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A conversion method of young hornbeam coppices and its possible impact on future stand structural attributes

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Abstract. The paper analyse the substitution of hornbeam coppice stands and conversion into high forest stands, formed by species that better valorise the site conditions. An improved alternative for the method of substitution in corridors is presented. The main goal of this new substitution-conversion alternative is to gradually conduct the actual structure of the coppice stands towards the target structure imposed by the forest management objectives, without a total elimination of the species that will be substituted. Two plot areas were selected in order to put into practice the proposed method. Bands were created for reducing the effective costs of the substitution process. 450 respectively 468, small seedlings (of beech, pedunculate oak and sessile oak) per hectare were planted in the created bands. The planting scheme took into account the shadow tolerance of the species from the target composition. Based on the field data and using the yield tables, the evolution of the stands in the two selected plots was simulated. In this respect, the forest treatments were parameterized according to the Romanian forest rules regarding the application of thinning and regeneration cuttings. The substitution-conversion process started from an almost pure hornbeam coppice and, simulating the application of the proposed method for 120 years, it was predicted that the method allows directing the actual stand structure to the target structure. The dynamics of species and structural diversity were assessed and the results of 120 years simulation indicate an important increase of both the species (the Shannon species index increases from 0.203 to 1.073) and structural diversity (the Gini structural index increases from 0.032 to 0.200).
Keywords forest species substitution, forest conversion, forest management, hornbeam coppice, high forest, biodiversity.

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Introduction

Different types of disturbances cause discontinuities of forest stands, but these are important for biodiversity, age-stand heterogeneity, and long-term forest stability (Waring & Running 1998). If properly conducted, the human disturbances might increase the productivity, the stability and the diversity of forest stands (Duduman 2009).

Substitution of a forest stand consists in the replacement of the actual species with other species assumed to better meet the objectives of forest management. In this paper, the conversion generally refers to changing the way a stand is regenerated. Both these processes are realised by human disturbances (interventions) in the forest stands.

The techniques and concerns about substitution and conversion of forest stands have evolved over time as several studies have provided new information about the functioning of forest ecosystems. Substitution of species and conversion of coppice into high forest stands are known to impact the productivity, diversity and carbon sequestration capacity of forest ecosystems (Deheza & Bellassen 2010). The conversion of coppice into high forests can be framed as a process from a silvicultural system based on clear cutting towards a silvicultural system based on continuous cover (Ciancio et al. 2006) and such conversion methods are widely presented in the literature (Amorini et al. 1996, Canellas et al. 2004, Giannini & Piussi 1976, Serrada et al. 1998). The question of conversion from pure to mixed stands has been intensively studied (Hasenauer 2000, Gadow et al. 2002, Schütz 2002, Spiecker 2003, Hansen et al. 2004, Spiecker et al. 2004) but the methods of coppice conversion into high forests, associated with species substitution in order to improve the stand productivity (Dafis 1966), still need to be clarified.

The studies carried out in Romania generally aimed at the substitution technique of low productive stands (Lupe 1968, Marcu 1968, Hanganu 1969, Popa 2003); other studies were focused strictly on the substitution technique in some particular forest types like degraded black locust (*Robinia pseudoacacia* L.) (Dănescu et al. 2003) or European beech (*Fagus sylvatica* L.) (Urechiatu 1991, Ştefănescu 1966a) stands, or meadows stands considered inappropriate according to the forest management goals (Lefter 1964).

In Romania, various substitution techniques were explored such as: plantations and seeding under canopy (Petrescu 1939), plantations and seeding in canopy gaps, plantations and seeding in corridors (Dămăceanu 1954, Ştefănescu 1966b), plantations and seeding after clear cuttings (Hanganu 1969). Generally, the technique of soil preparation for forest substitution in Romania comprised mechanized removal of stumps where the land configuration allows this process (Lefter 1964) or, in special conditions, the use of chemicals for the devitalisation of stumps from non target species (Lupuşoru et al. 1997).

Based on the method of corridors – which involves planting or seeding the desired tree species in corridors created in the stand which has to be converted (Dămăceanu 1954) – some environmentally friendly and economically advantageous techniques were designed and presented in this paper. Their main objective is to control the tree species when their behaviour becomes invasive (e.g. hornbeam – *Carpinus betulus* L.), but they do not follow up the complete removal of these species from the future composition of the stands; on the contrary, their concern is to benefit from the strengths of secondary species. Thus, they look for maintaining or creating stands with a high species and structural diversity.

The research is focused on young hornbeam coppice stands created by illegal logging of high forests that have undergone the restitution process of ownership (Anonymous 1991). Therefore, this paper attempts to address the following objectives: (i) to propose a combined method for the substitution-conversion of (young hornbeam) coppice stands (SCCS), (ii) to simulate the evolution of the stands created through the SCCS method, (iii) to assess the advantages of the SCCS method in terms of species and structural diversity.

Materials and methods

Study area

The study area is located in Suceava Plateau, north-eastern Romania, at altitudes between 400 and 420 m above the sea level, in mixed forests dominated by beech (*Fagus sylvatica* L.) (*BH*), pedunculate oak (*Quercus robur* L.) (*PO*) oak and sessile oak (*Quercus petraea* Mattuschka) (*SO*).

To test the proposed SCCS method, two hornbeam (*HB*) coppice stands were selected, their main characteristics being presented in table 1. 15 years ago the two stands were illegally clear cut, immediately after ownership restitution. In both stands, prior to these illegal cuts, hornbeam was a secondary species (with maximum 40% of total tree number) helping the proper development of the main species: pedunculate oak and beech. Due to the lack of appropriate pre-commercial thinning, the *HB* stumps strongly sprouted and the canopy has been closed in just 2 - 3 years after the clear cuts. After less than 15 years since the cutting, the *HB* amounted to 95% of total tree number, leaving the other tree species (poplar, willow and pedunculate oak) to only 5% (all tree species have the same age).

The selected stands are located at similar elevations and they are part of the hilly forest layer with pure beech, pure sessile oak and mixed forests with sessile oak and beech. According to the forest management plans, the following target compositions on standing volume were established: 40*SO* 30*BH* 20*PO* 10*HB* in *AD* (Adâncata) plot and 50*BH* 30*SO* 20*HB* in *PT* (Pătrăuți) plot (The number in 'stand composition' represents the percentage of each species from a total 100%).

In each of the two stands, a one hectare rectangular sample plot was established (figure 1); in these two plots the proposed SCCS method has been implemented.

Used method

In February 2011 the *HB* sprouts were extracted in the two sample plots in bands whose width varies between 4 and 7 m. The width of the bands was determined in relation to the current average height of trees (the average height is about 5 m) and with the dynamics of hornbeam height growth in the inner-bands (figure 2).

