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Basic features of a group selection system modification aimed to sustian regular-uneven-aged stand structure

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Abstract. Proposed modification of group selection system is aimed to successfully combine its elements with biological peculiarities (such as sympodial growth, distinct heliotropism and crown growth plasticity, heavy seeds and difficult dissemination, etc.) of shade-intolerant and mid-tolerant tree species, stands of which may be managed under the same system. Principles, on which the modification is based, are: (i) application of well founded extended rotations in order to increase the proportion of tree groups above 90-100 years age in the stand, where upon the height increment and crown side spread by most of the main tree species in Bulgary drop to considerably lower level, and (ii) optimum systematic spatial positioning of openings in the stand canopy (and tree groups respectively) over the stand area, so that new gaps created by consecutive selection cuttings adjoin to a minimum number of middle aged (40-80 y. age) tree groups. Such clumps of vigorous trees with high growth rates, heliotropism and plasticity carry certain risks of spoiling the target regular-uneven-aged stand structure. Factors of significance are discussed by determining the rotation age, size of gaps opened in the stand canopy, selection cutting cycle, a regular-uneven-aged stand structure design and the minimum area that enables realisation of full selection system cycle. Definitions and determination of selection system elements in their mutual connections are presented in consecutive steps when designing a particular application of group selection system for exemplary pure stand of common beech (*Fagus sylvatica* L.). By the proposed group selection system modification the amount of combinations of various factors having impact upon processes in the tree groups are diminished compared to that by random spatial arrangement of the gaps over the stand area. Silvicultural activities aimed to maintain a stable uneven-aged stand structures are thus getting more predictable, easier to schedule and efficient.
Keywords: group selection system modification, regular-uneven-aged stand structure, *Fagus sylvatica* L.

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Introduction

Group selection system is recommended for stands formed by light demanding and mid-tolerant tree species, particularly in forests where close-to-nature management is mostly required. The system is considered to mimic the structural diversity caused by small-scale natural disturbances resulting in canopy gaps (Smith et al. 1997).

The system is based on creating openings, preferably with a round form in the stand canopy, which are not expanded. Also, the commonly accepted principle is that, in order to form balanced group selection stand structure, tree groups of successive generations dispersed in the stand area should be evenly distributed in the distinct age classes and should cover similar amounts of space (Nyland 1996).

A lot of diversity, variability and freedom of silvicultural operation are put in the numerous other regulations and recommendations about group selection system.

According to commonly accepted opinion, the system may be applied in uneven-aged stands with various age-classes spatial distribution. The treatments recommended for the release and used of the available advance natural regeneration are routine. Besides that, it is considered that the openings created in the stand canopy by group selection system may be irregularly distributed over the stand area. Recommended sizes of openings range, by authors: with an area from 0.04 ha up to 1.2 ha (Schenk 1905), 0.03-0.09 ha (Matthes 1910, cited in Schütz 1999), 0.08-0.2 ha (Nyland 1996), and even 0.1-1.0 ha (Smith 1986), and i.e. with diameters from one-two tree heights (Rafailov 2003), up to several tree lengths. In this connection, J-Ph. Schütz particularly noted that a regeneration system with the size of openings created in the canopy larger in area than 0.1 ha should not be referred to as a group selection (Schütz 1997).

The liberalism in silvicultural interventions when applying group selection system following regulations given above may, in some cases, be the cause for certain difficulties and problems in maintaining target uneven-aged stand structures. There are some uncertainties about details of implementation of this system, e.g. about the effects associated with edge/interior trees ratio by creating openings of various sizes (Leak & Filip 1977, Bradshaw 1992). Biopeculiarities, such as sympodial growth, distinct heliotropism and crown growth plasticity of young and, especially, middle aged trees, heavy seeds and difficult dissemination, characteristic of some of the broadleaved tree species, e.g. oaks (*Quercus* sp.), common beech (*Fagus sylvatica* L.), sweet chestnut (*Castanea sativa* Mill.), may carry risks of spoiling the quality of a considerable number of trees, poor natural regeneration and insufficient ingrowth of new generations in the stand and losing its balanced uneven-aged structure (Dittmar 1990, Schütz 1997).

Besides, random, irregular spatial distribution of variously shaped and sized openings (tree groups, respectively) over the stand area makes difficult the mapping, monitoring, as well as inventory and marking operations, and complicates planning of a skid trail system, fitted to ensure suitable access to each of the tree groups by the consecutive cutting entries (Roach 1974, Murphy et al. 1993, Nyland 1996).

