Spatial structure of spruce-stone pine mixed forest from Calimani Mountains (Eastern Carpathians)

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Abstract. The aim of the paper is the analysis of the spatial structure of a natural spruce-stone pine mixed forest ecosystem developed after a major disturbance (windthrow catastrophe) in Calimani Mountains. The forest ecosystem which was studied is located at 1550 m elevation. For statistical analysis of the data were used classical statistical methods: analysis of statistical indicators (mean, standard deviation, coefficient of variation, etc.) and the distribution of the number of trees in diameter classes. Description of the spatial structure of the forest ecosystem was analyzed by point process analysis techniques in relation to the basal diameter at both individual species and total stand (univariate and bivariate Ripley K function). The distribution of the number of trees per hectare on diameter classes for the Norway spruce (*Picea abies*), stone pine (*Pinus cembra*) and Mountain ash (*Sorbus aucuparia*) is typical to the relatively even aged stands. Norway spruce, Mountain ash and total trees stand curves have a positively skewed distribution to the left while stone pine curve has a negatively skewed distribution to the right. Norway spruce forest ecosystem has an aggregate structure for the distance lower than 15 m and bigger than 25 m. For the distances between 15 m and 25 m the spatial structure is randomized. Stone pine has an aggregate structure and Mountain ash a randomized spatial structure. In the case of Norway spruce and total stand the trees with the diameter lower than 20 cm have an aggregate structure until the distance of 20 m and after it become randomized. Trees with more than 20 cm in diameter have a randomized spatial distribution. Knowledge of the dynamics and spatial structure of the forest is an essential condition for ensuring a sustainable forest management especially in the perspective of a close to nature forestry.
Key Words: natural forest ecosystems, trees diameter, spatial structure, Ripley K function.

Introduction. In the current context of global economic development, resulted in the depletion of natural resources and increasing pollution, creation of stable forest ecosystems has become the priority in international debates (Duduman 2009). Natural mountain forest ecosystems have a great structural diversity, the result of the interaction between competitive processes and disturbances, impressing by high stability (Popa 2007).

Natural forests are a source of valuable information regarding the natural dynamics by the action of natural hazards and the evolution of forest ecosystems affected by the direct influence of human action (Motta et al 2010). Although the stand is understood as a homogeneous part of the forest with the same structure (organization), the populations of trees within stands and individual trees are subjected to structural and functional variability as a result of highly complex relationships that make forest biosphere to be characterized by a specific dynamic equilibrium (Avăcăriţei 2005). Natural forest has been and should be in the future a valuable natural research laboratory leading to the selection and recommendation of appropriate structural models for the sustainable management of planted forest ecosystems (Florescu et al 2002).

Spatio-temporal structure study provides useful information in interpreting the functioning and development of forest ecosystems, such as regeneration, development, mortality processes, disturbances regime and competition relations established between trees (Rademacher et al 2010).

In that context the present paper aims the analyzing of the spatial structure of a natural spruce-stone pine mixed forest ecosystem developed after a major disturbance (windthrow catastrophe) in Calimani Mountains.

Material and Method. In order to achieve the proposed goals it was established a permanent experimental plot (70 x 70 m) with a size of 0.49 ha, located at an altitude of 1550 m in Calimani Mountains (Figure 1).

The stand comes from natural regeneration following a catastrophic windthrow from the second half of the nineteenth century (Popa, pers. comm.). The forest vegetation is represented by a mixture of Norway spruce (*Picea abies*) and Stone pine (*Pinus cembra*) with elements of Mountain ash (*Sorbus aucuparia*).
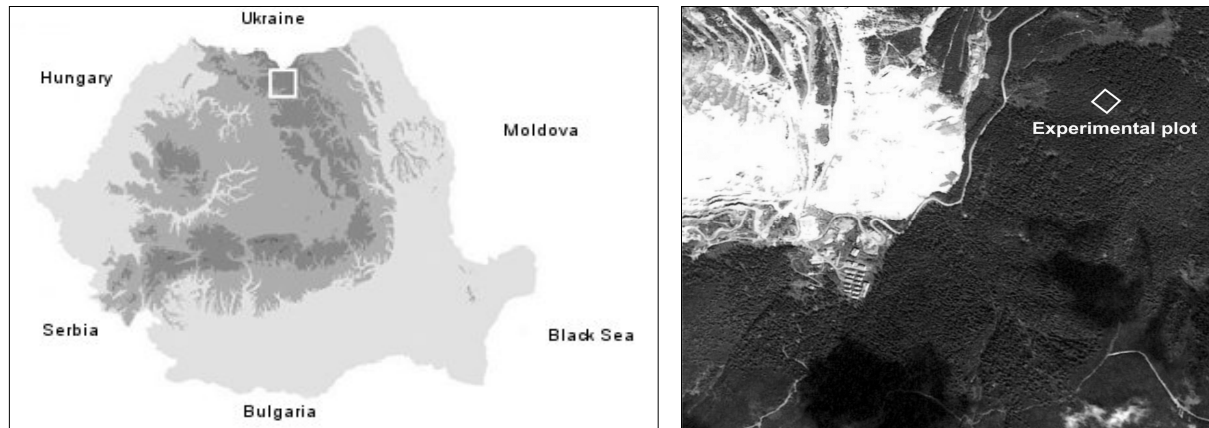

