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INTRA-AND INTERSPECIFIC COMPETITION OF ENDANGERED PLANT *TETRACENTRON SINENSE* OLIV.

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Abstract

Tetracentron sinense Oliv., is the East Asian endemic species, broad-leaved tree distributed in south-central China. The current intra- and interspecific competition of *T. sinense* is unknown, but is vital to its conservation. Based on a field investigation of 56 subject trees and 626 associated trees in *Tetracentron sinense* communities, the intra- and interspecific competition intensity of *T. sinense* was analyzed using the competition indices model for individual tree. The intraspecific competition index of *T. sinense* (53.10) was far less than the interspecific competition index (170.50), indicating a striking effect of interspecific competition. At the community level, the maximum competition intensity was detected for intraspecific competition of *T. sinense*, followed by that of *Pterocarya stenoptera*, *Acer pictum*, *A. franchetii*, *Davidia involucrata*, *Padus brunnescens*, *Cercidiphyllum japonicum*, *Bothrocaryum controversum*, *Betula utilis*, and *Euptelea pleiospermum*, whereas the minimum intensity was in *Aesculus wilsonii*. The competition intensity of *T. sinense* decreased inversely with increasing diameter at breast height (DBH) above 20 cm. The relationships between the competition intensity and DBH of *T. sinense* individuals followed the strength function ($CI = AD^{-B}$), which could effectively predict the intra- and interspecific competition intensities of this species. To promote natural regeneration of *T. sinense* populations, forest gaps should be introduced to stimulate seed germination, and selective cutting of rival trees should be adopted at DBH < 20 cm to lessen interspecific competition. It provides a theoretical basis for revealing the community status of endangered plants and predicting the development trend of population competition.

Key words: Competition indices model for individual tree; Interspecific competition; Intraspecific competition; *Tetracentron sinense* Oliv.

Introduction

The growth and development of trees are generally affected by the combined effects of biotic and abiotic factors, in which the competition among individual trees is a fundamental ecological process that plays a major role in population dynamics, survival, structural composition and species replacement (Bella 1971, Peet & Christensen, 1987, Weiner 1990). By definition, competition is an interaction between individuals, which has an impact on the growth and development of individuals, reproduction of offspring, and population development (Begon *et al*., 1996). The inter- and intraspecific competition in plants is pervasive and an important element of plant growth, morphology, and survival (Yokozawa *et al*., 1998, Duan *et al*., 2008, Huang *et al*., 2016). At present, competition is considered to be a key factor in shaping the structure and dynamics of forests, and has become one of the core issues in plant ecology research (Duan & Wang, 2005). Many competitive index models have been developed to describe the intra- and inter-species competition of different species (Zou & Xu, 1998, Duan & Wang, 2005, Wang *et al*., 2013, Xiang & Wu, 2015, Huang *et al*., 2016). The competition index model for individual tree proposed by Hegyi (1974) reflects the relationship between the growth demand and occupation of individual trees for resources (Xiang & Wu, 2015). The model has been recently applied in the evaluation of inter- and intraspecific competition relationships between many endangered plants and their associated species (Xu & Liu, 2018, Liu & Li, 2020). The knowledge of inter- and intraspecific competition is of great significance for effective species conservation and management.

Tetracentron sinense Oliv., the species in the Trochodendraceae, is a tall deciduous tree mainly distributed in the central and southwest regions of China (Fu, 1992, Luo *et al*., 2010).

Owing to extensive deforestation and exploitation of the species, this tree is found just deep in the mountains, in valleys or on steep cliffs. Under natural conditions, *T. sinense* seedlings are scarce, resulting in poor natural regeneration. The species is listed as a national secondary key protection plant in China (Fu, 1992) and registered in CITES Appendix III (https://cites.org/eng/node/41216). Reproduction and development (Gan *et al*., 2012), pollination characteristics (Gan *et al*., 2013), the community structure and niche (Tian *et al*., 2018)), seed and seedling ecology (Li *et al*., 2015, Xu, 2016, Han *et al*., 2017, Wang *et al*., 2017), and conservation genetics (Li *et al*., 2018; Li *et al*., 2021) have been studied to explore the conservation strategies and factors contributing to the endangered status of various species. Tian *et al*., (2018) found relatively high niche overlaps among *T. sinense* and its associated tree species, indicating a strong interspecific competition between these species. However, the intensity of inter- and intraspecific competition and its influence on natural regeneration of *T. sinense* populations are yet unclear.

