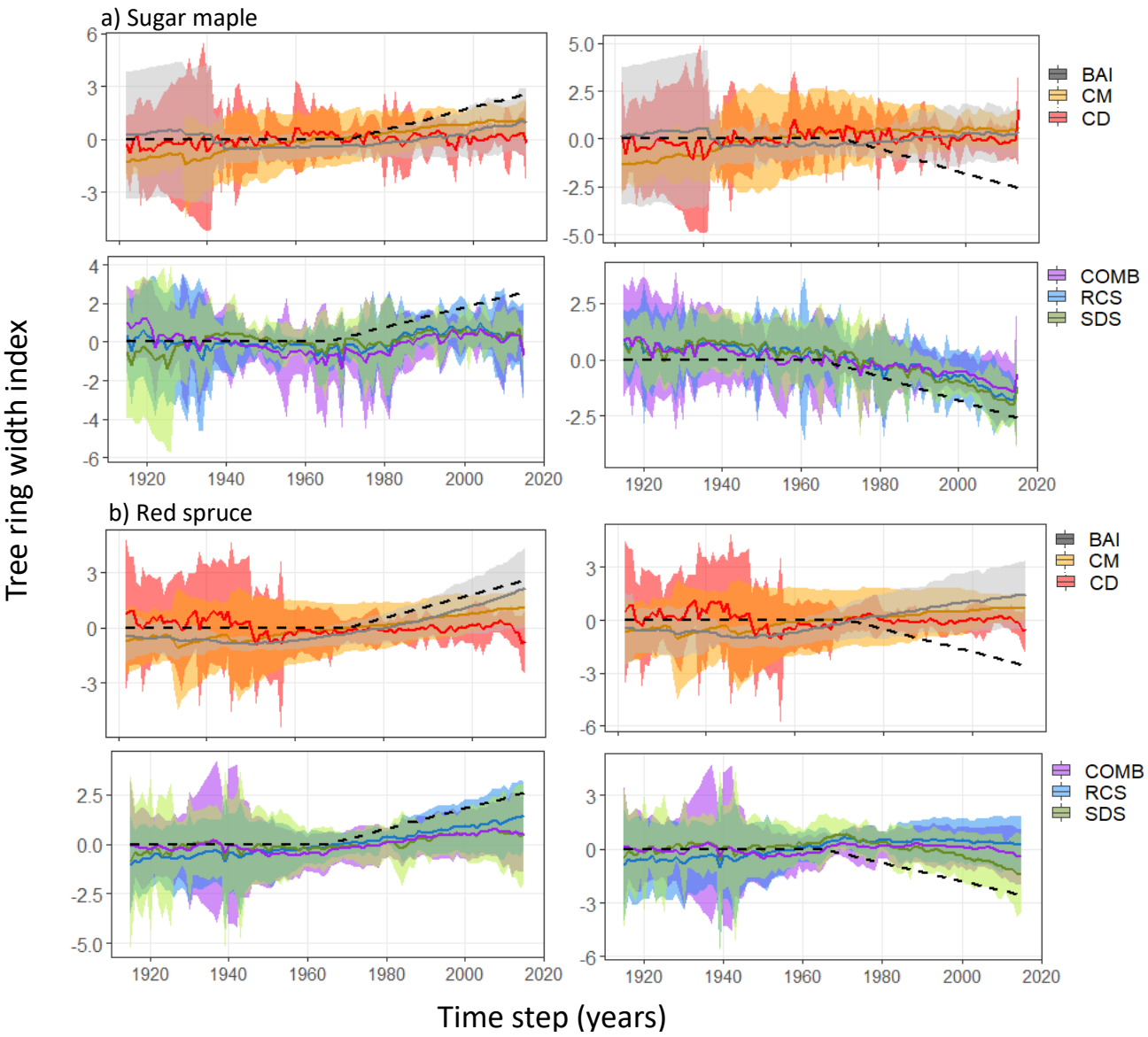

Figure S3: Standardized chronologies produced by each standardization method (legend right side) applied to tree ring series from a) sugar maple (n=6) and b) red spruce (n=12) stands. Solid lines represent the resultant model-wise mean chronologies across all stands considered while ribbons represent respective 95% confidence intervals. Dotted lines indicate the standardized increasing (left side) or decreasing (right side) linear trend that was added to the raw tree ring data.

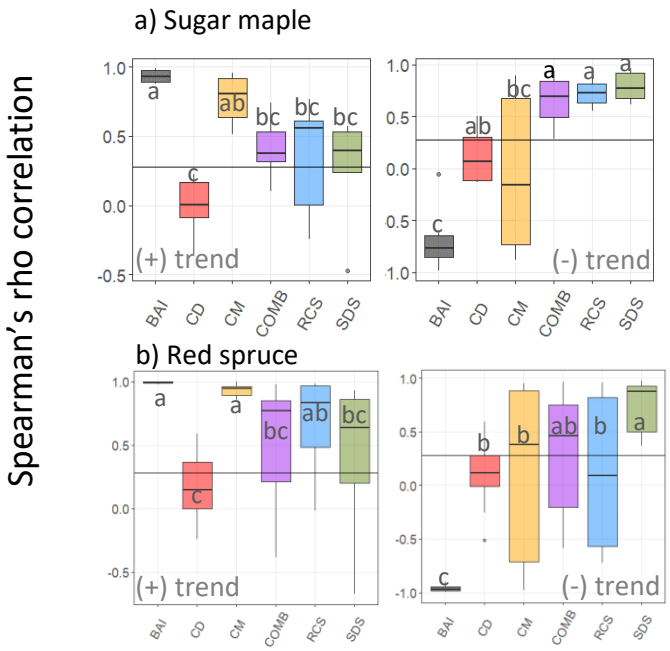

Figure S4: Spearman's correlation between chronologies produced by each of the five standardization methods and the imposed increasing (left column) or decreasing (right column) linear trend in tree ring series from (a) sugar maple and (b) red spruce stands. Horizontal lines indicate threshold for significant Spearman's rho (a=0.05) for correlation between chronologies and the imposed trend. Letters indicate significant differences among samples as estimated by Tukey honest significant differences (a=0.05).

Supplement S3 – Sampling methods

Stands were considered suitable for this study given that they were multi-cohort, self-replacing, pure maple stands (<5% composition of other species). Within stands all trees >5cm dbh were sampled in three 7-meter radius plots. Tree cores were collected at a height of 1.3m from all sampled trees; with large trees cored twice and smaller trees destroyed, and cross sections removed from the site (in permitting locations). This method improves accuracy of ring measurements and increases the likelihood of sampling the pith, and thus proper age estimation. Tree cores were mounted, sanded, and measured using WinDENDRO^{TM} image analysis. Cores were cross-dated visually and checked graphically and statistically, using the dplR program in R.