ACTA SCIENTIARUM POLONORUM
Acta Sci. Pol.
Silv. Colendar. Rat. Ind. Lignar. 5(2) 2006, 109-121

HORIZONTAL DISTRIBUTION OF THE YOUNG GENERATION OF TREES IN FIR-BEECH (*ABIES ALBA* MILL., *FAGUS SYLVATICA* L.) STANDS DEVELOPED WITH THE IMPROVED GRADUAL GROUP CUTTING SYSTEM

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Abstract. This study concerns the analysis of the type of horizontal distribution of trees in fir and beech undergrowth layer, growing under the canopy of two-generation felling stand. The purpose of the analysis was to investigate the spatial structure (horizontal distribution) of young generation in conditions of the improved gradual group cutting (IVd), as well as the evaluation of the applied regeneration method. The direction of further regeneration development was observed, too. Material was collected in 2001 from the area located in Krasiczyn Forest Division (Regional Direction of the State Forests in Krosno) in five two-generation fir-beech stands. The analysis was performed on 23 test plots. Size of each plot was 0.04 ha. Obtained results allow to evaluate positively the applied way of forest regeneration in the investigated stands. The improved gradual group cutting system assures the appropriate conditions of growth and development for beech at the proper group arrangement of trees in the Carpathian beech forest, which was observed very often in the undergrowth layer of this species. In case of fir-undergrowth trees generally characterized with random distribution. It seems to confirm the author's opinion that fir can be only an admixture in *Dentario glandulosae-Fagetum* association. However, applied cutting system (IVd) creates the suitable conditions for artificial regeneration of this species in groups. It perfectly realizes the postulates of natural direction of silviculture.

Key words: distribution of trees, Carpathian beech forest, undergrowth layer, beech, fir, improved gradual group cutting system

INTRODUCTION

Recently, in forest ecology the importance of the horizontal distribution of trees – referred to as spatial pattern of trees – is taken into consideration. Such information in case of plant ecosystems allows to understand to the greater extend the interactions

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between individuals, e.g. cooperation and competition as well as their mortality. It also allows to get knowledge on population dynamics [Szmyt 2004]. In the forest management information on spatial arrangement of trees within the stand may be applied in planning or in construction of new growth models of trees and stands [Daniels 1978, Payandeh 1974, Tomppo 1986, Night 1996, Pretzsch 1997]. It can help to rationalize the regeneration methods of stands and their tending [Zajączkowski 1994, 1995, Sekretenko and Gavricov 1998]. Nowadays, the improving of the forest management based on the ecological background is being applied in practice in Poland. It is connected with implementation of multifunctional model of forest management [Bernadzki 1994]. That way is in accordance with the concept of silviculture based on natural processes [Chodzicki 1976] that has a special meaning in case of mountain forestry, which should reflect the pattern of natural forests, in case of forest composition, structure and dynamic [Jaworski et al. 2000].

In forests of Central Europe, especially in mixed ones, the natural regeneration in clumps is often observed under the canopy and it dominates. Single tree mixture or group mixture of regeneration is rather rare [Jaworski 1990]. In case of mountain beech forests management, in which long period of regeneration is observed, the regeneration has a form of smaller or bigger groups. Wałecki [1984, 1990] suggests to use the stepwise cutting. These group of cuttings fulfill all postulates, e.g. protection, quality ones, and they allow to make use of the increment resulting from thinning. According to Jaworski et. al. [2000] small and large groups, and higher volume as well as better quality of timber in beech forests should ensure the use of improved gradual-group cutting system or modified shelterwood group system (regeneration only on non-extended spots of size 0.2 ha, established in few cycles during 20 years of regeneration period).

The aim of this paper is the investigation of horizontal distribution of young trees in fir-beech mixed forests (regeneration class), where improved gradual-group cutting system was applied. It allows to get the knowledge of spatial structure of such forests as well as evaluation of the applied regeneration method.

OBJECTS AND METHODS

Materials were collected in September 2001 in the Krasiczyn Forest Inspectorate (Cisowa forest district) belonging to the Regional Directorate of the State Forests in Krosno. Forests are located in VIII Natural Forest Region (Carpathian) and in 2nd natural forest district Pogórze Środkowobeskidzkie, in the mesoregion Pogórze Przemyskie, compartment Krasiczyn and in the mesoregion Pogórze Ciężkowicko-Dynowskie, compartment Hołubla.