In order to prevent or overcome these difficulties and to facilitate the group selection practice, it was suggested that regular-uneven-aged stand structure and extended rotations to be introduced as elements of the system (Efremov 2003a, 2003b, 2005). Incorporation of these elements alters group selection system and, actually, leads to its modification. The effect of the changes in question, on determining the main elements of the system in their interrelationships and logical succession, in the planning process of a particular group selection application, has not been discussed in detail until now. The purpose of the matter set forth below is to contribute, towards better lucidity, in this respect, by giving more comprehensive description of the modification.

Materials and methods

Elements of group selection system are determined below by application and in the context of concept and approaches proposed by the author, for modifying the system, aiming to make it more strictly definable, flexible, reliable and safe at the same time, as follows.

1. The foremost place in the methodology for working out the group selection system modification and for designing its applications is given to optimum spatial positioning of openings in the canopy (or of tree groups/generations, respectively) over the stand area. Tree clumps from different generations are required to be systematically positioned over the stand

area, so that new gaps created by consecutive selection cuttings adjoin to a minimum number of middle aged (40-80 y. age) tree groups. The rates of growth in height and crown side growth are high by these groups, which mostly carry risks for spoiling stem and crown quality of a considerable number of trees, closing gaps in the canopy and losing the target stand structure (Efremov 2003a, 2005).

2. The usage of well founded extended rotations is proposed to be adopted, in order to increase the proportion of tree groups above 90-100 years age in the stand. In this way, it is contributed to the stability of designed uneven-aged structures, since height increment and crown side spread by most of the main tree species in Bulgary, oaks and beech inclusive, according to the "Yield tables for main tree species in the forests of Bulgary" (Nedyalkov et al. 1983) drop to considerably lower level in proportion to their age overtopping the 90-100 year age threshold (Efremov 2003b, 2005).

Part of the considerations concerning determination of the rotation age, optimum size of openings created in the canopy, and cutting cycle, are based on the known rules of group selection system, combined with and transformed by elements and peculiarities of the above approaches.

Ideas and considerations concerning the number of gaps (and established and tended tree generations, respectively), created per unit of area, design of regular-uneven-aged stand structure, minimum area which enables implementation of one full cycle of the group selection system modification, are for the first time worked out and stated.

For exemplifying how, in principle, elements of a particular application of the group selection modification are determined, illustrative decisions for common beech stand of middle productivity - yield class III - are given in parallel, which are based on data from abovementioned (Nedyalkov et al. 1983) and results from research in mature beech stands in the belt of beech growth optimum in Central Balkan Range (Tourlakov 1973, Garelkov 1979, Efremov 1989; 1996) and other investigations.

Results and discussion

By taking decisions concerning the main elements of a particular group selection system application, their interrelationship (natural or imposed by reason of expedience) are taken into consideration, as well as direct or indirect effects that various natural and anthropogenic factors have on them.

Considerations and making a decision on the rotation

Extended rotations (above 150 years) are preferable, because they contribute for the presence of higher number of groups of mature trees around the newly cut gaps, thus facilitating the forester` actions for maintaining stable, uneven-aged stand structure (Fig. 1). Extended rotations involve higher proportion of older tree groups in the stand, in which low grade silvicultural intervention is needed during last decades, before final crop cutting. Thus, they cause certain reduction in the yield that may be harvested from unit of area by any of the cutting entries.

Decision about the rotation should be based on data about longevity and viability of a particular tree species, under certain site conditions. In the case of *Fagus silvatica* L., investigations in Europe have shown that the dura-

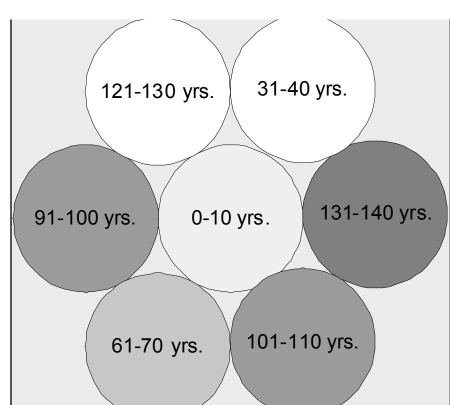

Figure 1 An exemplary particular case of a set of trees groups from different age class es around newly cut opening in the stand canopy by extended rotation

tion of life cycle for virgin stands is 250-300 years (e.g. Lemee 1989, Korpel 1992, Piovesan et al. 2005, Chernyavskyy 2005). Data for the Central Balkan Range National Park in Bulgary show that in forest reserves affected by human activities in the distant past, the oldest beech stands and trees are 230-250 years age as in Management Plan of Central Balkan Range National Park (1996).