Figure 1. Location of the study area.

The experimental plot was installed and inventoried in 2013. Both dendrometric elements (species, diameter, height etc.) and space elements (the carthesian coordinates in a local reference system) were recorded, according to enshrined methodology (Cenuşă 1996).

For statistical analysis of the data classical statistical methods were used: analysis of statistical indicators (mean, standard deviation, coefficient of variation, etc.) and the distribution of the number of trees in diameter classes (Giurgiu 1972).

Description of the spatial structure of the forest ecosystem was analyzed by point process analysis techniques in relation to the basal diameter at both individual species and for total stand. Ripley K function allows univariate statistical quantification of the intensity of second order point process by revealing the spatial interaction between events and the way of their variation in relation to the distance (Ripley 1977; Hasse et al 1996). The null hypothesis is represented by a homogeneous Poisson process, respectively of a random spatial distributions calculated statistically by mathematical simulation (1000 replications) for a coverage probability of 99% (Hardisty 1999). The analysis of the aggregated point processes existence, random or regular (univariate analysis) was achieved for a distance of 35 meters, with step of 5 m. Description of the spatial structure of the forest ecosystem was analyzed by point process analysis techniques in relation to the basal diameter in the case of Norway spruce and on the whole stand. Two tree classes were differentiated in dimensionally terms: thin trees (d < 20 cm) and thick trees (d > 20 cm) (Popa 2006). Statistical calculations were performed with the software SpPack (Perry 2004) and Microsoft Office (Excel).

Results and Discussion. The analyzed forest ecosystem composition is 68% Norway spruce, 30% Stone pine and 0.2% Mountain ash, calculated in relation to basal area. Dendrometric parameters analysis (Table 1) highlights the fact that the standard deviation of the basal diameter has lower values for Mountain ash and higher for Stone pine, Norway spruce having intermediate values. Variation coefficient of Stone pine diameter has the lowest values, while for Norway spruce and Mountain ash this parameter have the highest values. Total basal area is 55.3 m^2 ha^{-1}, distributed by species as follows: 38.1 m^2 ha^{-1} for Norway spruce, 16.6 m^2 ha^{-1} for Stone pine and 0.6

m^2 ha^{-1} for Mountain ash. The average Stone pine basal diameter is higher than double compared with the Norway spruce.

Dendrometric parameters for the experimental plot from Calimani Mountains

Dendrometric parameter	Norway spruce	Stone pine	Mountain ash
Mean diameter (cm)	14.67	34.25	10.75
Variance	73.79	104.31	29.17
Standard deviation	8.59	10.21	5.40
Variation coefficient (%)	58.57	29.82	50.24
Number of trees per hectar	1669	163	49
Basal area per hectare (m^2)	38.1	16.6	0.6

The distribution of the number of trees per hectare on diameter classes is typical to the relatively even aged stands in the case of all three species studied (Figure 2). Experimental distribution is typical for a stand in the phase of optimal development with very active competitive processes. The current structure is the result of regeneration of a mixed stand of Norway spruce with Stone pine and Mountain ash in an area affected by a major disturbance in the past (windthrow catastrophe) in conjunction with long-term competitive processes. Dendroecological analysis allowed the dating of the catastrophic windthrow in the decades 1840-1850 (Popa pers. comm.).

Experimental distribution curves of Norway spruce, Mountain ash and total stand shows a left positively skewed, the asymmetry being more pronounced for Norway spruce and total stand. This type of distribution reflects horizontal stand structure and characterizes the competition relationships (in this case intraspecific) as a result of trees position in the stand. In the case Stone pine the distribution curve of the number of trees per hectare on diameter classes shows right-negative asymmetry due to the fact that this species, compared with Norway spruce, has put into value better the stationary conditions reflected in the increase in diameter.