In this study, the inter- and intraspecific competition of *T. sinense* was studied in the Meigu Dafengding Nature Reserve in southwest China using the competition index model for individual tree. The aims of the study were: (1) to evaluate the competitive power of *T. sinense* to its associated dominant tree species, (2) to discuss the factors limiting the natural regeneration of *T. sinense*, and (3) to provide effective strategies for conservation and management of *T. sinense* in natural populations.

Materials and Methods

Area of study: The study was carried out in the Meigu Dafengding of Nature Reserve (MDNR, 102°52′–103°20′N, 28°30′–28°50′E), which lies on the southwest of Sichuan Province, at the junction of the Hengduan Mountains in the southeast of the Qinghai–Tibet Plateau and the southwest edge of the Sichuan Basin. The reserve is influenced by the subtropical monsoon climate, and the mean annual rainfall is 1,110 mm. Average annual temperatures is 11.4 ° C, the hottest months is July (19.5°C), average annual relative humidity is about 80%. The *T. sinense* communities in the reserve are distributed in the mixed evergreen and deciduous broadleaved forests at an altitude of 2,000-2,400 m. The associated tree species in those communities include *Acer franchetii*, *Pterocarya stenoptera*, *Davidia involucrata*, *A. pictum*, *Padus brunnescens*, *Cercidiphyllum japonicum*, *Bothrocaryum controversum*, and *Euptelea pleiospermum*, whereas the undergrowth shrub layer is composed of *Ribes nigrum*, *Viburnum betulifolium*, *Lindera limprichtii*, *Berberis diaphana*, and *Spiraea salicifolia*. The herbaceous layer includes *Pilea notata*, *Oxalis acetosella*, *Mentha haplocalyx*, *Fragaria orientalis*, and *Elatostema involucratum*.

Field investigation: Because *T. sinense* is sparse and infrequently distributed in the MDNR, we selected 10 plots of 20 m × 20 m after a comprehensive survey of the area to investigate the intra- and interspecific competitive power in *T. sinense* community from July to August 2015. All *T. sinense* trees with a height >130 cm in the sample plots were tagged and considered as subject trees. The diameter at breast height (DBH), height, clear length, crown width, and seed setting was recorded for each objective tree.

Following the methods described by Liu & Liao (2010) and Xiang & Wu (2015), the competitive scope was determined based on the radius of the forest gap, the influencing range of upper trees, and the height and crown width of trees in sample plots. Field investigations verified that the radius of *T. sinense* gaps was about 6 m. therefore, all trees with DBH > 5 cm in a sample circle with 6 m radius were chosen as competitor trees. The competitor trees were identified, and their DBH, height, and distance from objective trees was measured.

Data analysis

In this study, the competition model for individual tree proposed by Hegyi was used to calculate the intraspecific competition intensity as follows:

$$CI = \sum_{j=1}^{N} D_j D_i^{-1} L_{ij}^{-1},$$

where CI is the competition index, D_j and D_i are DBH of the competitor and objective trees, respectively, L_{ij} is the distance between the objective tree and the competitor tree, and N is the number of competitor trees.

First, we calculated the competition index of each competitor tree to the subject tree, and the obtained competition indices of N competitive trees were added up to obtain the competition intensity of *T. sinense* and its associated tree species (Liu *et al.*, 2010, Maleki *et al.*, 2015, Xiang & Wu, 2015).

All data statistics were completed in Excel 2013, and data analysis was conducted in Origin 2017 64Bit (OriginLab, Northampton, Massachusetts). Regression analysis was used to evaluate the relationship between DBH and the competition index of object trees.

Results

Intraspecific competition: A total of 56 objective individuals (*T. sinense*) was recorded in 10 plots, with the average DBH of 27.26 cm, the minimum of 5.10 cm, and the maximum of 70.00 cm (Table 1, Fig. 1). The proportion of *T. sinense* with medium and small diameter class was higher, and the objective trees with DBH < 30 cm accounted for 67.86 %, indicating a prevalence of younger trees. The intensity of intraspecific competition in *T. sinense* was 53.10, accounting for 23.75 % of the total competition intensity (223.60), and it was far less than the interspecific competition intensity (170.50).

