Forest Tree Competition: A Method for Assessing Distance-Dependent and Independent Competition Indices Using FIA Data

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INTRODUCTION

- Tree competition is a complex ecological process influenced by factors such as species composition, stand density, resource availability, and environmental conditions.
- Spatial arrangement of trees strongly affect survival, diameter growth and stand productivity.
- Competition indices is time consuming and tedious, thus, a need for a standardized and easily replicable method for assessing competiton.

OBJECTIVE

- To develop method for evaluating both distance-dependent and independent competition indices for fixed area plots using Forest Inventory and Analysis (FIA) data.

METHODS

STEP 01 — DATA COLLECTION AND PREPARATION
We are currently using data FIA (Mississppi data)

STEP 02 — DATA PREPROCESSING
We filtered missing values for diameter, azimuth and distances and tree not remeasured.

STEP 03 — COMPUTE DISTANCES
We calculated the distances between trees at subplot level in R using cosine rule.

STEP 04 — COMPETITION INDEX CALCULATION
We wrote R functions to compute the selected competition indices based on the distance.

STEP 05 — STATISTICAL ANALYSIS
We did data exploration, anlysis, visualization and interpretation

STEP 06 — CODE AND DATA SHARING
We intend to package the R code and analysis scripts and share to facilitate reproducibility and transparency.

DISCUSSION AND IMPLICATION

- All the R-squared values are very low indicating that the competition indices explain only a small proportion of the variance in diameter growth.
- The bias values are close to zero, and bias percentages are small, suggesting low prediction bias.
- CI2 is the better performing distance dependent index compared to CI1 and CI3 based on slightly lower RMSE, higher R-squared values and consistency across all the evaluation criteria.
- All three distance-independent competition indices (CI4, CI5, and CI6) performed well with similar RMSE values, very small biases, and high R-squared values.
- CI4 is better based on its slightly lower RMSE and higher R-squared values.

EQUATIONS

$$\text{Average diameter growth rate} = \frac{d2 - d1}{ni}$$

$$\text{Average diameter growth Model: } ADG = \beta_0 + \beta_1 * CI + e$$

$$\text{Bias} = \frac{Yi - \hat{Y}i}{n}$$

$$\text{Bias \%} = \frac{\text{bias}}{\text{mean (Yi)}} \text{ X } 100$$

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(Yi - \hat{Y}i)^2}{n}}$$

$$\text{RMSE \%} = \frac{RMSE}{\text{mean (Yi)}} \text{ X } 100$$

Distance-Dependent Competition Indices

(Hegyi, 1974) $CI1 = \sum_{j=1}^{n}\left(\frac{dj}{di} \text{ x } \frac{1}{Lij}\right)$

(Martin & Ek, 1984) $CI2 = \sum_{j=1}^{n}\left(\frac{dj}{di}\right) \text{ x } e^{(16 \text{ x } Lij)/(di+dj)}$

(Alemdag, 1978) $CI3 = \sum_{j=1}^{n}\left\{\left(\frac{Lij \text{ x } di}{di + dj}\right) \text{ x } \left[\frac{di/Lij}{\sum\left(di/Lij\right)}\right]^2\right\}$

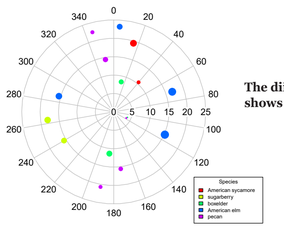
Distance-Independent Competition Indices

(Tomé & Burkhart, 1989) $CI4 = \frac{di}{d_{max}}$

(Tomé & Burkhart, 1989) $CI5 = \frac{gi}{g}$

(Tomé & Burkhart, 1989) $CI6 = \frac{gi}{g_{max}}$

Where:
CI1, CI2,..., CI6 are competition indices; i, target tree; j, neighboring tree; di, dbh of target tree (cm), dj, dbh of neighbor tree (cm); gi, basal area of target tree (m^2); dmax, maximum dbh of the tree with the largest diameter in the sample plot; g, mean basal area of sample plot (m^2 ha^{-1}); gmax, basal area of the thickest diameter in the sample plot (m^2); gj, basal area of neighbor trees, Lij, distance between target and the neighboring trees (m); RMSE = root mean squared error; Yi, observed value; $\hat{Y}$, predicted value from the model; n, sample size; d1, initial dbh and d2 last dbh measurement; ni, time (years) between the two measurements.



