AES BIOFLUX

Advances in Environmental Sciences - International Journal of the Bioflux Society

The influence of competition and dimensional-spatial characteristics of trees on their radial growth in Old-Growth Slătioara forest, Romania

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Abstract. The paper tries to identify how the radial growths of trees from old-growth forests are influenced by some forest structural elements, but also how the radial growths depend on the biometric characteristics of trees. The analysis was made for mixed natural stands of coniferous and beech from Slătioara Natural Reserve. All selected natural stands have an uneven-aged structure. The main results have showed that tree diameter influences the radial growth especially in the case of shadow intolerant species (Norway spruce); when the preferences for light are decreasing, the correlation level between the two mentioned characteristics is also decreasing (beech, silver fir). The influence of neighbouring competitors on the radial growths of trees from the three main species was determined. The first ten competitor trees were identified and their competition on the reference trees was calculated according to the Hegyi pattern. It was found that, in natural uneven-aged stands, radial growths are mostly influenced by the competition exerted by the first nine competitor neighbours for Norway spruce, the first two competitor neighbours for silver fir and the first seven in case of beech. The competing neighbours that mostly influence the radial growth were analysed with respect to their azimuth against the reference trees. It was observed that the radial growths of Norway spruce are mostly influenced by the competitors located in S and SE. For silver fir and beech the highest influence over the radial growths comes from the competitors located in NE and E.
Key Words: radial growth, trees competition, old-growth forest.

Rezumat. În această lucrare s-a determinat modul în care creşterile radiale ale arborilor din arborete cu structuri pluriene naturale sunt influenţate de o serie de elemente structurale dar şi de unele caracteristici biometrice ale arborilor. Analiza a fost realizată pentru amestecuri naturale de răşinoase şi fag din cadrul Rezervaţiei Naturale Slătioara. Toate arboretele selectate au structură plurienă. Principalele rezultate obţinute arată că diametrul arborilor influenţează creşterea radială în special în cazul speciilor mai puţin rezistente la umbrire (molidul); odată cu reducerea preferinţelor speciilor pentru lumină scade şi nivelul corelaţiei dintre cele două caracteristici menţionate (fag, brad). De asemenea, a fost determinată şi influenţa vecinilor competitori asupra creşterii radiale a arborilor aparţinând celor trei specii principale. În acest sens au fost identificaţi primii zece vecini competitori, iar nivelul competiţiei exercitată de către aceştia asupra arborilor de referinţă a fost determinat prin intermediul modelului Hegyi. S-a constatat că, în arboretele pluriene naturale, creşterile radiale sunt influenţate în special de competiţia exercitată de primii nouă vecini competitori în cazul molidului, de primii doi vecini competitori în cazul bradului şi de primii şapte în cazul fagului. Aceşti vecini competitori au fost apoi analizaţi în raport cu orientarea lor faţă de arborii de referinţă. S-a observat că la molid creşterile radiale sunt influenţate în special de nivelul competiţiei exercitată de vecinii din S-ul şi SE-ul arborilor de referinţă. În cazul bradului şi fagului influenţa cea mai mare asupra creşterilor radiale este exercitată de vecinii competitori poziţionaţi în NE şi E.
Cuvinte cheie: creştere radială, competiţia arborilor, pădure pluriенă.

Introduction. Radial growth of trees is conditioned by numerous factors, biotic and abiotic. Among biotic factors, the populational ones contribute directly for individual development of the trees in a stand. Therefore, one of most important populational factors is the competition (both intraspecific and interspecific), which has a major effect on increasing the size of trees (Harper 1977; Pardé & Bouchon 1988).

Broadly speaking, the competition is defined as the interaction between organisms (e.g. trees), which consume resources that are currently used by other organism/s. Due to the competition, some of the competitive organisms develop faster than the other

(Begon et al 1990). In fact, (Connell 1990) defines competition between two trees as the result of their interaction with respect to the use of shared resources.

The outcome on radial growth of the trees is reflected in the annual ring characteristics (structure, thickness etc.). These characteristics may describe the cumulative effect of influence factors: climate, natural or anthropogenic disturbances, site conditions and the effect of competition (Holdaway 1984; Fritts & Swetnam 1989; Cook & Kairiukstis 1990; Piutti & Cescatti 1997; Popa 2004a).

Based on growths of the trees, on other structural elements and the position of trees in stands, many authors have developed different competition indices (Becker 1992; Ung et al 1997; Pretzsch et al 2002; Prévosto 2005). These indices are classified by (Munro 1974) in (i) indices depending on the distance between trees (Schütz, Glover, Hegyi, Martin-Ek, Pretzch) and (ii) indices independent of the distance (based on vertical and horizontal angles). One of the most popular and frequently used competing indices is that proposed by (Hegyi 1974).

In Romania some researches have also approached the issue of competition between trees. Thus, (Popa 2004b) assessed the spatial variability of competition indices in natural forests and (Palaghianu 2009) studied how competition affects height growth of seedlings.

Radial growth of trees, which is influenced by their competition with neighbouring trees, clearly depends on the following aspects: (i) development stage of each tree, reflected by its dimensional characteristics and (ii) the structure of cohort where it lives.

Based on these considerations, these researches have been focus on assessing the degree to which the radial growths of trees in mixed coniferous and beech stands found in Slătioara old-growth forest are influenced by the dimensional characteristics of the *reference trees* (RT) (the one from which growth boring-samples have been collected), but also by the spatial characteristics of neighbouring *competitor trees* (CT).

The followings research objectives were laid:

1. to determine how the radial growths of RTs are influenced by a series of dimensional elements, such as diameter at breast height (*dbh*), height (*h*), crown length (h_c), crown diameter (d_c), crown volume (V_{cor}), slenderness index (I_z);
2. to assess the influence of competition exerted by CTs on radial growths of RTs;
3. to assess the influence of azimuth (θ) of CTs against RTs on radial growths of RTs.

Material and Method. The research was conducted in the Natural Reserve "Old-Growth Slătioara Forest", Romania. The reserve is situated in the northern Oriental Carpathians, the south-eastern boundary of Rarău Mountains, at altitudes between 800 m and 1510 m above the sea level. This natural reserve corresponds to IUCN forth category (management area for habitats/species: protected area managed especially for conservation), being one of the few old-growth forests which still exist in Romania. The total area of Slătioara Reserve is 1064.2 ha, from which 1044.8 are woodlands.

Fieldwork where carried out in six plot areas, rectangular shaped with size of 0.5 hectares (50 x 100 m). The plots were oriented such that the length (*Ox* axis) was on the line of greatest slope. The plots are located at altitudes between 850 and 1050 m. The investigations were restricted to a single forest type: mixed forest with coniferous and beech and *Mull* flora (Romanian classification), which is encountered on 38% of the reserve area. The plots were placed in areas with similar sites and stand conditions, without human influence (see Table 1).

Data collection and processing. For 232 RTs (Norway spruce – 68 RTs, silver fir – 92 RTs, beech – 72 RTs) from all diameter classes, boring-samples were extracted, measured and analysed. For all these trees there were also measured:

- two perpendicular diameters (at breast height, one against the highest slope line and the other one on the contour line; the inventory threshold was set at 60 mm) expressed in *mm*, used to calculate *dbh*;
- *h* expressed in *dm*;
- pruned height – h_{el} (from the ground up to the insertion of the first green branches) used to determine crown length expressed in *dm* (h_c=h-h_{el});

- two perpendicular diameters of the crown, expressed in *dm*, measured on the line of greatest slope, respectively on the level curve, used to calculate d_c.