The intraspecific competition intensity of *T. sinense* was correlated with the diameter size and individual number. The competition intensity of the small- and medium-diameter trees was relatively higher and increased with the increasing number of the individuals. As the diameter class increased, the average *CI* decreased significantly (r = 10.846, p = 0.016). At DBH ≤ 20 cm, the intraspecific *CI* for each diameter class was greater than 18, and the total *CI* reached 43.81, accounting for 82.50 % of the total competition intensity (223.60). At DBH > 20 cm, the intraspecific *CI* for each diameter class was less than 6 (Table 1).

Table 1. The intraspecific and interspecific competition intensity of *T. sinense*.

Diameter-classes (cm)	Objective tree		Intraspecific competition index		Interspecific competition index	
	Number	Percentage (%)	CI	Average of CI	CI	Average of CI
≤10	10	17.86	25.02	2.50	84.47	8.45
10-20	20	35.71	18.79	0.94	61.67	3.08
20-30	8	14.29	5.59	0.70	11.20	1.40
30-40	3	5.36	1.21	0.40	4.65	1.55
40-50	5	8.93	1.26	0.25	3.74	0.78
50-60	4	7.14	0.53	0.13	1.88	0.47
60-70	6	10.71	0.69	0.11	2.89	0.48
Total	**56**	**100.00**	**53.10**		**170.50**	

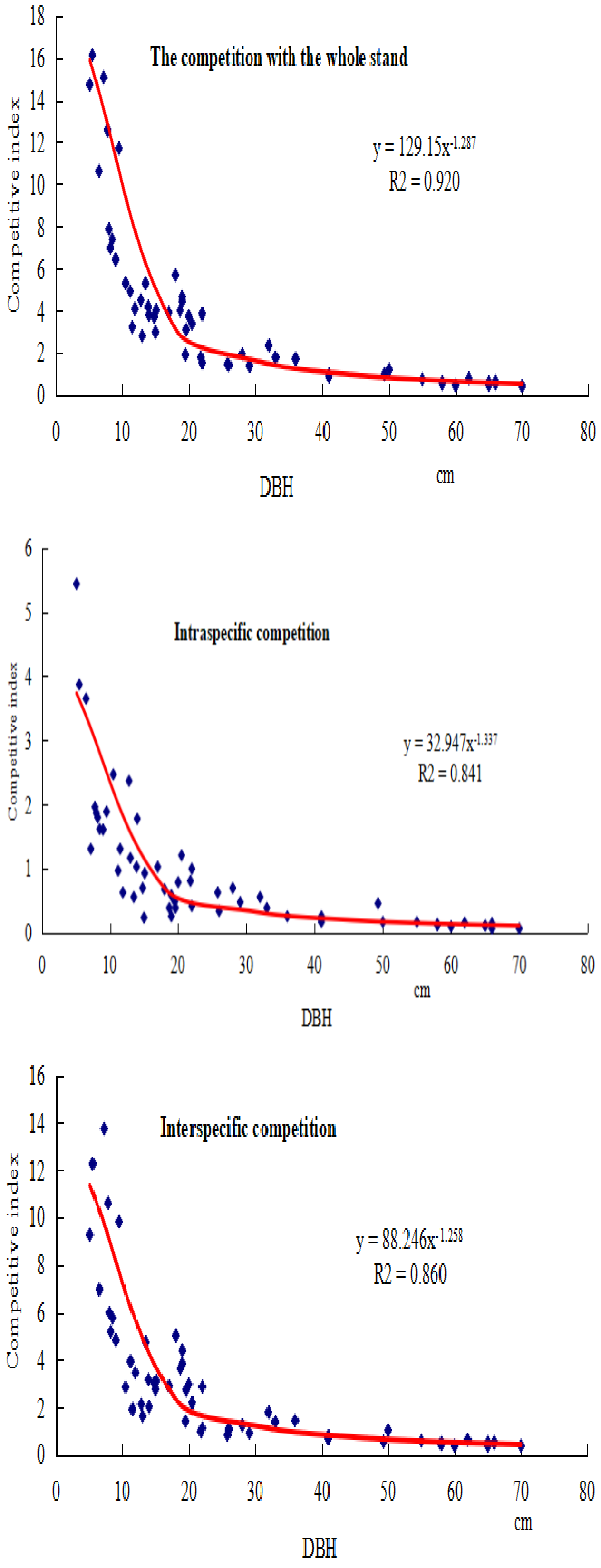

Fig.1. Regression curves of competition index and the DBH of *T. sinense*.

