THE CHANGES OF THE FOREST ENVIRONMENT AND BIODIVERSITY IN A NORWAY SPRUCE ECOSYSTEM WITH CLEARCUTTING REGENERATION ON THE ORIGINAL BEECH SITE

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Abstract


The subject of the Rájec project (the Drahanská vysočina Upland) consists in the analysis of ecological impacts of intensive management in spruce monocultures growing on original sites of beech. Long-term studies were aimed at particular stand and environment stages after clear-felling regeneration and at the origin of a spruce monoculture of the 2nd generation. The establishment of the spruce monoculture can be considered to be most important. The highest attention was paid to the monoculture both from the aspect of carbon and nitrogen in particular components of the forest stand and their transport processes as well as from the aspect of water regime and biodiversity. The study was also aimed at the first stage of the clear-felled area development after felling a mature stand and also at functions of the herb vegetation, which reached its maximum production 4 to 7 years after felling.

The paper objective was to assess spruce monocultures even outside their natural range from the aspect of changes in the forest environment as well as from the aspect of possible global changes of climate.

spruce clearcutting, carbon stock, water balance, biodiversity
According to an old map of the tree species composition from 1830, on the territory of the experimental site in that time, a young beech stand (10–30 years) prevailed. According to the above mentioned map from 1864 and 1884 as well, there was a beech forest stand in an age of 30 and 50-55 years respectively. But the state from the year 1933 already shows a basic change in the species composition of stands, viz. significantly in favour of spruce. At that time, it was about 30 years old. It means that the beech stands originated on devastated areas after fires and wind storms in the first half of the 18th century had been harvested during the 19th century at the turn of the century; consequently it is in its first generation being about 90 years old.

Clear-cutting regeneration started in 1977 and after cutting using the technology of whole-tree harvesting, we oriented our study on the period immediately after cutting (1977–1978) and on the next period after establishing a new Norway spruce stand and the rich growth of a herb layer (1980–1986) and the period of development of the 2nd generation of the spruce stand.

DESCRIPTION OF THE LOCALITY
The Rájec-Němčice long-term experiment station is situated in a geographical complex of the Drahanšká vrchovina Upland.

It is located on the eastern slope of the watershed ridge oriented in the N-S direction. The slope can be interpreted as a cryoplanatic terrace with weathered fragments of granodiorite scattered by frost.

The original forest stand: 

*Fagus sylvatica*

Actual forest stand: *Picea abies* Karst. of the 1st generation (80 years)

Soil type: acid Cambisol

Mean annual precipitation: 638 mm

Mean annual temperature: 6.3 °C

Altitude: 625 m (590–640 m)

METHODS

Carbon and nitrogen

1. For the calculation of carbon sequestration and accumulation in the biomass of a tree and herb layer there was a relationship to data on the primary production (Vyskot, 1981; Vašček, Viewegh, 1992; Palát, Janiček, Matovič, 1992), the weight of carbon being calculated according to Divignaud (1988).

2. Total carbon in precipitation and soil water was determined by the modification of the Tjurin's method; evaporated sample was oxidized using chromosulfuric acid at 124°C; after oxidation, the surplus chromosulfuric acid was determined.

3. N-NO₃ was determined in precipitation and soil waters using a modification of the Madžerá et al. method through colorimetry by natricum salicylan in a cuvette at 410 nm wave length.

4. To intercept lysimetric water under particular soil horizons, a lysimeter of Shilovova type (1955) was used.

5. The determination of carbon and nitrogen in an organic horizon was carried out for C in a LECO TruSpec CN analyzer at the combustion temperature 950/850°C.

6. The surface humus weight in a mature stand was determined by sampling on plots of 0.5m² with fivefold repetition and the forest floor weight on a clear-felled area after cutting with 21 repetitions.

7. Carbon respiration from soil was calculated according to Grunda, Kuhlavy (1992).

8. The statistical processing of analytical data was carried out in BASIC using an ADT computer. Methods of testing (t-test, pair test) were applied.

