SPATIAL STRUCTURE OF NEIGHBOURHOODS OF SMALL AND LARGE TREES IN GAMBARI NATURAL FOREST RESERVE, NIGERIA

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ABSTRACT

Structure of forest is spatially and temporally dynamic and therefore, effective prediction of structural diversity is difficulty. Correlation between spatial species diversity and size inequality regulates structure of tree community. Hence, estimation of tree structure around small and large tree sizes will provide understanding on process regulating tree distribution in Gambari Natural Forest Reserve. Therefore, the study was designed to investigate neighbourhood structure of small and large trees in Gambari Natural Forest Reserve, Oyo State. Two parallel line transects ranged 800 m to 1km long separated by 50 m were demarcated in Gambari Natural Forest Reserve. At least, four (30m x 30m) sample plots were established systematically on each transect. Minimum and Maximum DBH stems were selected at the centre of the plots, designated as Small and Large reference trees, respectively. A circular subplot (radius=10m; 314.2m^2) was established around reference tree. Trees with diameter at breast height (DBH) ≥5 cm were enumerated, identified to species level, and DBH and their distances to reference tree were measured in each subplot. The species diversity indices of trees in each subplot were computed. Data collected were analysed using Descriptive statistics, Clark and Evans index. Species mingling and Diameter differentiation indices at $\alpha_{0.05.}$ A total of 26 and 21 tree species was identified in the subplots of Large and Small reference trees, respectively. The species diversity indices (H´=3.0, 1-D =0.94 and M=6.24) around Large reference trees were higher than (H´=2.69, 1-D=0.91 and M = 4.99) of Small reference trees. *Strombosia pustulata* and *Hildegardia barteri*, and *Strombosia pustulata* and *Triplochiton scleroxylon* were the dominant tree species around Large and Small reference trees, respectively. Hundred percent (100%) and (55.56%) of subplots of Large and Small reference trees expressed regular pattern at 10m distance. The proportion of heterospecifics of Large reference trees was higher than Small at highest mingling value. Smallest DBH trees were less than 50% and 40% size around Large and Small reference trees, respectively. Trees with smallest DBH were less than 50% and 40% tree size around most of Large and Small reference trees, respectively. Neighbourhood of Large reference trees exhibited structural heterogeneity than Small reference trees.

Keywords: Tree interaction, tree neighbourhood distance, tree spatial arrangement, tree species diversity

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INTRODUCTION

Structure of tree communities has been described as the horizontal and vertical distributions and the abundance of tree species (Miren *et al.*, 2004). Conversely, structure of tree distribution is spatially explicit concept for understanding heterogeneous structure of forest (Li *et al.*, 2009). Therefore, proper analysis of tree community structure must take distance and size into consideration for spatial description. Presently, description of spatial structure of trees in a forest involves three most important components; spatial pattern of tree distribution, species mingling and size differentiation. These three components shape the forest heterogeneous structures. However, species mingling is often applicable to mixed tree species communities.

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Spatial arrangement of trees in a population describes distribution pattern and the distribution may be based on species and sizes (Xin *et al*., 2022). The distribution of species and size are not regulated by the same process (Shackleton, 2002). Spatial pattern can be expressed as; aggregation, random or regular (Li *et al*. 2009) and pattern may occur at relatively short or long spatial scales. Therefore, distance at which individual pattern occur around small and large trees is yet to be investigated in Gambari Natural Forest Reserve. This is required so as to understand the processes structuring the forest. The process structuring the pattern and response of trees to pattern are control by different processes (Seifert *et al*., 2014). The assessment of response of tree to pattern is usually long term and labour intensive while process responsible for the pattern can be easily identified by one time inventory data.

Mingling is defined as the proportion of neighbouring tree species that do not belong to the same species as the reference. The proportion of species that belong to the same or different species as reference tree; refers to as con-specifics and hetero-specifics, respectively. Therefore, interaction occurs either among con-specific or hetero-specific neighbours in any community (Maleki *et al*., 2015). However, intensity of competition among con-specific or hetero-specific neighbours is not explicitly clear. According to niche theory (Bruno *et al*. 2003), tree species within the same niche space are more competitive than those in different niche spaces. However, situation become more critical when size of trees of con-specifics or hetero-specifics are not the same. Zhu *et al* (2018) and Wright, (2002) stated that understanding the mechanisms controlling trees interaction is essential to separate con-specific from hetero-specific neighbours. Therefore, size differentiation give more information on the processes operating among con-specific or hetero-specific neighbours when size of trees of con-specifics or hetero-specifics are not the same. Size of tree is essentially for resources utilization, growth and reproduction. Conversely, oftentimes trees influence immediate surrounding through their sizes and therefore create greater impact on the dynamics of neighbour trees. Small and large trees singly interact with other neighbour differently and competitive effect of this interact is not the same. Therefore, distinct neighbourhood structure may be formed around small and large trees (Chen and Bowman, 2022 and Fibich *et al*., 2021). Hence, spatial scale of tree distribution is not the same for various patterns.