Interspecific competition: In the *T. sinense* communities, the associated tree species were relatively abundant, and the dominant competitor tree species included the following 11 species (Table 2). A total of 12 species and 682 competing trees were investigated in this study, and the total interspecific competition intensity of *T. sinense* was 223.60 (Table 2).

Interspecific competition intensity of *T. sinense* increased significantly with an increase in average DBH ($r = 0.624$, $P = 0.030$) and individual number ($r = 0.681$, $P = 0.015$) of competitor trees. Interspecific competition intensity of *T. sinense* was significantly different from that of other competitor tree species. The species with the greatest competition intensity was *T. sinense* ($CI = 53.10$), followed by *Pterocarya stenoptera* ($CI = 33.79$). The minimum competition intensity was calculated for *Aesculus wilsonii* ($CI = 0.041$). In addition, *Acer pictum* and *Davidia involucrata*, both with greater size and individual number, had a relatively strong competitive power against *T. sinense* ($CI = 26.39$ and $CI = 23.39$, respectively); despite their smaller size, *Acer franchetii* and *Padus brunnescens* had a strong impact on *T. sinense* ($CI = 24.66$ and $CI = 20.41$, respectively) owing to their greater individual number. The interspecific competition of *T. sinense* against dominant associated trees decreased from *Pterocarya stenoptera* to *Acer pictum*, *A. franchetii*, *Davidia involucrata*, and *Padus brunnescens.*

Relationship between the DBH of objective tree and competition intensity: The relationship between the size of *T. sinense* objective trees and competitive intensity was assessed by curve fitting using the DBH of objective trees as an independent variable and logarithmic, linear, hyperbolic, and power regression analysis. The greatest correlation coefficients were obtained by the power model (Fig. 1), indicating that that the power regression model best described the relationship:

$$\mathrm{CI} = AD^{-B},$$

where CI is the competition index, D is the DBH of objective tree, and A and B are model parameters (Wang *et al.*, 2013).

We analyzed the relationship between DBH of the objective tree and the competition indices of the total stand, intraspecies, and interspecies for the 56 *T. sinense* trees. The results showed that the competition index gradually decreased with increasing DBH of the objective tree. With the DBH of the objective tree at less than 20 cm, the competitive pressure was relatively strong, whereas at DBH larger than 20 cm, and the intensity of competition tended to stabilize.

The test of significance confirmed a significant correlation between DBH and all competition levels (Table 3), and the power model was therefore used to simulate and predict the intensity of intra- and interspecific competitions (Table 4). The simulations predicted a gradual decrease in the intra- and interspecific competition intensity with increasing DBH of *T. sinense*. At DBH of *T. sinense* greater than 20 cm, the competition index varied weakly, which was in agreement with the previous results (Table 1). The selected model can predict the intra- and interspecific competition of *T. sinense*.

Table 2. Competitive tree species and their competitive indices.

Species	Competitive tree					
	Number	**Percentage (%)**	**Average DBH**	**CI**	**Average of CI**	**Ranking of CI**
T. sinense	56	8.21%	25.23	53.10	0.95	1
Pterocarya stenonptera	121	17.74%	12.80	33.79	0.28	2
Acer pictum	95	13.93%	17.30	26.39	0.28	3
Acer franchetii	158	23.17%	13.32	24.66	0.17	4
Davidia involucrata	98	14.37%	20.86	23.39	0.24	5
Padus brunnescens	78	11.44%	15.12	20.41	0.26	6
Ceridiphyllaceae japonicum	31	4.55%	19.93	19.62	0.63	7
Bothrocaryum controversum	21	3.08%	25.40	13.48	0.64	8
Betula utilis	8	1.17%	22.60	4.64	0.58	9
Euptelea pleiospermum	8	1.17%	28.03	2.95	0.37	10
Decaisnea insignis	4	0.59%	19.40	0.76	0.19	11
Aesculus wilsonii	4	0.59%	10.30	0.41	0.1	12
Total	**682**	**100%**		**223.60**		

Table 3. Model parameters of competition intensity and DBH of objective tree.

Item	Sort			
	A	***B***	R^2	**Significance**
T. sinense and forest	129.153	2.87	0.920	P<0.01
Intraspecific in *T. sinense*	32.947	1.337	0.841	P<0.01
T. sinense and other species	88.246	1.258	0.860	P<0.01

Table 4. Model prediction of interspecific and intraspecific competition intensity and DBH.

