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Horizontal structure of forest stands on permanent research plots in the Krkonoše Mts. and its development

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ABSTRACT: Horizontal structure on 38 permanent research plots is described for juvenile growth and developmental phases (natural seeding, advance growth, plantations) and tree layer of a parent stand. Hopkins-Skellam index, Pielou-Mountford index, Clark-Evans index and Ripley's *K*-function were computed. The results are presented separately for beech stands, mixed stands, spruce stands, stands in the timberline ecotone and relict pinewood. The numbers and distribution of natural and combined regeneration recruits are mostly sufficient from the aspect of ecological, environmental and production functions of forest. The horizontal structure of juvenile growth and developmental phases of natural and combined regeneration shows mostly clustering; it is random or moderately regular at places with a single dominant proportion of artificial regeneration. In the tree layer the horizontal structure of forest stands is mostly random to moderately regular. In the future silvicultural measures should be aimed to support the structure of homogeneous stands of younger growth phases that have originated on a large scale after the air-pollution disaster.

Keywords: Clark-Evans index; forest stands; Hopkins-Skellam index; horizontal structure; K-function; Krkonoše Mts.; Pielou-Mountford index

The spatial structure of forest stand is a stand framework assessed in a horizontal and vertical direction. Stand density, stocking and canopy closure are usually investigated in forest stands from the aspect of horizontal structure while from the aspect of vertical structure it is the formation of one or several stand storeys and of stand layers within them (Vacek 1982). In addition, Schütz (2002) differentiated between irregularity within the crown layer, full vertical diversification at the stand level (selection structure) and horizontal diversification (patchiness). In this aspect, appropriate management of forest stands may contribute to an increase in diversification at all three above-mentioned levels. The horizontal distribution of trees is influenced to a greater extent by the way and procedure of stand origination and by the way of reducing the tree number by natural elimination and systematic measures of forest managers. Man-made stands mostly have the regular original distribution of trees whereas stands from natural regeneration (seeding and sprouts) usually have the clustered to randomly irregular original distribution (cf. Vacek et al. 2009). In the course of stand development these types of distribution converge to a moderately regular distribution. Quite an even distribution of trees on the stand area, in connection with optimum canopy, allows good utilisation of production space, production of high-quality stems and maximum volume increment. On a large scale, however, Boncina (2002) reported higher patchiness and finer texture in managed stands than in original stands. The vertical stratification of stand is influenced to the greatest extent by tree age, followed by different growth rates of the particular tree types and their coenotic relations at a given site. Accordingly, the trees take permanent or temporal positions in stand layers. The vertical

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structure can be substantially influenced by silvicultural practices. Early crown thinnings may lead e.g. to diversification of tree positions within the canopy (Štefančík 2006) with a positive impact on stand stability while more pronounced vertical diversification of permanent type can be achieved at opportune sites by the application of selection principles in a small-area shelterwood system or by a selection system (cf. Emborg et al. 2000). This procedure basically simulates the dynamics of natural forests by intentional disturbance of the crown canopy and by initiation of natural regeneration at favourable microsites in gaps. A specific problem of the spatial structure of even-aged, uneven-aged stands and conversion stands was studied by Hanewinkel (2004). In a forest of age classes the standing volume and the largest trees were evenly distributed on the area. With more progressive phases of conversion and with a taller height of the understorey its pronounced clustered pattern, which is connected with regeneration in gaps in the initial phase of conversion, disappears. The gaps should not be enlarged, on the contrary, in uneven-aged stands selective measures should lead to the random distribution of trees of medium and small dimensions across the stand area.

To assess possibilities of optimizing the forest ecosystem management in national parks of the Krkonoše Mts. the horizontal structure of forest stands was exactly evaluated on 38 permanent research plots, both in juvenile growth and developmental phases (natural seeding, advance growth, plantations) and in the tree layer.

MATERIAL AND METHOD

Description of permanent research plots

In the territory of the Krkonoše Mts., 32 permanent research plots, designated PRP 1 to PRP 32, were established in the 5th to 8th forest altitudinal zone. These PRP represent beech, mixed (spruce with beech to beech with spruce) and spruce stands in different site conditions, with different level of air-pollution impacts and different rate of subsequent acidification. After some time, six plots were added to reach the total number of 38 PRP: two plots in the timberline ecotone where research was aimed at natural vegetative forest regeneration – spruce and beech layering, and four plots were established in Poland, where those stand types were selected that either do not occur in the Czech part of the Krkonoše Mts. or occur only sporadically there (relict pinewood, beech stand with fir, eutrophic beech stand and acidophilic mountain beech stands at a high elevation). The majority of these plots were established in 1980 while PRP 11 to 15 were already established in 1976. The plots are mostly 50 × 50 m in size, i.e. 0.25 ha, exception are listed in Vacek et al. (2010). A description of all 38 PRP, where forest regeneration was studied, is presented in the first paper (Matějka et al. 2010).