Understanding the process that is maintaining high tree species coexistence and diversity can help to adopt close to nature silvicultural thinning by manipulating tree arrangement and density among neighbouring individuals so as to induce appropriate micro-habitat conditions that can facilitate suitable biological and ecological processes.

The hypotheses of this study are; Is there difference in the pattern of nearest neighbour trees of small and large trees and also, does size of tree affect nearest neighbour trees for species and size diversity. The objective was designed to investigate structure of neighbourhood trees of Small and Large trees in the study area.

MATERIALS AND METHODS

Study area

The study area was carried out in Gambari Natural forest reserve, Ibadan, Nigeria. The reserve was created by the resolution of Ibadan council on the 14th September 1899 and takes the name of Gambari a nearby village to the reserve. The reserve is located on latitude 7°25' and7°55'N and longitude 3°53' and 3°9'E (Figure 3.1). The forest reserve, which used to be part of the lowland rainforest and covers a total land area of 13932.18 hectares consisting of five zones: Mamu, Onigambari, Busogboro, Odo-Ona/Onipe, and Alonge. Gambari Forest Reserve has the average annual rainfall in the area is 1592.3mm with high relative humidity (72–86.5%) and high mean daily temperature of 30°C.

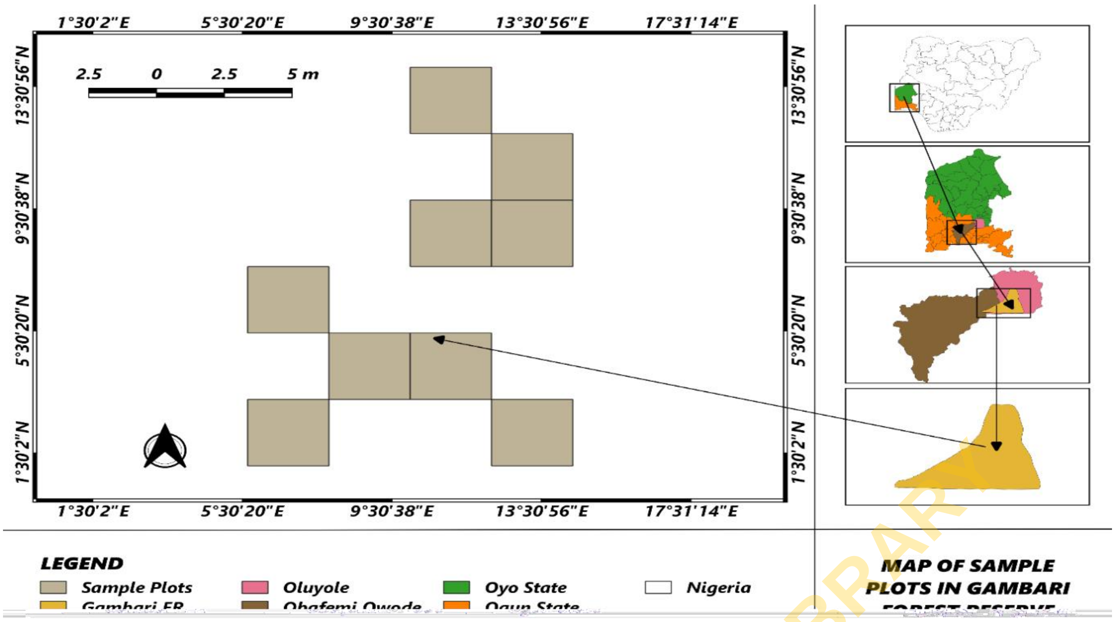

Figure **1:** Map showing the study area with the sample plots laid

Sampling design

Two (2) parallel line transacts ranged 800 m to 1km long separated by 50m were demarcated in the core zone of Gambari Natural Forest Reserve. At least, four (30m x 30m) temporary sample plots were established systematically on each line transact. The distance between the sample plots was 150 m and between the transect lines was 50 m. A total of nine (9) (30 m x 30 m) temporary sample plots were used for this study. Two trees (Maximum and Minimum diameter-at-breast height; DBH) were selected at the centre of sample plots and designed as Large and Small reference trees. A circular subplot (radius=10m; 314.2m^2) were demarcated around each of reference trees. Trees (DBH)≥5 cm) within each subplot were enumerated, identified to species level and DBH and their distances to reference tree were measured.

