THE USE OF RIPLEY FUNCTION FOR SPATIAL STRUCTURE STUDY OF NATURAL FOREST "HUMOSU OLD GROWTH BEECH FOREST"

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The objective of this paper is to study the spatial structure of the Humosu natural beech forest through the Ripley function. The analysis was based on five punctual processes related to different stages in the dynamics of the natural forest, using as criteria the diameter at breast height; for each process, the spatial structure type was determined by means of the Ripley function. The presence of a randomized structure for the processes H1 and H2 (the trees with diameters >80 cm and between 40–80 cm) is due to the decrease of the intensity of competitive processes and self-thinning taking place in time. The H3 spatial process presents a randomized structure, explained by the continuous density reduction within the wholes in the crown done by the elimination of old trees. Tree aggregation of the H4 process is due to the dynamics and growth of the trees originating in the anterior regeneration bio-groups, with high intensity competition, aspect that confirm the hypothesis according to which the aggregation becomes statistically significant at higher distances to the initial regeneration process. H4 process, assimilated to regeneration, presents an aggregated spatial structure, significant for distances between than 5 and 30 m. In eastern limit conditions, the optimum dimensions of the regeneration gap should be 20 m. The H5 process, constituted by the deadwood, stumps and dead trees in the sample plot presents a randomized structure, regardless of the distance, explained by the fact that the disturbing factors do not act unvaryingly.

Key words: Ripley function; Humosu old growth beech forest; Spatial structure; Punctual processes.

INTRODUCTION

Knowing and understanding the spatial structure of forest ecosystems is one of the key elements for assuring a sustainable forest management[21]. The tree growth is directly influenced by the spatial context of vegetation and the biomass accumulation processes influence the spatial organization mode. Spatial structure study offers very useful information in interpreting the functioning and development of forest ecosystems, showing the regeneration, development, mortality processes, the most important disturbing factors as well as competition relations established between the individuals[17, 26].

Within the forest ecosystems, the ecological processes have a spatial character; that is why the study of the spatial structure registered a strong development in the last years [4]. The quantification of spatial structure permits the understanding of its dynamics and the identification of development stages.

The horizontal structure study in the forest ecosystems permitted the evidencing of the structural elements and the complex connections that characterize the spatial-temporal dynamics of the forest. Expressing the structural dynamics of forest ecosystems in Retezat National Park trough the Poissonian model shows that tree distribution tends to randomize with age, becoming very similar to Poisson theoretical distribution[3, 33] considers that the evidencing of the microstructure is a mathematical matter, solved by a mathematical function. For establishing the structure type,[4] suggested the computation of the Green and Morisita indices.

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Cenusă[5, 6] using the method of structural profiles with the biometric and structural parameters has quantified different development stages in natural forest. More recent researches recommend for natural ecosystems study the appliance of spatial distribution indices[23]. Avăcăriței[2] shows the randomized structure of old age beech stands and catches the aggregation tendencies of the trees in stands in which systematic tending activities were applied. The spatial structure may offer useful information regarding the organization of trees with flaws or illness. In this manner, in Northern Moldavia there were identified aggregated structures formed by trees with cancer in the crown (infection centres for neighbouring trees) and by healthy trees (resistances cores)[30]. Popa[24] applied the Ripley function for spatial structure analysis of natural spruce stand in Giumalau Secular Forest evidencing some point processes with complex structures.

The analysis of the spatial organization of biological communities is based on simple statistics – quadrate method and nearest neighbour being the most used due to the simplicity of the calculus and interpreting mode[7, 20, 8], and also on complex mathematical models – examples regarding the appliance of analysis methods at fundamental level[28, 29, 27] and also at applicative level in general ecology[14, 11, 12]. The spatial structure has an important role in modeling the structure and dinamycs of the stands[25].

In this paper we show the spatial organization mode for trees in natural beech ecosystems found on the Eastern limit of the natural area trough the univariate Ripley function.