Water balance and the moisture regime of soil

In 1977 to 1984, precipitation/runoff conditions, the moisture regime of forest soils and water balance were monitored in the Rájec-Němčice research area. Sensors and measuring devices for monitoring all partial parameters of precipitation/runoff processes were selected in such a way complete water balance could be carried out on the given locality.

Only the value of evapotranspiration as the last directly measured parameter had to be determined by calculation.

Runoff conditions were monitored using specially constructed soil “lysimeters” for the measurement of surface and slope runoffs from a layer of 1.0 m, namely on a limited area of 100 m². Subsurface runoff was determined by a special procedure on the basis of monitoring and calculating the dependence of intensity of spring runoff on the amount of precipitation (Fig. 1).

Spring outflow was situated in the immediate vicinity under the spruce stand (Prax, 1985). The moisture regime of soils was measured by a capacity method (Kuráž, 1979) in combination with gravimetric samplings necessary to construct calibration lines (Prax and Palát, 1983). Moisture retention lines including their hysteresis (Fig. 2) were determined in the laboratory. The moisture regime dynamics in the growing season was expressed by means of storage soil moisture (mm) for the 0–40 cm layer and also for the layer of 0–90 cm. Its graphic course was completed by values of the wilting point and of the water retention capacity (roughly field water capacity). To determine soil evaporation, the method of Popov evaporimeters was used. Values of potential evapotranspiration were determined according to Turc's method.

Attention of the number of our and foreign hydrologists was paid to the problem of the soil moisture regime and water balance in forest ecosystems. Our results could be confronted with their papers (Benecke, 1978; Rachmanov, 1981; Pobedinskij and Krečmer, 1984; Brechtel, 1985; Swank and Crossby, 1987 etc.).
Biodiversity

Research work on the plots was realised by usual methods of phytocoenological sampling (Zlatník, 1978; Randuška, Vorel, Plíva, 1986). Information published by Zlatník (1970, 1978) is used with revision by Ambros and Štykar (2004) and Ambros (1986). Indices and coefficients of vegetation characteristics were calculated according to papers of Jurko, Moravec and Slavíková (Jurko, 1990; Moravec, 1994; Slavíková, 1986). To express ecological characteristics of herb synusiae, relative representations were used based on their degrees of coverage; data processing was made using the TYP geobiocoenological database programme.

All procedures used for the assessment of the abiotic environment characteristics by means of phytoindication are based on a more or less verified knowledge that certain, often close correlations exist between the occurrence of certain plants and their abiotic environment (Ambros, 1987). As it would be difficult to monitor all components of the environment, we usually select those that are most significant for growth of plants or for given correlation. Moreover, individual taxa respond to the effect of abiotic agents in linkage with other organisms in the biocoenosis. Indicated characteristics of the abiotic environment (eg climate, soil) cannot be identified with values measured by instruments (Zlatník, 1978).

Ecotope indication by means of plant indicators describing symbolically (often even by means of numerals as symbols) the behaviour of plant species observed in the field and partly verified by measurements was used by many authors (Zlatník, 1970, 1978; Ellenberg, 1992; Ambros, 1986; Ambros and Štykar, 2004 etc.). Plant indicators respond to properties of the biocoenosis layer where they live. Therefore, information on the taxa of higher plants differs from information on the taxa of terrestrial mosses and lichens and, thus, it is necessary to proceed according to biocoenosis layers. The representation of particular groups of phytoidicators (ecoelements, ecological groups of species etc.) is calculated through estimated cover and expressed relatively from the total degree of coverage. The degree of coverage was determined by means of vegetation relevés on Zlatník’s scale (Zlatník et Randuška, Vorel, Plíva, 1984), which is a modification of Braun-Blanquet’s scale. Data on vegetation were collected in respective years by several authors and published in research reports (Vašíček, 1978, 1985; Ambros, 1987, 1990; Klímo, 1987; Viewegh, 1990; Štykar, 2002).