Measurements were conducted in 5th two-generation fir-beech forests (mature stands) with the structure of regeneration class (30% of the forested area is in this class), at the upland forest site. The age of these stands varied from 75 to 135 and their total area was 101.67 ha. 50 circular plots were established according to the square net of 100 × 100 m where the measurements of different structural characteristics of different plant layer were conducted (size of plot: in old trees layer – 400 m^2, up-growth layer – 40 m^2, seedlings layer – 4 m^2). Measurements mentioned above are described in earlier papers [Miś and Sugiero 2004, Sugiero 2005]. Besides, on all plots the azimuths of each tree, as well as the distance from the center of the plot to all trees from old-tree layer and up-growth were measured. Because of the small number of trees in case of few plots only selected plots were taken into consideration for the analysis of horizontal distribution, and their number was 23. To the up-growth layer belonged fir and beech trees of the minimum height 0.5 m and diameter (DBH) below 7 cm.

On the basis of the collected data (azimuths and distances between trees from the center of plot of the radius "r", calculated in the dependence to the slope inclination) the Cartesians X, Y coordinates were calculated for each tree in up-growth layer (Fig. 1). These coordinates were used to analyse the spatial pattern of trees on all plots.

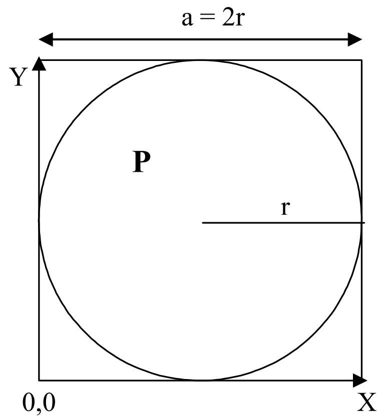


Fig. 1. Coordinate of trees calculation scheme on a test plot (P) in the under-growth layer
Rys. 1. Schemat obliczenia współrzędnych drzew na powierzchni próbnej (P) w warstwie podrostu

Type of the spatial pattern was analysed according to Ripley's function. This method is based on the knowledge of all distances between trees on the particular plot and allows the evaluation of the spatial pattern type in different spatial scale [Szwagrzyk and Ptak 1991, Moeur 1993, Haase 1995, 2001]. It is based on the calculation of Ripley's function K(t) and then its transformed form L(t) for empirical data.

For particular distance "t", if trees are randomly distributed the function L(t) is 0. Deviations from 0 testify that trees at particular distance show other than random spatial type of distribution on the plot. In case of regular distribution of trees function $L(t) < t$ and in case of groups $L(t) > t$, the significance of the deviations from the randomness (called CSR = Complete Spatial Randomness) can be tested using Monte Carlo test [Szwagrzyk and Ptak 1991, Moeur 1993, Haase 1995, Night 1996, Duncan and Fangliang 2000, Reich and Davis 2001]. For current calculations and analysis the software SPPA ver. 2.0 by Peter Haase was applied [Haase 1995, Moeur 1993].

RESULTS

The investigated stands mainly consisted of beech and fir. According to the statistical elaborations of the collected data the average age of beech trees was ca. 111 years and firs 110 (Table 1). Tested stands were characterized by good quality of timber and broken crown closure, resulting from the tending operations conducted according to the improved gradual-group cutting system. These treatments gradually put aside the abundant natural regeneration of beech and fir.

All measured features in the young generation characterized relatively high diversity. Coefficient of variability of most features in undergrowth varied ca. 60% and the most differing feature was the length of crown (ca. 70%). The most important results for this trial concerned the measure of the number of trees and resulting type of spatial distribution of trees in stands. Frequency analysis of the particular plant layers in the tested stands showed that this feature characterized the high differentiation, increasing

Table 1. Statistical analysis of empirical data
Tabela 1. Analiza statystyczna materiału badawczego