MATERIAL AND METHODS

The researches have taken place within a natural beech ecosystem in Humosu Secular Forest, located on the Eastern border of the specie's area (Suceava Plateau). We installed a permanent sample area of one hectare, located in Harlau Forest District, Production Unit III Humosu, parcel 64, at an altitude of 455 m, with the coordinates 47°30'02'' Northing, and 26°43'27'' Easting. Geomorphologically speaking, the sample plot is located on a wavy slope with a 12 degree declination. The main type of soil is luvosol, and the specific flora is formed by the species of the *Asperula* genus.

The installing of the sample area has been done according to the well known methodology for studying forest ecosystems trough structural profiles,[5, 6, 10]. The position of trees and deadwood has been computed with the total station (±0.05m precision). For each tree with diameter at breast height greater then 4cm we measured the next characteristics: diameter at breast height, height, crown length, social position, crown form, crown diameter, Cartesian coordinates (*x,y*). Primary data have been processed using Proarb software v3.0[22], elaborating thematic maps regarding the stands spatial organization.

The Ripley K function is an analysis and quantification instrument for second order intensity of the point processes completely positioned. The general expression of the K function is[12, 18]:

$$K(d)=\frac{1}{\lambda}E(\#\,events \le d\ to\ a\ randomized\ event) \quad (1)$$

where *E()* represents the average of the number of events located at a smaller distance than any other chosen randomized event; λ average intensity of events on area unit. The Ripley K function can be mathematically estimated for a multitude of theoretical point processes. In case of null hypothesis (the completely randomized process – homogeneous Poisson) the *K* theoretical function has this form:

$$K(d)=\pi d^2 \quad (2)$$

If the analyzed point process is aggregated we will have an excess of events on short distances, the estimated K function being larger than the theoretical one. The estimation of the K function for a spatial point process is relatively easy, being a ratio between the average number of events within a *d* radius circle centered in a randomized point and the average intensity of the process.

$$\hat{\lambda}=\frac{N}{S}$$
$$\hat{K}(d)=\frac{1}{\hat{\lambda}}\frac{1}{N}\sum_{j=1}^{N}\sum_{j\neq i}k_{ij} \quad (3)$$
$$\text{where:}\quad k_{ij}=\begin{cases}1 \text{ if } d_{ij}\le d\\ 0 \text{ if } d_{ij}>d\end{cases}$$

where *K(d)* represents the Ripley function, N total number of events, *S* the analyzed area, d_{ij} distance between *i* and *j* events.

To establish the variance (growing proportional with d distance) and linarite the Ripley K function, Getis and Franklin [9] recommend the next formula:

$$L(d)=\sqrt{\frac{K(d)}{\pi}}$$
$$or \qquad (4)$$
$$L(d)-d$$

that is much easier to interpret. In completely randomized distribution conditions the value $L(d) - d$ is null for any d. Positive values indicate an aggregated punctual process and the negative ones indicate a regular process. The trust interval for the theoretical process is obtained by Monte Carlo simulation of 100 point processes for a transgression probability of 5%[15].

RESULTS

The experimental distribution of the trees on diameters categories is considered to be a very good structural index for the quantitative and qualitative analysis of biometrical parameters of forest ecosystems[10] (Fig. 1).

The distribution of the trees on diameters categories is specific to a forest in a terminal development stage, observing the differentiation of two distinct elements formed by trees originated from regeneration on one hand and trees at the physiological limit of their existence. The distribution of the number of trees on diameters categories presents a positive asymmetry with a 0.66 asymmetry coefficient. The average diameter encountered in the sample plot is 35.47cm and the maximum is 98cm, but in the reservation we found old trees over 150 cm.

For obtaining an overall image on the sample plot we characterized it from a biometrical point of view, volume is 947.457 m^3ha^{-1}, the average height 40.25 m, the maximum height is 48 m, dead trees volume is 41.27 m^3ha^{-1}.

To identify specific structural particularities of the Eastern limit ecosystems we used the structural profile method, consisting in graphical analysis of the organization mode in horizontal, vertical and three-dimensional view. The analysis of spatial structure trough horizontal profile shows relatively high complexity degree, characteristic to a natural beech at the Eastern limit of its area, found in terminal stage with regeneration (Fig. 2).

Analyzing the diagram we noticed the alternation of high variability area with uniform areas. There can be delineated in the North East part of the plot an area of maximum structural diversity, specific to uneven aged stands; in the central and South we encountered homogeneous areas, characteristic for even aged stands, were the biomass concentrators are located.

