## Summary

Carpathian forests are less anthropogenically altered than the central European forests or those from the Alps. So, a great part of forests located up to 700-800 meters, at the end of the 19th century were even primeval forests. In the large belt of forests in the Carpathians, only the lower and the upper part (timberline and subalpine forests) were more altered in relation with agriculture and sheep hurdling.

For some regions of the Carpathians, like Bukovina and the Transsilvania's Alps, where the transport of wood and forests products were favored by rafting, the alteration of structure and composition is more obvious.

Last 50 years, specially after the socialization of forests (1948), on the grounds of forest management plans, based on the age-class system, a great part of Carpathian forests were accessibilised and extensively cut. In 1950-1980, most part of clear-cut areas were artificially regenerated through plantations and artificial seedlings. Most of old mixed forests were regenerated by spruce plants and are very unstable to wind and snow.

After 1980, as a result of reduction of clear-cut areas (less than 5 ha), natural regeneration is more representative in our forests. Management of natural regeneration of Norway spruce stands (naturally or artificially regenerated) represents one of the great challenges for the actual silviculture in Romania, but also in Europe.

Norway spruce regenerates easy ("… even on the hut of the forester", says a Romanian proverb), but the most difficult problem is to conduct the regeneration process with the objective to ensure a new organization (spatial and temporal) of forests and to reach high stability against snow, wind and game (red deer) damages. In artificial Norway spruce stands, the frequency of wind and snow damaged volume represents more than 70 % of total cuts. At the same time, different ecological factors (microclimatic, soil and geographical conditions) and stand structure parameters (density, seed production), can limit the success of natural regeneration.

The purpose of this book is to put together the researches made in the last 25 years in permanent and semi-permanent plots, which have conducted to relevant conclusions concerning the possibilities of the forester to manage the natural regeneration process, by managing the solar radiation in the best microclimatic condition, controlled through cuts and gap characteristics (shape, size and orientation) in the frequently wind-damaged stands. At the same time, natural regeneration ensure is not only the regeneration of spruce, but also the regeneration of other species (silver fir, beech etc.), even when these are less represented in the old stand.

The studied area is situated in the northern part of East Carpathians, where more than 70 % of natural and artificial spruce stands are located. All the belt of forests in which Norway spruce appears in natural or artificial stands, from 600 to 1700 meters altitude, was investigated. The most part of pre-subalpine and timberline forests are classed as protection forests in which managed cuts are prohibited and only salvage cuts after wind and snow damages are permitted.

Methods for investigation of regeneration success are based on permanent and semi-permanent plots, located in different ecological conditions and structure of stands. A special attention was given to the natural regeneration in the forest gaps, made by wind and snow.

Experimental cuts (clear cuts in blend and shelter-wood cuts at the border of stands - Blendersaumschlag, in German acceptation) were installed in very different geographical conditions (altitude, slope inclination and exposition, geological substrate, position on the slope) and special soil (humus, water and nutrients regime), and microclimatic (temperature, evapotranspiration, water reserves etc.) influences. Other factors (age of stand, age after cutting, degree of fructification and the quality of seeds, degree of colonization of microsites, by herbs or shrubs and the intensity of light) were also studied in relation with the colonization of site by Norway spruce and other forest trees species quantified by special parameters (no/ha, height, high increment, rate of survival and rate of mortality and damage caused by natural or anthropic factors from which the technology of harvesting are the most important).

The results of research are coupled in two parts: (a) managed natural regeneration and cuts and (b) natural regeneration in gaps produced by wind and snow in Norway spruce stands.

The main conclusions of research described in part (a) of the study are the following:

➔ the influence of site characteristics and stand parameters on the Norway spruce natural regeneration

- natural regeneration must be in a fructification year, especially in dense and managed stands;
- germination of seeds and the hatching of seedlings are less influenced by the light intensity in stand and the degree of herbs cover in the first 3 months after germination;
- by the shelter-wood cuts in the border of stand (first cut) in the interval blend the density of the stand would be not less than 0,7 because of herbs risk;
- for a good result of natural regeneration in the fructification year is recommended that the surface of the forest where were made regeneration cuts special measure, to help the regeneration, are necessary if more than 50% is covered by herbs and litter
- for a successful natural regeneration in the first fructification year the internal blend would be prepared for a better germination of seeds;
- for better results, the gaps of natural regeneration installed before or all area in regeneration would be protected against red deer by fencing;
- the percent of naturally regenerated area is inverse correlated with the density index of old stands;
- by the same density index the % of regenerated area diminishes with altitude;
- by a density index of 0,3-0,5 the seedlings aged more than 4 years represent 45%-60% of total seedlings in regenerated area;
- by a density index of more than 0,8 the proportion of seedlings age 4 or more represents only 20%-25% of total;