Table 1

Characterization of plot areas

Plot area	Altitude (m)	Exposition / θ_{Ox} (deg.)	Slope (deg.)	Stand composition	Stems per ha	Volume ($m^3 \cdot ha^{-1}$)	Number of reference trees
Slătioara 1	920	S-E / 332	34	46*SF* 36*NS* 17*BH* 1*OS**	1926	602.0	45
Slătioara 2	940	S-E / 332	33	44*SF* 33*NS* 20*BH* 3*OS*	2338	383.8	24
Slătioara 3	1010	E / 276	16	18*SF* 33*NS* 49*BH*	754	760.0	34
Slătioara 4	1000	N / 191	32	74*SF* 4*NS* 22*BH*	1374	659.4	44
Slătioara 5	860	N / 186	30	52*SF* 6*NS* 41*BH* 1*OS*	820	608.5	42
Slătioara 6	930	N-E / 205	27	44*SF* 12*NS* 44*BH*	1110	680.7	43

* SF – silver fir; NS – Norway spruce; BH – beech; OS – other species; the number in 'stand composition' represents the percentage of each species from a total 100%.

The analysis was based on the radial growth expressed through the tree ring width (*trw*) of the last year before the measurements (2006) that corresponds with the year in which the competition index was computed. Therefore, the influence of time changes over the spatial structure of stands was eliminated.

The crown volume was computed using the equations proposed by Jurčo (1958):

- for deciduous:

$$V_{cor} = \frac{1}{8} \cdot d_c^2 \cdot h_c \quad (1)$$

- for coniferous:

$$V_{cor} = \frac{1}{12} \cdot d_c^2 \cdot h_c \quad (2)$$

For each RT, slenderness index (I_z) was computed with the equation:

$$I_z = \frac{h}{dbh} \quad (3)$$

The Cartesian coordinates of each tree were determined and *dbh* was measured (for 3929 trees, excepting the 232 RTs) (Tab. 1). Based on the coordinates, for each reference tree, the first 10 competitor neighbours were determined using the pattern proposed by (Palaghianu 2009). According to this pattern, a tree can be considered as competitor only if it effaced the crown of RT, and if the maximum shading that can occur during daytime corresponds to a 45° incidence angle of sunlight with the earth surface.

Thus, trees are considered competitors if:

$$d_{ij} \le h_{cor-i} - h_{V\_j}, \quad (4)$$

where: d_{ij} is the horizontal distance between RT and the neighbouring tree *i*; h_{cor-i} – height of *i* tree adjusted for the field slope; h_{V_j} – height to the insertion point of the crown measured for the RT.

To adjust the height of CTs with field slope, the following equation was used:

$$h_{cor-i} = h_i - (x_j - x_i) \cdot \tan\alpha \quad (5)$$

where: h_i is real height of CT; x_j and x_i – plane coordinates measured on abscise (the line of greatest slope of the plot) of RT, respectively of the neighbouring tree *i*; α – slope between the two considered trees, measured in *degrees* on the abscise (see Figure 1).

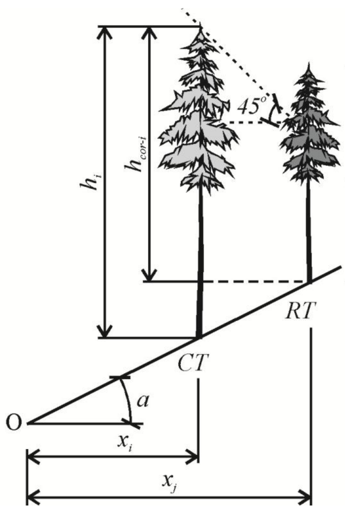

Figure 1. Model used for identifying the competitor trees

According to equation (5), the following situations might occur: *i*) if $x_j>x_i$, then $h_{cor-i}<h_i$; *ii*) if $x_j=x_i$, then $h_{cor-i}=h_i$; *iii*) if $x_j<x_i$, then $h_{cor-i}>h_i$. Also, once the field slope and the difference x_j-x_i get higher, and if $x_j>x_i$, there might occur the situation when $h_{cor-i}\leq 0$. The neighbouring trees in this situation can not be considered competitors because they have no influence on the RT in terms of light competition.

Then, only the first 10 CTs nearest to each RT were taken into account. It was considered necessary to introduce this condition since, according to equation (4), for the plot areas with a high density of trees, a very large number of remote CTs results (e.g.: 70÷100). Obviously, a remote tree cannot be considered a competitor of RT due to the large number of competitors' in-between. The threshold of 10 CTs was adopted empirically but, in this study, the average number of neighbouring CTs with direct influence on the RT in Slătioara reserve was determined.

The level of competition between RT and CTs was determined by calculating the index proposed by Hegyi (1974) for each of the 10 neighbouring CTs, individually (CI_i) and cumulatively (CI_{c-k}):

$$CI_i = \frac{d_i}{d_j} \cdot \frac{1}{l_{ij}} \tag{6a}$$

$$CI_{c-k} = \sum_{i=1}^{k} CI_i \tag{6b}$$

where: CI_i is individual Hegyi index of the competitor tree *i*; d_j – diameter of RT; d_i – diameter of CT; l_{ij} – distance between RT and CT; CI_{c-k} is cumulated Hegyi index of the nearest *k* CTs of a RT (1<k≤10; $k \in N_+$).

Based on plan coordinates of the trees and on the azimuth (θ_{Ox}) of *Ox* axis, the azimuth (θ) of each CT against the corresponding RT was calculated. In the field it was measured only θ_{Ox} using a magnetic compass. The equations used for calculating the azimuths are:

– if $x_j \leq x_i$ and $y_j \geq y_i$, then $\theta' = \theta_{Ox} + 90° - arctg\frac{x_i - x_j}{y_j - y_i}$; (7)

– if $x_j \leq x_i$ and $y_j \leq y_i$, then $\theta' = \theta_{Ox} + 270° + arctg\frac{x_i - x_j}{y_i - y_j}$; (8)

– if $x_j \geq x_i$ and $y_j \leq y_i$, then $\theta' = \theta_{Ox} + 270° - arctg\frac{x_j - x_i}{y_i - y_j}$; (9)

- if $x_j \geq x_i$ and $y_j \geq y_i$, then $\theta' = \theta_{Ox} + 90° + arctg\dfrac{x_j - x_i}{y_j - y_i}$; (10)
- if $\theta' \leq 360°$, then $\theta = \theta'$; if $\theta' > 360°$, then $\theta = \theta' - 360°$ (11)

where: x_i, y_i are the plane coordinates of CT; x_j, y_j – plane coordinates of RT (Figure 2).