For underlining the spatial structure of the studied stand trough the Ripley function we constituted five representative point processes for standing and brought down trees, using the diameter as a criteria (Table 1 and Fig. 3).

The choosing of the point processes offers a view on the organization of natural forest, regeneration process, development and mortality, structural dynamics. The dynamics in time of a natural forest can be noticed by comparative analysis of point processes of different dimensional categories[24].

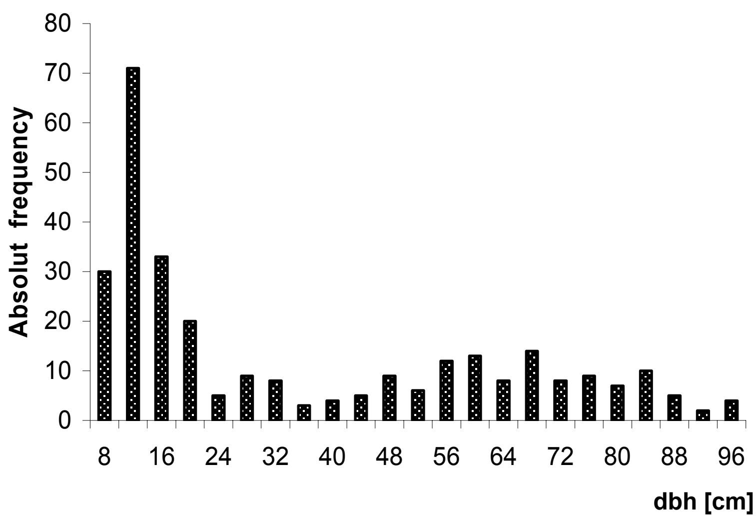

Fig. 1. The experimental distribution of trees on diameter categories.