The FieldMap technology was used to determine the structure of the upper storey of the tree layer of tree species on PRP. On each PRP a transect 50 × 5 m in size (250 m^2) was demarcated and stabilised, only on PRP 6 and 7, the area of which is 0.5 and 1.0 ha, respectively, there were 2 and 4 transects, i.e. one transect per 0.25 ha. The place of the transect demarcation was selected so that it would represent the average abundance and maturity of advance growths on the whole PRP. The transects were stabilised in the terrain with wooden stakes. All trees present in the particular transects, of diameter at breast height smaller than 12 cm, were included in measurements of natural and combined regeneration.

The horizontal structure was evaluated on the particular plots in all recruits of regeneration and tree layer. These indices were calculated: Hopkins-Skellam index (Hopkins, Skellam 1954), Pielou-Mountford index (Pielou 1959, Mountford 1961), Clark-Evans index (Clark, Evans 1954) and Ripley's *K*-function (Ripley 1981; Lepš 1996). The horizontal structure of regeneration relates to 2009 and of the tree layer to the year of PRP establishment. The respective expected values of these indices were computed by means of numerical simulations for each specific case separately. In tables describing the particular PRP the column of expected value shows the value of the index for random distribution. The columns of lower limit and upper limit show the interval around this expected value in which the randomness of distribution cannot be rejected yet. Only when the value of the index exceeds the upper limit of the interval, it is possible to state (at a 0.05 significance level) that the point structure is aggregated (for Hopkins-Skellam and Pielou-Mountford index) or regular (for Clark-Evans index). On the contrary, if the value of the index does not reach the lower limit of the interval, it shows regularity in Hopkins-Skellam and Pielou-Mountford index or aggregation in the case of Clark-Evans index.

Differences in the horizontal structure were quantified by Ripley's *K*-function and represented graphically. The x-axis shows a distance between recruits of natural regeneration in metres and the y-axis shows the value of *K*-function – $K(r)$. This value documents the mean number of recruits that would occur in a circle of the radius *r* around a randomly selected recruit on condition that the recruits on the plot showed unit density (i.e. 1 recruit per 1 m^2 in this case). In the figures the black line represents the *K*-function for actual distances of natural regeneration recruits in the transects of PRP and the three central curves illustrate the *K*-function for the random spatial distribution of trees and its 95% reliability interval. When the black line of the tree distribution on PRP is drawn above this interval, it indicates the trend of recruit clustering; if the line is drawn below this interval, it shows the trend of regular distribution.

Ripley's *K*-function can be defined (Diggle 1983) as follows:

$$K(r) = \frac{E\left(n_r\right)}{\lambda} \qquad (1)$$

where:

$E(n_r)$ – the mean number of points (trees), the distance of which from a randomly chosen point is smaller than *r*,

λ – density, i.e. the number of points per unit area.

If the mechanism generating point distribution on the plot is known, it is also possible to calculate the expected form of *K*-function. E.g. for obviously random point distribution it holds good $K(r) = \delta r^2$. In case that the value $K(r)$ calculated from real data is higher than the above-mentioned expected value, it can be interpreted as a trend of point clustering along distance *r*. On the contrary, the lower value $K(r)$ indicates the trend of repulsion, i.e. of the formation of regular point structures.

When the *K*-function is estimated from real data in operational conditions, it is necessary to solve problems arising from definite dimensions of a sample plot, especially the influence of the edge effect. In this case the estimation of *K*-function was done according to the formula (Penttinen et al. 1992):

$$\hat{K}(r) = \sum_{0<\left\|x_i - x_j\right\| \le r} \frac{1}{\hat{\lambda}^2 s\left(\left\|x_i - x_j\right\|\right)} \qquad (2)$$

where: $s(r)$ is Ohser's correction of edge effect, the value of which for a sample plot in the shape of a rectangle with sides *a* and *b*, $a < b$, is calculated from the equation

$$s(r) = ab - r(2a + 2b - r)/\delta \qquad 0 < r < a \qquad (3)$$

The test of significance of $K(r)$ deviations from the values expected for a random point pattern was done by means of Monte Carlo simulations. The mean values of *K*-function were estimated as arithmetic means of *K*-functions calculated for a large number (3,999) of randomly generated point structures. In the figures these mean curves are represented by a solid blue line. The envelope tangent to 95% of the values of *K*-functions for randomly generated structures is represented by thinner blue lines. The randomness of the mechanism generating a real point structure will be rejected (on a 0.05 significance level) for distances where the respective *K*-function exceeds this envelope.