Item	Diameter scale (cm)						
	≤10	**10-20**	**20-30**	**30-40**	**40-50**	**50-60**	**60-70**
T. sinense and forest	6.67	2.73	1.62	1.12	0.84	0.66	0.55
Intraspecific in *T. sinense*	1.52	0.60	0.35	0.24	0.18	0.14	0.11
T. sinense and other species	4.87	2.04	1.22	0.85	0.64	0.51	0.42

Discussion

Competition is a widespread phenomenon in the plant kingdom. Plants compete primarily for living resources and space above ground and underground (Xiang & Wu, 2015). The competition index model for individual tree proposed by Hegyi (1974) describes the competition intensity of plants to living resources and space (Zhang, 1993, Wang *et al*., 2013), and it is commonly used to define the intra- and interspecific competition. This model was used to study the intra- and interspecific competition of *T. sinense* in the MDNR. The intraspecific competition of *T. sinense* (*CI* = 53.10) was far less than its interspecific competition (*CI* = 170.50), indicating that *T. sinense* in the MDNR was exposed primarily to competition from other species; similar results were reported for *Pinus dabeshanensis* (Xiang & Wu, 2015) and *Taxus yunnanensis* (Li & Xu, 2013) that are endangered species as well (Liu & Ma, 2020). The small abundance of endangered plants in natural communities may thus contribute to competition pressure, mainly interspecific (Xu & Liu, 2018, Liu & Ma, 2020).

Competition is influenced by the size, quantity, and species of competitive trees (Xu & Liu, 2018). Interspecific competition ability is mainly attributed to ecological habit and ecological amplitude of the species. Different plant species with similar ecological habits tend to compete more intensely because of similar requirements for resources and spatial utilization. A dominant species in an ecosystem will exhibit the strongest competitive ability and the least competition pressure (Zhang & Hang, 2006). In the *T. sinense* communities surveyed in the present study, 12 tree species competed for space and resources. Among them, *Pterocarya stenoptera*, *Acer pictum*, *A. franchetii*, *Davidia involucrata*, and *Padus brunnescens* were the main species competing with *T. sinense* in the MDNR. Having the largest average DBH and greater abundance, *T. sinense* was dominant in the communities, indicating that the largest competition pressure stemmed from the intraspecific competition. Although *Pterocarya stenoptera* and *Acer franchetii* had smaller DBH, their greater abundance in the communities placed them at the second and fourth most influential species in the interspecific competition.

The model predicted a decrease in the competition intensity with the increase in *T. sinense* DBH, which was in accordance with the power function relation (Hegyi, 1974, Mao & Yang, 2008). This result is similar to those reported for *Davidia involucrata* (Li & Su, 2006), *Pteroceltis tatarinowii* (Zhang *et al*., 2012), *Taxus yunnanensis* (Li & Xu, 2013 2013), *and Pinus dabeshanensis* (Xiang & Wu, 2015). The competitive pressure on *T. sinense* was greater at DBH less than 20 cm, and it gradually decreased as the DBH of *T. sinense* increased above 20 cm, eventually leveling down with further increase in DBH. This may be due to the different adaptability of different age-class individuals of *T. sinense* younger individuals usually occupy the lower and middle layers of communities, and have a relatively weak competitive power for light, water, and other resources, resulting in intense competition from associated trees, especially from *Pterocarya stenoptera*. With their continuous growth, *T. sinense* gradually occupy the upper tree layer, increasing their dominance in the communities and enhancing their competitive ability for resources, thereby weakening the competitive pressure.

Previous studies have shown that a lower conversion rate from seeds to seedlings in *T. sinense* natural populations leads to scarcity of younger age classes, decreased population size, and eventually endangered status (Lu *et al.*, 2020). During the field investigations in the MDNR, we encountered very few seedlings and young trees, but many adult individuals in the existing *T. sinense* populations, which indicated an incomplete age structure of the populations (Li *et al.*, 2020). Considering the light requirements for *T. sinense* seed germination, forest gaps should be created to promote the establishment of young seedlings and increase the population size. According to the model predictions about the correlation between the competition intensity and DBH of objective trees, selective cutting of competitor trees should be adopted in stands of *T. sinense* individuals with DBH less than 20 cm in order to promote their growth. Selective cutting will enlarge the survival space and ensure that sufficient resources such as light, temperature, and water, are available to the *T. sinense* individuals, which will promote the normal growth of small- and medium-sized individuals and support the regeneration of the natural forest.

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