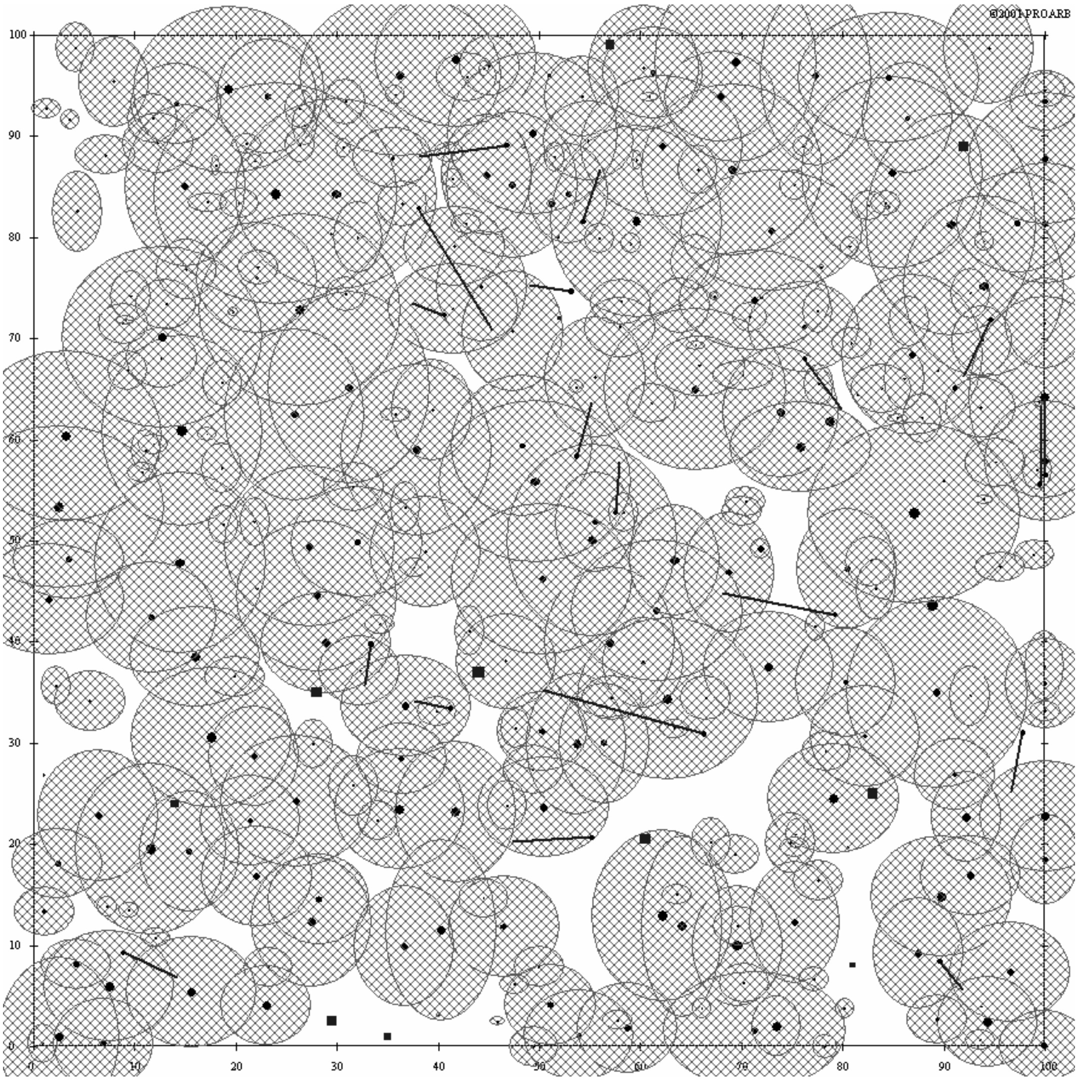

Fig. 2. The horizontal profile of Humosu old growth beech forest
(the hatched areas – crown projection; continuous line fallen trees, squares - stumps).

Table 1
The studied punctual processes

Point process	*Dbh*	Number of trees per hectare
H1	>80	22
H2	40–80	94
H3	20–40	35
H4	<20	137
H5	Deadwood, stumps, Dead trees	43