RESULTS AND DISCUSSION

Beech stands

PRP 31 – U Hadí cesty F

Forest stand 542 C15/1b with PRP 31 – U Hadí cesty F is situated on a slope of medium gradient and northeastern exposure. It is quite a closed grown-up beech high forest with interspersed sycamore maple and Norway spruce. From the aspect of the small forest development cycle this stand is at the ultimate stage of optimum to the initial stage of disintegration with regeneration phase.

The total number of natural regeneration recruits highly exceeds the values recommended for the density of artificial regeneration of beech in production forests (5,000–10,000 recruits per ha according to Burschel, Huss 1997), reaching 73,800 recruits per ha for all tree species: beech accounted for 68%, sycamore maple for 22% and rowan for 9%, and the representation of the other species (Nor-

Table 1. The values of indices of the horizontal structure of natural regeneration and tree layer recruitment on PRP 31 – U Hadí cesty F

Index	Natural generation				Tree layer			
	values		bound		values		bound	
	observed	expected	lower	upper	observed	expected	lower	upper
Hopkins-Skellam	0.686	0.488	0.481	0.525	0.345	0.498	0.401	0.608
Pielou-Mountford	2.079	1.019	1.002	1.121	0.800	1.114	0.831	1.524
Clark-Evans	0.892	0.990	0.986	1.046	1.267	1.049	0.920	1.170

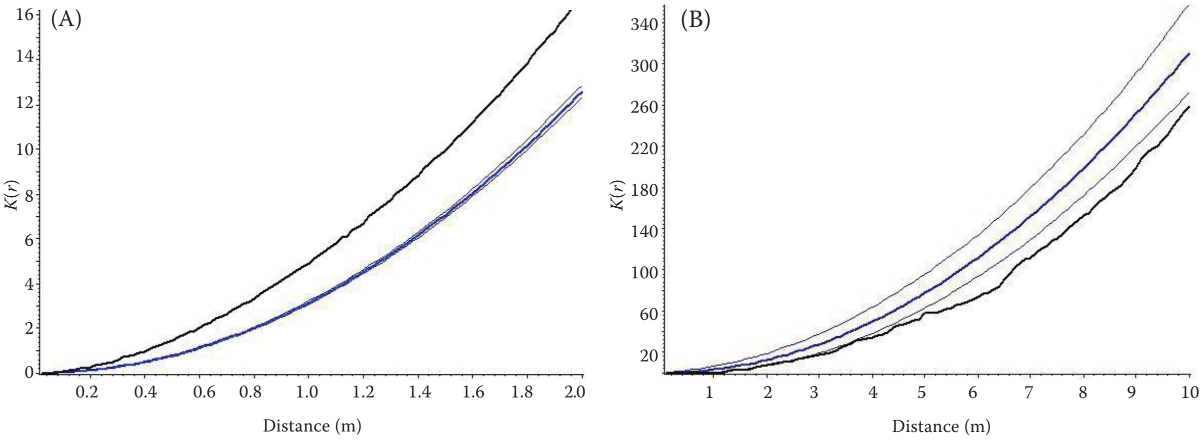

Fig. 1. (A) Horizontal structure of natural regeneration and (B) tree layer on PRP 31 – U Hadí cesty F expressed by *K*-function

way spruce, European ash and red elderberry) was mostly lower than 1%. Due to the relatively slow and irregular opening-up of the canopy the height and diameter differentiated natural regeneration is gradually formed there.

Table 1 shows the values of indices of the horizontal structure of recruits and tree layer. According to all three determined structural indices (Hopkins-Skellam, Pielou-Mountford and Clark-Evans) natural regeneration on this PRP is aggregated and the distribution of the tree layer recruits is moderately regular. The relatively considerable clustering of recruits according to their distance (spacing) is also documented by Ripley's *K*-function (Fig. 1); the distribution of individuals of the tree layer is moderately regular according to this function.

Mixed stands

PRP 7 – Bažinky 1

Forest stand 311 A17/4/1a with PRP 7 – Bažinky 1 is situated on a slope of medium gradient and eastern exposure. It is a partially open grown-up spruce-beech high forest with abundant natural seeding of mainly European beech and Norway spruce of different age and height. From the aspect of the small forest development cycle this stand is at the medium-advanced disintegration stage with regeneration phase.