- between the number of seedlings aged less than 1 year and the density index of stand no correlation was found;
- by the same density index of stands the degree of colonization by herbs is higher at low altitudes;
- by altitudes higher than 1200 m the frequency of seedlings less than 3 years represents only 41 %-45 % than in spruce stands with the same characteristics located at 800-1000 m;
- on the slopes with 26-35 degrees the number of seedlings (naturally regenerated) aged > 3 years is higher by 20 %-25 % than on the slopes with 10-25 degrees inclination;
- in the gaps opened in the last 3-6 years the number of naturally regenerated seedlings is higher in the border exposed to north and east. In the border oriented to west and south the frequency of seedlings represents 75%-87% of others.

➔ the microclimatic condition at the stand border
- the mean and maximum daily temperatures are higher at the open border of stand with 1-3 degrees Celsius in comparison with the interior of stand;
- in the anti-cyclone periods (open sky) the potential evapo-transpiration ETP at the open border of stands is higher with 45%-75% than in the interior of stand;
- in spring, when the interior of stand is covered with 25-30 cm of snow (100%); at the border of stand the exposition of border induces important differences:
    - on the border oriented to south, the snow is melted;
    - on the border oriented to north, the snow-cover represents 200%-230% of interior;
    - on the border oriented to east, the snow-cover represents 50%-75% of interior;
    - on the border oriented to west, the snow-cover represents 40%-45% of interior.

➔ the influence of lighting degree on the natural regeneration
- in the first year after dissemination, in relation with microclimatic conditions, the frequency of young seedlings (≤ 1 year) represents:
    - 45-50 % under the canopy (density index 0,7-0,8);
    - 4-5 % in the border exposed to south and west;
    - 10 % in the border oriented to north;
- in the second year, the mortality of young plants from the past years represents 70% in the border oriented to west and 50% in the north oriented border;
- when the light intensity under the canopy represents 3%-4% of total light in field, the seedlings are totally eliminated after2-3 years;
- when lighting under the canopy represents 10% of the value in open field, the annual high increment of seedlings by 12-15 years represents only 30% of increment in open field;
- the development and increment of seedlings on the border of the stands is highly influenced by the degree of herbs cover;

- under the canopy, in the first 3 years after germination of seeds the optimal density index is 0,8 (lighting = 10%);
- after 3-4 years after installation of natural regeneration (Nmin > 7000/ha) is recommended to reduce the density index to 0,5-0,7 (lighting 12-20 %). With the objective to stimulate high increment;
- if the minimal number of seedlings is not reached (N min ≥ 7000 uniform distributed) the lighting of stand is risky (herbs colonisation);
- the orientation of stand border has a reduced influence on the seedlings (≤ 1 year) under the canopy and high influence on the regeneration at the border;
- at the border oriented to north, the frequency of seedlings is 3 times higher than in other orientations;

➔ the influence of the time between the first cut and the results of regeneration
- the maximum number of seedlings (≥ 3 years), natural regeneration is reached at 3-6 years after the first cut
- three years after the clear cut in the border of stand the degree of colonisation by herbs is 90%-100% in external blend and 70%-80% in the internal blend

➔ the influence of works on helping the natural regeneration of spruce
- if the works are made in stands with I.D. ≤ 0,5 (lighting ≥ 25%) in which herbs covers 50%-80% of area, after 3 years the degree of colonisation by herbs on worked area is more intense than in the control plots;
- in the first years after the mobilisation of humic horizons of the soil, the number of seedlings installed is 2 times higher than that in controlled plots;
- the best results are obtained when the works are made in the internal blend and the I.D. ≥ 0,7;
- the works meant to help natural regeneration don't have the desired effect in the external blend because after 3 years the herbs density is higher than in the control plots;
- when the regeneration check-up is made, it is recommended to consider only the seedlings aged 3 or more (seedlings younger than 2 years have a mortality rate of more than 90% in the 3 years after checking);
- in the area not protected by fencing, the frequency of seedlings damaged by game through greasing of tips represents 41-52 % and the frequency damaged through stepping on represents 26-56 %;