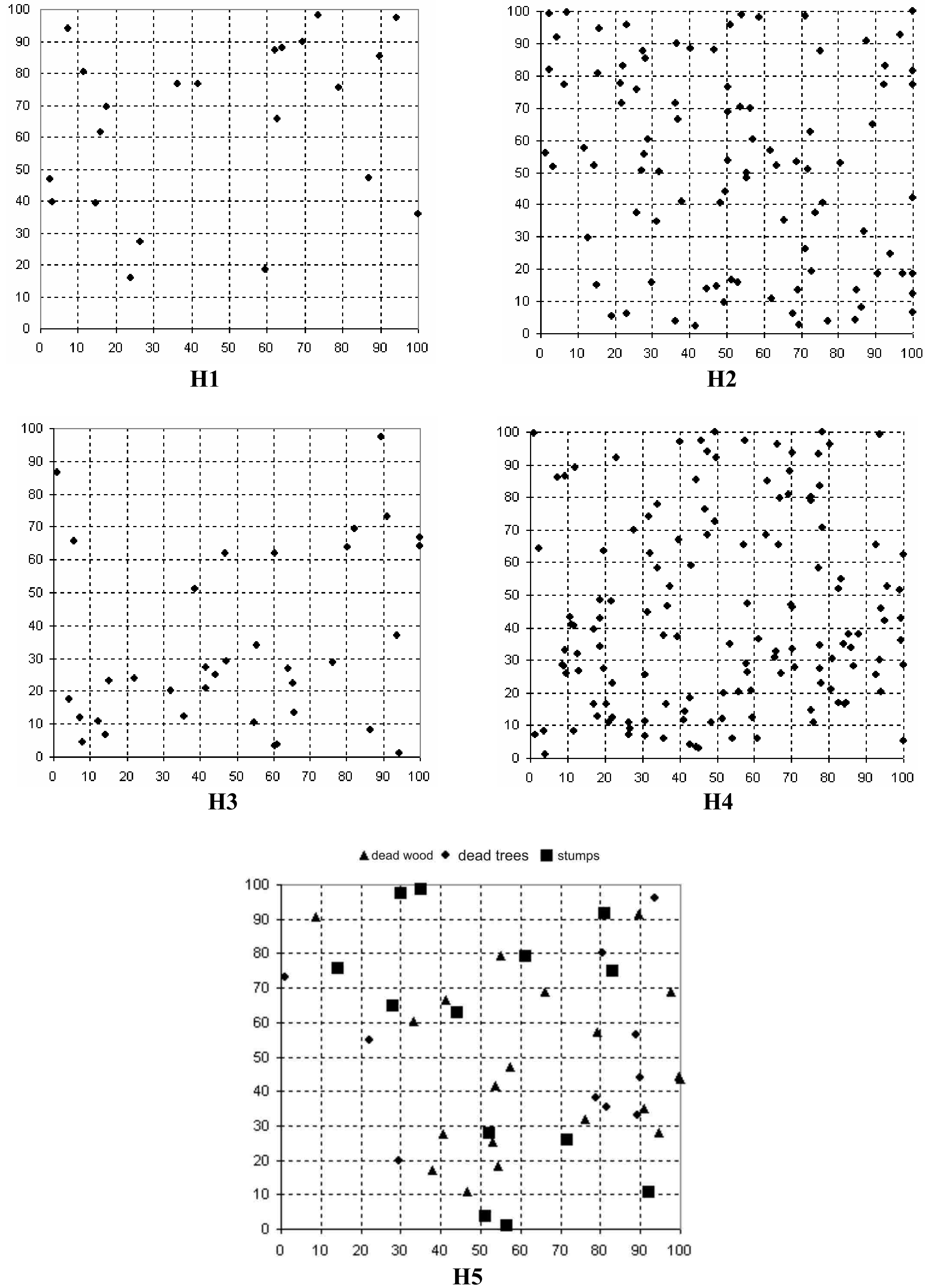

Fig. 3. The main punctual processes within the sample plot.

The graphical analysis of the spatial organization of each point process permits the delineation of specific spatial distributions. We notice, for the H1 point process, a randomized distribution; in case of process H2, represented by trees with diameters between 40 and 80 cm, the spatial repartition shows an aggregation tendency in the center of the plot. The aggregation tendency is more obvious in case of H3 and H4 processes. In the case of mortality, we can say that the general spatial distribution is randomized, observing a light aggregation tendency in the center.

To confirm and statistically validate the hypothesis stated above (based on visual interpretation of the graphics), we used the Ripley function (Fig. 4).

One can notice the existence of a randomized in case of H1 point process, constituted by trees with diameters higher than 80 cm. this aspect can be explained ecologically by showing that with the age increasing trees age, their spatial distribution tends to randomize, due to reduced competition processes and "self thinning" occurred in time. In case of H2 spatial process we can say that it has a regular structure, for distances between 3,5 and 5,0 m, and randomized in the rest. The presence of a regular structure indicates an old age stage of the forest, in which the pressure of the regenerating story. The point process H3, formed by trees with average dimensions (20 and 40 cm) is randomized