The total per-hectare number of natural regeneration recruits exceeds the values of the preceding PRP: 96,720 recruits, of them European beech accounts for 87%, Norway spruce for 12%, rowan for 1% and the proportion of goat willow is minimal. Due to the gradual opening-up of the canopy with continuing stand disintegration the height and diameter largely differentiated natural regeneration was formed there.

Table 2 documents the values of indices of the horizontal structure of natural regeneration and tree layer recruitment. According to all three determined structural indices (Hopkins-Skellam, Pielou-Mountford and Clark-Evans) natural regeneration on this PRP is aggregated. Two structural indices (Hopkins-Skellam and Pielou-Mountford) show moderate clustering of the tree layer recruits on this PRP while the Clark-Evans index indicates their random distribution. Relatively considerable clustering of natural regeneration recruits according to their distance (spacing) also follows from Ripley's *K*-function (Fig. 2A); the distribution of the

Table 2. The values of indices of the horizontal structure of natural regeneration and tree layer recruitment on PRP 7 – Bažinky 1

Index	Natural regeneration				Tree layer			
	values		bound		values		bound	
	observed	expected	lower	upper	observed	expected	lower	upper
Hopkins-Skellam	0.783	0.486	0.479	0.524	0.604	0.499	0.440	0.568
Pielou-Mountford	3.168	1.012	0.985	1.116	1.452	1.068	0.901	1.284
Clark-Evans	0.831	0.991	0.990	1.044	0.977	1.027	0.958	1.101

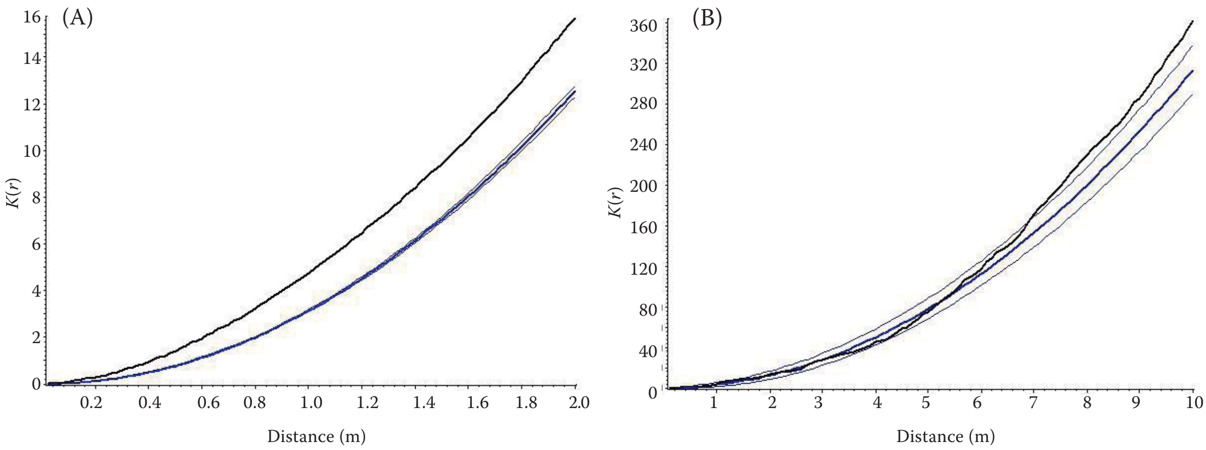

Fig. 2. (A) Horizontal structure of natural regeneration and (B) tree layer of spruce-beech stand expressed by *K*-function on PRP 7 – Bažinky 1 – transect 1a

tree layer individuals is mostly random according to this function whereas trees with spacing larger than 7 m show a clustering pattern (Fig. 2B).

Spruce stands

PRP 21 – Modrý důl

Forest stand 233 A14 with PRP 21 – Modrý důl is situated on a slope of medium gradient and southern exposure. It is quite a closed grown-up spruce high forest with the partial incipient natural seeding of Norway spruce. From the aspect of the small forest development cycle this stand is at the stage of optimum with the incipient unpronounced phase of regeneration.

The total per-hectare number of natural regeneration recruits is 7,360, and this is only Norway spruce recruitment. Individual trees of rowan (*Sorbus aucuparia* subsp. *glabrata*) occur sporadically on this PRP only outside the studied transect. Due to the irregular opening-up of the canopy the height and diameter differentiated natural regeneration of Norway spruce was formed, mostly in small biogroups or individually at markedly elevated places (mostly around root swelling) or in rows on rotting stems.