Cecha Trait	Species Beech/Fir Gatunek Bk/Jd	Mean Średnia	Median Mediana	Min.	Max.	Range Rozstęp	Variance Wariancja	Standard deviation Odchylenie standardowe	Standard error Błąd standardowy	Variability coefficient Współczynnik zmienności
Old stand trees – Starodrzew										
Size, trees Liczebność, szt.	Bk+Jd	6	5	0	14	14	9.56	3.09	0.44	55.60
Age, years Wiek, lata	Bk	111	115	75	135	60	109.61	10.47	0.84	9.42
	Jd	110	115	75	115	40	160.09	13.66	3.42	12.42
Height, m Wysokość, m	Bk	30.1	31.5	13.0	38.0	25.0	27.13	5.21	0.42	17.29
	Jd	19.2	15.5	8.0	40.0	32.0	75.67	8.70	0.78	45.20
Breast height diameter, cm Pierśnica, cm	Bk	46.7	46.0	16.0	89.0	73.0	247.97	15.75	1.27	33.72
	Jd	29.5	21.5	9.5	93.0	83.5	303.38	17.42	1.56	59.05
Volume, m^3 Miąższość, m^3	Bk	3.23	2.79	0.17	10.42	10.25	5.54	2.35	0.19	72.97
	Jd	1.21	0.29	0.03	9.35	9.32	3.19	1.79	0.16	147.33
Quality Jakość	Bk	1.4	1	1	3	2	0.26	0.51	0.04	35.46
	Jd	1.4	1	1	3	2	0.25	0.50	0.05	36.58
Stand density Zwarcie	Bk+Jd	3.4	3	2	4	2	0.41	0.64	0.09	18.88
Udergrowth – Podrost										
Size, trees Liczebność, szt.	Bk+Jd	11	9	0	42	42	92.39	9.61	1.36	89.33
Age, years Wiek, lata	Bk	17	17	5	33	28	55.09	7.42	0.39	43.75
	Jd	23	24	7	42	35	63.26	7.95	0.59	34.54
Height, m Wysokość, m	Bk	1.9	1.5	0.3	7.0	6.7	1.40	1.18	0.06	63.10
	Jd	4.2	3.8	0.6	14.0	13.4	6.93	2.63	0.20	62.54
Thickness at 1/2 of height, cm Grubość w 1/2 wysokości, cm	Bk	1.3	1.0	0.5	5.5	5.0	0.69	0.83	0.04	64.67
	Jd	4.3	4.0	0.5	12.0	11.5	6.71	2.59	0.19	60.59
Crown length, m Długość korony, m	Bk	1.5	1.2	0.3	6.7	6.4	1.17	1.08	0.06	69.93
	Jd	3.2	2.8	0.2	12.2	12.0	5.39	2.32	0.17	72.48
Crown width, m Szerokość korony, m	Bk	1.2	1.0	0.2	4.7	4.5	0.51	0.72	0.04	61.31
	Jd	2.2	2.2	0.4	6.1	5.7	0.85	0.92	0.07	42.10
Cover, % Pokrycie, %	Bk+Jd	50.2	50	10	90	80	663.00	25.75	3.76	51.28
Natural seeding – Nalot										
Size, trees Liczebność, szt.	Bk+Jd	6	2	0	146	146	423.87	20.59	2.91	323.71
Age, years Wiek, lata	Bk	4	4	1	6	5	1.10	1.05	0.20	27.00
	Jd	3	3	1	6	5	3.44	1.85	0.37	67.20
Cover, % Pokrycie, %	Bk+Jd	19.5	10	5	90	85	306.64	17.51	2.88	89.99

towards the forest carpet and varied from 56% in old-tree layer, through 89% in up-growth layer and up to 324% in case of seedlings. In Carpathian beech forest because of the specific natural regeneration (abundant in gaps) and relatively rarely appeared period of seed crop (for beech every 5-10 years; for fir – 3-5 years) the most often observed type of plant distribution is in groups (clumps) what means that trees are distributed in clumps and they forms larger groups. It results in the higher differentiation of number of trees between randomly selected plots, especially in case of undergrowth layer.

Spatial pattern analysis of trees from the undergrowth layer was conducted in case of both species.

Fir undergrowth

In case of fir undergrowth the distribution of trees was examined on 9 plots. The number and the area of the particular plots are shown on Figure 2.

