Integrating the intra- and inter-species-groups competition effects into an individual diameter at breast height growth model for mixed-species forests in Mexico

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Introduction

Individual distance-dependent modeling approach was used to model the growth of diameter at breast height (*dbh*) and to evaluate neighborhood effects for four species groups in natural mixed-species stands in Durango Mexico. Twenty-two species were grouped into four species groups; *Pinus* (**P**; seven species), other conifers (**OC**; three species), other broadleaves (**OB**; four species), and *Quercus* (**Q**; eight species). Four methods were used to select neighboring trees and 12 competition indices (CIs) were calculated. Several assumptions such as nonequivalent neighborhood effects were tested using the model approach.

Materials and methods

Study area and data

The data came from 44 stem-mapped re-measurement plots in two forest polygons: San Diego de Tezains Ejido and Lobos & Pescaderos Community. The plots were distributed in a systematic grid of 3 km × 3 km and measured in 2008 and were re-measured in 2013 (Figure 1).
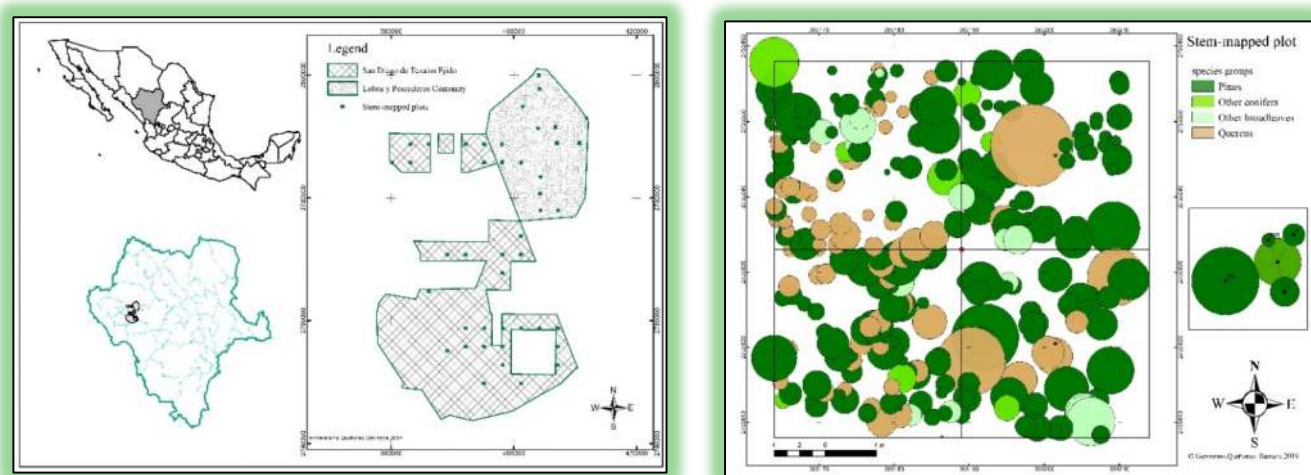

Figure 1. Study area and locations of the 44 stem-mapped plots in Durango Mexico (left side) and trees distribution in a stem-mapped plot (right side).

Distance-dependent competition indices

A crown-overlapping distance-weighted size ratio (SR) index (Tomé and Burkhart 1989) was used to calculate Cis:

$$CI = \sum_{j=1}^{n} R_{ij} f(S_{ij}) \qquad (1)$$

where n is the number of competitors of a subject tree i, R_{ij} is the size ratio between the subject tree i and its jth neighbor tree, and $f(S_{ij})$ is a function of the distance (S_{ij}) between the subject tree i and its neighbor tree j.

The combinations of three SRs (*dbh*, *height* and *crown width* ratios) and four distances functions ($1/S_{ij}$, $1/S_{ij}^2$, $e^{S_{ij}}$, and $1 - e^{S_{ij}}$) resulted in 12 CIs. The preliminary analysis showed that the following five CIs were better:

$$CI1 = \sum_{j=1}^{n} \frac{dbh_j}{dbh_i} \frac{1}{S_{ij}} \qquad (2)$$

$$CI4 = \sum_{j=1}^{n} \frac{dbh_j}{dbh_i} \left(1 - e^{S_{ij}}\right) \qquad (3)$$

$$CI7 = \sum_{j=1}^{n} \frac{h_j}{h_i} e^{S_{ij}} \qquad (4)$$

$$CI8 = \sum_{j=1}^{n} \frac{h_j}{h_i} \left(1 - e^{S_{ij}}\right) \qquad (5)$$

$$CI9 = \sum_{j=1}^{n} \frac{Cw_j}{Cw_i} \frac{1}{S_{ij}} \qquad (6)$$

The neighbor trees for a given subject tree were defined as follows:

$$N_j = \begin{cases} 1 \text{ if } S_{ij} < \left(\frac{\delta C w_i}{2} + \frac{\delta C w_j}{2}\right) \\ 0 \qquad\qquad\qquad \text{Otherwise} \end{cases} \qquad (7)$$

where N_j is the neighbor tree for the subject tree i and δ could be 1.0, 1.5, 2.0, or 2.5.