Table 3 shows the values of indices of the horizontal structure of natural regeneration recruits. According to all three determined structural indices (Hopkins-Skellam, Pielou-Mountford and Clark-Evans) natural regeneration on this PRP is largely aggregated and the distribution of the tree layer individuals on the plot is random. Ripley's *K*-function (Fig. 3A) also shows very pronounced clustering of natural regeneration recruits according to their distance (spacing); the distribution of the tree layer individuals is mostly random according to this function while the pattern is moderately regular at a spacing of 4.6–4.8 m and 5.6–5.8 m (Fig. 3B).

PRP 3 – U Lubošské bystřiny

Forest stand 514 A2/1a with PRP 3 – U Lubošské bystřiny is situated on a slope of medium gradi-

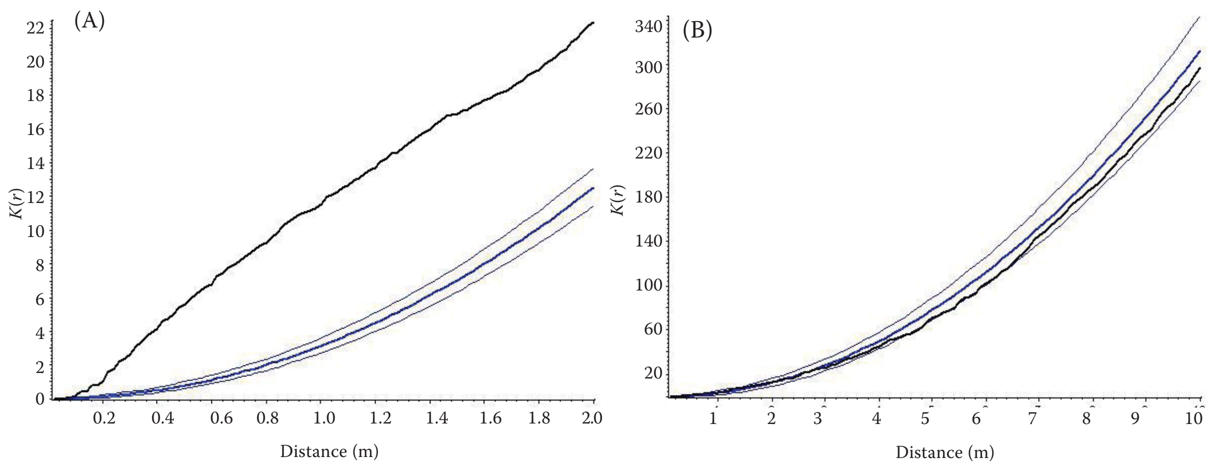

Fig. 3. (A) Horizontal structure of natural regeneration and (B) the tree layer of spruce stand expressed by *K*-function on PRP 21 – Modrý důl

Table 3. The values of indices of the horizontal structure of natural regeneration recruitment on PRP 21 – Modrý důl

Index	Natural regeneration				Tree layer			
	values		bound		values		bound	
	observed	expected	lower	upper	observed	expected	lower	upper
Hopkins-Skellam	0.860	0.499	0.434	0.571	0.493	0.498	0.424	0.583
Pielou-Mountford	4.500	1.132	0.932	1.389	1.128	1.088	0.872	1.382
Clark-Evans	0.575	1.051	0.967	1.136	1.052	1.037	0.944	1.129

ent and southwestern exposure. It is a highly differentiated young plantation to young growth that mostly originated by artificial regeneration in the stand that was at the stage of disintegration due to the impacts of air pollution and bark beetle (*Ips typographus*). After the declining stand was felled, reforestation with blue spruce (*Picea pungens*) and dwarf pine (*Pinus mugo*) was carried out. On the contrary, Norway spruce and rowan mostly originated from natural regeneration. The open young plantation to young growth of blue spruce with admixed dwarf pine and Norway spruce and interspersed rowan is quite even-aged even though the reforestation including repeated repair planting lasted for 9 years. Losses of the first reforestation were 42% while they amounted to 57% on average in subsequent 4 repair plantings. The highest losses of 68% were recorded in blue spruce, in dwarf pine they were only 19%. From the aspect of the great forest development cycle it is a pioneer forest with some traits of transitional forest. The proportion of artificial regeneration recruits is 91%.

Not very prosperous regeneration in the transect on PRP 3 is relatively sufficient only from the aspect of the soil-conservation function. Its total per-hectare number is 3,240 recruits while blue spruce is a markedly dominant species (78%), dwarf pine (12%) and Norway spruce(9%) are admixed, and rowan (1%) is interspersed.