Data analysis

Tree species diversity Indices of Small and Large trees

Shannon-Weiner and Simpson diversity indices and Margalef index of richness were used to compute species diversity values of tree species around Large and small reference trees.

(a) Shannon-Weiner index

$$H = -\sum P_i \, lnP_i \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(1)$$

$$P_i = \frac{N}{n} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(2)$$

Where:

N = total number of individuals of species,

n = total number of individuals of all species, *ln*= natural logarithm

(b) Simpson diversity index

$$D = 1 - \sum \frac{n(n-1)}{N(N-1)} \qquad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where:

n = the total number of individual of a particular species

N = the total number of individual of all species

(c) Margalef's index of species richness: It represents the distribution of number of individuals of the tree species. Margalef's index of richness (M) is express as:

$$M = \frac{(S-1)}{lnN} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (4)$$

Where;

S = Total number of species in the community, N= Total number of all individual trees

ln = Natural logarithm

Clark and Evans index was used to determine the spatial pattern of trees at 10 m radius around Large and Small reference trees (Clark and Evans, 1954; Dayong, 1990 and it is express as:

$$C - E = \frac{rA}{rE} = \frac{\frac{1}{N}\sum_{i=0}^{n} 1ri}{0.5*\left(\frac{A}{N}\right)1/2+0.0514*\frac{P}{N}+0.041*\frac{P}{N^{3}/_{2}}} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (5)$$

Where r_a is the mean observed nearest neighbour distance

r_e is the expected mean nearest neighbour distance given random dispersion

r_i is the distance between tree I and its nearest neighbour (in m)

N is the total number of trees in the sample plot

Mingling index was used to determine number of tree species that are similar to the reference trees.

The mingling index M_i is the mean heterospecific fraction of plants among the k nearest neighbours of a reference tree i. It was used to distinguish between con- and hetero-specific neighbours of reference tree. It is expressed as:

$$M_i = \frac{1}{k}\sum_{j=1}^{k} 1(\text{species}_i \neq \text{species}_j) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (6)$$

Also expressed as;

$M_i = \frac{1}{k}\sum_{j=1}^{k} v_j$ (Aguirre *et al*., 2003)

Where,

K= number of nearest neighbours, i= the reference tree, j= neighbour tree

v_j= when the value equals 1, neighbour j belongs to the same species as reference tree i when it is 0, they are not of the same species

According to von Gadow (1993), size differentiation is defined as the mean ratio of smaller and larger tree sizes of the k nearest neighbours subtracted from one. It is expressed as:

$$T_{i=}\ T_i = 1 - \frac{1}{k}\sum_{j=1}^{k}\frac{\min DBH}{\max DBH} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (7)$$

RESULT

The mean diameter of trees around Large reference trees (94.25±8.87cm DBH) was higher than Small reference trees (87.27±9.45cm DBH) (Table 1). The diameter distribution of trees around Large reference trees ranged from 11.00 to 330.00 cm DBH while Small reference trees ranged from 14.20 to 285.00 cm DBH. The skewness and coefficient of variation of diameter distribution of trees around Small reference trees (1.58 and 10.83%, respectively) were higher than Large reference trees (1.12 and 9.42%). The diameter distribution of trees around Small reference trees ranged from 14.20 to 285.00 cm DBH while Large reference trees ranged from 11.0 to 330.00 cm DBH.