Table 1: The number of subject trees and neighboring trees by species groups and values of δ

Species group	subject trees	Neighbors			
		$\delta = 1.0$	$\delta = 1.5$	$\delta = 2.0$	$\delta = 2.5$
P	3203	11881	**16708**	19198	21954
OC	256	849	**1183**	1326	1446
OB	182	758	**1032**	1153	1315
Q	1192	4568	**6240**	7149	8150
Total	4833	18056	**25163**	28826	32865

Individual tree dbh growth model without explicitly age was developed, based on the Chapman-Richards equation (Richards, 1959).

$$dbh_{(1+a)} = \alpha_0 \left[1 - e^{-\alpha_1 a} \left(1 - \left(\frac{dbh_1}{\alpha_0}\right)^{1/\alpha_2}\right)\right]^{\alpha_2} \qquad (8)$$

where a is the time interval between measurement and re-measurement (5 years), α_i are parameter to be estimated.

Adding neighborhood effects and error term resulted in the following full model:

$$dbh_{ik(1+a)} = \alpha_{i0} \left[1 - e^{-\alpha_{i1} a} \left(1 - \left(\frac{dbh_1}{\alpha_{i0}}\right)^{1/\alpha_{i2}}\right)\right]^{\alpha_{i2}} + \sum_{j=1}^{n} \beta_{ij} CI_{ijk(1)} + \varepsilon_{ik(1+a)} \qquad (9)$$

where $dbh_{ik(1+a)}$ is the dbh of the kth subject tree in the ith species group at measurement $(1+a)$, $CI_{ijk(1)}$ are the competition indices calculated for subject tree k of species group i from its neighbors that belong to species group j, and $\varepsilon_{ik(1+a)}$ is the error for the kth tree of the species group i.

Due to the convergence problem, the α_o´s were fixed as 97.7 cm, 73.3 cm, 68.2 cm, 90.0 cm, the largest **dbh,** for species groups P, OC, OB, and Q, respectively.

Results

Table 2: Parameters estimates and their standard errors (SE) and fitting statistics of dbh growth model without competition effects

species group	Parameter	Estimate	SE	RMSE	R²	AIC	LL
P	α_1	0.0066	0.0003	1.2602	0.9819	10935	-5462
	α_2	1.3838	0.0661				
OC	α_1	0.0042	0.0009	1.2972	0.9773	935	-463
	α_2	0.7374	0.0879				
OB	α_1	0.0072	0.0015	1.3326	0.979	627	-309
	α_2	0.9963	0.1703				
Q	α_1	0.0093	0.0007	1.0918	0.9897	3709	-1849
	α_2	4.1389	1.1978				

Table 3: The log-likelihood of equivalent-neighborhood-effects models by species group and CI

species group	Equivalent neighborhood effects (all combined species groups)				
	CI1	CI4	CI7	CI8	CI9
P	(−5458)*	(−5452)*	(−5456)*	(−5462)	(−5460)*
OC	(−461)*	(−461)*	(−463)	(−463)	(−463)
OB	(−303)*	(−305)*	(−309)	(−309)	(−306)*
Q	(−1849)	(−1849)	(−1849)	(−18475)*	(−1849)

Red, green, and yellow colors represents negative, positive and null equivalent neighborhood effects.

Table 4: The log-likelihood of nonequivalent-neighborhood-effects models by each species group and by CI

Species group	Nonequivalent neighborhood effects																			
	CI1				CI4				CI7				CI8				CI9			
	P	OC	OB	Q	P	OC	OB	Q	P	OC	OB	Q	P	OC	OB	Q	P	OC	OB	Q
P		(−5448)*				(−5454)*				(−5452)*				(−5455)*				(−5456)*		
OC		(−461)				(−460)				(−463)				(−463)				(−463)		
OB		(−302)*				(−305)*				(−309)				(−307)*				(−307)		
Q		(−1849)				(−1849)				(−1849)				(−1844)*				(−1849)		

* indicates that nonequivalent-neighborhood-effects model was better than equivalent-neighborhood-effect model.

Conclusions

Nonequivalent neighborhood effects assumption was supported. The negative con-group neighboring effects existed for all species groups, except for *Quercus*. All detectable hetero-group effects were negative, except that species group *Pinus* had positive effects on species group *Quercus*.

Literature cited

Tomé M, Burkhart HE (1989) Distance-dependent competition measures for predicting growth of individual trees. Forest Science 35:816–831.

Richards F (1959) A flexible growth function for empirical use. Journal of Experimental Botany 10:290–301.