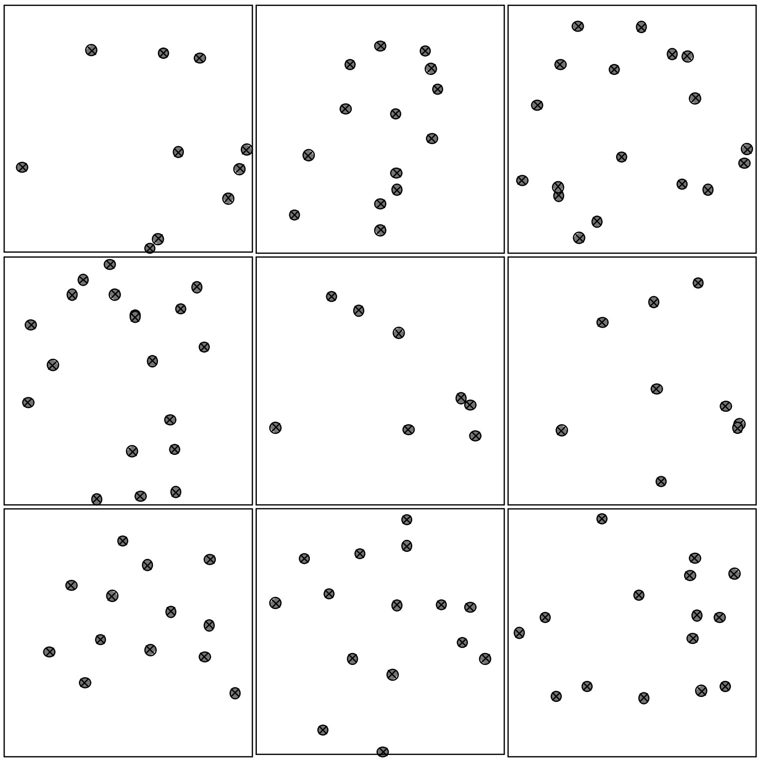


Fig. 2. Maps of trees arrangement on test plots in fir-undergrowth layer (from left part verses: no. 7, 8, 11, 13, 14, 16, 22, 23, 29) in scale 1:100
Rys. 2. Mapki rozmieszczenia drzew na powierzchniach próbnych w warstwie podrostu jodłowego (od lewej strony wierszami: nr 7, 8, 11, 13, 14, 16, 22, 23, 29) w skali 1:100

Table 2. Number of trees on selected plots for fir undergrowth
Tabela 2. Liczba drzewek na wybranych poletkach w warstwie podrostu jodłowego

Plot number Numer poletka	Area, m^2 Powierzchnia, m^2	N – number of trees N – liczba drzewek
7	40	10
8	40	14
11	40	18
13	40	19
14	40	8
16	40	9
22	40	13
23	40	15
29	40	15

On all tested plots the analysis of the spatial arrangement of undergrowth trees was random, however in all cases deviations from the CSR were observed. The most similar type of spatial distribution to CSR showed trees on plot 29, where the deviations from theoretical pattern were very small. On 4 plots (no. 7, 11, 16 and 23) the deviations ran towards regular type of spatial distribution at almost whole range of distances. The most clearly it was observed on plots 11 and 23. Distinct deviations towards clumped distribution were observed only on plot 8. On the rest of the tested plots (13, 14 and 22) the observed deviations ran towards both, regular and clumped distribution type. The first was especially stated at smaller distances and the second – in case of larger ones. This trend was clearly shown on plots 13 and 22, and in opposite situation was stated in case of plot 14.

Beech undergrowth

The analysis of the spatial pattern of young beech was conducted on 14 plots. The number as well as the plot sizes are presented in Table 3.

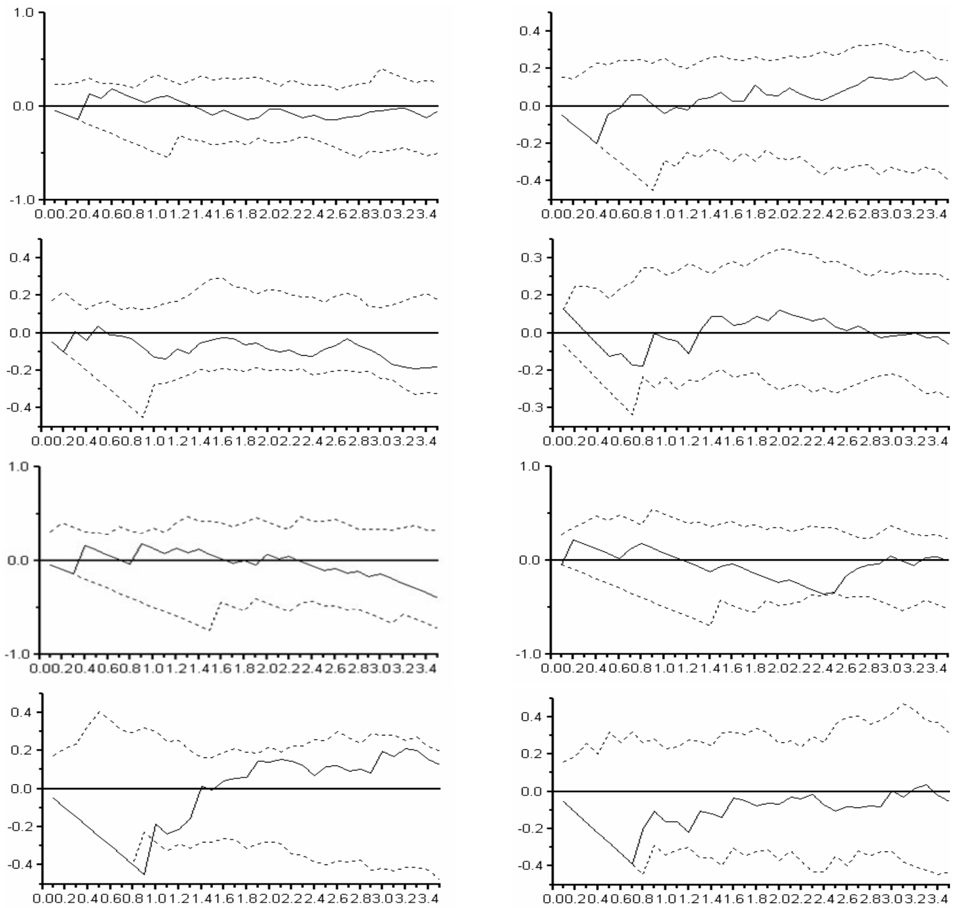
Table 3. Number of trees on selected plots for beech undergrowth
Tabela 3. Liczba drzewek na wybranych poletkach w warstwie podrostu bukowego