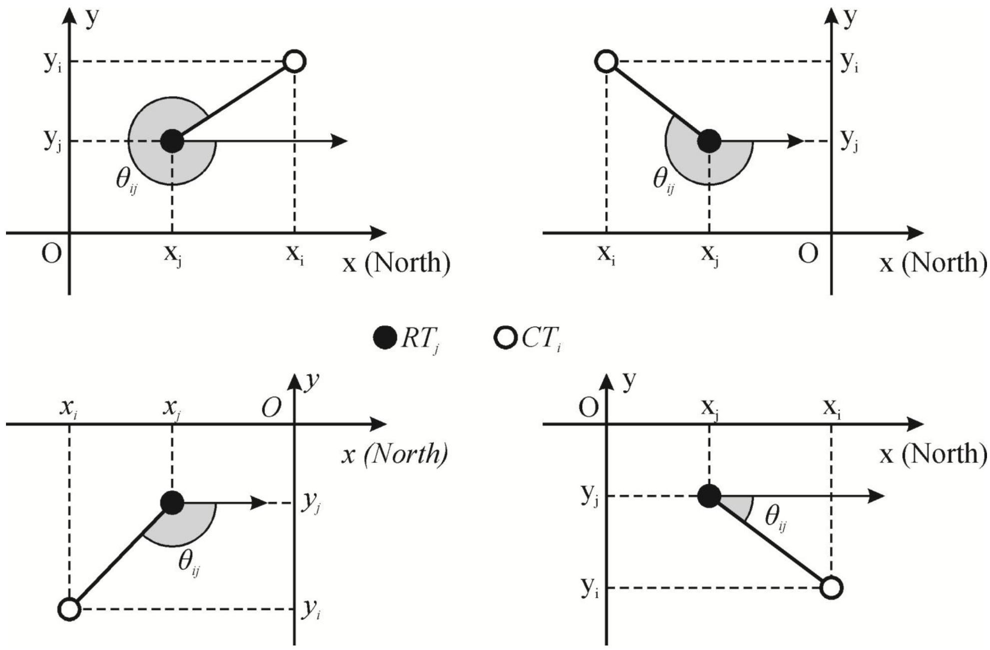

Figure 2. Possible situations between a CT, it's corresponding RT and their azimuths

To make the results feasible, CTs were classified against expositions, respectively against group of expositions, considering different threshold values for *θ*. Then, total Hegyi index was computed on expositions and groups of expositions, respectively. It represents, for each RT, the sum of individual Hegyi indices calculated for the CTs from the same exposition, respectively from the same group of expositions expressed in respect with RT.

Then, it was determined the correlation between total Hegyi index and *trw*. For the three main species the relationship was expressed through an exponential function proposed by Meyer (1933) to assess different biological processes:

$$y = k \cdot e^{-\alpha \cdot trw}, \quad (12)$$

where *y* accounts for the total competition of trees from one exposition/group of expositions expressed by Hegyi index; *k* and *α* – the coefficients of function; *e* – the basis of natural logarithm.

To evidence the influence of some characteristics of trees (*dbh*, *h*, etc.) on *trw*, and the influence of competition between trees over them slenderness, the tendency lines were map out. In case of *dbh* and *h* influence on *trw* the observations were grouped in classes and the average value and standard deviation of each class were computed. The regression analysis and Pearson correlation coefficient were used to determine how radial growth is influenced by the crown volume and by the slenderness of stems. Their appropriateness was described using Fisher Coefficient through ANOVA analysis and, when regression analysis was used, the residual values were analysed to verify the normality hypothesis. In this analysis R software version 2.11.1 was used (R Development Core Team 2010).

Results. **The influence of *dbh*, *h*, h_c, d_c, V_{cor}, I_z on *trw* of RTs. Diameter at breast height.** For the main tree species the tendency line between radial growth and *dbh* is similar (see Figure 3). In case of silver fir and Norway spruce, *trw* riches a maximum for diameters near to 60 cm (silver fir: $n=2$; $df=18$; $F=57.49$; $p=2.7E\text{-}08$; Norway spruce: $n=2$; $df=17$; $F=55.47$; $p=6.4E\text{-}08$). In case of beech two tendency lines were mapped out: the continuous line was mapped without the extreme values underlined in figure 3. These extreme points are not characteristic for the entire stand and they correspond to some old beech trees that were favoured in the last years in terms of growth condition (beech: $n=2$; $df=15$; $F=68.91$; $p=5.7E\text{-}08$).

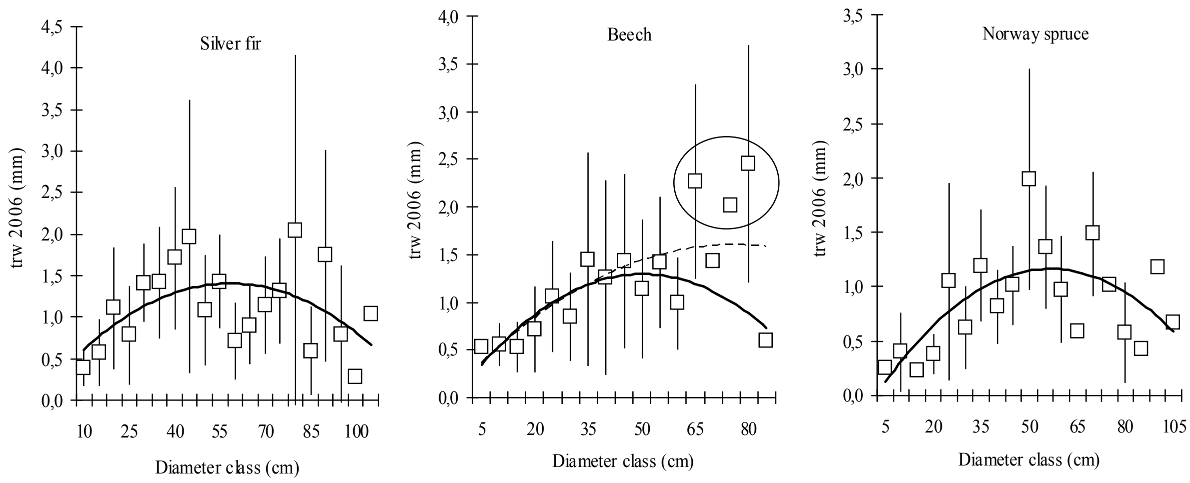

Figure 3. Tree ring width of the last year against diameter classes

Height. Total height of trees (so-called social position) is a primary indicator of the competition between them. Figure 4 pinpoints how the radial growths of RTs depend on their total heights. The highest radial growth for Norway spruce is recorded for trees with 37 m heights ($n=2$; $df=8$; $F=101.54$; $p=6.8E\text{-}06$). Then, the radial growth starts to decrease due to the age of trees; they achieve the decay stage (more than 300 years old) and the radial growth is declining.

In case of silver fir the maximum radial growth is reached at smaller heights than the Norway spruce ($n=2$; $df=8$; $F=81.4$; $p=1.4E\text{-}05$).

The highest radial growths are reached for beech when trees enter upon the dominant and co-dominant classes and they form very large crowns with a high capacity of CO_2 assimilation ($n=2$; $df=6$; $F=25.2$; $p=0.0024$).