Table 1: Descriptive statistics of tree diameter around Large and Small reference trees in Gambari Natural Forest Reserve.

	cm DBH			Skewness	Coefficient of variation
	Mean	Minimum	Maximum		
Large reference trees	94.25±8.87	11.00	330.00	1.12	9.42 %
Small reference trees	87.27±9.45	14.20	285.00	1.58	10.83%

The species diversity around Large and Small reference trees in Gambari Natural Forest

A total of 26 and 21 tree species were identified around Large and small reference trees, respectively. The values of Shannon-Weiner, (H´); Simpson, (1-D); and Margalef, (M) of tree species around Large reference tree (0.94; 3.00 and 6.23, respectively) were higher than Small reference tree (0.91; 2.64 and 4.99, respectively) (Table 2). *Strombosia pustulata* was common to subplots of Large and Small reference trees. *Strombosia pustulata* and *Hildegardia barteri*, and *Strombosia pustulata* and *Triplochiton scleroxylon* were the dominant tree species in the subplots of Large trees and Small reference trees, respectively.

Table 2: The values of species diversity of nearest neighbourhood of Large and Small reference trees in Gambari Natural Forest

Species diversity indices	Large reference trees	Small reference trees
Species richness	26.00	21.00
Simpson (1-D)	0.94	0.91
Shannon Weiner (H´)	3.00	2.69
Margalef	6.24	4.99
Dominant tree species	*Strombosia pustulata*, *Hildegardia barteri*	*Strombosia pustulata*, *Triplochiton scleroxylon*

The mean basal area and height of trees in the subplots of Large reference trees (1.18 m^2/ha and 19.01 m, respectively) was higher than the Small reference trees (0.87 m^2/ha and 16.77 m, respectively). Conversely, the mean stem density of trees in the subplots of Small reference trees (67.90 stems/ha) was higher than the Large reference trees (69.12 stems/ha).

Table 3: Structural attributes of neighbourhood of Maximum and Minimum DBH trees in Gambari Natural Forest Reserve

Attributes	**Large reference trees**	**Small reference trees**
Tree density(stems/ha)	67.90	69.12
Basal area(m^2)/ha	1.18	0.87
Tree Height(m)	19.01	16.77

Spatial pattern of trees distribution around Large and Small reference trees

According to Clark and Evans index, approximately nine (9) subplots (100%) showed regular pattern of tree distribution at 0-10 m radius of Large reference trees. There was no aggregate and random patterns of distribution at 0-10 m radius of Large reference trees (Table 4a). Therefore, regular distribution of trees was the dominant spatial pattern. Four (4) subplots (44.4%) and five (5) subplots (55.56%) expressed aggregate and regular patterns of distribution in the subplots of Small reference trees (Table 4b). Therefore, regular distribution of trees was the dominant spatial pattern in the neighbourhood of Small reference trees.

Table 4a: Spatial patterns of tree distribution around Large DBH reference trees in Gambari Forest Reserve

Distance	Distribution Pattern	No. of subplots	Density (tree/m^2)	Clark and Evans	0.05 significant	0.01 significant
Radius=10m (314.2m^2)	Aggregate	0				
	Random	0				
	Regular	9.0	0.02			

Table 4b: Spatial patterns of tree distribution around Small DBH reference trees in Gambari Forest Reserve

Distance	Distribution Pattern	No. of subplots	Density (tree/m^2)	Clark and Evans	0.05 significant	0.01 significant
Radius=10m	Aggregate	4.0	0.02			
(314.2m^2)	Random	0				
	Regular	5.0	0.01			

Species mingling around Large and Small reference trees in Gambari Natural Forest

The very low mingling class indicated that nearest neighbour trees had one species similar to the reference trees while very high mingling indicated that neighbour trees had many different tree species. There was no reference tree in the first four mingling classes in around Large and Small reference trees. Approximately 11.0% and 89.0% of Large reference trees had mingling values of 0.8 and 1.0, respectively. Also, 33.3% and 66.7% of Small reference trees had mingling values of 0.8 and 1.0, respectively, when five neighbours were used for computation. Most of neighbourhood trees of Large reference trees extended to optimum distance of radius 10 m while only two neighbourhoods Small reference trees extended to optimum. Therefore, the small reference trees express relatively low average mingling and high density of heterospecific neighbours (short optimum distances) compared to Large reference trees. Furthermore, six of the first two basal area were smaller than the last two basal area in the neighbourhoods of Large reference trees while five of the first two basal area were smaller than the last two basal area in the neighbourhoods of Small reference trees.