Plot number Numer poletka	Area, m^2 Powierzchnia, m^2	N – number of trees N – liczba drzewek
2	40	12
3	40	23
4	40	24
15	40	13
17	40	18
19	40	9
25	40	13
28	40	8
31	40	14
38	40	25
43	40	12
44	40	34
45	40	42
49	40	29

In case of 5 plots the analysis showed that young beech trees were randomly dispersed, with smaller or greater deviations from CSR (plots: 3, 4, 19, 28 and 49). Most deviations ran towards clumped type of distribution.

The most often observed spatial pattern of distribution in beech undergrowth was clumped. From 15 tested plots, 8 showed the spatial described as clumped at most distances. It is worth noting that there was no plot on which regular pattern of trees could be observed.

For better presentation of spatial analysis on particular plots maps (Fig. 2, 4) of distribution, as well as graphs of L(t) function (Fig. 3, 5) are enclosed.



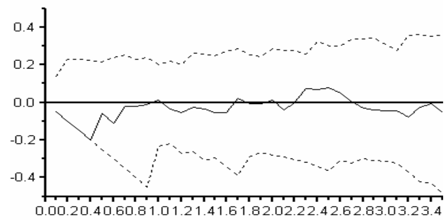


Fig. 3. Diagrams of function L(t) for analyzed test plots with fir-undergrowth (from left part verses: no. 7, 8, 11, 13, 14, 16, 22, 23, 29)
Rys. 3. Wykresy funkcji L(t) dla analizowanych powierzchni próbnych z podrostem jodłowym (od lewej strony wierszami: nr 7, 8, 11, 13, 14, 16, 22, 23, 29)