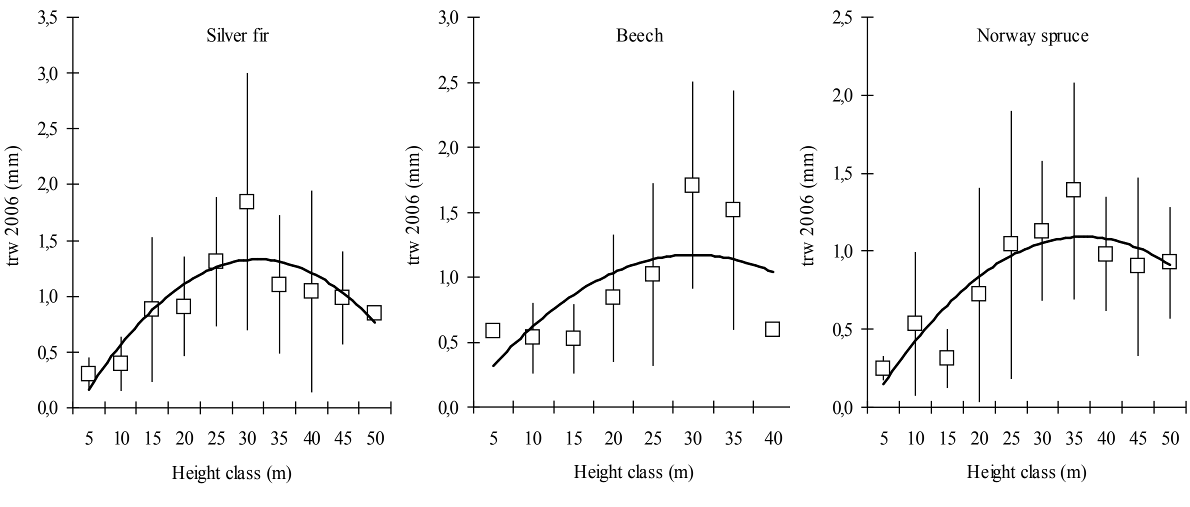

Figure 4. Tree ring width of the last year against total height classes

Crown length, crown diameter and crown volume. For coniferous, *trw* reaches the highest value when h_c is about 20 m. When crown lengths are greater than 20 m, the radial growth decreases. For all main species *trw* is positively correlated with d_c. A greater d_c means a greater CO_2 assimilation area, greater photosynthesis capacity and greater radial growths on stems.

The correlation between V_{cor} and *trw* (see Figure 5) is positive and very significant for all the species (silver fir: $r_{Pearson}=0.309$; $p=0.0027$; beech: $r_{Pearson}=0.405$; $p=0.00042$; Norway spruce: $r_{Pearson}=0.402$; $p=0.00068$). The crown volumes of Norway spruce and silver fir are comparable and, usually, do not exceed 120 m^3; if V_{cor} is about 100 m^3, *trw* is 1.6 mm·year^{-1} for silver fir and 1.3 mm·year^{-1} for Norway spruce. Instead, beech crowns are much larger, reaching even 400 m^3 but, on average, at such a volume *trw* reached only 2.1 mm·year^{-1} and for a V_{cor} of 100 m^3, *trw* reached on average only 1.1 mm·year^{-1}. Some outlying observations appear for the analysed species; they correspond to some trees that are not disturbed by competitors. Their elimination from the analysis was not necessary because their influence over the regression lines is insignificant.

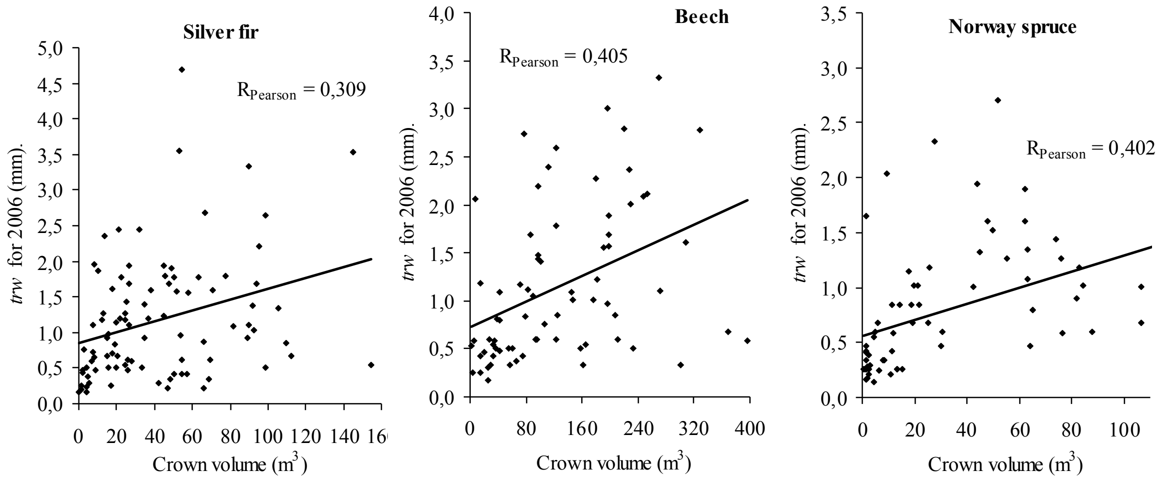

Figure 5. Tree ring width of 2006 against crown volume

Slenderness index. Beech trees reached the greatest values of slenderness index (see Figure 6). As for the silver fir the correlation between the slenderness of stems and *trw* is not significant and the level of correlation is very low ($r_{Pearson}=0.046$; $p=0.66$). For beech and Norway spruce the correlation between the two characteristics is negative and very significant (beech: $r_{Pearson}=0.375$; $p=0.00116$; Norway spruce: $r_{Pearson}=0.380$; $p=0.0014$). In case of beech, the effect of height growth influences the value of I_z. Usually, for beech, very small values of I_z (below 0.6) occur if trees have advanced ages and, in consequence, the radial growths are diminished.

Competition influence of CTs on *trw* of RT. Hegyi competition index was calculated with respect to the first 10 CTs of each RT (CI_{c-10}). As expected, the radial growth is decreasing once the competition level becomes higher (see Figure 7). The level of determination coefficient (r^2) gets higher once the light preference of analysed species gets higher: from silver fir to Norway spruce (silver fir: $r^2=0.141$; $n=1$; $df=90$; $F=14.79$; $p=2.2E-04$; beech: $r^2=0.220$; $n=1$; $df=70$; $F=19.77$; $p=3.2E-05$; Norway spruce: $r^2=0.324$; $n=1$; $df=66$; $F=31.6$; $p=4.1E-07$).