Table 5a: Mingling value of trees around Large reference trees in Gambari Natural Forest Reserve

Reference Tree	DBH (cm)	Mingling value	Subplots (%)	Basal Area		Mean Distance (m)	Optimum Distance (m)
				First two Trees	Last Two Trees		
		0.0	0				
		0.2	0				
		0.4	0				
		0.6	0				
Triplochiton scleroxylon	350.0	0.8	11.0	0.73	1.39	6.0	9.0
Triplochiton scleroxylon	410.0	1.0	88.9	1.94	1.90	6.6	10.0
Hildegardia barteri	111.2			0.46	0.45	6.8	10.0
Triplochiton scleroxylon	357.0			1.41	1.92	6.8	10.0
Sterculia rhinopetala	360.0			0.38	0.24	5.2	9.0
Chytranthis macrobatrys	165.0			0.55	0.85	5.6	8.0
Cola gigantea	305.0			0.15	0.17	7.0	10.0
Ceiba pentandra	370.0			0.33	2.02	5.8	10.0
Pterocarpus erinaceus	390.0			0.74	2.20	4.8	8.0
Average mingling		0.97					

Where Mingling value 1=very high diversity, 0.8= high diversity, 0.6=moderate diversity, 0.4= low diversity, 0.2=very low diversity, 0.0 = no diversity

Table 5b: Mingling value of trees around the Small reference trees in Gambari Natural Forest Reserve

Reference Tree	DBH (cm)	Mingling value	Subplots (%)	Basal Area		Mean Distance (m)	Optimum Distance (m)
				First two trees	Last two trees		
		0.0	0				
		0.2	0				
		0.4	0				
		0.6	0				
Cola millenii	12.0	0.8	33.33	0.68	0.97	3.80	6.00
Trichilia monadelpha	14.0			0.28	0.46	3.80	6.00
Celtis zenkeri	30.0			0.61	0.94	5.40	8.00
Sterculia rhinopetala	18.0	1.0	66.67	1.78	0.52	4.20	8.00
Ricinodendron heudelotii	11.0			1.52	0.87	7.80	10.00
Funtumis elastica	10.0			0.36	0.48	3.60	6.00
Malacantha alnifolia	18.0			0.72	1.93	5.60	8.00
Chytranthus macrobatrys	11.0			1.86	1.64	6.25	10.0
Myrianthus arboreus	12.0			1.36	0.68	5.60	8.00
Average mingling		0.93					

Where Mingling value 1=very high diversity, 0.8= high diversity, 0.6=moderate diversity, 0.4= low diversity, 0.2=very low diversity, 0.0 = no diversity

Approximately, 66.0% and 33.0% of subplots of Large reference trees were in low and moderate diameter differentiation, respectively while 44.0% and 44.0% of subplots of Small reference trees expressed no and low diameter differentiation, respectively. Therefore, the small reference trees express relatively high density diameter differentiation of neighbours (short optimum distances) compared to Large reference trees.

Table 6a: Diameter differentiation of nearest neighbour of Large reference trees in Gambari Natural Forest Reserve

Reference Tree	DBH (cm)	DD class	Subplots (%)	Basal Area		Mean Distance (m)	Optimum Distance (m)
				First two Trees	Last Two Trees		
Sterculia rhinopetala	360.0	0.0–0.2	22.22	0.38	0.24	5.2	9.0
Cola gigantea	305.0			0.15	0.17	7.0	10.0
Triplochiton scleroxylon	410.0	0.2–0.4	44.44	1.94	1.90	6.6	10.0
Ceiba pentandra	370.0			0.33	2.02	5.8	10.0
Triplochiton scleroxylon	350.0			0.73	1.39	6.0	9.0
Pterocarpus erinaceus	390.0			0.74	2.20	4.8	8.0
Hildegardia barteri	111.2	0.4–0.6	33.33	0.46	0.45	6.8	10.0
Triplochiton scleroxylon	357.0			1.41	1.92	6.8	10.0
Chytranthis macrobatrys	165.0			0.55	0.85	5.6	8.0
–	–	0.6–0.8	0.0				
–	–	0.8–1.0	0.0				

Where DD=Diameter Differentiation, DD values 0.0-0.2=low differentiation, 0.2-0.4=medium differentiation, 0.4-0.6=obvious differentiation, 0.6-0.8=strong differentiation and 0.8-1.0=very strong differentiation

Table 6b: Diameter differentiation of nearest neighbour of Small reference trees in Gambari Natural Forest Reserve