Table 4 documents the values of indices of the horizontal structure of combined regeneration and tree layer recruits. According to Hopkins-Skellam and Clark-Evans indices the combined regeneration on this PRP shows a moderately regular pattern whereas according to Pielou-Mountford index its pattern is random. The distribution of the tree layer individuals was random according to two structural indices (Hopkins-Skellam and Pielou-Mountford) and regular according to Clark-Evans index. Ripley's *K*-function (Fig. 4A) also indicates the mostly moderately regular distribution and only edge random distribution (in the smallest and largest spacings) of combined regeneration recruits according to their distance (spacing); according to this function the distribution of the tree layer individuals was regular at a tree spacing smaller than 3.1 m and random at a larger spacing (Fig. 4B).

Forest stands in the timberline ecotone

PRP 34 – Liščí hora

Forest stand 405 B15a/4 with PRP 34 – Liščí hora is situated on a slope of medium gradient and southwestern exposure. It is mostly rather an open spruce stand with pronounced spatial and age differentiation. From the aspect of the small forest development cycle the stand is at the stage of optimum with regeneration phase. It is a stand of phenotype class C, characterized by two storeys. Due to the large opening-up of the canopy of the upper tree layer (25% canopy) spruce crowns touch the ground, which is a basic pre-

Table 4. The values of indices of the horizontal structure of combined regeneration recruitment on PRP 3 – U Lubošské bystřiny

Index	Natural regeneration				Tree layer			
	values		bound		values		bound	
	observed	expected	lower	upper	observed	expected	lower	upper
Hopkins-Skellam	0.389	0.497	0.391	0.613	0.440	0.498	0.384	0.625
Pielou-Mountford	0.997	1.203	0.867	1.665	1.070	1.132	0.807	1.611
Clark-Evans	1.298	1.084	0.943	1.219	1.242	1.056	0.915	1.200

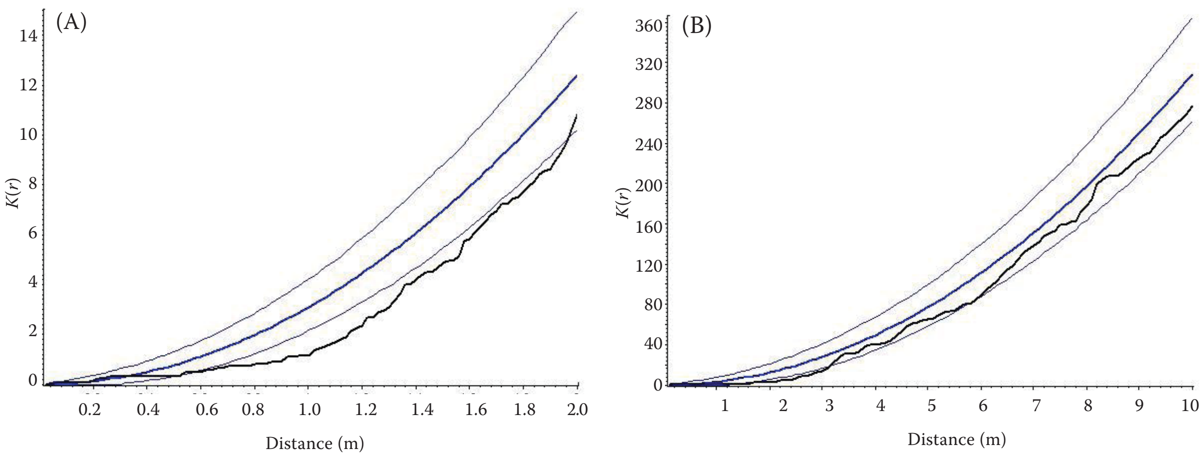

Fig. 4. (A) Horizontal structure of combined regeneration (B) the tree layer of spruce stand expressed by *K*-function on PRP 3 – U Lubošské bystřiny

condition for layering. Under the influence of quite favourable soil conditions (modal Podzol) and ground vegetation the natural vegetative regeneration of spruce takes place there. The total per-hectare number of layered spruce branches is 68.