Also, the inner-bands width depended on the possibility of realizing the bands in the field, considering that the cumulated area of hornbeam inner-bands should represent about 50% of the total sample plot. When the bands were positioned, an incidence angle of solar radiation by 45° was considered (Palaghianu 2009) and the azimuth of the sample plot was taken into account, together with the overall aspect, slope and water supply capacity of the soil. Considering this, the bands were positioned as

Table 1 Main characteristics of the selected stands

Stand	Forest district	PU*	Elevation (m)	Aspect	Slope (°)	Regeneration type	Stand age (years)	Soil type**	Plot name	Plot area (ha)
34%	Adâncata	VI	405	-	-	Coppice	15	Luvisol	AD	1,0
30A%	Pătrăuți	III	400-420	South	12	Coppice	15	Cambisol	PT	1,0

Note: * PU (production unit) is an administrative division of forest district. ** IUSS Working Group WRB 2006

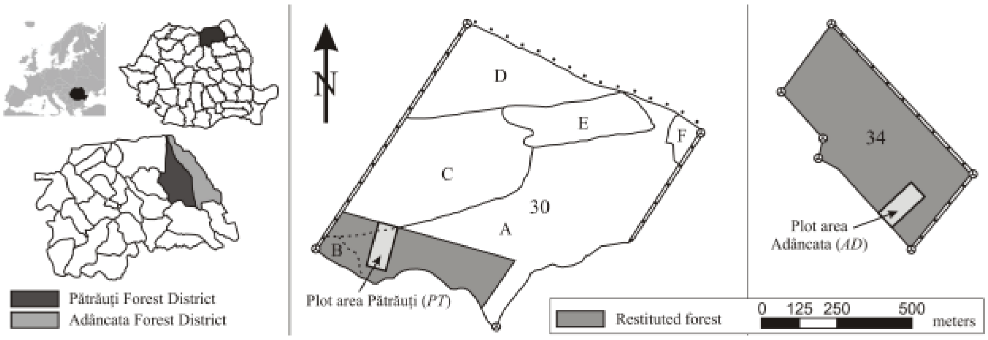

Figure 1 Location of selected plots

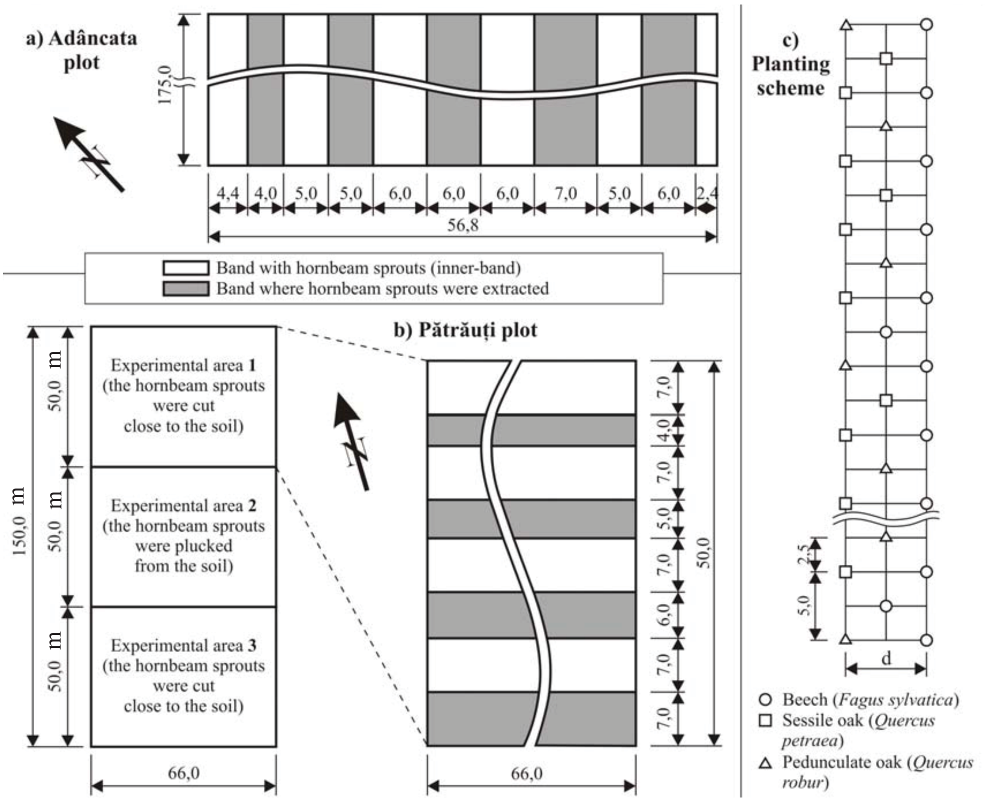

Figure 2 Presentation of: i) bands' orientation and location (a – AD plot, b – PT plot) and ii) proposed planting scheme (c)

follows: (i) parallel with the long side of the *AD* sample plot, from NE to SW, as the slope is 0° (ii) from east to west and parallel with the short side of the *PT* sample plot due to the southern slope, in order to reduce the water loss through evapo-transpiration and drainage on slope.

In the *AD* sample plot, only one experimental area was installed (figure 2a) which consists of *HB* extraction in bands by plucking the sprouts from the soil. Due to the short length of the bands in *PT* sample plot, three experimental areas were installed (figure 2b), in order to analyse the dynamics of the newly created stands in two different situations: (i) the *HB* was extracted by cutting the sprouts close to the soil (experimental areas 1 (*EA1*) and 3 (*EA3*)); the assumption is that, after cutting, the stumps will sprout and the *HB* will remain in the bands, additional cuttings being required in order to avoid planted seedlings being overgrown; (ii) the *HB* was removed by plucking the sprouts from the soil (experimental area 2 (*EA2*)); the assumption is that the maintenance costs in the bands will be significantly reduced till the closure of the canopy.

The bands were created in order to reduce the effective costs of the substitution process, especially when the artificial regeneration was not properly performed through the application of an appropriate silvicultural treatment and the *HB* occupied the land, overgrowing the seedlings of the main species. The costs are further reduced if the SCCS method is applied immediately after the treatment.

Small seedlings (h ≈ 0.4 m) were planted in the created bands. The *BH* seedlings were taken from natural regeneration of adjacent stands, and those of *SO* and *PO* were obtained in nurseries. The same composition was used in the bands of both sample plots (40*BH* 40*SO* 20*PO*). The afforestation scheme is shown in figure 2c, and the density of the planted seedlings in the bands is: (i) 450 trees per hectare in the *AD* plot (or 918 trees per hectare if the inner-bands are excluded), (ii) 468 trees per hectare in the *PT* plot (respectively 1074 trees per hectare).

The planting distance from the *HB* inner-bands was determined with respect to the width of the band (table 2). Considering this distance and the width of the band, the planting distance (*d*) between the two outer seedlings' lines of the bands was determined (figure 2c).

The planting scheme was conceived considering the shadow tolerance of the species from the target composition. The *BH* seedlings were placed in the shaded part of the band (to reduce the effects of insolation), and the *SO* and *PO* seedlings were placed in the sunlit part (figure 2): (i) in the *AD* plot the line with *BH* seedlings was placed on the north-eastern side of the band, (ii) in the *PT* plot, the *BH* line was located on the southern side of the band.