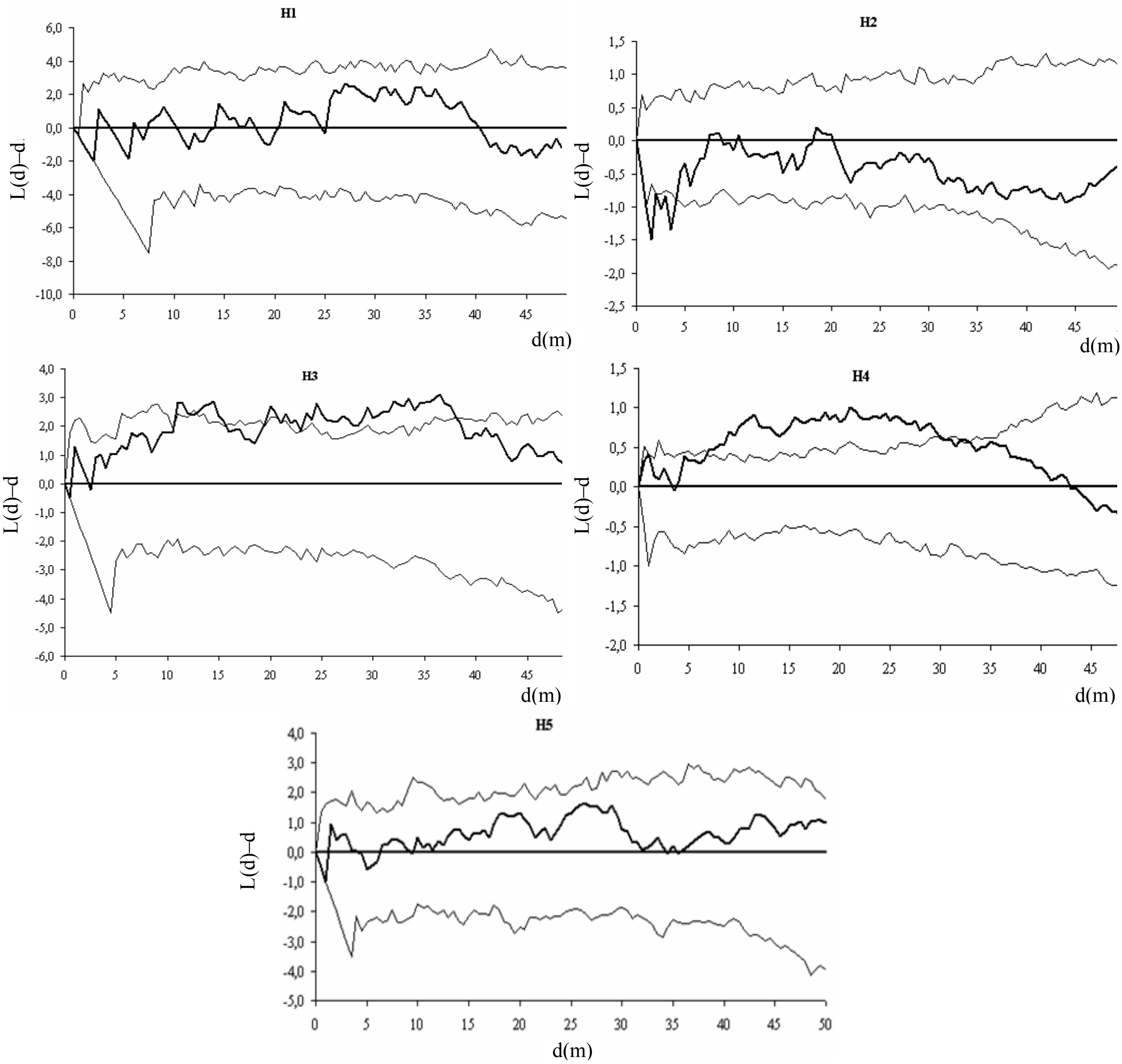

Fig. 4. Spatial structure analysis for each spatial process using the Ripley function.

for distances smaller than 6.5 m, and aggregated for larger distances. This phenomenon can be justified by the fact that the trees originate from an older regeneration group, with very intense competition and natural elimination processes. In case of regeneration, we noticed an aggregated structure for distances higher than 5 m, aspect explained by the forming of gaps in the canopy as a result of fallen trees, in which the saplings are installing. The H5 point process, formed by deadwood, stumps, dead and broken trees, presents a randomized structure independent of distance, due to the fact that the disturbing factors act not uniformly.

DISCUSSIONS

In the present paper we showed the spatial structure of the beech natural forest at the Eastern border of its area trough Ripley function. Assuming this hypothesis, we formed five point processes that represent the different development stages and the dynamics and development of natural forest; for each forest the type of structure was visually identified based on the spatial distribution maps and statistically validated trough the Ripley function. In the spatial analysis techniques this function shows us whether we have an aggregated, randomized or regular structure[28].

The presence of randomized structures in the case of H1 and H2 spatial processes, formed by trees with *dbh* larger than 80 cm, respective between 60 and 80 cm, confirms the researches of Boşcaiu and Lungu[3] in natural beech stands within the Retezat National Park. We have shown the stabilizing tendency of trees frequency on quadrates with age, taking into account that old trees reach a statistic independency against one another, indicating an homogeneity of internal pressure In case of H2 spatial process we have shown a regular structure, statistically significant for distances between 3.5 and 5 m, distance considered large in the literature[3, 20], specific to standswith high number of trees with high competitive relations. Greig-Smith[13] consider that al wood species show regular distribution tendencies, even though they remain vague. Boşcaiu and Lungu[3] consider that the randomized structure appears when in a population can be found a powerful competitive rejection, as a result of a positive antagonism.