Reference Tree	DBH (cm)	DD Class	Subplots (%)	Basal Area		Mean Distance (m)	Optimum Distance (m)
				First two trees	Last two trees		
Cola millenii	12.0	0.0– 0.2	44.44	0.68	0.97	3.80	6.00
Ricinodendron heudelotii	11.0			1.52	0.87	7.80	10.0
Chytranthus macrobatrys	11.0			1.86	1.64	6.25	10.0
Myrianthus arbareus	12.0			1.36	0.68	5.60	8.00
Trichilia monadelpha	14.0	0.2– 0.4	44.44	0.28	0.46	3.80	6.00
Sterculia rhinopetala	18.0			1.78	0.52	4.20	8.00
Funtumia elastica	10.0			0.36	0.48	3.60	6.0
Malacantha alnifolia	18.0			0.72	1.93	5.60	8.0
Celtis zenkeri	30.0	0.4– 0.6	11.11	0.61	0.94	5.40	8.00
–	–	0.6– 0.8	0.0				
–	–	0.8– 1.0	0.0				

Where DD=Diameter Differentiation, DD values 0.0-0.2=no differentiation, 0.2-0.4=low differentiation, 0.4-0.6=moderate differentiation, 0.6-0.8=strong differentiation and 0.8-1.0=very strong differentiation.

DISCUSSION

The mean stem diameter of trees in the neighbourhoods of Large reference trees (94.25±8.87 cm dbh) was higher than the Small reference trees (87.27±9.45 cm dbh). High skewness and coefficient of variation of trees indicated higher structural diversity and stability in the neighbourhoods of Small reference trees. According to Liu and Burkhart (1993), coefficient of variation increases with an increase in stem density of tree population. The largest tree stem was a distinct feature that was present in the neighbourhoods of Large reference trees. The high value of skewness of diameter distribution around Small reference trees may be caused by high density of small size trees.

A total of 26 and 21 tree species were identified around Large and small reference trees, respectively. The neighbourhoods of Large reference trees harbour more trees species than the Small reference trees. Also, The Large reference trees had higher tree species diversity value than the Small reference trees in Gambari Natural Forest Reserve. The Large reference trees probably created more suitable micro sites for growth and survival of most tree species. High mean basal area and height of trees showed high structural development of trees around Large reference trees compared to Small reference trees in Gambari Natural Forest Reserve.

Frequency of aggregate and regular spatial patterns were almost the same around the Small reference trees. This showed interaction of two processes at the same spatial scale around Small reference trees. Forest dynamics was observed in the neighbourhoods of Small trees than Large trees. Regular distribution of trees was the dominant spatial pattern in the neighbourhood of Large and Small reference trees.

The result of species mingling showed that Large and Small trees had a high proportion of heterospecific nearest neighbours. Most Large reference trees belong to highest mingling value because they had no conspecific neighbours. Wang et al. (2021) confirmed that mean species mingling and diversity are great in tropical forest. Wang et al. (2021) further confirmed the study of Wang et al. (2018) that large trees are often surrounded by heterospecific immediate neighbours. Therefore, this localized situation can further increase neighbourhood species and size diversity. The sum of size of two trees at close proximity to reference tree is usually smaller than the size of two randomly chosen trees farther from reference trees in the stand and this referred to as negative spatial dependence in the tree communities (Bastias *et al*., 2020). Five nearest neighbour trees were at varying distances around a reference tree. The distance among neighbourhood trees of Large reference trees were generally larger than Small reference trees. This indicated that Small reference trees expressed high density but low strength heterospecific neighbours while Large reference trees had low density but high strength heterospecific neighbours. Also, Small reference trees exhibited relatively high density (optimum distance of 8.0 m) but low size inequality of neighburs (0.0-0.4; 88.0%) compared to Large reference trees while large reference trees exhibited low density (optimum distance of 8.0 m) but moderate size inequality of neighbours (0.2-0.6) compared to Small reference trees.

CONCLUSION

Large size trees had mostly regularly arranged heterospecific neighbours while Small size trees had both aggregation and regularly arranged heterospecific neighbours. It showed that tree distribution and survival were not due to random events but regularly arranged by specific mechanisms. Neighbourhood structures of Large and Small trees were enhanced by species diversity and recruitment, respectively. Comparatively, Small reference trees expressed high density heterospecific and low size inequality neighbours while Large reference trees expressed low density heterospecific and moderate size inequality neighbours. This is an indication of negative density dependence among tree communities in Gambari Natural Forest Reserve.

REFERENCES

Aguirre, O., Hiu, G., von Gadow, K. and Jimenez, J. (2003). An analysis of spatial forest structure using neighbourhood based variables. *Forest Ecology and Management* 183: 137-145.