Data collection and processing

Initial state of the stands. In both sample plots, 30 2x2 m square plots were systematically distributed to assess the composition of the stand (i.e. the number of trees per species) and to determine for each species: the average diameter at breast height ($\overline{dbh_i}$), the average height ($\overline{h_i}$) and the number of trees per hectare (n_i). $\overline{dbh_i}$ and $\overline{h_i}$ were computed based on the individual values measured in the field. The total volume per hectare (V_{tot}) was then estimated with the relations:

Table 2 Planting design in the bands

Width of the band (m)*	Planting distance from the hornbeam inner-band (m)	Distance (d) between the seedlings from the exterior lines of the band (m)
4	0.5	3.0
5	0.6	3.8
6	0.8	4.4
7	1.0	5.0

Note: * Different widths of the band were used to study the future development of planted tree species in various light conditions (this is not the objective of the present paper)

$$V_{tot} = \sum_{i=1}^{k} \overline{vui} \cdot n_i \quad (1)$$

of the silvicultural system simulated to direct the actual stand composition toward the target one. Based on average values of *dbh* and

$$\log_{10} \overline{vui} = a_{0i} + a_{1i} \cdot \log_{10} \overline{dbhi} + a_{2i} \cdot \log_{10} \left(\overline{dbhi}\right)^2 + a_{3i} \cdot \log_{10} \overline{hi} + a_{4i} \cdot \log_{10} \left(\overline{hi}\right)^2 \quad (2)$$

where: *k* is the number of species, $\overline{vui}$ is the average single tree volume computed by species using the logarithmic equation and the coefficients a_{0i}, a_{1i}, a_{2i}, a_{3i}, a_{4i} of i^{th} species proposed by Giurgiu & Drăghiciu (2004).

Simulation of the development of the newly created stands. The simulation of the growth dynamics of the newly created stands was based on the Romanian yield tables (Giurgiu & Drăghiciu 2004). The following hypotheses were considered to perform the simulation: (i) the species in the stand composition are: *HB* (medium productivity), *SO*, *PO* and *BH* (high productivity), (ii) based on the values presented in the yield tables, the number of trees per hectare is reduced once the stand age increases by applying a silvicultural system adapted to the stand structure and using a natural elimination rate, (iii) in the experimental areas where the *HB* trees were cut close to the soil, the stumps will continuously produce sprouts (*EA1* and *EA3*), (iv) a yearly simulation was done in the *PT* plot for a 10 years simulation period in order to explain how the initial structure of the stand was directed towards the structure corresponding to the values presented in the yield tables, (v) a decennial simulation – based only on the data from the yield tables – was done in *AD* plot for a 120 years period.

Starting from the yield class of each analysed species, the average *dbh*, the average height and the average tree number per hectare were taken from the Romanian yield tables, for 10 years periods. For each species, the number of trees per hectare was adapted to the stand composition corresponding to moment T_i but, at the same time, it is a consequence heights taken from the yield tables and considering the average values of variation coefficients of these characteristics presented in the literature (Giurgiu 1979, Avăcăriței 2005) for the analysed species, individual values of *dbh* and height were generated randomly for the number of trees already established per species. These values allowed computing the volume of each individual tree using relation (2) and creating the distribution curves of the number of trees against diameter classes.

The simulation of tree number for the first 10 years in *PT* plot was achieved by applying three non-commercial thinning (*NCT*) in the *HB* inner-bands: one at T_0 (about 55% of trees were harvested), one at T_3 (35%) and one at T_7 (25%). In addition, in *EA1*, the *HB* sprouts (produced by the resulted stumps after the bands creation) were totally harvested through cutting close to the soil to avoid the overgrowing of *SO*, *PO* and *BH* planted seedlings. The sprouting of *HB* stumps (*SHS*) in the bands of *EA1* was simulated taking into account that new sprouts were produced by: 80% of the stumps resulted after the first *NCT*; 60% of the remaining stumps after the second *NCT* and 50% of the stumps resulted after the third *NCT*. These sprouting rates were established knowing that most of angiosperm trees with trunks less than 10 - 15 cm produce numerous sprouts after logging (Burns & Honkala 1990), the sprouting capacity reduces with the increase of stumps' age and the timing of cutting (Johnson 1975), by the end of the first growing season more than 80% of all stumps produce sprouts and, if not harvested, the majority of these sprouts (75-90%) die within five to ten years (Wendel 1975). Also, in both experimental areas, when no tending operations were carried out, the decrease of trees number due to the natural elimination (*NE*) was simulated considering a rate between 6.5% and 2.9% starting from T_1 to T_{10}.

The evolution of trees number over an 120 years period in *AD* plot was made by simulating the application of a number of: i) three *NCTs* in the first 10 years whose intensity with respect to the number of trees varies between 38 and 53%; ii) ten thinning (*T*) whose intensity varies between 6 and 19% (Anonymous, 2000), depending on age and stand density at the time of simulation and focused especially on reduction of *HB* in inner-bands until the closure of canopy in bands, iii) a number of five sanitary cuttings (*SC*) whose intensity is between 8 and 17%. The percentages for *NCT* and *SC* include the natural elimination rate between the interventions because, at these stages, the application of tending operations first involves the extraction of dead or dying standing trees and secondly the reduction of stand density in the established limits of harvesting intensities presented above. For inner-bands the thinning intensity derived from the yield tables for pure *HB* stands, but in bands, where a mixture of *SO*, *PO* and *BH* was created, the harvesting intensity was established taking into account the species composition before harvesting, the target composition corresponding to the cutting age and the *HB* density in the inner-bands.

Species and structural diversity of the stands. Species and structural diversity was assessed against the simulation results of the two analysed stands. The species diversity was computed using the Shannon (1948) index:

$$H = -\sum_{j=1}^{k} \frac{n_j}{N} \ln \frac{n_j}{N} \quad (3)$$

where: *k* is the number of species; n_j represents the number of individuals from *j* species; and *N* is the total number of individuals. Shannon index ranges between 0 (homogeneity) and ln(*k*) (heterogeneity).

As recommended by literature (Lexerød & Eid 2006, O'Hara et al. 2007, Duduman 2009, 2011), the Gini index was used to assess the structural diversity. The Gini index (G) was computed as the ratio of: *i*) the area separated by the Lorenz (1905) curve and the diagonal and *ii*) the whole area below the diagonal (figure 3). The Gini index ranges between 0 and 1. The more homogenous a population is, the smaller the Gini index is (Gini 1912, 1921). The general formula of Gini index is:

$$G = 1 - \sum_{i=1}^{k} \left[(ba_{i-1} + ba_i) \cdot (n_i - n_{i-1}) \right] \quad (4)$$

where ba_i (ba_{i-1}) is the cumulative fraction of the basal area (%) of the trees from all diameter classes thinner that or equal to the i^{th} (i-1) diameter class (for $i = 1$, $ba_{i-1} = 0$); n_i (n_{i-1}) is the cumulative fraction of the number of trees (%) from all diameter classes thinner that or equal to the i^{th} (i-1) diameter class (for $i = 1$, $n_{i-1} = 0$); and *k* represents the number of diameter classes.