Spatial structure on species and for total stand from the studied experimental plot (Figure 3) is different for all of three species and for total stand. Norway spruce has an aggregate structure only for distances up to 15 m and over 25 m. Uniform spatial structure is the result of a strong intraspecific competition (Pielou 1960). For distances between 15 and 25 meters the structure is random. In the case of Stone pine the structure is aggregated and in the case of Mountain ash the spatial arrangement is random.

Spatial structure of the total stand is aggregated for distances up to 15 metres and after the arrangement is random. Regarding the categories dimensional analysis (spruce and stands total) of the spatial point processes (Figure 4) was revealed that for both Norway spruce and total stand the trees with the diameter smaller than 20 cm has an aggregate structure for distances up to 20 meters after which it becomes random. Trees with diameter higher than 20 cm have a random arrangement both in the case of Norway spruce and total stand. Similar situations was identified by the analysis the spatial structure of a natural Norway spruce stand from Giumalău Old-Growth Forest, trees with diameters between 20 and 40 cm having a random arrangement (Popa 2006).

Bivariate analysis of the spatial point processes via the Ripley function allows emphasizing the processes of attraction or repulsion between different dimensional categories or species (Popa & Sidor 2013). Between Norway spruce and Stone pine it was found a spatial rejection process for distances between 10 and 20 metres, being indifferent for the rest the distances (Figure 5).
A similar process has been highlighted in the case of Norway spruce and Stone pine located at the upper elevation in Calimani Mountains at an altitude of about 1700 m (Popa & Sidor 2013).
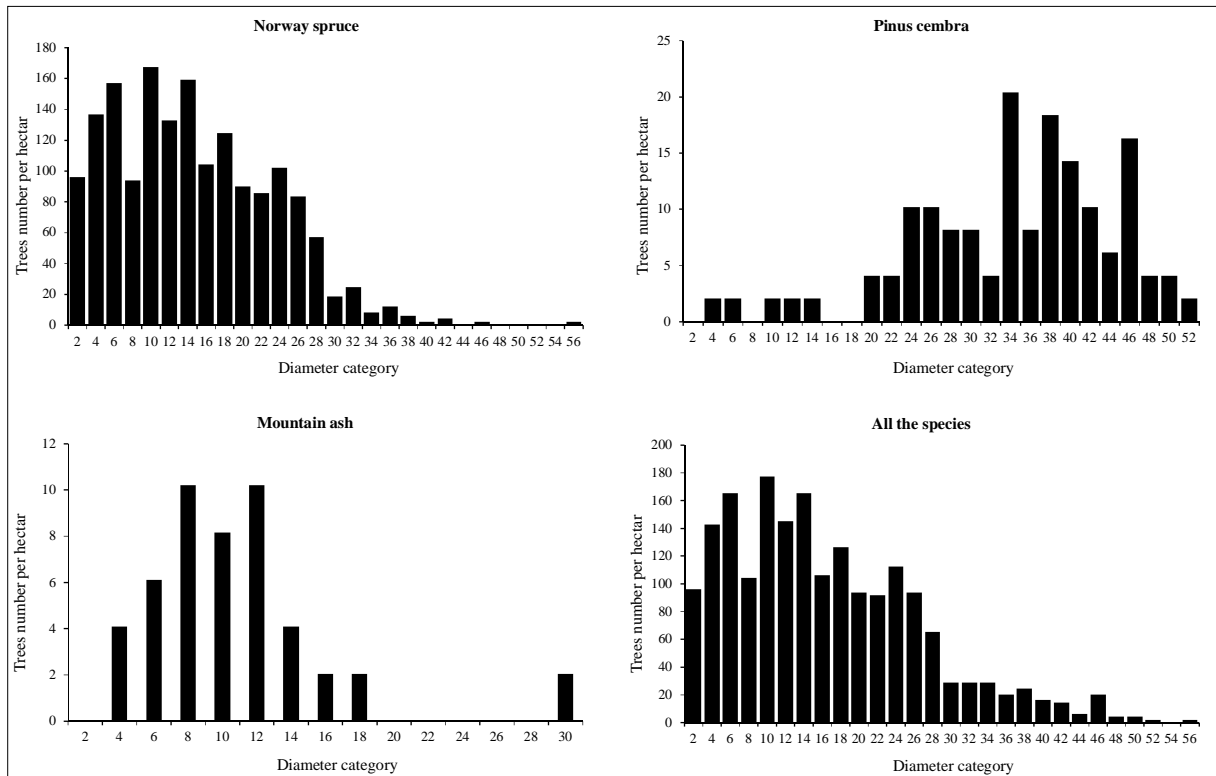
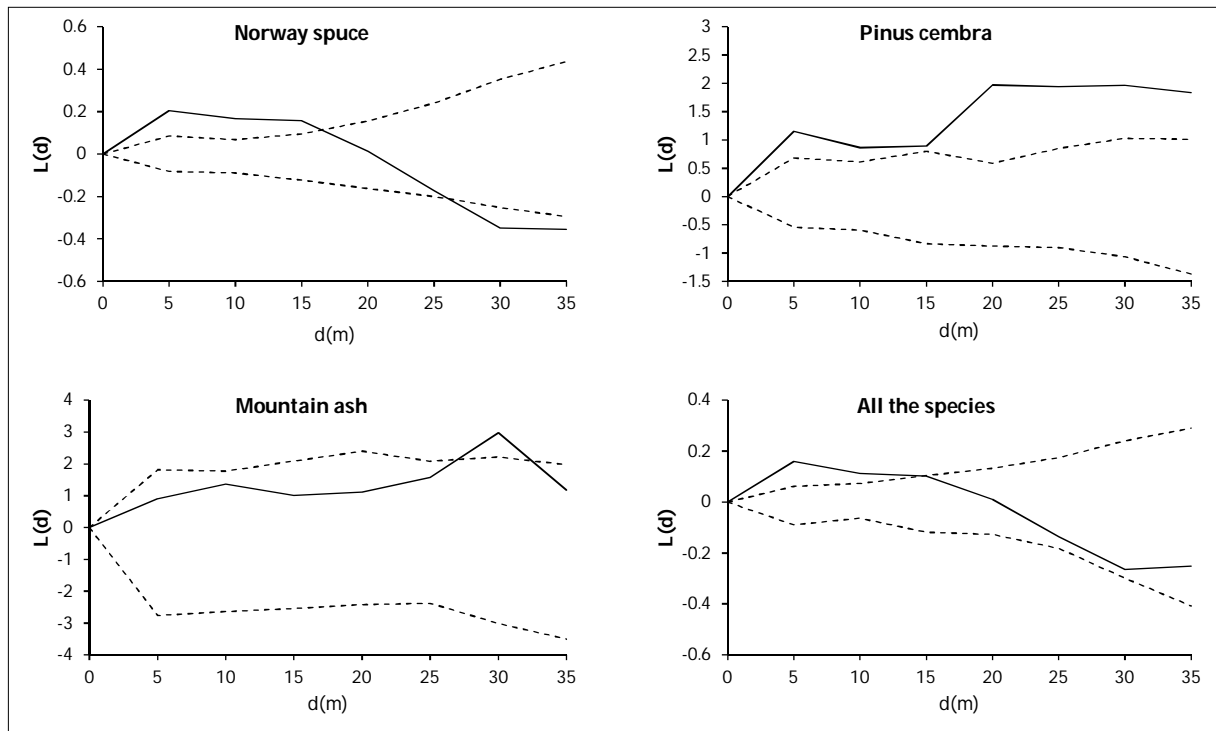Figure 2. Distribution of trees number on diameter classes.