With a number of dominant beech trees about and above 140-150 years in managed single-storied stands of the optimum altitudinal belt for beech (800/900 - 1200/1300 m alt.) in the Central Balkan Range, seed production from different portions of tree crowns tends to occur almost every year or two, depending on the site quality (Efremov 1989). The health conditions of some 180-190 years old semi-virgin beech stands was assessed as good in the management plan. Big beech trees with well-developed crowns are more disease-resistant and decay-resistant and with delayed aging (Schütz 1999, Monserud & Sterba 1999). In managed stands, forester's actions are systematically aimed to ensure sufficient growing space for symmetric growth of the crowns of selected crop trees.

In the view of the above findings, the rotation age of 180 years was accepted for the exemplary beech stand of middle productivity (yield class III) in the belt of beech growth optimum in Central Balkan Range.

Determination of optimum size of openings in the stand canopy, created by group selection cuttings

Determining the optimum size of gaps for particular group selection system application considerations should be given to the course of various processes going in and round new openings and tree groups of different ages.

Establishment and growth of viable natural regeneration in the gaps area and rhythmical recruitment of new generations in the stand

The size of openings in the stand canopy should reflect bio-peculiarities of the main tree species. Deciduous species with heavy seeds, such as common beech, small sized openings (with diameters not higher than 20-25 m and area not larger than 500 m^2, respectively) ensure better sustained seeding and filling up with new seedlings over the total gap area, thus, also making possible timely compensation of eventual damages (e.g. from browsing animals -Efremov 1989).

Slope steepness and aspect is of importance when making decisions on size of the openings, because of their effect on the level of light and hydrothermal regime in the opening plots and on the conditions for regeneration of the particular main tree species and growth of its seedlings therein, respectively. From steep south slopes to steep terrains on north aspects, increasingly large sized gaps are used, as a rule. For even-aged beech stands of middle productivity in the Balkan Mountain Range, the recommended optimum gap sizes range between 10/15 and 25/30 meters (Tourlakov 1973, Garelkov 1979, Efremov 1989, 1996) (Fig. 2).

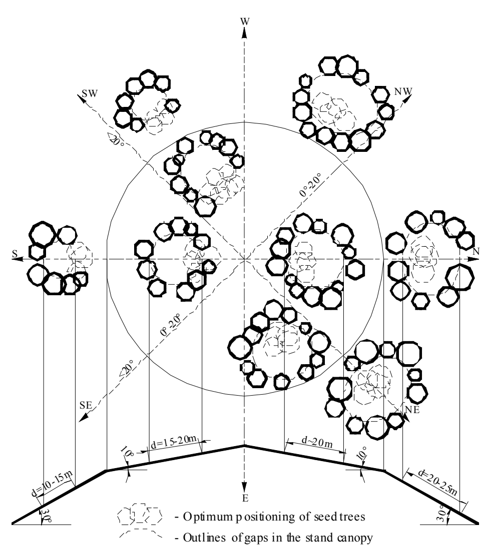

Figure 2 Optimum (initial) diameters of gaps in the canopy, depending on the forest site aspect and slope, in beech stands of medium productivity, managed under uniform, group or irregular shelterwood system, in the region of beech growth optimum belt in Central Balkan Range Bulgary`s (Efremov 1989)

The number of beech seedlings in such canopy openings, 7-10 years after their formation, amounts between 60 and 550 thousand per ha, with a stem biomass of 0.5-2.5 m^3/ha (Efremov 1996). However, the risks increase for closure of gaps in the course of time, if they are too small - less than 10-12 m in diameter, and the light intensity, and direct solar illumination, tend to become insufficient for satisfactory undergrowth development in gaps smaller than 20 m in diameter on steeper slopes with northern aspects particularly (ibid.). Besides that, in stands with tree groups taking small area, the risks increase that crowns of some of the harvested large sized and final crop trees with falling in the area of adjoining groups may cause, there, some damages to trees and regeneration. Openings with larger sizes (800-1000 m^2) give more space for safe felling and skidding operations in the oldest tree groups.

Following regulations regarding establishment and growth of sufficient natural regeneration in gaps, those should be applied when regular-uneven-aged stand structure is created by means of extended rotations, as follows.