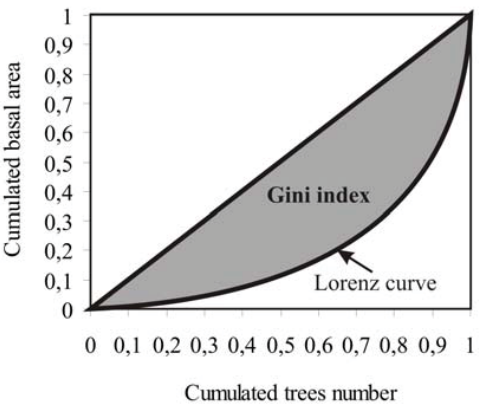

Figure 3 Lorenz curve against the basal area

Results

Initial state of the analysed stands

Before installing the bands in the field, both selected stands were coppice hornbeam based, with a 15 years average age of the sprouts (table 3). There are no important differences between the two selected stands in terms of structure, mainly because the trees were harvested 15 years ago and the hornbeam sprouts invaded the field, eliminating most of the main tree species seedlings.

Simulation of the evolution of the newly created stands

Short term (10 years) simulation results in PT plot. In both types of experimental areas the tending works were the same. The difference between the two distinct situations is that in the experimental areas where the hornbeam was extracted by cutting (figure 4-a), the stumps have produced new sprouts. For this reason, the field work in this case consisted of thinning the hornbeam in the inner-bands and cutting all the new sprouts close to the soil in the bands. In *EA2* the *HB* was removed from the roots, so no *HB* sprouts will appear in the bands (figure 4b); the tending works in the bands consist only in monitoring the status of planted seedlings and in thinning the trees in the inner-bands as in the *EA1* and *EA3*.

The structural dynamics of the stand in the *PT* plot in the first 10 years of SCCS method application is as a consequence of the simulated silvicultural system described in table 4.

Long term (120 years) simulation results in AD plot. The simulated silvicultural system (table 5) applied in the first 30 years was focused only on reducing the number of *HB* trees in the inner-bands (figure 5).

In the bands, the tending operations will be oriented only to ensure the necessary condi-

Table 3 Initial stand characteristics

Plot name	Composition*	Average dbh (cm)	Average height (m)	Number of trees per hectare**	Standing volume ($m^3 \cdot ha^{-1}$)
AD	98% HB, 2% other species	3.9	5.4	26030	89
PT	94% HB, 6% other species	4.0	5.5	22410	77

Note: * HB: hornbeam; other species: beech, sessile oak, aspen (*Populus tremula* L.), birch (*Betula pendula* Roth.), willow (*Salix caprea* L.), ** Represents the number of trees per hectare before performing the bands

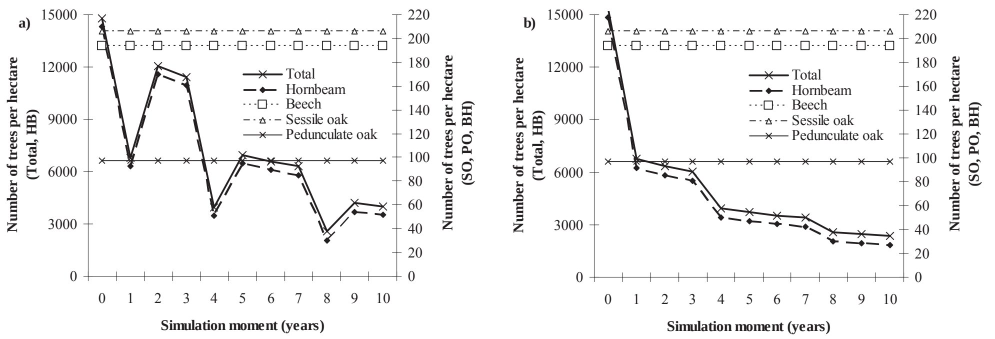

Figure 4 The dynamic of trees per hectare in the two types of experimental areas from the PT plot: a) the *HB* sprouts were cut; b) the *HB* sprouts were plucked

Table 4 Harvesting parameters used to simulate stand dynamics in PT plot

Simulation moment	Process	Trees per hectare						
		EA 1 (cut sprouts)				EA 2 (plucked sprouts)		
		Before process	Harvested	New sprouts	After process	Before process	Harvested	After process
T0	NCT 1	14794	7988	0	6806	15345	8597	6748
T1	NE (+ SHS)	6806	408	5660	12058	6748	424	6324
T2	NE	12058	622	0	11436	6324	306	6018
T3	NCT 2	11436	7488	0	3948	6018	2103	3915
T4	NE (+ SHS)	3948	198	3217	6967	3915	197	3718
T5	NE	6967	379	0	6588	3718	188	3530
T6	NE	6588	282	0	6306	3530	139	3391
T7	NCT 3	6306	3742	0	2564	3391	846	2545
T8	NE (+ SHS)	2564	103	1733	4194	2545	103	2442
T9	NE	4194	185	0	4009	2442	97	2345
T10	NE	4009	128	0	3881	2345	67	2278

Note: NCT: Non Commercial Thinning; NE: Natural Elimination; SHS: Sprouting of Hornbeam Stumps.

Table 5 Harvesting parameters used to simulate stand dynamics in AD plot

Decade	Standing trees per hectare		Type of cutting	Harvested trees		Simulation moment
	Total, from which:	*HB*		Total, from which:	*HB*	
1	13721	13196	NCT 1	7258	7258	T_0
	6463	5938	NCT 2	2672	2672	T_0 + 3 yrs.
	3791	3266	NCT 3	1496	1496	T_0 + 7 yrs.
2	2295	1770	T 1	443	443	T_{10}
	1852	1327	T 2	258	258	T_{10} + 5 yrs.
3	1594	1069	T 3	130	130	T_{20}
	1464	939	T 4	105	105	T_{20} + 5 yrs.
4	1359	834	T 5	133	80	T_{30}
	1226	754	T 6	70	46	T_{30} + 5 yrs.
5	1156	708	T 7	116	70	T_{40}
	1040	638	T 8	99	61	T_{40} + 5 yrs.
6	941	577	T 9	123	77	T_{50}
7	818	500	T 10	98	62	T_{60}
8	720	438	SC	120	76	T_{70}
9	600	362	SC	104	102	T_{80}
10	496	260	SC	40	39	T_{90}
11	456	221	SC	55	55	T_{100}
12	401	166	SC	43	43	T_{110}
-	358	123	Stop simulation			T_{120}

Note: NCT: Non Commercial Thinning; T: Thinning; SC: Sanitary Cutting

tions for the planted seedlings, to check their status and, eventually, to replace them in the first years after cutting if damaged or dried. With respect to the number of trees, stand composition will evolve from 96*HB* 2*BH* 2*SO* 1*PO* at moment T_0 to 34*HB* 37*BH* 27*SO* 12*PO* at moment T_{120}.