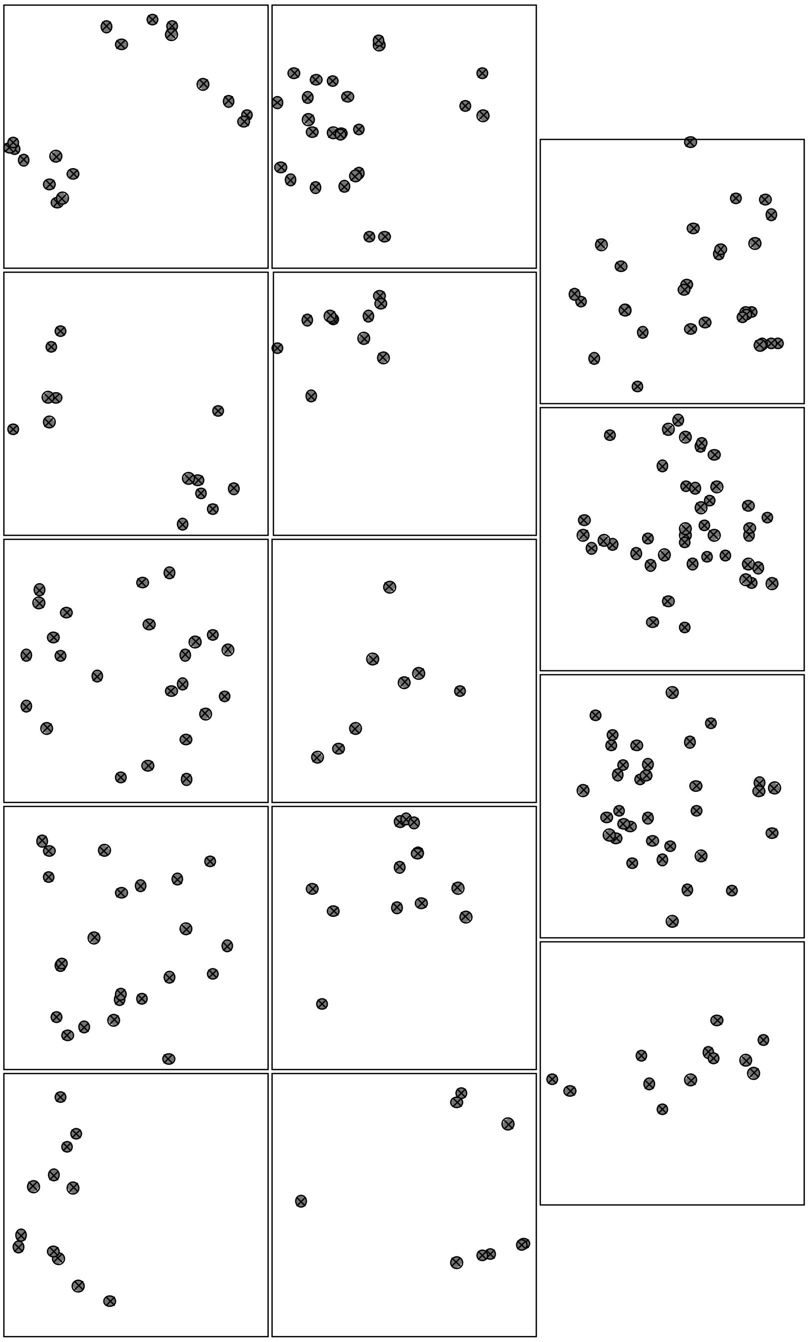


Fig. 4. Maps of trees arrangement on test plots in beech-undergrowth layer (from left part verses: no. 2, 3, 4, 15, 17, 19, 25, 28, 31, 38, 43, 44, 45, 49) in scale 1:100

Rys. 4. Mapki rozmieszczenia drzew na powierzchniach próbnych w warstwie podrostu bukowego (od lewej strony wierszami: nr 2, 3, 4, 15, 17, 19, 25, 28, 31, 38, 43, 44, 45, 49) w skali 1:100