During the cutting entry (entries), preceding the final cut in the groups reaching rotation age, part of the large sized trees 30-40-50%, depending on the slope aspect and steepness - will be removed in order to ensure advanced regeneration in the intended-opening area.

At least 2, and normally 3 groups at ages above 90-100 (up to 180) years should adjoin the newly cut gaps and ensure further filling up of natural regeneration and making up for respective damages, eventually, caused to it.

The alternation of tree groups with different heights around the newly cut gaps guaranties that conditions of insufficient illumination will not be created for the young growth.

Growth of the crop trees in groups with optimum growing space ensured

In order to ensure sufficient growing space for selected final crop trees, the growing space for one crop tree is determined using data about the number of trees of a particular tree species at a certain rotation age, per unit of area, available from the local yield tables for the same species or, preferably, analogous data for the particular (type of) forest site and stand, if there is such information at hand.

After finding the suitable growing space for one crop tree at an accepted rotation age, the total area of the growing space necessary for all crop trees in a group is determined. This area should be approximately equal to the area of the optimum sized opening in the stand canopy. Graphically, openings are presented with a round form (Fig. 1, 3 and 4). It should be considered that ground areas between the ideally round outlines are split up between the gaps, thus increasing their area with about 10 %.

For the illustrative example, the following peculiarities of beech should be taken into consideration: beech nuts are heavy, trees above 140-150 years an age of tend to alternate one with another in the producing of a quantity of seeds almost every year or two. Beech seedlings suffer from browsing, height of crop trees is likely to reach 21-22 m as an average (according to yield tables data for 170-180 year-old beech stands of III yield class). In order to ensure natural regeneration and facilitate felling and logging operations, intermediate size of the openings was approved - 25 m in diameter with about 550 m^2 total area. Sufficient growing space for a 180 years old tree is about 22 m^2 (according to the yield tables), i.e. the provisional number of crop trees in a gap in this particular case will be 25.

Cutting cycle determination

Decision on the interval between successive entries is based on information about tree growth rates and the period for reclosure of thinned canopy in young and middle-aged groups, with most accelerated increment after intermediate cuttings (thinning). It depends also on the forest owner's attitude toward toleration of self-regulation (self-thinning) processes and debris formation in the stand.

A ten year illustrative cutting cycle may be decided on, based on data that repeated canopy closure in the middle aged (40-80 years) beech stands of middle yielding capacity occurs at about the same 10 year interval after thinning of moderate grade, without symptoms of substantial tree growth stagnation (dieback etc.).

Group selection stand unit and number of gaps, and established tree generations in it

Regular-uneven-aged stand structure with one full set of tree groups of different generations may be created in smaller or larger area, depending on the specified rotation age, optimum opening size and cutting cycle. Such forest area may be considered as elementary structural unit in a stand managed under group selection system and can be termed group selection stand unit (Fig. 3).

The total number of openings and tree generations in such a unit, necessary and sufficient for perpetual group selection management cycle, are determined by means of the following formula:

$$Ng = r / cc, \quad (1)$$

where:

Ng - total number of gaps (generations) in a group selection stand unit,
r - rotation age (age of final crop trees),
cc - cutting cycle, or interval between consecutive entries in the stand.

Small adjusting corrections may be necessary, in order to make the result of this proportion a whole number. The number of openings and generations in a group selection stand unit for the exemplary beech stand is *Ng* = 180/10 = 18.

Regular-uneven-aged stand structure design

In stands managed for maintenance of regular-uneven-aged structure, different generations (groups of trees) have their permanent places on the terrain. These places are defined according to elaborated and adopted scheme of gap arrangement over the stand area, based on the elements of the selection system, already determined: rotation, gap size, cutting cycle, number of generations and group selection stand unit area. Roughly, the whole area of the stand managed under the group selection modification comprises a certain number of group selection stand units adjoining to each other. In the next example, for convenience in working out expedient gap arrangement scheme, six merged age classes are created within the rotation age: 0-30 years, 31-60 years, 61-90 years, 91-120 years, 121-150 years and 151-180 years, e.g. each class consists of 3 generations (Fig. 3 and 4).

The number of these auxiliary age classes was chosen so that to coincide with geometrically predetermined number of tree groups (6), joining up with each of the gaps, provided all openings have approximately equal (round) form and size.

