ASSESSMENT OF FOREST STRUCTURE AND DIVERSITY USING THREE DIFFERENT APPROACHES

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INTRODUCTION

Forest structural diversity, which may be defined as the diversity of tree species and tree dimensions, and their spatial arrangement, can be indicative of overall biodiversity and habitat suitability. The ability to assess and to describe spatial structures with affordable cost is the key to mananging uneven-aged multi-species forests. The knowledge of forest structure is useful in forecasting tree growth and for monitoring the modifications caused by timber harvesting operations. Many authors have suggested variables that can be used to describe forest structure and diversity, and numerous structural indices have been proposed (e.g. Shannon, 1949; Clark and Evans, 1954; Pielou, 1977). To assess the different scales and levels of forest structure within a given area, more integrated and comprehensive approaches are required which include not only species diversity, but also the distribution of the tree positions and the special arrangement of the tree dimensions (e.g. Albert and Gadow, 1998; Hui and Gadow, 2002).

One of the main problems is to characterize and describe forests with different spatial characteristics more accurately, using affordable assessment techniques. This study describes an analysis of three groups of indices: (1) aggregation index of Clark and Evans combined with the segregation index of Pielou and the Shannon index, (2) the three neighbourhood-based parameters “contagion”, “species mingling”, and “dominance”; (3) pair-correlation function and mark-correlation function which is based on point pattern analysis.

Specifically, the objectives of this study were: (a) To describe the forest structutal diversity of three forest types using different approaches; (b) To compare the performance of three groups of forest structural diversity attributes for three forest types.

MATERIAL AND METHODS

The specific forest structures were studied using fully enumerated plots with measured tree positions from three different forest types: a boreal forest from Northern Mongolia, a temperate forest from Europe, and a subtropical forest from Southern Africa (Table 1).

Table 1. Information about the plots from the three different forest types used in this study

Plot	Plot size (ha)	Average rainfall (mm/year)	Species ≥ 10 cm dbh	Individuals ≥ 10 cm dbh
Khentii (Mongolia)	0.25	322	4	135
Lensahn (Germany)	0.60	737	13	386
Virée 20 (Southern Africa)	1.18	873	22	845

Traditional methods for describing forest structure and diversity of a forest stand have been widely used to measure structural diversity attributes at forest stand level by a single average value. Here, the well-known aggregation index of Clark and Evans (Clark and Evans, 1954) was used to describe aspects of variability of tree locations. Values below 1 indicate an aggregated distribution of the trees, while values greater than 1 point to a tendency to regularity. The Shannon index is an ecological standard measure for diversity (Shannon, 1949). Values smaller than 2 indicate low diversity, while values greater than 2 point to a high diverse stand. Spatial segregation between species can be determined through the segregation index of Pielou (Pielou, 1977), which gives the average distance from random sample points to the nearest tree. Values greater than 1 indicate a cluster distribution of the trees, whereas values lower than 1 point to a regular distribution. Each of these methods were used for assessing forest structural diversity at the stand level.

The second approach used in this study was a set of three types of neighbourhood-based parameters: (1) The aggregation index (W_i) that takes into account the regularity of the tree positions; (2) the spatial species mingling index (M_i) which takes into consideration the diversity of species; and (3) the tree dominance index (U_i) that is quantified on the basis of diameter (Gadow et al., 1998; Albert, 1999; Hui and Hu, 2001). With four neighbours, there are five possible values that W_i can assume: 0 (very regular distribution of the trees), 0.25 (regular distribution), 0.50 (random distribution), 0.75 (irregular distribution), and 1 (clumped distribution). M_i can assume the values of: 0 (none of the neighbours are of a different species), 0.25 (one of the neighbours is of a different species), 0.5 (two of the neighbours are of a different species), 0.75 (three of the neighbours are of a different species), and 1 (all of the neighbours are of a different species).

A forest stand can be reduced as a finite set of "points" to represent horizontal locations of trees in the stand and "marks" are tree characteristics such as dbh (diameter at breast height), tree species, or degree of damage by environmental factors. Models of point process is a single-tree modelling that gives simulation tools for investigating forest structures. Two different methods to describe forest structure at the point pattern level was used in this study: (1) The pair correlation function (*g(r)*) which takes into consideration pairs of neighbours separated by a distance *r*. *g(r)* = 1 indicates a random distribution of the trees, values greater than 1 a cluster distribution, and values lower than 1 has a tendency to regularity (Stoyan and Stoyan, 1994); (2) The mark correlation function ($K_{mm}(r)$) is an application of the theory of marked point processes and describe the distribution of trees associated with its diameters at the forest stand (Stoyan and Stoyan, 1994). Small values of $K_{mm}(r)$ (smaller than the value 1) suggest negative correlation (mutual inhibition) between the marks at distance of size *r*, and large values (higher than the value 1) indicate a positive correlation (mutual attraction) at distance *r*.