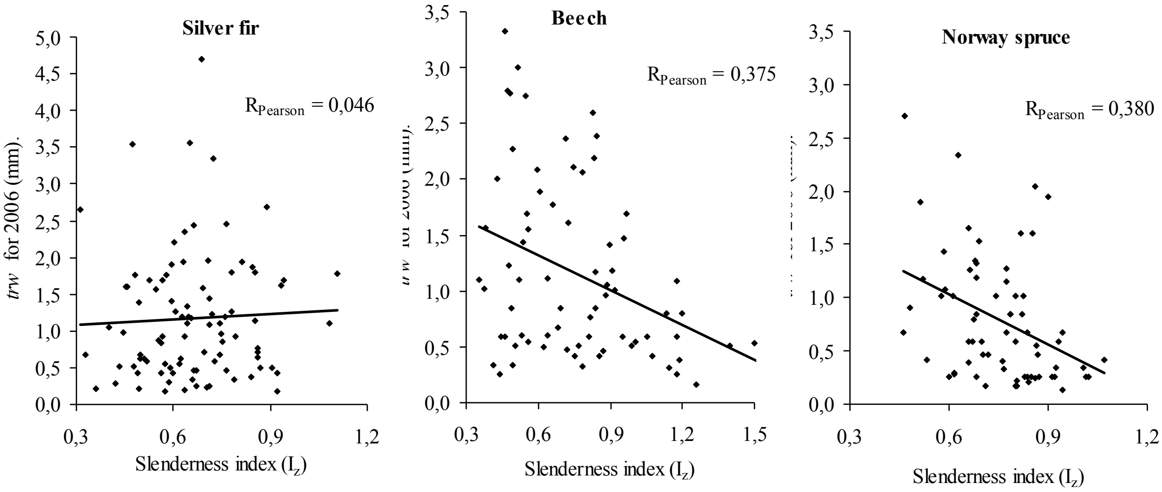

Figure 6. Tree ring width of 2006 against slenderness index

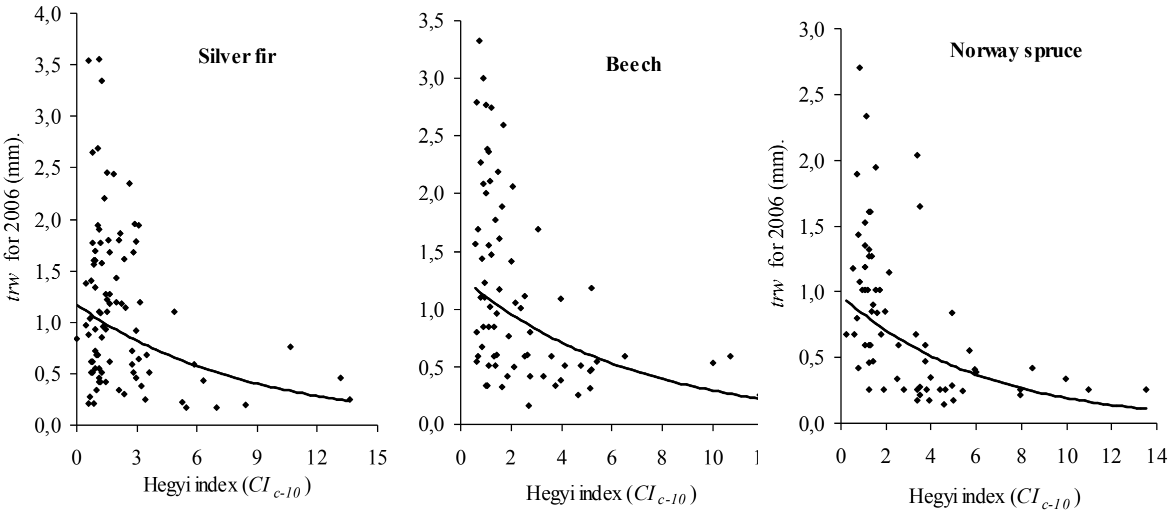

Figure 7. The influence of competition expressed by Hegyi index on *trw*

Considering the slenderness of stems and the competition level of the first 10 neighbouring competitors (see Figure 8), it might be said that, for middle classes of the Hegyi index, I_z riches the highest values (silver fir: *n=2*; *df=90*; *F=28.71*; *p=2.4E-10*; beech: *n=2*; *df=70*; *F=27.45*; *p=1.7E-09*; Norway spruce: *n=2*; *df=66*; *F=14.93*; *p=4.6E-06*). This maximum I_z is the threshold between a high radial growth and a high growth of trees' heights. The highest values of slenderness index are reached in case of Norway spruce for a higher level of competition (CI_{c-10}=10.5) than in case of silver fir (CI_{c-10}=7,5) or beech (CI_{c-10}=8).

Most RTs are described through values of CI_{c-10} between 0 and 4, for all analysed species. In this interval, the concentration of observations clearly indicates that once competition level gets higher, the stems become more slender and individual stability of trees to windstorms decrease. Beyond the threshold of CI_{c-10}=4, the tendency lines become flatten and the influence of competition on slenderness index in diminishing.

As Hegyi competition index increases, the crown volume decreases (see Figure 9).

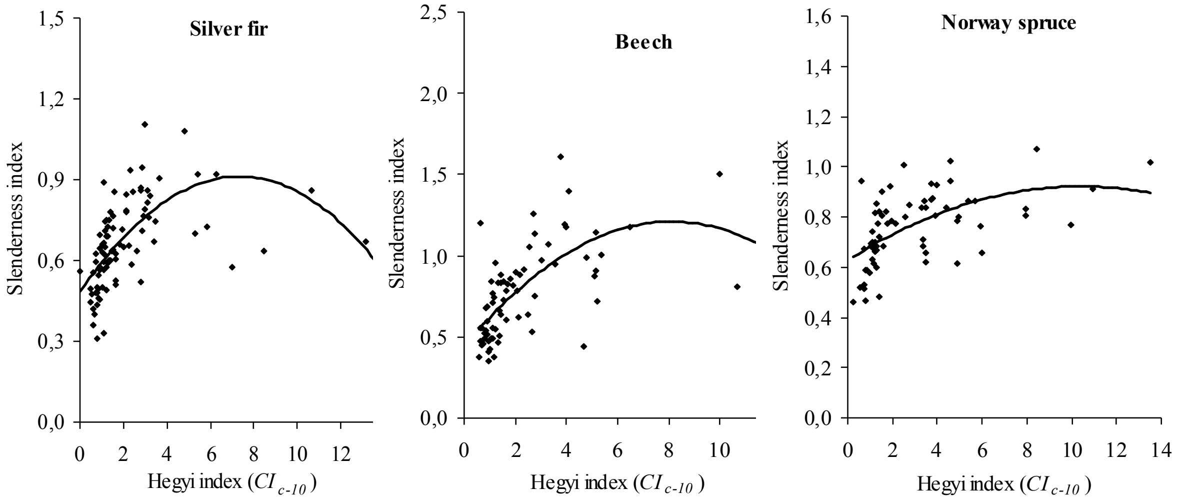

Figure 8. The influence of competition expressed by Hegyi index on I_z

The values of r^2 between CI_{c-10} and V_{cor} show the dependency between the two characteristics for all the analysed species (silver fir: $r^2=0.602$; $n=1$; $df=90$; $F=136.21$; $p=1.04E-19$; beech: $r^2=0.700$; $n=1$; $df=70$; $F=163.55$; $p=5.47E-20$; Norway spruce: $r^2=0.649$; $n=1$; $df=66$; $F=122.23$; $p=1.15E-16$). For silver fir there is a threshold of CI_{c-10} included between 3 and 5; beyond this value the crown volume decreases more slowly. In case of Norway spruce, this threshold appears for CI_{c-10} between 2 and 4, and in case of beech, though hard to distinguish, for CI_{c-10} between 3 and 5. For beech, a higher level of competition occurs on a much larger range of trees' variation on crown volume classes. In absolute terms, based on crowns sizes, the highest level of competition is reported for the silver fir and spruce trees whose crowns' volumes are less than 30 m^3. In this interval CI_{c-10} frequently reaches values above 2.

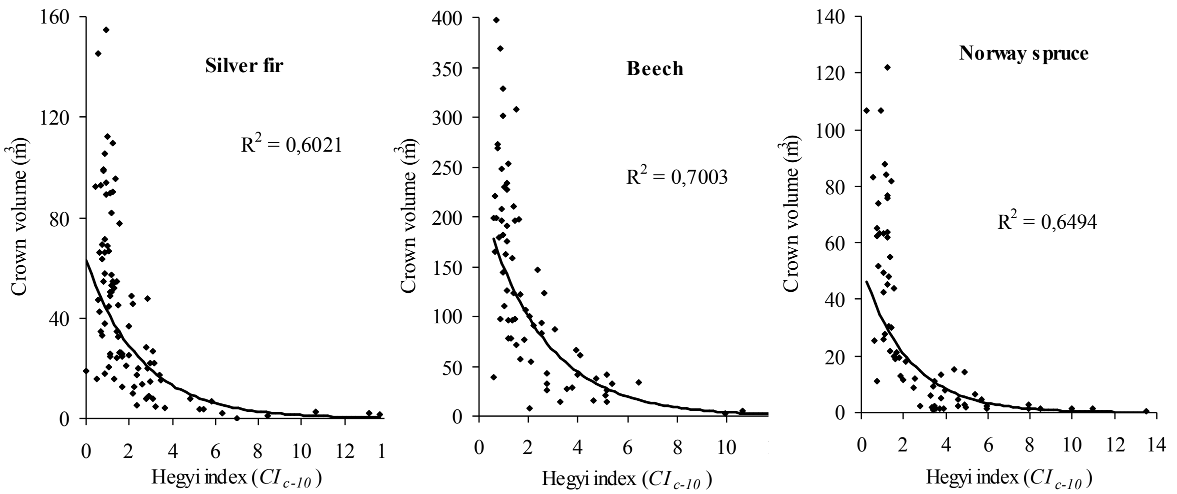

Figure 9. The influence of competition expressed by Hegyi index on the crown volume