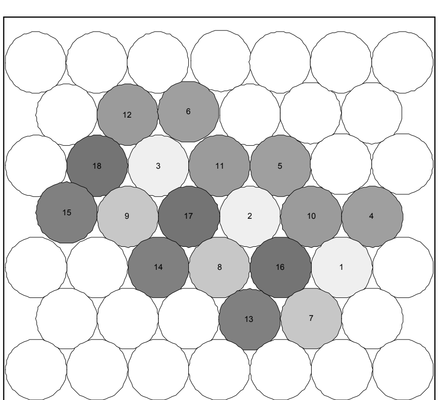

Figure 3 Graphical picture of a group selection stand unit by rotation age 180 years and cutting cycle 10 years. Circular contours of the openings which roughly compose the unit are coloured in grey tones

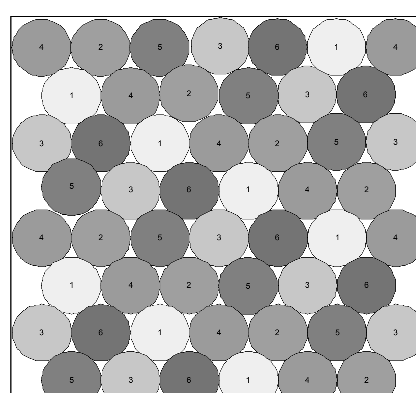

Figure 4 Particular gap arrangement scheme with six auxiliary age classes (coloured in 6 different grey tones) of thirty year range each

The uneven-aged structures may be considered as appropriate for use, if they meet the requirement for lack of contact of newly-cut gaps with each other, and for their minimum adjacency with tree groups between 41 and 80-90 years age. One of the many possible versions of arrangement of the tree groups in space and time is shown in the Figure 4, that newly cut gaps don't adjoin to each other, and each of them mostly adjoins to not more than 2 groups 31-90 years in age and to not less than 3 groups above 90-100 years age (of the range 91-180 years).

Detailed planning (working out, analysis and selection) of regular-uneven-aged stand structures deserves special attention and should be separately treated in a different work.

Minimum area which enables full cycle of group selection system implementation

The minimum area (S_{min}), enough for complete realisation of particular regular-uneven-aged stand structure, actually coincides with the area of one unit of the respective stand, managed under the proposed group selection system modification (Fig. 3). In the graphical example, S_{min} includes a set of 18 openings, with 3 openings from each of the 6 auxiliary age classes (Fig. 3).

The size of the minimum area depends on the particular local environment and is determined by the following formula:

$$S_{min} = S_g \cdot N_g \qquad (2)$$

where: S_{min} - area of a group selection stand unit, ha; S_g - optimum area of an opening, ha ; N_g - number of gaps (generations) determined by using formula (1)

The elements of the system should correspond (to be adapted) to the local environment. Some complications, difficulties or limitations in applying the modification may take place under the conditions of rough and rocky terrains, with considerable, abrupt and rapid alterations on the slope aspect and steepness. Extended rotations are not appropriate for low-productive sites with rather poor, shallow and dry soils.

The silvicultural and technical activities, which are to be done by designing, marking, formation and maintaining of the target group selection stand structures, and by the monitoring, the inventory and the registration of changes in space and time, are possible due to, and by only, utilising the tools of recent innovations of information technologies - geographic information systems (GIS), global positioning system (GPS) etc.

Conclusions

1. By regular-uneven-aged stand structures, the amount of combinations of various factors having impact upon processes in the trees groups are diminished, compared with that from random spatial arrangement of the gaps over the stand area, characteristic of the known group selection system. The silvicultural activities aimed at maintaining stable uneven-aged stand structures are getting more predictable, and efficient, and easier to schedule. Tree clumps are easier to locate and to inventory, because of their systematic spatial arrangement over the stand area.

2. The set of tree groups needed for implementation of a complete group selection system cycle can be arranged in a favourable and compact pattern in a minimum area (in some cases less than 0.5 ha). This makes the modification suitable for small-scale wood management.

3. The establishment of virgin looking stands with regular-uneven-aged structure proves to be feasible by means of the system modification with well founded extended rotations of up to 200 years and more. This approach may be applicable in various particular cases, e.g. for close-to-nature management of transition zones of forest reserves. Even the presence of a portion of dry-topped or hollow trees in the oldest tree groups may be roughly planned out and tolerated in such forests, e.g. for wildlife preservation purposes.

4. By regular-uneven-aged stand structures, elements and interrelations take place, characteristic partially of even-aged single-storied tree clumps and partially for (edges of) uneven-aged stands with irregular structure. Investigations and experiments are necessary aiming at gathering additional data about behaviour peculiarities of the main tree species

growing under variously combined such conditions, in order to further improve the measures taken to sustain this kind of target stand structures.

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