After about 25 years, the *PO* exceeds the

HB in terms of average diameter and, after 40 years, the *HB* is also exceeded by *SO* and *BH* and remains far behind them at T_{120}. The *PO* reaches the largest diameters and, at the same time, the standard deviation of the *PO* diameters recorded the highest values (figure 6). Up to 25 years, the standard deviation of the *HB* diameter is greater compared to other species; after which the diameter growth of planted species is activated. So, after 25 years, the simulation reveals a sharper stem differentiation of the planted seedlings compared with the *HB*. Beech is a shadow tolerant species and it has standard deviations of diameter smaller than those of *PO* and *SO* under similar site conditions.

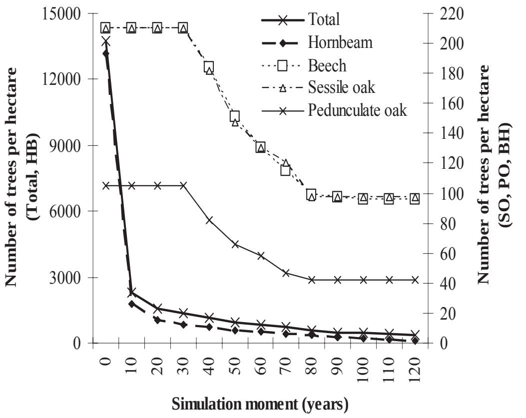

Figure 5 Dynamics of tree number per hectare in AD plot

In terms of height growth, the *PO* exceeds the *HB* after about 25 years from the moment T_0, and the *PO* and *BH* exceed it after 35 years (figure 7). The height growth of beech is sini-ficantly activated after 35 years and, at moment T_{50}, the *BH* gets into the higher side of the canopy, competing with the *PO*. The simulation shows that after the first 35 years the *SO* remains in the second canopy layer and the *HB* below it. After about 55 years of simulation, the differences between the three thresholds increase and the tendency is maintained until T_{120}. The highest values of standard deviation of height meet at *SO* (± 2.98 m at T_{120}) and the lowest at *BH* (maxim ± 2.26 m at T_{120}). The *HB* and *PO* recorded higher values than the *BH*, but significantly lower than the *SO*.

Compared with the other analyzed species, at the age of 120 years, the *PO* reg-

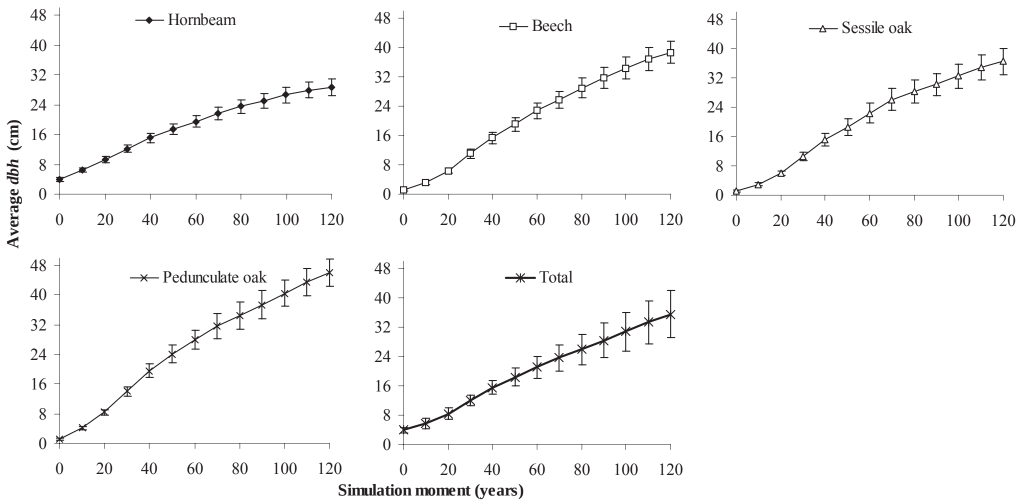

Figure 6 Simulation of average dbh and standard deviation of dbh in the AD plot for the next 120 years

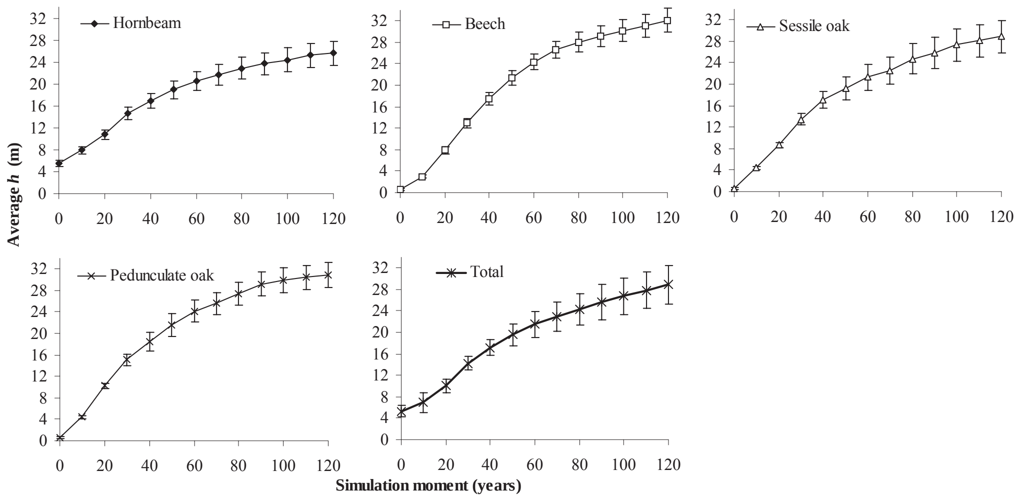

Figure 7 Simulation of average height (h) and standard deviation of h in AD plot for the next 120 years

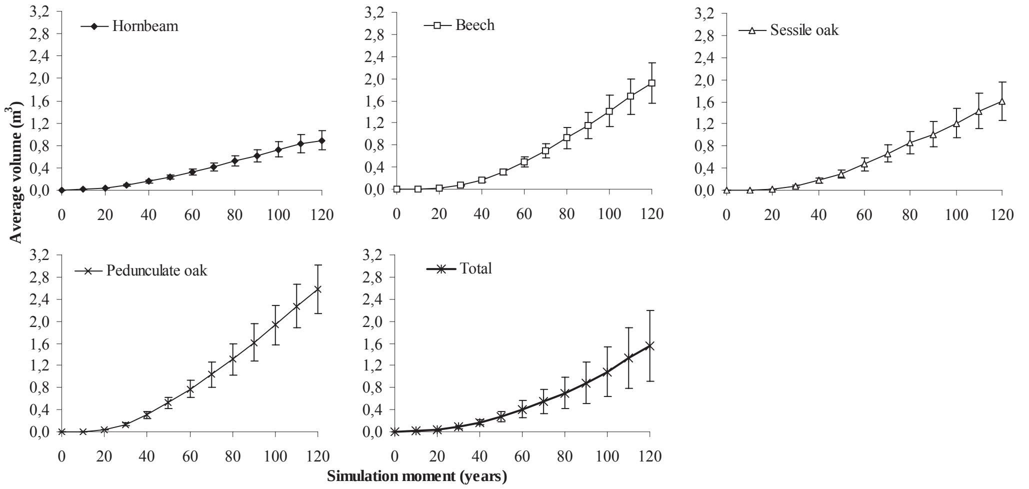

Figure 8 Simulation of trees' average volume (v) and standard deviation of v in AD plot for the next 120 years

isters the largest volumes and also the highest values of standard deviation of volume (figure 8). As a result of growth reducing and due to the silvicultural system applied, the *HB* volume per hectare is significantly reduced especially starting with T_{80} (figure 9). At T_{120} the stand will have an estimated total volume of 558 m^3ha^{-1}, and the composition according to the volume will be 20*HB* 33*BH* 19*PO* 28*SO*.