Bruno, J. F., Stachowiez, J. J. and Bertness, M. D. (2003). Inclusion of facilitation into ecological theory. *Trends in Ecology and Evolution* 18: 119-125

Bastias, C. C., Truchado, D. A., Valladares, F., Benavides, R., Bouriaud, O., Bruelheide, H., Coppi, A., *et al*. (2020). Species richness influences the spatial distribution of trees in European forests. Oikos 129: 380-390

Chen, X. and Bowman, K. A. (2022). The patterns of nearest neighbour trees in a temperate forest. *iForest* 15: 315-321. doi. 10.3832/ifor4035-015

Clark, P. J. and Evans, F. C. (1954). Distance to nearest neighbor as a measure of spatial relationship in populations. *Ecology* 35(4): 445-453

Dayong, Z. (1990). Detection of spatial pattern in desert shrub populations: A comment. *Ecological Modelling* 51.3-4: 265-271.

Fibich, P., Novotny, V., Ediriweera, S., Gunatilleke, S., Gunatilleke, N., Molem, K., Weiblen, G. D. and Leps, J. (2021). Common spatial patterns of tree in various tropical forests: small trees are associated with increased diversity at small spatial scales. *Ecology and Evolution* :1-11. doi.10.1002/ece3.7640

Li, L., Huang, Z., Ye, W., Cao, H., Wang, Z., Lian, J., Sun, I-F., Ma, K. and He, F. (2009). Spatial distributions of tree species in a subtropical forest of China. *Oikos* 118: 495-502. Doi.10.1111/j.1600-0706.2009.16753.x

Liu, J. and Burkhart, H. E. (1993). Dynamics of size-variable distribution parameters in juvenile loblolly pine (*Pnnus taeda* L.) stands. *Forest Ecology and Management* 58: 321-347

Maleki, K., Kiviste, A and Korjus, H. (2015). Analysis of individual tree competition effect on diameter growth of Silver Birch in Estonia. *Forest Systems* 24, e023. doi.10.5424/fs/2015242-05742

Miren, O., Domingueza, I., Albizu, I., Garbisu, C., Amazaga, I. (2004). Vegetation diversity and vertical structure as indicators of forest disturbance. *Forest Ecology and Management*, 195(3): 341 354

Seifert, T., Seifert, S., Seydack, A., Durrhelm, G. and Gadow, K. (2014). Competition effects in an afrotemperate forest. *Forest Ecosystem*, :1-13. http://www.forestecosyst.com/content/1/1/13

Shackleton, C. (2002). Nearest neighbour analysis and the prevalent of woody plant competition in South African Savanna. *Plant Ecology*, 158 (2): 65-76

Stoll, P. and Weiner, J. A. (2000). Neighborhood View of Interactions among Individual Plants. 2000. Available online: https://edoc.unibas.ch/15365/1/20180110105505_5a55e2f91b17e.pdf (accessed on 27 June 2023).

von Gadow, W. K. and Hui, G. (1999). Modelling forest development. Amsterdam. Kluwer Academic Publisher. 213p

Wang, H. X., Huang, S. X., Zhang, S. S., Pang, H. and Cao, K. F. (2021). Localized neighbourhood mingling is correlated with individual tree size inequality in natural forests in South China. *Annals of Forest Science* 78:102. doi. 10.1007/s13595-021-01111-x

Wang, H., Peng, H., Hui, G., Hu, Y. and Zhao, Z. (2018). Large trees are surrounded by more heterospecific neighboring trees in Korean pine broad-leaved natural forests. *Scientific Reports* 8:9149. doi. 10.1038/s41598-018-27140-7

Wright, S. J. (2002). Plant diversity in tropical forests: A review of Mechanisms of species coexistence. *Oecologia* 130: 1-14. doi.10.1007/s004420100809

Xin, H., Jackson, T., Cao, Y., Zhang, H., Lin, Y. and Shenkin, A. (2022). Spatial pattern analysis of forest trees based on vectorial mark. *Journal of Forest Research*, 33: 1301-1315. doi.10.1007/s11676-021-01417-6

Zhu, Y., Quenborough, S. A., Condit, R., Hubbell, S. P., Ma, K. P. and Comita, L. S. (2018). Density-dependent survival varies with species life-history in a tropical forest. *Ecology Letter* 21: 506-516. doi.10.1111/ele.12915