The regression lines were mapped out for each species successively starting with the first competitor to the tenth competitor (see Figure 10 and Table 2) and they were computed as exponential function (see equation 12) in order to determine the correlation between cumulated Hegyi indexes for a successive number of CTs and tree ring width. To be compared, all these regression lines were centralised in figure 11. Thus, it was noticed that in natural uneven-aged stands, the level of competition start to decrease: from the sixth neighbour for silver fir; from the fifth neighbour for beech; from the fifth competitor neighbour for Norway spruce.

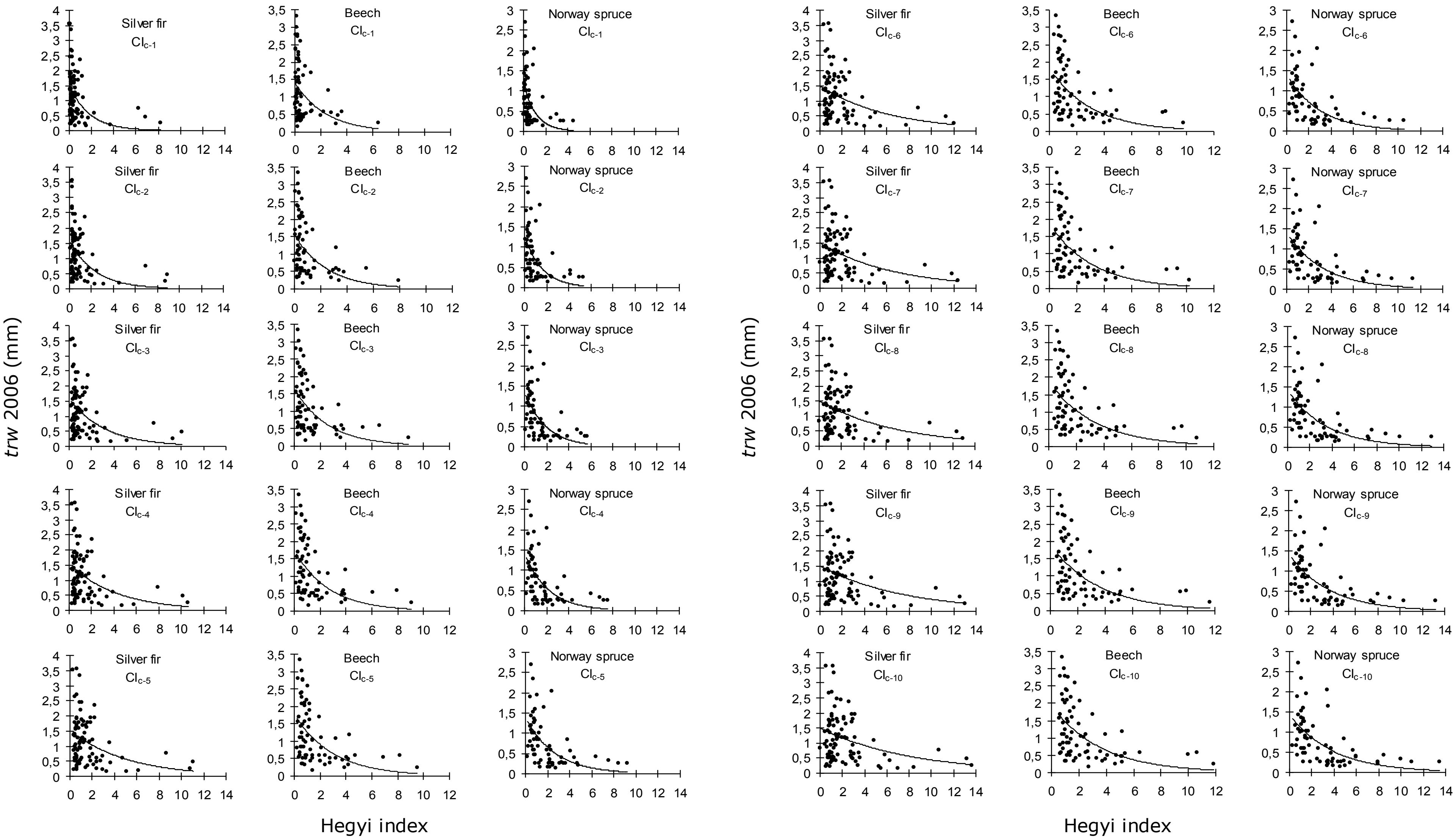

Figure 10. The influence of competition expressed through cumulated Hegyi index (in respect with the number of CTs) on *trw* of RT

Table 2

The competition influence of first 1÷10 neighbours on *trw* 2006

Number of competitors	*Silver fir (df=90)*		*Beech (df=70)*		*Norway spruce (df=66)*	
	Fisher coefficient (F)	*F significance (p)*	*Fisher coefficient (F)*	*F significance (p)*	*Fisher coefficient (F)*	*F significance (p)*
1	5.670	0.019	7.560	0.008	8.756	0.004
2	7.415	0.008	10.402	0.002	12.298	0.001
3	7.555	0.007	11.342	0.001	17.563	<0.0001
4	7.945	0.003	12.598	0.001	16.008	0.0002
5	7.966	0.006	14.204	0.0003	17.201	<0.0001
6	8.059	0.006	14.321	0.0003	18.271	<0.0001
7	8.071	0..006	14.689	0.0003	19.851	<0.0001
8	8.212	0.005	14.688	0.0003	19.612	<0.0001
9	8.213	0.005	14.865	0.0002	20.912	<0.0001
10	8.093	0.006	15.417	0.0002	20.956	<0.0001

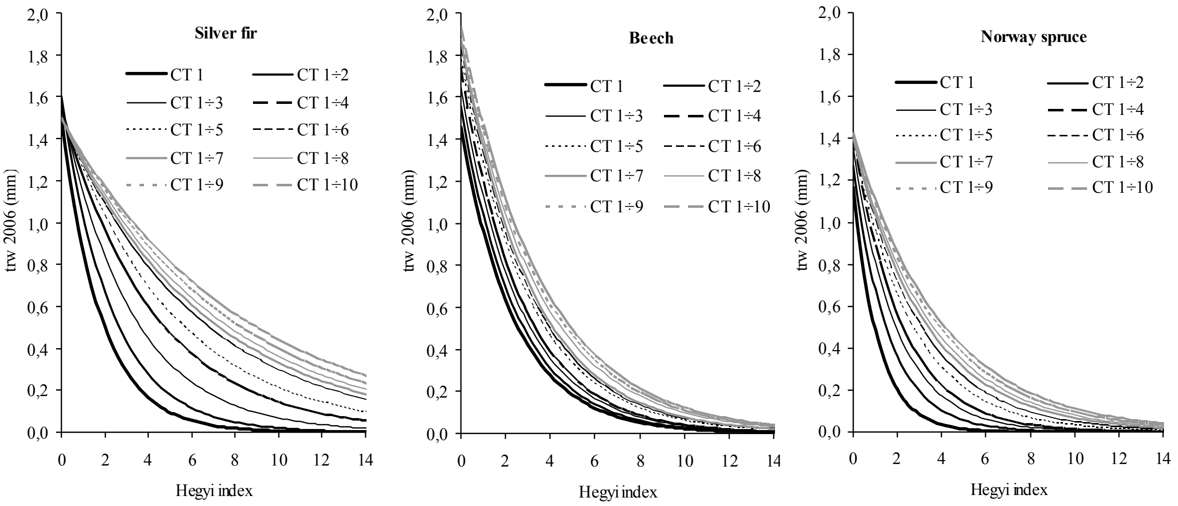

Figure 11. The influence of competition expressed through cumulated Hegyi index on *trw* of RT – centralized data