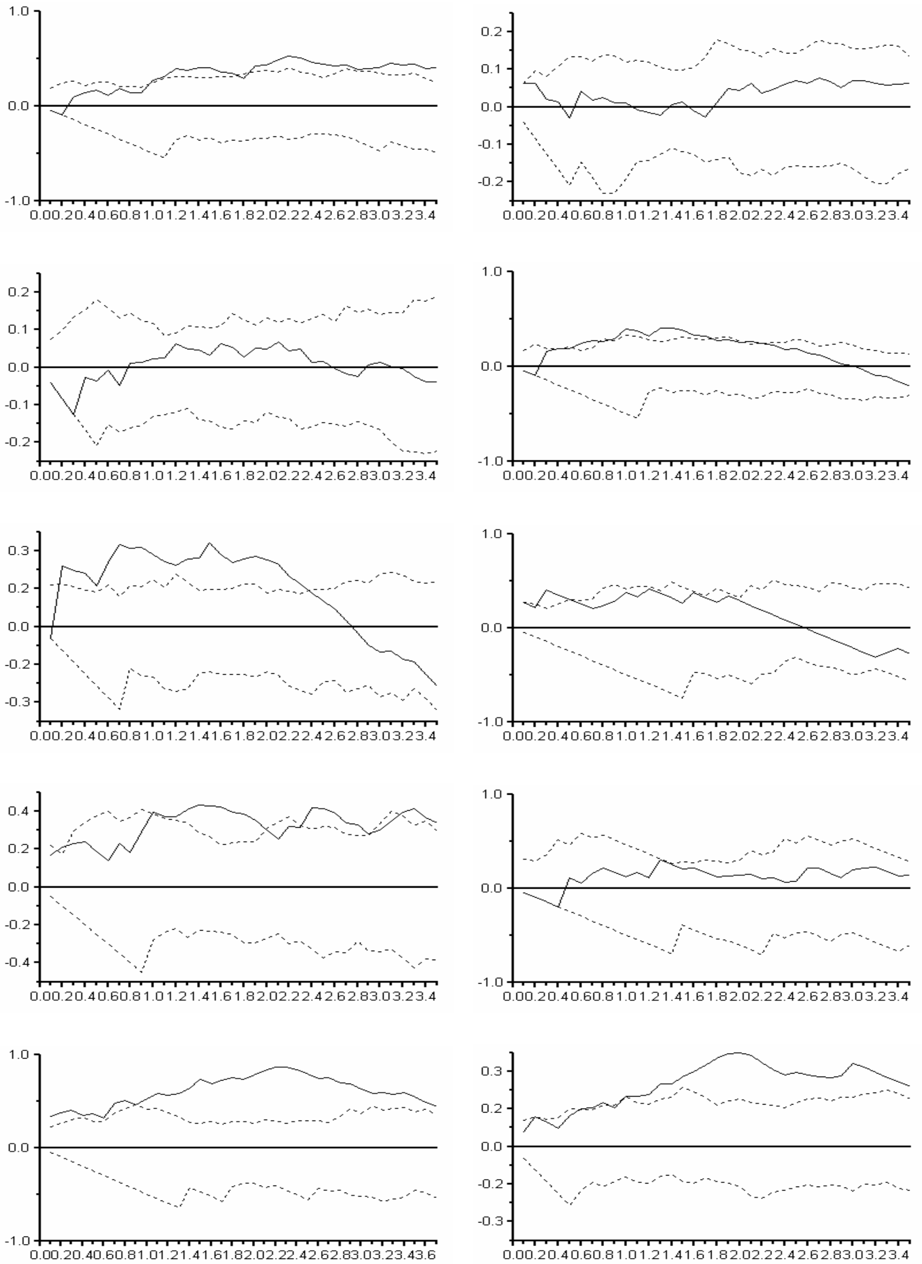


Fig. 5. Diagrams of function L(t) for analyzed test plots with beech-undergrowth (from left part verses: no. 2, 3, 4, 15, 17, 19, 25, 28, 31, 38)
Rys. 5. Wykres funkcji L(t) dla analizowanych powierzchni próbnych z podrostem bukowym (od lewej strony wierszami: nr 2, 3, 4, 15, 17, 19, 25, 28, 31, 38)

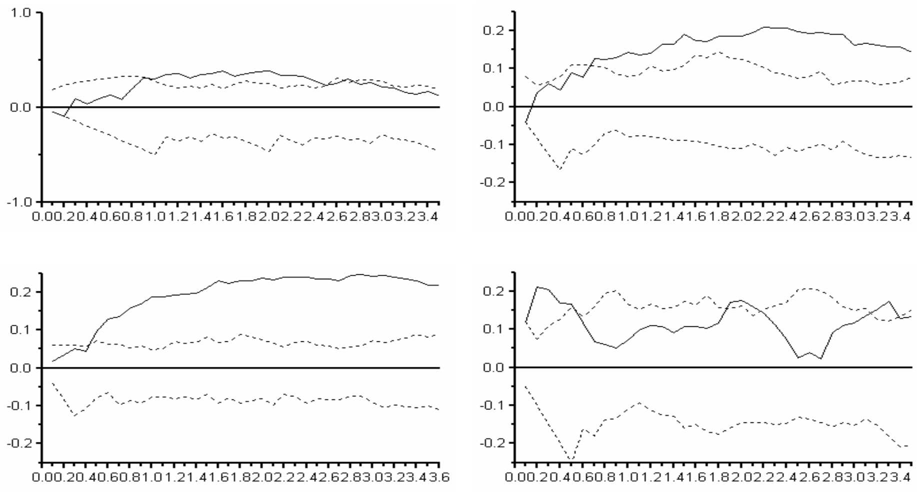


Fig. 5 cont. Diagrams of function L(t) for analyzed test plots with beech-undergrowth (from left part verses: no. 43, 44, 45, 49)
Rys. 5 cd. Wykres funkcji L(t) dla analizowanych powierzchni z podrostem bukowym (od lewej strony wierszami: nr 43, 44, 45, 49)

DISCUSSION

The obtained results of spatial pattern analysis for beech and fir showed distinct differences between these forest tree species. Fir undergrowth characterized random dispersion on plots more often, with deviations towards regular distribution. Young beeches were distributed more often in clumps, rare randomly and regularity was not observed at all.