RESULTS

According to the aggregation index of Clark and Evans, the tree positions in the plots Khentii, Lensahn, and Virée 20 are randomly distributed because of the values close to 1 (Table 2). The aggregation index W_i was estimated for examining the spatial location of neighbouring trees at a fine scale. The overall W_i mean values of 0.48 in Khentii, 0.50 in Lensahn, and 0.49 in Virée 20 indicate a random distribution of the tree positions (Figure 1). The pair correlation function also confirmed the random distribution of the tree positions at all inter-tree distances *r* because of the values around 1 (Figure 1).

The Shannon index of diversity suggests that the plot Virée 20 is the most diverse stand with a Shannon index of 2.49, followed by the plots Lensahn and Khentii, respectively (Table 2). The overall mingling distribution in the plot Khentii shows a mingling mean value of 0.52 which indicates that by four neighbours two of the neighbours are of a different species. The plot Lensahn presents the lowest mean mingling value of 0.39 indicating a low degree of mixture of trees, while the plot Virée 20 has the highest mingling mean value of 0.86 which suggests a high diverse stand (Figure 1). The segregation index of Pielou also suggests that the plot Virée 20 has the highest mixture of trees because of the value 0.80 (Table 2).

Figure 1 presents the dominance (U_i) distribution values for the plots Khentii, Lensahn, and Virée 20. The dominance distribution shows that the trees in the three plots are well distributed through the different dominance classes. The mean dominance values of 0.50, 0.52, and 0.50, respectively, indicate a moderate dominance pattern. The mark correlation function (Kmm (r)) for the plots Khentii and Lensahn shows a negative correlation for distances lower than 8 m, which suggests competition between trees with smaller diameters. The plot Lensahn also present a slight negative correlation between, approximately, the distances 11 to 14 m. On the contrary, the plot Virée 20 indicate that no spatial correlation of the diameters exist on inter-tree distances (Figure 1).