The diiferent point sizes shows variation in dbh

Figure 1. Stem map to visualize tree distribution within one of the plots.

RESULTS

Table 1. Contribution of distance-dependent indices to diameter growth

Year	CI Model	RMSE	RMSE (%)	Bias	Bias%	R2	p-value	Sig. (∝ =. 0 5
2009	CI1	0.1287	73.06	-3.8145×10^{-13}	-2.1655×10^{-10}	1.574×10^{-05}	0.01155	***
	CI2	0.1287	73.06	-3.8161×10^{-13}	-2.1665×10^{-10}	2.012×10^{-05}	0.004302	***
	CI3	0.1287	73.06	-3.8159×10^{-13}	-2.1663×10^{-10}	1.026×10^{-05}	0.04142	***
2010	CI1	0.1572	80.22	1.0202×10^{-13}	5.2068×10^{-11}	6.102×10^{-08}	0.8905	-
	CI2	0.1572	80.22	1.0198×10^{-13}	5.2048×10^{-11}	1.194×10^{-05}	0.05408	-
	CI3	0.1572	80.22	1.0203×10^{-13}	5.2075×10^{-11}	2.261×10^{-07}	0.9332	-
2011	CI1	0.1820	90.73	7.4237×10^{-14}	3.5457×10^{-11}	1.279×10^{-05}	0.02556	***
	CI2	0.1820	90.73	7.4290×10^{-14}	3.5481×10^{-11}	1.556×10^{-05}	0.01377	***
	CI3	0.1820	90.73	7.4132×10^{-14}	3.5406×10^{-11}	1.217×10^{-05}	0.02942	***
2012	CI1	0.2084	85.12	-1.3689×10^{-13}	-5.5920×10^{-11}	2.079×10^{-05}	0.02044	***
	CI2	0.2084	85.12	-1.3682×10^{-13}	-5.5891×10^{-11}	1.786×10^{-05}	0.03168	***
	CI3	0.2084	85.12	-1.3646×10^{-13}	-5.5320×10^{-11}	1.215×10^{-05}	0.07633	-
2013	CI1	0.2202	103.81	7.748×10^{-14}	3.653×10^{-11}	5.094×10^{-06}	0.1942	-
	CI2	0.2201	103.80	7.744×10^{-14}	3.652×10^{-11}	3.284×10^{-05}	0.0009802	***
	CI3	0.2202	103.81	7.754×10^{-14}	3.656×10^{-11}	1.532×10^{-07}	0.4765	-
2014	CI1	0.2108	85.70	-3.412×10^{-14}	-1.387×10^{-11}	4.623×10^{-06}	0.5449	-
	CI2	0.2108	85.70	-3.408×10^{-14}	-1.385×10^{-11}	1.239×10^{-08}	0.975	-
	CI3	0.2108	85.70	-3.407×10^{-14}	-1.385×10^{-11}	1.094×10^{-07}	0.9258	-
2015	CI1	0.1554	69.79	1.434×10^{-16}	6.439×10^{-14}	0.0003814	0.7225	-
	CI2	0.1554	69.79	1.507×10^{-16}	6.765×10^{-14}	0.0004607	0.6963	-
	CI3	0.1554	69.80	1.417×10^{-16}	6.361×10^{-14}	0.8823	6.823×10^{-05}	0.8806

The competition index with the highest R-squared value is the best predictor of growth.

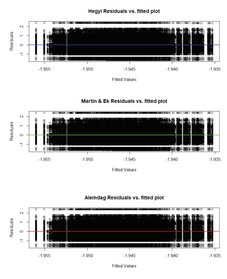


Figure 2. Residuals vs. fitted for distant dependent indices.