Figure 3. Analysis of the spatial point processes with univariate Ripley function, on species and total stand.
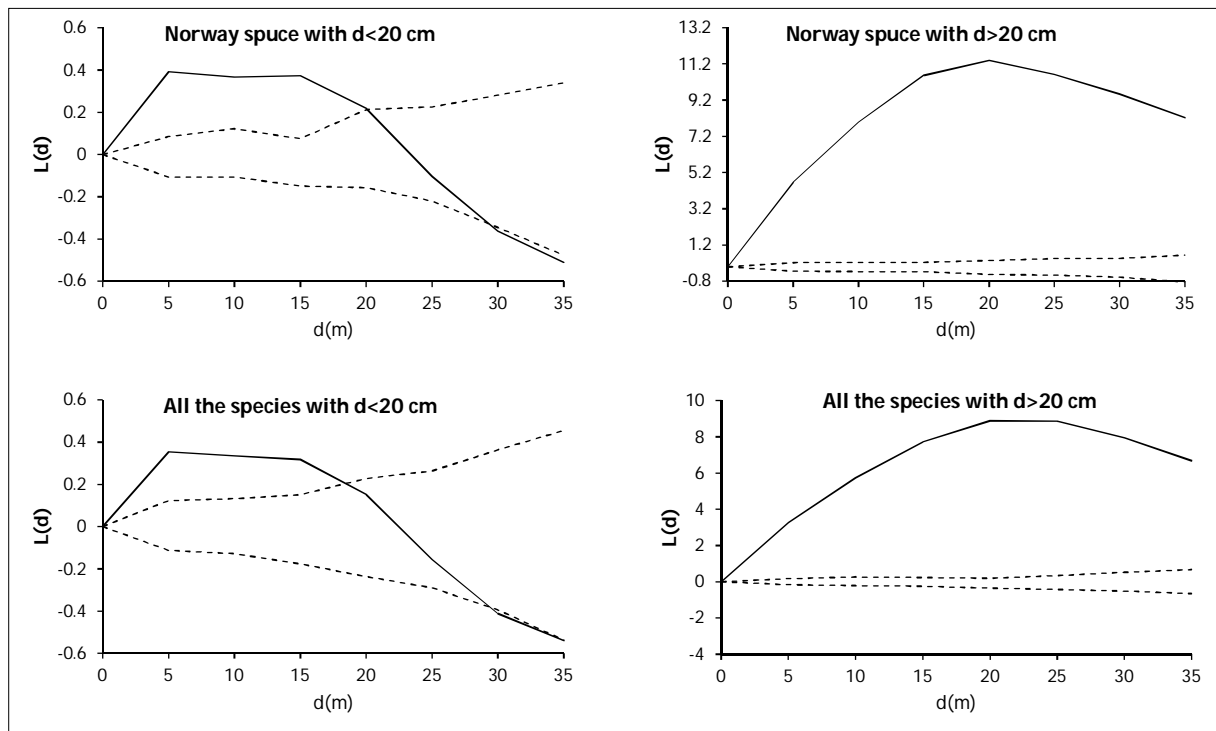
Figure 4. Analysis on dimensional categories (Norway spruce and total stand) of the spatial point processes with univariate Ripley function.
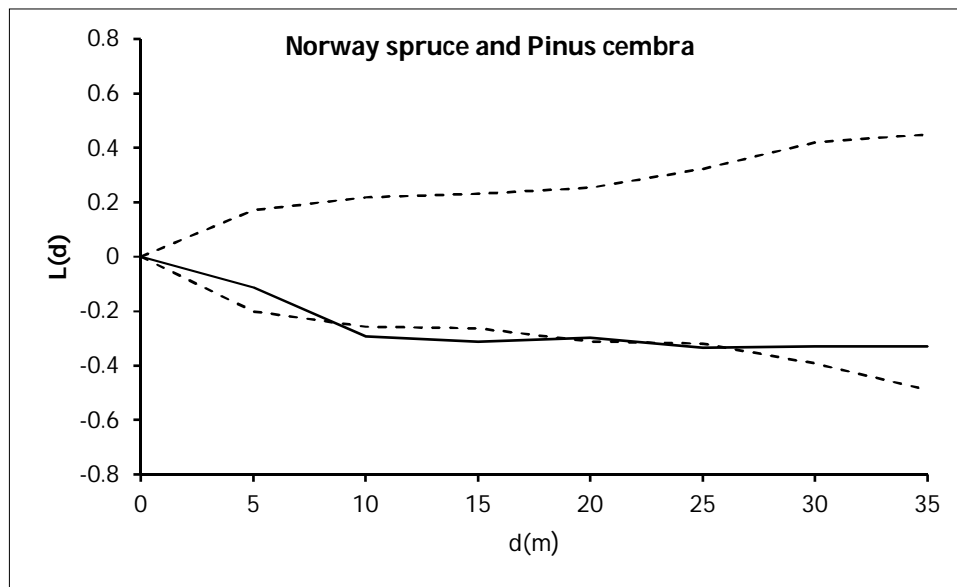

Figure 5. Analysis of the spatial point processes with bivariate K-function Ripley- Norway spruce and Stone pine.

Conclusions. Structural analysis of forest ecosystems integrated with a detailed knowledge of the spatial relationships between different components of those and combined with disturbance regimes, help getting a complex and very close to the true view of the dynamics and spatial organization of the forest. This is an essential condition for ensuring a sustainable forest management especially in the perspective of a close to nature forestry.

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