Species composition and structural diversity: a 120 years simulation period

Dynamics of the species diversity. The species diversity of the stand in the *AD* plot expressed through the Shannon index (figure

10) progressively increases in time with the application of the considered silvicultural system which is focused on preferably extracting the *HB*. The maximum species diversity was computed considering four species in stand composition: *HB*, *PO*, *SO* and *BH*. It can be said that the proposed SCCS method and its application as indicated equilibrates the actual composition and directs it to the target composition as mentioned in the forest management plans in order to use in the best way the site conditions. At the same time, after 120 years, it might be achieved a level of species diversity very close to the maximum possible level under the present conditions.

Dynamics of the structural diversity. The dynamics of the tree distribution per diameter classes is characterized by widening and flattening of the diameter distribution curve, aspects that contribute to an increase in structural diversity. The increased structural diversity is also a consequence of increasing species diversity: different characteristics of analysed species in stand composition led to the shaping of two floors in the canopy at T_{120} (figure 11a). The Gini index evolution during the simulation confirms the mentioned aspects. The high values of Gini index registered at T_{10} and T_{20} are a consequence of the dimensional differences between the *HB* sprouts in inner-bands

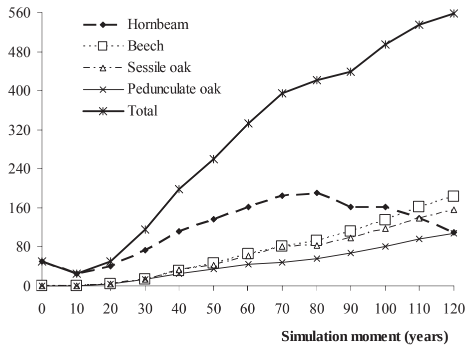

Figure 9 Dynamics of the stand volume per hectare in the AD plot

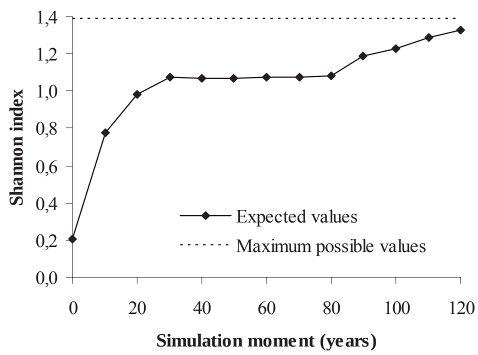

Figure 10 Simulated dynamics of species diversity in the AD plot (120 yrs.)

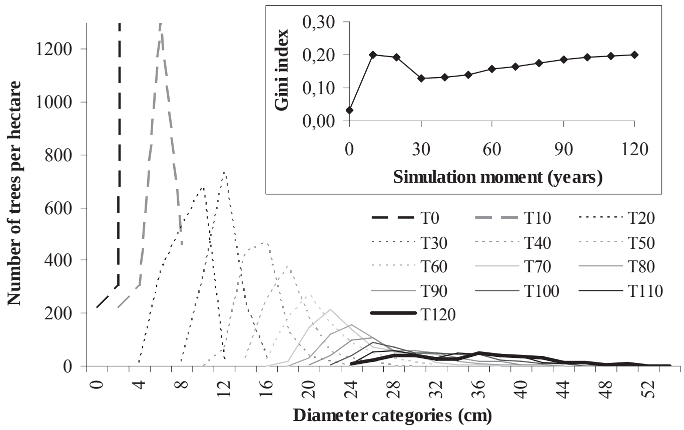

Figure 11 Simulated dynamics of the structural diversity in the AD plot (120 yrs.)

and the seedlings planted in bands. After T_{30} these differences have been recovered by the planted species and, by the end of the simulation period, the structural diversity of the stand has improved continuously: Gini index has registered increasing values in this segment of the simulation (figure 11b).

Discussion

This article proposes a substitution-conversion method whose idea is based on the characteristics of clear cuts in alternate bands (Negulescu et al. 1973) and on the substitution methods in corridors (Dămăceanu 1954). This method derives from the need to reduce economic and environmental losses due to some inappropriate logging procedures in the forests that have led to unproductive coppice stands.

Once the method described, the simulation of new created stands was done in order to assess its applicability. The simulation of stand development was done based on the hypothesis that conversion of coppice into high secondary forest, corroborated with the substitution of hornbeam with more valuable species, will increase the capacity of new created forest stands to optimally use the site conditions and to reach a structure and a biomass level similar to those of the primary forests in the region.

The simulation results at the stand level reveal that, at the beginning of the simulation, the *HB* bands are well defined but, in time, the *HB* will be confined to the second canopy layer and becomes a secondary species, helping the proper development of main and valuable species: *PO*, *SO* and *BH*. After T_{30}, a great importance was granted to the future valuable trees and the *HB* was preferably harvested in order to create appropriate growth conditions for the main species. The *HB* was not radically harvested, but it was preserved in the stand composition for its ecological and quality improving value. It is expected that after about 35-40 years, the main species will dimensionally exceed the hornbeam, leading to a two-layered structure due to the fact that the *HB* sprouts have high growth rates only in younger stages and for shorter periods than the seedlings of *PO*, *SO* and *BH*. After the formation of the two canopy layers, it can be said that the main species are no longer in danger to be overgrown and, when they reach the fructification age, most of the remaining hornbeam trees can be harvested. So, the necessary gaps for natural regeneration of the main species are created.

In the *AD* plot the initial number of trees per hectare after plantation in bands was 13721, from which 13196 were *HB* trees naturally regenerated and 525 were planted seedlings of *SO*, *PO* and *BH*. After 120 years, only 358 trees per hectare remained, namely 123 HB trees and 235 trees from the main tree species. So, in order to achieve the target composition, almost 45% of planted seedlings should reach the cutting age. This requires a special and long term attention from foresters to select and manage the most valuable trees of main species, able to win the competition with the neighbouring trees. Comparing the simulated stand composition on volume with the target composition suggested by the management plan and knowing that the substitution-conversion process started from an almost pure hornbeam stand, it might be said that, the application of SCCS method allowed directing the real structure of the stand in the *AD* plot towards the target structure.