The H3 spatial process presents a randomized spatial structure, explained by the continuous breaking-up of tree density in gaps formed by old trees disappearance. The aggregation of tree forming the H3 is statistically significance for distance over 20 m, justified by the dynamics and development of trees originating in former regeneration gaps, in which the competition and natural elimination processes are intense, aspect that confirm the hypothesis stating that the aggregation is becoming statistically significant at larger distances from the initial regeneration process.

The H4 process, assimilated to regeneration, presents an aggregated spatial structure for distances larger than 5 m. In the present case we notice a randomized spatial structure for distances smaller than 5m, characteristic for the influence zone of the crown. One can notice that the aggregation phenomenon is statistically significant for distances between 5 and 30 m, strongly influenced by the presence of gaps in the crown due the disappearance of old trees. A great importance in future development of saplings is given to size of the regeneration gap. In the Eastern limit conditions, the soil humidity being considered to be the limitative factor, the size of the gap must ensure stronger lateral shading and that’s why it should be approximately 20 m Pielou[20] explains the regeneration using two hypothesis, based on regeneration and dispersion of trees mechanisms, in relation with site conditions. The author considers that the plants originating from vegetative regeneration present a higher degree of aggregation than the ones with generative reproduction. Boşcaiu and Lungu[3] consider that the regeneration of natural beech stands remains a slow process, subject to endogen constrains from the population, but able to actualize in every moment of pressure reduction by means of biodisperssion (areas with lower density). The same authors say that regeneration is adjusted trough the tendency of evolution to regular model. According to some researches done in beech stands of Cantabria it has been shown that trees smaller than 30 cm in diameter are distributed aggregately, but with low intensity; the trees with higher diameters are randomly or uniformly distributed[31, 32]. Another explanation could be that the deadwood is unequally distributed along the plot, determining a large variability of the saplings. The point process H5, formed by deadwood, present a randomized structure due to the fact that disturbing factors don’t act uniformly, and the stand passes trough the terminal phase, with regeneration, phase that corresponds to a smaller amount of deadwood.

The volume of deadwood is 41,27 m^3ha^{-1}, smaller than the one in the Serrahn forest (94 m^3 ha^{-1}), but larger than the one from the beech reserves in Albania (30 m^3ha^{-1})[19]. In beech forests in Cantabria region we observed that dead trees are present in the small categories; the living trees form an uniform model for very small distances. Standing trees present a spatial attraction for small and average distances[31]. In other cases, the mortality is not a randomized process, but the consequences of intra-specific competition between neighboring trees (distances between 0–2 m)[1, 16]. Using the Clark-Evans index we showed that dead and broken trees are randomly distributed. The separate analysis of different types of deadwood proved the existence of differences against the general model, underlining the fact that up-rooted trees present an aggregated structure, and the spatial model of large dimensions dead trees is randomized in all analyzed cases[19].

CONCLUSIONS

The paper had the objective of studying the spatial structure of natural beech forests at the Eastern limit of the specie's area, using the Ripley function. To achieve this objective we established six point processes representative for standing and fallen trees using as a criterion the diameter at breast height. In this manner we proved that trees with diameters larger than 80 cm present a randomized structure. The functional explanation is given by the reduced intensity of the competition processes and self-thinning. The point process H2 presents a regular structure statistically significant for distances between 3,5–5,0 m and indicate ageing stage of the stand. The trees with diameters between 40 and 60 cm present a randomized structure, explained by the continuous breaking-up of stand density in gaps formed along with the disappearance of old trees. We can say that the aggregation of trees forming the H4 spatial process confirms the hypothesis according to which this phenomenon becomes significant at larger distances from the initial position of the regeneration process. The point process H5, assimilated to regeneration, presents an aggregated structure, statistically significant for distances between 5 and 30 m. The study of organization and dynamics in natural forest can offer a model for applying close to nature sylviculture.

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