Leemans [1991] in research conducted in spruce stands analysed the spatial distribution of young spruces of the height up to 1.3 m. On the basis of the obtained results he stated that the youngest trees were randomly dispersed most often and with the age this type of spatial pattern was changed to clumps. Very similar results were obtained by Szwagrzyk [1990] in case of natural regeneration of Norway spruce. According to him the random distribution of seedlings at the beginning was changed towards clumps in older stands. Norway spruce and its spatial distribution was analysed by Holeksa [1998]. He conducted his investigations in the Carpathian upper-zone coniferous forest. Among different tree categories he analysed undergrowth. Similar to the others he stated that young trees were often distributed in clumps. The Carpathian beech forest is characterized by bigger clumps of natural regeneration and it covers a greater area comparing to a fir forest or pure beech forest. As noted by Mazur [1984] such a spatial arrangement, with large aggregations, makes the possibility higher to survive for young trees than in case of random distribution. In case of fir and beech undergrowth on the tested plots, similar results were obtained only in case of beech. Fir most often was distributed according to random pattern. The reason for that may be the fact that fir in the Carpathian beech forest usually forms only admixture.

CONCLUSIONS

1. Horizontal spatial distribution analysis of trees classified as undergrowth in case of beech in fir-beech forests showed that young beeches were distributed in clumps more often. Stated in few cases random dispersion of this species should be treated as non-stable feature of the stand and in older stands this spatial type ought to change into clumped distribution type.

2. The analysis of the spatial distribution of fir undergrowth in such a forest type seems to confirm the role of this species in the stand. In forest associations with *Fagion* fir plays usually the role as admixture. It is confirmed by the random distribution of firs on most plots being tested. Observed deviations towards regularity are results of artificial method of its regeneration on spots.

3. The improved gradual-group cutting system applied in fir-beech forests forms advantageous conditions for beech growth, that forms clumps in the Carpathian beech forests ensures the optimal spatial structure of such forests.

4. Appropriate structure of the Carpathian beech forests forms very suitable conditions for fir growth that regenerates very well under the canopy of the mature beech stand and gives very valuable timber. So, it seems fir is worth regenerating on spots according to the improved gradual-group cutting system. Maybe it will help us to increase its share in our forests.

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POZIOME ROZMIESZCZENIE DRZEW MŁODEGO POKOLENIA W DRZEWOSTANACH JODŁOWO-BUKOWYCH (*ABIES ALBA* MILL., *FAGUS SYLVATICA* L.) ZAGOSPODAROWANYCH RĘBNIĄ STOPNIOWĄ GNIAZDOWĄ UDOSKONALONĄ

Streszczenie. Praca dotyczy analizy typu poziomego rozmieszczenia drzew w warstwie podrostu jodły i buka wzrastającego pod okapem drzewostanu macierzystego o budowie klasy odnowienia (KO). Celem analizy było zbadanie struktury przestrzennej rozmieszczenia młodego pokolenia w warunkach rębni stopniowej gniazdowej udoskonalonej (IVd), a także ocena zastosowanej metody odnowienia oraz kierunku jego rozwoju. Materiał badawczy zebrano w 2001 roku na terenie Nadleśnictwa Krasiczyn (RDLP Krosno) w pięciu dwugeneracyjnych drzewostanach jodłowo-bukowych. Analizę przeprowadzono na 23 powierzchniach próbnych o wielkości 0,04 ha. Uzyskane w opracowaniu wyniki pozwalają pozytywnie ocenić stosowany w badanych drzewostanach sposób odnawiania lasu. Rębnia stopniowa gniazdowa udoskonalona zapewnia odpowiednie warunki wzrostu i rozwoju buka przy właściwym w buczynach karpackich grupowym rozmieszczeniu drzew, które obserwowano najczęściej w warstwie podrostu tego gatunku. Natomiast w podroście jodłowym drzewa charakteryzowały się na ogół rozmieszczeniem losowym, który zdaje się potwierdzać wyłącznie domieszkowy charakter jodły w drzewostanach z zespołu *Dentario glandulosae-Fagetum*. Rębnia IVd stwarza jednak możliwość sztucznego wprowadzania tego gatunku na gniazdach, doskonale realizując postulaty naturalnego kierunku hodowli lasu.

Słowa kluczowe: rozmieszczenie drzew, buczyna karpacka, podrost, buk, jodła, rębnia stopniowa gniazdowa udoskonalona

Accepted for print – Zaakceptowano do druku: 28.09.2006

For citation – Do cytowania: Szmyt J., Sugiero D., 2006. Horizontal distribution of the young generation of trees in fir-beech (Abies alba Mill., Fagus sylvatica L.) stands developed with the improved gradual group cutting system. Acta Sci. Pol., Silv. Colendar. Rat. Ind. Lignar. 5(2), 109-121.