One limitation of the simulation based on the yield tables derives from the fact that, in these tables, data are presented for pure stands with full canopy closure (1). In practice, the canopy closure (which ranges from 0 to 1) varies between 0.7 and 0.8 in 120 years old mixed stands with *SO*, *PO*, *BH* and *HB*. Related to this, it might not be realistic to have such high volumes per hectare like those presented in figure 9 because they might create difficulties with the survival of shadow non-tolerant species like *PO* and *SO*. These species have a much higher light compensation point compared to *HB* (Le Due & Havill 1998). The SCCS method meets this challenge and it can lead to good results by creating and maintaining bands where the planted trees receive more light than their light compensation point. Anyway, higher harvesting intensities are needed to reduce more the number of trees than the values presented in the yield tables in order to create appropriate growth conditions for the valuables planted species. Another limitation of the simulation based on yield tables is related to the lack of information regarding the interspecific competition which appears in mixed-species stands and, connected to this, the fact that thinning cannot be properly derived from the yield tables for these types of stands.

Applying the proposed substitution-conversion method, more diverse stands, formed by valuable species which correspond to the local site conditions, are expected to be created. As a result of simulation, it could be expected that species and structural diversity of trees layer improve (the Shannon species index increases from 0.203 to 1.073 and the Gini structural index increases from 0.032 to 0.200). The oak is known as a tree species able to improve the stand structure over a wide range of habitats (Liira et al. 2011). Therefore, the substitution of hornbeam with oak species will increase both the ecological and economical value of the stands but, in the analysed case study, the oak species require the greatest attention due to their light preferences. The oak is a species that needs protection and its cultivation in bands led to satisfactory results (Lupe & Catrina 1954). Dămăceanu (1954) describes a 1x1.5 m planting scheme used to plant sessile oak in corridors. The planting scheme proposed by this paper leads to a reduced density of seedlings in bands and requires careful monitoring of the progress of each planted tree until it becomes vigorous enough to compete with the neighbouring hornbeam trees. Even if the stand density is low in the bands, a sufficient number of trees is provided in order to choose and to care those trees who will reach the cutting age. Moreover, maintaining a low density in the bands, appropriate conditions will be created to keep the hornbeam in the stand composition in order to achieve a better vertical structure.

Experience has indicated that the seedlings from the central lines of the corridors are most vigorous (plantations with a single species), and those from the outer lines have suffered due to competition of the neighbouring trees from the inner-bands (Dămăceanu 1954, Ştefănescu 1966b). To avoid this drawback, the planting scheme presented in figure 2c was adopted: the beech was introduced on the shaded side of the band and the sessile and pedunculate oak on the sunlit side. Besides, during an experiment of afforestation with sessile oak in felling sites, Gubka (2000) showed that, after plantation, the bigger losses of seedlings occurred on the southern (shaded) site edges.

The proposed method has also the advantage that some tending operations will be done only in a part of the area, whose size depends mostly on the desired proportion of hornbeam in the future stand composition. The SCCS method should be carefully applied in the field. It must be implemented only where the site conditions and the environmental requirements of species from the target composition of the stand are compatible. Moreover, as indicated by this paper, the substitution in bands can lead to good results if applied especially in young stands, being confirmed by the results of Lupe (1968). The advantages of SCCS method should be considered but the simulation need to be improved. Therefore, the future researches should be oriented on a more realistic simulation taking into account the ecological processes meted in mixed forests with beech, hornbeam and oak species.

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References

Amorini E., Bruschini S., Cutini A., Di Lorenzo M.G., Fabbio G., 1996. Treatment of Turkey oak (*Quercus cerris* L.) coppices. Structure, biomass and silvicultural options. Annali del Istituto Sperimentale per la Selvicultura Arezzo 27: 105–111.

Anonymous, 1991. Legea nr. 18 din 19.02.1991 – Legea fondului funciar [Low no. 18 from 19.02.1991 – Land low]. Monitorul Oficial 37/20.02.1991.

Anonymous, 2000. Norme tehnice pentru amenajarea pădurilor [Technical standards for forest management planning]. Romanian Ministry of Waters, Forests and Environmental Protection, 170 p.

Avăcăriței D., 2005. Cercetări auxologice în arborete de fag aflate în perioada de regenerare [Auxologycal researches in regenerating beech stands]. PhD thesis, Faculty of Forestry, „Ştefan cel Mare" University, Suceava, 387 p.

Burns R.M., Honkala B.H. (eds.), 1990. Silvics of North America. Volume 2, Hardwoods. USDA Forest Service Handbook 654.

Canellas I., Del Rio M., Roig S., Montero G., 2004. Growth response to thinning in *Quercus pyrenaica* Willd. coppice stands in Spanish central mountains. Annals of Forest Science 61(3): 243–250.

Ciancio O., Corona P., Lamonaca A., Portoghesi L., Travaglini D., 2006. Conversion of clearcut beech coppices into high forests with continuous cover: A case study in central Italy. Forest Ecology and Management 224: 235–240.

Dafis S., 1966. Standorts und ertragskundliche Unter-suchungen in Eichen und Kastanienniederwäelder der nordostlichen Chalkidiki [Site and yield research in oak and chestnut coppices of NE. Chalkidiki]. Aristotle University of Thessaloniki, 120 p.

Dămăceanu C.E., 1954. Substituirea pădurilor de tip provizoriu din podişul central al Moldovei [Substitution of provisional forest in the central plateau of Moldova]. Revista Pădurilor 2: 19-23.

Dănescu F., Roşu C., Surdu A., 2003. Cercetări privind fundamentarea staţională a substituirii arboretelor de salcâm necorespunzătoare din staţiuni de cvercinee situate în partea externă a zonei de silvostepă [Researching concerning the site substantiation of inadequate acacia stands substitution from quercine sites located in the external part of the forest steppe zone]. Revista Pădurilor 3: 16-24.

Deheza M., Bellassen V., 2010. Climate report no. 20 - Getting carbon value out of the forestry and wood sector in Annex I countries: the French example. CDC Climate Research, Arcueil, France, 47 p.

Duduman G. 2009. Fundamentarea ecologică a calculului posibilității în pădurile tratate în codru grădinărit. [An ecological approach for establishing the allowable cut in forests where single tree selection system is applied]. Editura Universității Suceava, 300 p.

Duduman G., 2011. A forest management planning tool to create highly diverse uneven-aged stands. Forestry 84(3): 301-314.

Gadow K.v., Nagel J., Saborowski J., (eds.), 2002. Continuous Cover Forestry: Assessment, Analysis, Scenarios. Kluwer Academic Publishers, Dordrecht, 368 p.

Giannini R., Piussi P., 1976. La conversion de taillis en futaie. L'expérience italienne [The conversion of coppice into high forest. The Italian experience]. In: Proceedings XVI IUFRO World Congress, Oslo, pp. 388–396.

Gini C., 1912. Variabilità e mutabilità [Variability and Mutability]. Reprinted in: Pizetti E., Salvemini T. (eds.), Memorie di metodologica statistica [Memoirs of statistical methodology], 1955. Rome: Libreria Eredi Virgilio Veschi.