➔ the influence of harvest methods and game on the natural regeneration
- the passage of forest-track produces an increment of apparent density of soil in the first 30-40 cm, with 21-70% and the reduction of infiltration speed of water by 30-36 times;
- on the trasee of collection of wood by animal (horses) the increment of apparent density were registered only in the first 10-20 cm. The infiltration speed is diminished by 10-12 times;
- the frequency of seedlings damaged by harvesting is 3 times higher in the vicinity of collection trasees than in the interior of stand;

- the mean frequency of damaged seedlings by harvesting at the end of regeneration fences is 14-45 %;
- the most damaged seedlings by harvesting are those which are higher than 50 cm;
- it is recommended that the natural regeneration treatments end when the mean height of seedlings is over 40 cm.

➔ the management of treatments to ensure natural regeneration in the stand border
- on the basis of mathematical models of simulation a new methodology of organization of cuts are proposed;
- two different flow-chart are proposed for the best management of natural regeneration works.

The main conclusions concerning the part B of the work can be summarized as follows. The pure spruce stands and mixed stands (resinous and beech) were significativelly affected in the last 50 years by wind and snow damages, numerous parcels every 3-5 years. This aspect prove that disturbing factors must be take intro account in the management plans. The principal implication of quasicontinue action of disturbant factors were analyzed on the following aspects:
- on ecological plan, on the short and mean time an diminishing stability of stands to wind and snow;
- on the long period: changes in the ecosystemic process through self control of structure with significant effect in stability of trees and stand;
- sylvicultural: starting of natural regeneration process at young age (50-60 years);
- incremental: diminishing of trees number/ha under the critical values with consequences in the production capacity;
- larger year ring for the remaining trees.

In such conditions practical sylviculture must adopt a very flexible management to rich an optimal structure of stands in relation with the function, ecological conditions, nature and frequency of disturbant factor, degree of damages, seedling quality and succesional trends.

If in the natural-primeval forest the direction and rhythm of succession is strictly connected with the natural factors, in the man-made forest, the human intervention can induce important perturbations. Until now in such conditions the forest management plans prescribe conservation-cuts and transformations cuts to obtain uneven aged stands supposed less sensitive.

But the intensity of managed cuts were to low and the salvage cuts (after action of disturbing factors) represent even 90-100 % of total cuts with consequences as follows:
- hazardous distribution of damaged areas, party regenerated, in stands aged of 60 years;
- high instability of remaining trees with inadequate slenderness coefficient and length of crown and low density and yield.

In this circumstances the silviculturist need more freedom in their intervention with the following targets:
- valorization of natural regeneration;

- optimal use of ecological conditions for high quality production
- conduct the structure of stand in the direction of minimization of risks

Another conclusions and results of researches:

- in the even aged stands the proportion of affected trees increase highly after 60 years;
- the first gapes made by snow damages are registered until 30 years especially in young dense stands unthinned;
- the mean frequency of damages was estimate at 3-5 years with an very variable damages intensity (2-100 $m^3$/ha/year). No differences between pure spruce stands and mixed stands with beech were observed;
- the degree of instability is increasing with age until the critical high of stand are reached;
- the type of natural regeneration most frequent is classical tip of „regeneration through catastrophes". Natural installation of seedling, their development and relation with the characteristics of old stand and site conditions are good known from the theory of natural regeneration;
- recent researches have studied all the complexity of regeneration process and have conduct to the objectification of valorization of this „resources" to create new stands more stable and more productive;
- the best natural regeneration were observed in stands affected by disturbant factors with high intensity and low frequency but also in the stands affected frequent (1-3 years) with low intensity of damage;
- results concerning the frequency of damaging factors in relation with the productivity (yield class), type of regeneration and concurrence of herbaceous species were summarized in tables for each type of forest ecosystem from Romanian Carpathians;
- a complex flow-chart is proposed for the adoption of the most appropriate decisions concerning the valorization of natural regeneration installed in affected stands by disturbant factors The main entrances in the „decision – blocks" are the characteristics of stand, stage of natural regeneration and the targets for management, established through management plans with the objective to improve the stability and productivity of future stand.