Considering the value of r^2 and it's evolution with the number of competitor neighbours (see Figure 12), it was observed that the radial growth of trees in Slătioara reserve is mainly influenced: (*i*) for silver fir by the first two neighbours; (*ii*) for beech by the first seven neighbours (when competition index becomes relatively constant); (*iii*) for Norway spruce by the first nine neighbours.

Based on these successive analysis it was observed that the stabilization of determination coefficient between cumulated CI and *trw* for spruce and beech after the first 9 and, respectively, 7 CTs shows that on average, in Slătioara reserve, *trw* of Norway spruce is strongly influenced by the first 9 neighbouring competitors and *trw* of beech by the first 7 neighbouring competitors. Silver fir appears to be less sensitive to the influence of CTs. Only the first two CTs have a greater influence on radial growth of silver fir trees; from the third CT, r^2 decreases. In relation to the values of determination coefficients between the two characteristics it was found that the influence of CTs on *trw* of RT is manifested most strongly at spruce (r^2=0.315; p<0.0001 considering the first 9 CTs), followed by beech (r^2=0.237; p=0.0003 considering the first 7 CTs) and then by the silver fir (r^2=0.119; p=0.008 considering the first 2 CTs).

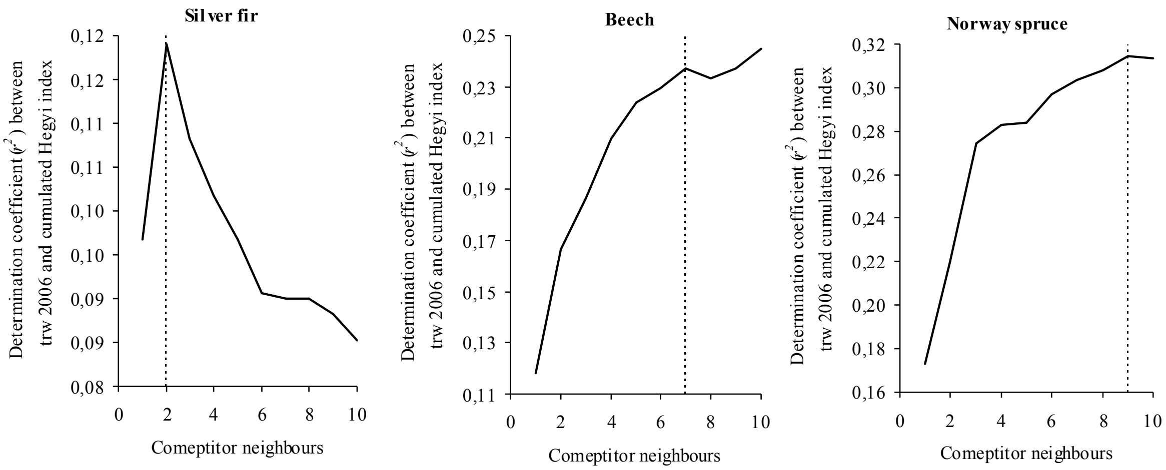

Figure 12. The variation of correlation coefficient between cumulated CI and *trw* in respect with the cumulated number of CTs

The influence of azimuth (ϴ) of CTs Against RT on *trw* of RT. Knowing the number of CTs which really influence the radial growth of a RT in Slătioara, the effect of azimuth of CTs on *trw* of RTs was determined taking into account only the first two CTs of silver fir RTs, the first 7 CTs of beech RTs and the first 9 CTs of Norway spruce RTs. The total competition index was determined according to expositions, respectively on group of expositions, considering the mentioned number of CTs in respect with tree's species. Then, it was determined the correlation between *trw* and total Hegyi index of each exposition or, respectively, group of expositions (see Table 3):

Table 3

The influence of competition in respect with the azimuth of CTs on *trw* of RTs

Species	*	*On exposition categories*								*On group of expositions*			
		N	*NE*	*E*	*SE*	*S*	*SW*	*W*	*NW*	*N-NW*	*NE-E*	*SE-S*	*SW-W*
Silver fir - 2 neighbours	*k*	0.205	0.393	0.554	0.290	0.362	0.465	0.359	0.352	0.284	0.466	0.350	0.441
	a	0.064	-0.251	-0.588	-0.086	-0.456	-0.382	-0.223	-0.154	-0.076	-0.475	-0.242	-0.265
	r^2	0.005	0.021	0.236	0.009	0.149	0.127	0.046	0.017	0.005	0.116	0.048	0.048
	df	12	17	17	24	20	31	22	17	31	34	40	48
	F	0.054	0.357	5.264	0.218	3.513	4.498	1.068	0.292	0.141	4.465	2.012	2.437
	p	0.8202	0.5583	0.0348	0.6449	0.0756	0.0420	0.3127	0.5962	0.7099	0.0420	0.1638	0.1251
Beech – 7 neighbours	*k*	0.388	0.356	0.503	0.276	0.318	0.459	0.300	0.381	0.562	0.568	0.441	0.601
	a	-0.446	-0.572	-0.587	-0.328	-0.276	-0.583	-0.268	-0.293	-0.412	-0.563	-0.355	-0.431
	r^2	0.130	0.260	0.220	0.085	0.040	0.153	0.035	0.078	0.121	0.210	0.082	0.097
	df	39	41	42	38	41	49	46	39	55	64	59	66
	F	5.807	14.398	11.824	3.527	1.689	8.830	1.675	3.290	7.556	17.028	5.258	3.290
	p	0.0208	0.0005	0.0013	0.0681	0.2010	0.0046	0.2020	0.0774	0.0081	0.0001	0.0254	0.0774
Norway spruce – 9 neighbours	*k*	0.558	0.577	0.454	0.919	0.543	0.610	0.588	0.544	0.848	0.698	1.151	0.854
	a	-0.715	-0.599	-0.460	-1.173	-0.933	-0.943	-0.818	-0.655	-0.612	-0.610	-1.083	-0.777
	r^2	0.160	0.159	0.090	0.322	0.185	0.238	0.204	0.213	0.157	0.128	0.275	0.162
	df	42	32	40	42	44	47	47	48	59	56	57	60
	F	7.998	6.037	3.969	19.965	9.958	14.658	12.021	12.959	11.009	8.197	21.665	11.587
	p	0.0071	0.0196	0.0532	0.0001	0.0029	0.0004	0.0011	0.0008	0.0016	0.0059	0.00002	0.0012

* *k*, a – coefficients of regression curve; r^2 – determination coefficient; *df* – degree of freedom; *F* – Fisher's coefficient; *p* – F significance.