Gini C., 1921. Measurement of inequality and incomes. The Economic Journal 31: 124-126.

Giurgiu V., 1979. Dendrometrie şi auxologie forestieră [Forest Biometry and Auxology]. Ceres Publishing House, Bucharest, 692 p.

Giurgiu V., Drăghiciu D., 2004. Modele matematico-auxologice şi tabele de producție pentru arborete [Mathematic-auxologic models and yield tables for forest stands]. Ceres Publishing House, Bucharest, 607 p.

Gubka K., 2000. Development dynamics of young stands of sessile oak after clear cutting during the conversion of coppice forests in south Slovakia. Sumarski List 124(9/10): 495-502.

Hanganu C., 1969. Aspecte ale substituirii şi refacerii unor păduri din Inspectoratul silvic Covasna [Aspects of substitution and restoration of forests from forest inspectorate Covasna]. Revista Pădurilor 2: 62-66.

Hansen J., Spiecker H., Teuffel K.v. (eds.), 2004. The question of conversion of coniferous forests. Abstracts of the International Conference 27 September – 02 October 2003, Freiburg im Breisgau, Germany. Freiburger Forstliche Forschung, Berichte 47, 2nd revised and advanced edition, 85 p.

Hasenauer H., (ed.), 2000. Forest Ecosystem Restoration – Ecological and Economical Impacts of Restoration Processes in Secondary Coniferous Forests, Proceedings of the International Conference held in Vienna, Austria 10–12. April, 2000, 418 p.

IUSS Working Group WRB, 2006. World reference base for soil resources 2006. 2nd edition. World Soil Resources Reports No. 103, FAO, Rome, 128 p.

Johnson P.S., 1975. Growth and structural development of red oak sprout clumps. Forest Science, 21(4): 413-418.

Kubota Y., Katsuda K., Kikuzawa K., 2005. Secondary succession and effects of clear-logging on diversity in the subtropical forests on Okinawa Island, southern Japan. Biodiversity and Conservation, Springer Netherlands, 14(4): 879-901.

Le Due M.G., Havill D.C., 1998. Competition between *Quercus petraea* and *Carpinus betulus* in an ancient wood in England: seedling survivorship. Journal of Vegetation Sciences 9(6): 873-880.

Lefter R., 1964. Unele aspecte de mecanizare a lucrărilor de substituire cu plop a arboretelor necorespunzătoare din lunci [Some mechanization aspects of the substitution of the inappropriate stands from meadows with poplar species]. Revista Pădurilor 10: 586-588.

Lexerød N.L., Eid T., 2006. An evaluation of different diameter diversity indices based on criteria related to forest management planning. Forest Ecology and Management 222: 17–28.

Liira J., Sepp T., Kohv K., 2011. The ecology of tree regeneration in mature and old forests: combined knowledge for sustainable forest management. Journal of Forest Research 16(3): 184-193.

Lorenz M.O., 1905. Methods of measuring the concentration of wealth. Publication of the American Statistical Association, 70(9): 209-219.

Lupe I.Z., 1968. Substituirea arboretelor slab productive – mijloc de sporire a productivităţii pădurilor [Substitution of low productive stands - means to increase forest productivity]. Revista Pădurilor 11: 589-591.

Lupe I., Catrina I., 1954. Contribuţii la îmbunătăţirea metodei coridorului în perdelele de protecţie [Contributions to improve the corridor method used for protection belts]. Revista pădurilor 6: 256-258.

Lupuşoru V., Diaconu M., Staconu S., Ionele A., 1997. Norme de timp şi producţie unificate pentru lucrări din silvicultură [Production and time unified rules for forestry]. Ministry of Waters, Forests and Environmental protection, Bucharest, 456 p.

Marcu G., 1968. Contribuţia cercetării ştiinţifice româneşti la elaborarea soluţiilor pentru refacerea şi substituirea arboretelor slab productive [Romanian scientific research contribution in developing solutions for the restoration and substitution of low productive stands]. Revista Pădurilor 4: 269-273.

Negulescu E.G., Stănescu V., Florescu I.I., Tîrziu D., 1973. Silvicultura – Fundamente teoretice şi aplicative [Forestry – Theoretical and practical fundaments]. Ceres Publishing House, Bucharest, 372 p.

O'Hara K.L., Hasenauer H., Kindermann G., 2007. Sustainability in multi-aged stands: an analysis of longterm plenter systems. Forestry 80 (2): 163-181.

Palaghianu C., 2009. Cercetări privind evaluarea regenerării arboretelor prin mijloace informatice [Researches on forests regeneration by informatical tools] Ph.D. thesis "Ştefan cel Mare" University, Suceava, 361 p.

Petrescu M.G., 1939. Regenerările naturale şi artificiale ale pădurilor din raza Ocolului Silvic Vaslui [Natural and artificial regeneration of forests from Vaslui forest district]. Bucharest, Manuscript I.C.E.S.

Popa B., 2003. Analiza lucrărilor de substituire şi refacere în arboretele din Podişul Covurlui [Ecological reconstruction methods and procedures applied in Covurlui plateau forest]. Revista Pădurilor 2: 13-17.

Schütz J.P., 2002. Silvicultural tools to develop irregular and diverse forest structures. Forestry 75: 329–337.

Serrada R., Allué M., San Miguel A., 1998. The coppice system in Spain. Current situation, state of art and major areas to be investigated. Annali del Istituto Sperimentale per la Selvicultura 27: 266–275.

Shannon C.E., 1948. A mathematical theory of communication. Bell System Technical Journal 27: 379–423 (July) and 623–656 (October).

Spiecker H., 2003. Silvicultural management in maintaining biodiversity and resistance of forests in Europe – temperate zone. Journal of Environmental Management 67: 55–65.

Spiecker H., Hansen J., Klimo E., Skovsgaard J.P., Sterba H., Teuffel, K.v. (eds.), 2004. Norway spruce conversion – options and consequences. European Forest Institute Research Report 18. Brill, Leiden, 269 p.

Ştefănescu P., 1966a. Despre substituirea şi refacerea unor arborete de productivitate inferioară din subzona făgetelor [About the substitution and restoration of lower productivity stands from beech forest zone]. Revista Pădurilor 6: 322-325.

Ştefănescu P., 1966b. În legătură cu refacerea sau substituirea în coridoare a unor arborete degradate din zona forestieră [About the restoration or substitution of damaged stands using the method of corridors]. Revista Pădurilor 10: 562-564.

Urechiatu M., 1991. Substituirea sau refacerea făgetelor degradate? Cu privire la stabilitatea arboretelor create în urma substituirii făgetelor degradate [Substitution or remarking of damaged beech trees? Regarding the stability of the stands created after the substitution of the deteriorated beech trees]. Revista Pădurilor 4: 181-185.

Waring R.H., Running S.W., 1998. Forest ecosystems: analysis at multiple scales. Academic Press, New York, 370 p.

Wendel G.W., 1975. Stump sprout growth and quality of several Appalachian hardwood species after clearcutting. USDA Forest Service Research paper NE-329, 9 p.