Table 5 shows the values of indices of the horizontal structure of spruce recruits from natural vegetative regeneration (layered branches). According to Hopkins-Skellam and Clark-Evans indices natural regeneration on this PRP is aggregated. According to Pielou-Mountford index the distribution of spruce layers on this PRP is random. The distribution of the tree layer individuals is random according to all three indices. The random pattern of layered spruce

Table 5. The values of indices of the horizontal structure of recruitment from spruce natural vegetative regeneration on PRP 34 – Liščí hora

Index	Natural regeneration				Tree layer			
	values		bound		values		bound	
	observed	expected	lower	upper	observed	expected	lower	upper
Hopkins-Skellam	0.644	0.498	0.382	0.629	0.606	0.496	0.369	0.648
Pielou-Mountford	1.367	1.133	0.806	1.628	1.244	1.146	0.770	1.736
Clark-Evans	0.884	1.057	0.909	1.199	0.928	1.066	0.894	1.239

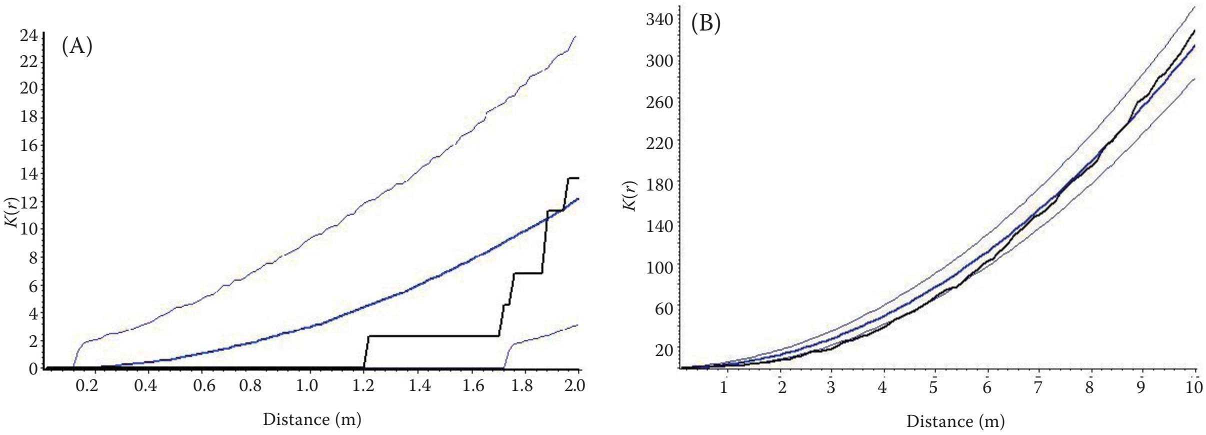

Fig. 5. (A) Horizontal structure of spruce natural vegetative regeneration (B) the tree layer of spruce stand expressed by *K*-function on PRP 34 – Liščí hora

Table 6. The values of indices of the horizontal structure of natural regeneration recruitment on RPR 37 – Chojnik – relict pinewood

Index	Natural regeneration				Tree layer			
	values		bound		values		bound	
	observed	expected	lower	upper	observed	expected	lower	upper
Hopkins-Skellam	0.810	0.499	0.445	0.554	0.569	0.500	0.441	0.565
Pielou-Mountford	3.174	1.107	0.960	1.292	1.276	1.072	0.904	1.289
Clark-Evans	0.710	1.040	0.976	1.110	0.947	1.028	0.954	1.101

branches according to their distance (spacing) also results from Ripley's *K*-function (Fig. 5A); the pattern of the tree layer individuals according to this function is mostly random (Fig. 5B).

Relict pinewoods

PRP 37 – Chojnik – relict pinewood

Forest stand 213g with PRP 37 – Chojnik – relict pinewood is situated on a slope of medium gradient and northeastern exposure. It is a considerably open grown-up high forest with the partial natural seeding of European beech, sessile oak, Scotch pine, silver birch and other tree species of different age and height.

The total per-hectare number of natural regeneration recruits is 12,080: European beech accounts for 72%, sessile oak for 15%, Scotch pine for 7%, silver birch for 3%, rowan for 2%, Norway spruce for 1% and the proportion of sycamore maple is minimal.

Table 6 shows the values of indices of the horizontal structure of natural regeneration recruitment. According to all three determined structural indices (Hopkins-Skellam, Pielou-Mountford and Clark-Evans) natural regeneration on the PRP is highly aggregated. The clustering of the tree layer individuals on this plot is documented by two structural indices (Hopkins-Skellam and Clark-Evans) while the Pielou-Mountford index shows their random pattern. Very pronounced clustering of natural regeneration recruits according to their distance (spacing) is also indicated by Ripley's function (Fig. 6A); the distribution of the tree layer individuals is mostly random according to this function while their clustering is shown at a spacing smaller than 2 m (Fig. 6B).