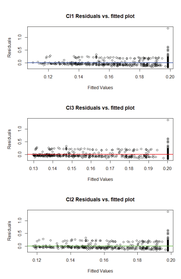


Figure 3. Residuals vs. fitted for distant independent indices.

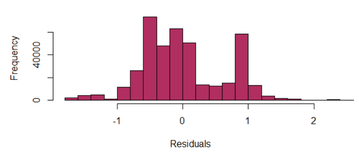


Figure 4. Histogram for distance-dependent competition indices.

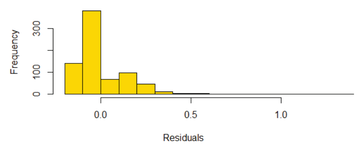


Figure 5. Histogram for distance-independent competition indices.

Table 2. Contribution of distance-independent indices to diameter growth

Year	CI Model	RMSE	RMSE (%)	Bias	Bias%	R2	p-value	Sig. (∝ =. 0 5
2009	CI4	0.1315	73.05	-3.800×10^{-16}	-2.112×10^{-13}	0.03378	3.876×10^{-07}	***
	CI5	0.1315	73.09	-1.474×10^{-16}	-8.190×10^{-14}	0.03288	5.571×10^{-07}	***
	CI6	0.1314	73.01	2.57×10^{-17}	1.428×10^{-14}	0.03484	2.531×10^{-07}	***
2010	CI4	0.1490	78.15	-3.108×10^{-16}	-1.63×10^{-13}	0.02362	1.088×10^{-05}	***
	CI5	0.1490	78.14	-2.005×10^{-16}	-1.052×10^{-13}	0.02363	1.082×10^{-05}	***
	CI6	0.1490	78.18	1.299×10^{-18}	6.813×10^{-16}	0.02279	1.56×10^{-07}	***
2011	CI4	0.1855	90.88	5.638×10^{-16}	2.762×10^{-13}	0.03073	1.035×10^{-06}	***
	CI5	0.1853	90.82	7.4290×10^{-14}	3.5481×10^{-11}	0.03209	5.932×10^{-07}	***
	CI6	0.1854	90.86	7.4132×10^{-14}	3.5406×10^{-11}	0.03113	8.788×10^{-07}	***
2012	CI4	0.2256	89.00	-3.721×10^{-15}	-1.468×10^{-12}	0.01511	0.00193	***
	CI5	0.2232	88.06	-2.037×10^{-15}	-8.038×10^{-13}	0.03579	1.607×10^{-06}	***
	CI6	0.2256	89.02	-2.745×10^{-15}	-1.083×10^{-12}	0.01469	0.002232	***
2013	CI4	0.2129	103.39	-5.085×10^{-16}	-2.469×10^{-13}	0.005345	0.0569	-
	CI5	0.2116	102.74	-1.847×10^{-16}	-8.969×10^{-14}	0.01786	0.0004801	***
	CI6	0.2129	103.37	-2.69×10^{-16}	-1.310×10^{-13}	0.005677	0.04971	***
2014	CI4	0.2100	88.86	-7.055×10^{-16}	-2.984×10^{-13}	0.01074	0.04547	***
	CI5	0.2112	89.33	-4.465×10^{-19}	-1.889×10^{-16}	0.0002507	0.7605	-
	CI6	0.2099	88.81	-4.153×10^{-16}	-1.757×10^{-13}	0.01196	0.03477	***
2015	CI4	0.1625	68.61	-1.049×10^{-16}	-4.426×10^{-14}	0.02289	0.4513	-
	CI5	0.1643	69.36	-3.238×10^{-17}	-1.367×10^{-14}	0.001457	0.8501	-
	CI6	0.1625	68.61	-6.733×10^{-17}	-2.842×10^{-14}	0.02289	0.4513	-

The competition index with the highest R-squared value is the best predictor of growth.

FURTHER WORK

- We are working on expanding to other indices such as crown-based competition indices and mixed-effects models to incorporate crown characteristics of trees, account for both fixed effects (site factors and climate variables) and random effects (plot-level or tree-level variation) on tree growth.
- We will expand the data to further explore the FIA for United States and the Canadian Forest Resource Data System.

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