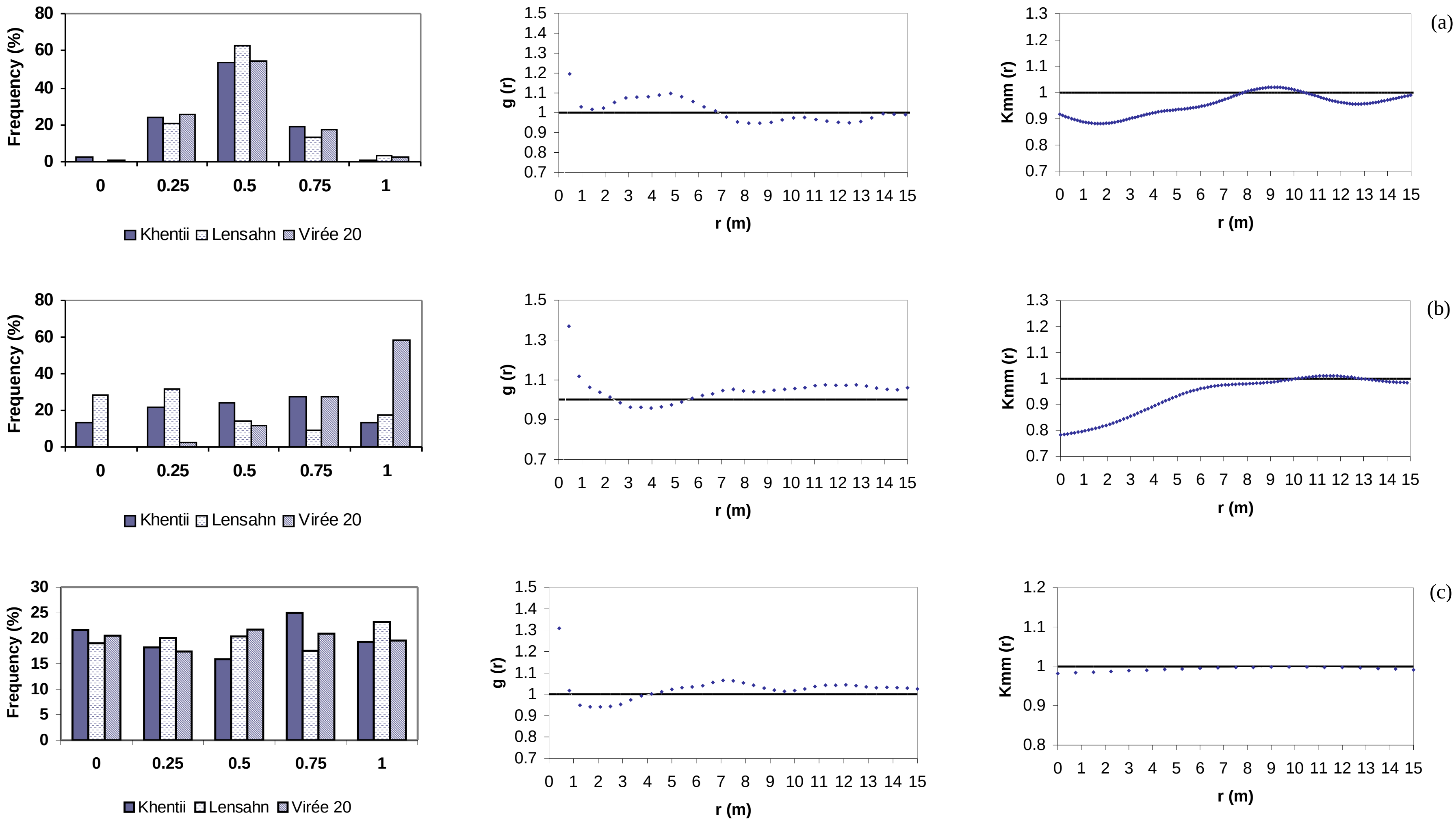

Figure 1. Neighbourhood indexes, pair correlation functions, and mark correlation functions for the plots Khentii (a), Lensahn (b), and Virée 20 (c)

Table 2. Structural diversity indices at the stand level for the three studied plots

	Khentii	Lensahn	Virée 20
Clark and Evans index	0.95	0.96	0.97
Shannon index	0.45	0.81	2.49
Pielou index	0.05	-0.07	0.80

CONCLUSIONS

The results from the aggregation index of Clark and Evans indicated that the tree species in the plots Khentii, Lensahn, and Virée 20 are randomly distributed. This pattern was also observed by the aggregation index (W_i). In addition, the W_i index provided the different patterns of the trees distribution per classes and has the advantage that it is easy to calculate using data that does not require inter-tree distances. The pair correlation function also indicated the random distribution of the tree positions but requires inter-tree distances.

Regarding species diversity, the plot Virée 20 was considered the most diverse when compared to the plots Khentii and Lensahn by the Shannon index, the segregation index of Pielou, and the mingling index (M_i). However, the M_i index had the advantage of detecting the occurrence of groups of trees of the same species and is also very useful when used in common forest inventories.

The dominance pattern was evaluated using the dominance index (U_i) and the mark correlation function. The U_i index indicated very similar variations in tree dimensions when the three plots were compared to each other. However, the mark correlation function presented more detailed information about the distribution of the trees acoording to their size dimensions (see Figure 1). The usefulness of using U_i index is the easy assessment in the field, while mark correlation function requires tree dimensions. In addition, for more detailed information about the pattern, mark correlation function has the advantage of detecting different patterns at different scales.

In conclusion, it is intended that the combined approaches presented in this study will make a significant contribution to improve the estimation of forest structural diversity attributes at various spatial levels in biodiversity monitoring and future research, especially in the tropics and subtropics.

REFERENCES

Albert, M. 1999. Analyse der eingriffsbedingten Strukturveränderung und Durchforstungsmodellierung in Mischbeständen. Ph.D. Dissertation, Faculty of Forest Sciences, University Göttingen. Hainholz, Germany, 63-68.

Albert, M., Gadow, K.v. 1998. Assessing biodiversity with new neighbourhood-based parameters. In Data Management and Modelling Using Remote Sensing and GIS for Tropical Forest Land Inventory. Y. Iaumonier, B. King, C. Legg and K. Rennolls (eds). Proceedings of the FIMP-INTAG International Conference, October 26-29, Jakarta, Indonesia, 433-445.

Clark, P.J., Evans, F.C. 1954. Distance to nearest neighbour as a measure of spatial relationships in populations. Ecology 35, 445-453.

Gadow, K.v., Hui, G.Y., Albert, M. 1998. Das Winkelmass - ein Strukturparameter zur Beschreibung der Individualverteilung in Waldbeständen. Centralblatt für das gesamte Forstwesen 115 (1), 1-9.

Hui, G.Y., Gadow K.v. 2002. Das Winkelmass. Herteilung des Optimalen Standarwinkels. Allgemeine Forst u. Jagdzeitung 10, 173-177.

Hui, G.H., Hu, Y.B. 2001. Measuring species spatial segregation in mixed forest. For. Res. 14 (1), 23-27.

Pielou, E. C. 1977. Mathematical ecology. Wiley, New York, 385.

Shannon, C. E. 1949. The mathematical theory of communication. In: Shannon, C.E; Weaver, W. (Eds.), The Mathematical Theory of Communication. Urbana, Univ. of Illinois Press, 29-125.

Stoyan, D., Stoyan, H. 1994. Fractals, random shapes and point fields: methods of geometrical statistics. John Wiley and Sons.