CONCLUSION

More than 30-year systematic research on the structure of forest ecosystems in national parks of the Krkonoše Mts. has brought about the knowledge of successions of developmental stages and phases in the most important stand types of the Krkonoše Mts. forests, both in relatively natural environmental conditions and in conditions of pronounced air-pollution stress in the eighties of the 20th century accompanied by rather heavy bark beetle disturbance. The acquired knowledge of stand structure and development will be applicable to the definition of close-to-nature manage-

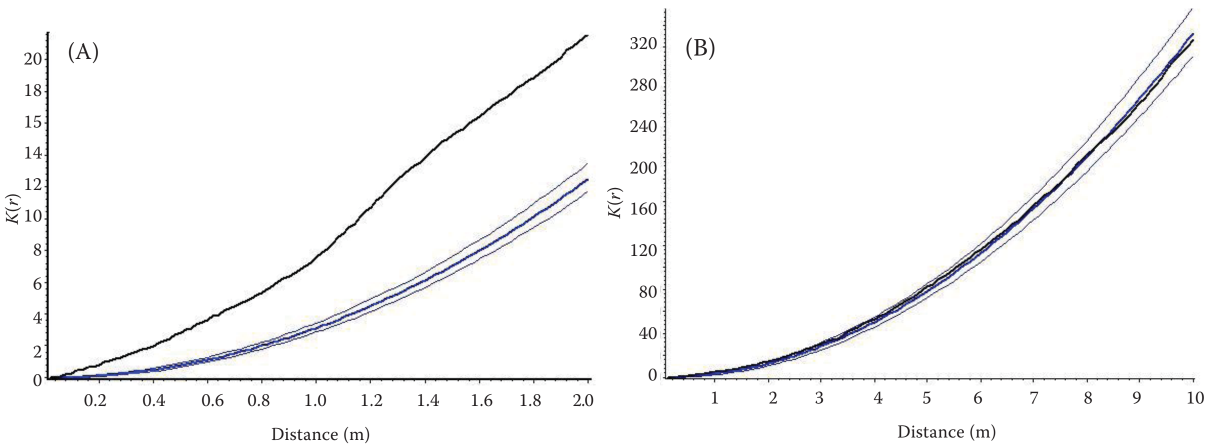

Fig. 6. (A) Horizontal structure of natural regeneration and (B) the tree layer with Scotch pine expressed by *K*-function on PRP 37 – Chojnik – relict pinewood

ment and to the documentation of a great impact of anthropogenic processes (mainly of air pollution and forest management) on the condition and development of the Krkonoše Mts. forests.

The numbers and distribution of natural and combined regeneration recruits are mostly sufficient from the aspect of ecological, environmental and production functions of forest. The horizontal structure of juvenile growth and developmental phases of natural and combined regeneration shows mostly clustering; it is random to moderately regular at places with a single dominant proportion of artificial regeneration. On the contrary, in the tree layer the horizontal structure of stands at the stage of optimum to incipient disintegration is random to moderately regular. In general, younger forest generations with spontaneous development show a tendency of clustering while older generations of trees tend to higher regularity with increasing age. According to Wolf (2005) two antagonistic sets of processes are behind these changes: on the one hand, competition among neighbors in dense groups leads to more regular distribution of trees on the plot, on the other hand, aggregations are conditioned by the patchiness of different microsites, gaps in the canopy and management system. Although it is not possible to determine the exact characteristics of horizontal structure of natural stands, according to the above author the monitoring of the spatial structure can be used as an indicator of the degree of forest stand naturalness but always with regard to given site conditions and stand type. From the aspect of horizontal structure, during the small forest development cycle, the majority of the stands in national parks of the Krkonoše Mts. proceed from a pronouncedly to moderately clustered pattern at the growing-up stage to random or moderately regular distribution of trees on the plot at the stage of optimum and at the incipient stage of disintegration. At the advanced stage of disintegration the horizontal structure of the tree layer is largely variable. The regular pattern of the horizontal structure is also influenced by the intensity of silvicultural measures, especially in the period of thinnings (it increases at their higher intensity).

Currently, the disintegration of old stands is continuous at some places, but its intensity is markedly lower. The clear-cut areas that originated after the air pollution disaster have been successfully regenerated for the most part, and now they are mostly at the phase of young growth or at small-pole stage with poor horizontal structure. In the nearest future these young stands will require more intensive silvicultural practices aimed at an increase in stability, species and spatial diversification and conversion of stands that are not suitable for a certain reason.

From methodological aspects, the horizontal structure of forest stands is described much better by *K*-function than by the assessed structural indices (Hopkins-Skellam, Pielou-Mountford and Clark-Evans). The Clark-Evans index has the lowest informative capacity of these indices.

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