The total number of observations for expositions does not match the one from group of exposition because, for the same RTs, the number of observations from a group of exposition (e.g.: N-NW) is not the sum of observations from the compounding expositions (e.g.: N+NW), but the united crowd of the number of observations on expositions that form the group of expositions (*N* U *NW*).

The results indicate the followings:

- the Norway spruce *trw* is mostly influenced by the competition of CTs located in SE and S ($r^2=0.275$; $F=21.67$; $p=0.00002$) of RTs;
- for silver fir it seams to appear some influence on *trw* from the competitors located in NE and E ($r^2=0.116$; $F=4.47$; $p=0.042$). More than that, CTs from the N and NW do not affect the *trw* of silver fir RTs;
- beech trees behave quite similar with silver fir trees: their *trw* significantly depend on the range and light intensity from NE and E ($r^2=0.210$; $F=17.03$; $p=0.0001$), but also from SW ($r^2=0.153$; $F=8.83$; $p=0.0046$).

Discussion. **The influence of some biometric characteristics of RT on *trw* of RT**. Regression analysis between *dbh* and *trw* shows that, in case of less tolerant shadow species, the cenotical position has a greater influence on the radial growths than it does with shadow tolerant species. Less tolerant shadow species react, in terms of growth, more rapidly at the changes of structural conditions inside the cohort and, therefore, at the competition of the neighbouring trees.

Regarding the influence of height on *trw*, it was observed that, for the silver fir trees with heights exceeding 30 m, *trw* significantly decreases as the trees accede in the upper stand layers, when natural pruning process is emphasized and the crown lengths are significantly decreasing. This also influences the assimilation capacity of the taller trees. Some particular observations appear, for all analysed species, in case of larger trees surrounded by smaller trees. These trees are advantaged against their neighbours and their radial growths become larger than in case of trees with similar dimensions but surrounded by competitor trees.

In respect with the effect of crown length on *trw* there is a double explanation for the decrease of coniferous *trw* when h_c is greater than 20 m: on the one hand the trees are getting older and the capacity of assimilation is decreasing, on the other hand the trees consume more resources to feed the crowns, reducing the radial growth of stems.

Regression analysis between V_{cor} and *trw* shows the silver fir as being the most effective for wood production. Thus, for a 1 mm *trw*, the silver fir needs a crown with a volume of 20.2 m^3; Norway spruce needs a crown volume of 59.7 m^3 and beech 86.1 m^3. However, due to the large volume of the crown, the beech is a significant competitor of coniferous in the struggle for light.

All this support a number of other statements in the literature that the radial growth of trees depends on their diameter (Curtis 1971; Giurgiu 1979; Avăcăriţei 2005; Prevosto 2005; Duduman 2008, 2009), their height (Cannell et al 1984; Roibu 2005; Palaghianu 2009) or the size of the crown (Popa 2005).

Competition influence of CTs on *trw* of RT. The most intense level of competition for silver fir trees occurs when crowns assimilation capacity expressed by V_{cor} is reduced. Regression analysis between CI and I_z indicates that for all tree species the graphs reach a maximum (see Figure 8). One may say that for high levels of competition, I_z begin to decrease because of (i) the imbalance between assimilation and consumption that occurs; (ii) diminution of height growths, followed finally by (iii) natural elimination. It might be concluded that Hegyi indexes corresponding to the highest I_z are thresholds for the natural elimination.

In addition, it was showed that the number of CTs (that have a noticeable influence upon radial growths of RT) increases as the light requirements of species get higher: only 2 CTs for silver fir (shadow more-tolerant species), but 9 CTs for Norway spruce (shadow less-tolerant species). Similar results regarding the influence of CTs on RTs are presented in several other studies for different tree species: Sitka spruce (*Picea sitchensis*) (Ford 1975, Cannell et al 1984), black spruce (*Picea mariana* (Mill.)) (Newton & Jolliffe 1998), balsam fir (*Abies balsamea* (L.) Mill.) (Mohler et al 1978), radiata pine (*Pinus radiata* D. Don) (West & Borough 1983), red pine (*Pinus resinosa* Ait.) (Brand & Magnussen 1988), pitch pine (*Pinus rigida* Mill.) (Thomas & Weiner 1989), sand pine (*Pinus clausa* Vasey) (Laessle 1965), eucalypt (*Eucalyptus populnea*) (Penridge & Walker 1986).

This study did not take into account the competition exerted by small neighbouring trees that are not considered competitors for light according to equation (4). As those reported by Newton & Jolliffe (1998), who studied black spruce in Canadian Boreal Forest, in Slătioara reserve the small neighbouring trees compete for belowground resources and may influence the radial growths of RTs, although this influence is reduced. To demonstrate this, however, it is necessary to run further studies.

The influence of azimuth (Θ) of CTs against RT on *trw* of RT. For all three species and regardless of CTs orientation against RT, *trw* decreases once the competition level gets higher; the higher values of *trw* are obtained at low values of the competition. The only exception occurred in the case of silver fir RT. In this case, the regression analysis between *trw* and the competition exerted by CTs from the north side of RTs indicates the increase of *trw* once Hegyi competition index increases. This reveals that neighbouring competitors from the north of silver fir RTs does not adversely affect the radial growths of RTs.

It was highlighted an antagonistic behaviour of Norway spruce compared with silver fir and beech when talking about the determination coefficient between *trw* and the competition exerted by neighbours in E, SE and S. For these expositions, when r^2 between the two features is increasing for Norway spruce, it decreases for beech and silver fir and vice versa. However, the three species coexist and form very stable and valuable stands. Thus, it confirms that the fast-growing, less-tolerant species and slow-growing, more-tolerant species can coexist stably (Kohyama 1987, 1993).

Conclusions. In terms of radial growth Norway spruce is the most influenced species by the competition level. The most important dimensional characteristics of trees that influence the radial growth are diameter at breast height and crown volume. These elements can be used in shadow management as defined by Baker et al. (1996) for the managed forests.

The neighbouring trees that highly influence the radial growth of a reference tree are: the first 2 for silver fir, the first 7 for beech and the first 9 for Norway spruce.

Besides the dimensional characteristics of RTs and the competition level registered in a cohort of trees, it was showed that the azimuth of CTs against RTs influences the radial growth of RTs. Thus, radial growths of Norway spruce are particularly influenced by the competition exerted by CTs located in SE and S of RTs. In case of silver fir and beech it appears that radial growths are particularly influenced by the CTs from NE and E, but the extent to which this effect is sizable is pretty low. In addition, in case of silver fir, the competition level from N does not affect at all the radial growths.

Acknowledgements. This paper is the outcome of a research project (grant TD CNCSIS 207/2007) being funded by the *Romanian Ministry of Research and Education* through the *National Council for Scientific Research in Higher Education*, whose contribution is gratefully acknowledged. We are also grateful to *Romanian Academy* for permission to install the plot areas in Slătioara natural reserve. We would like to express our appreciation to Dr. Marian Drăgoi who kindly looked over the English of the manuscript and to Dr. Olivier Bouriaud for his useful suggestions.

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Received: 28 September 2010. Accepted: September 30 2010. Published online: 05 October 2010.
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How to cite this article:
Duduman G., Roibu C.-C., Duduman M.-L., Miron-Onciul M., 2010 The influence of competition and dimensional-spatial characteristics of trees on their radial growth in Old-Growth Slătioara forest, Romania. AES Bioflux **2**(2):215-230.