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1: Rájec – summation lines of the average monthly values of the springs Nrs. 1 and 2 runoffs and of the precipitation sums for the period 1977–1981
CHANGES IN CARBON AND NITROGEN STOCK

At the change of the species composition of a beech stand to a spruce monoculture a marked increase occurred from the aspect of carbon and nitrogen accumulation, namely from about 20 to about 50 t (metric tonne) during 1900–1977 and, thus, an increase in the accumulation of both elements. This change became mostly evident in the H-layer (Tab. I).

The high accumulation of nitrogen in organic form makes possible to suppose negative impacts of this event on the nutrition of spruce stands by nitrogen. Analysis of needles in spruce stands did not prove this conclusion at the comparison of plots with the forest floor accumulation within the limits

<table>
<thead>
<tr>
<th>Layer</th>
<th>Beech stand</th>
<th>Spruce stand</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>C kg. ha⁻¹</td>
<td>N kg. ha⁻¹</td>
</tr>
<tr>
<td>L</td>
<td>5000</td>
<td>153</td>
</tr>
<tr>
<td>F</td>
<td>6300</td>
<td>161</td>
</tr>
<tr>
<td>H</td>
<td>250</td>
<td>7</td>
</tr>
<tr>
<td>Σ</td>
<td>11500</td>
<td>321</td>
</tr>
<tr>
<td>Humus forms</td>
<td>Moder</td>
<td>Mor-moder</td>
</tr>
<tr>
<td>Year</td>
<td>1900</td>
<td>1977</td>
</tr>
</tbody>
</table>

2: Rájec-KAS I – moisture retention curves

1: Supply of carbon and nitrogen in the forest floor in beech and Norway spruce stands (modified according to Klimo, 1991)
The changes of the forest environment and biodiversity in a Norway spruce ecosystem

50–85 t ha\(^{-1}\) and plots with the forest floor accumulation 120–140 t ha\(^{-1}\) (Klimo, Kulhavý, 2006).

In connection with the accumulation of organic matter in the forest floor of a spruce monoculture increased acidification occurred in the period of about 80 years (Tab. II). A change in the soil type in the direction of the podzol origin was not, however, noted as a result of the process of the organic matter accumulation and acidification of upper soil horizons.

Carbon stock in the aboveground of a tree biomass amounts 142 000 kg DM ha\(^{-1}\) and in the underground 24 500 kg, ie total carbon in an 80-year Norway spruce stand amounts 166 700 kg DM ha\(^{-1}\). It is a similar value, which was determined in an 87-year spruce stand of the Solling project in Germany, namely 158 000 kg (Reichle, 1981). In addition to carbon accumulated in the surface humus, there is relatively high accumulation of carbon also in the root zone of a soil profile, although as compared with a beech stand, the carbon accumulation occurs in a shallower layer. As for the transport processes of carbon, particularly litterfall, transport in precipitation and in throughfall, and carbon dissolved in the soil solution and processes of respiration from soil are important. These values are mentioned (Klimo, 2009) as follows:

- **Litterfall**
  - stand 2500 kg of C ha\(^{-1}\) y\(^{-1}\)
  - roots 600 kg of C ha\(^{-1}\) y\(^{-1}\)
  - in water
  - input into stand 19.6 kg of C ha\(^{-1}\) y\(^{-1}\)
  - input by throughfall 46.2 kg of C ha\(^{-1}\) y\(^{-1}\)
  - input by stemflow 4.2 kg of C ha\(^{-1}\) y\(^{-1}\)
  - output from L-layer 160.0 kg of C ha\(^{-1}\) y\(^{-1}\)
  - output from F-layer 175.0 kg of C ha\(^{-1}\) y\(^{-1}\)
  - output from H-layer 150.0 kg of C ha\(^{-1}\) y\(^{-1}\)
  - output from A-layer 13.0 kg of C ha\(^{-1}\) y\(^{-1}\)

- **Nitrogen accumulation in the biomass of an 80-year Norway spruce stand** was determined as follows:
  - Crown 289 kg ha\(^{-1}\), stems 114, roots 88, ie in total in the biomass 500 kg ha\(^{-1}\), in the upper horizon 780 kg ha\(^{-1}\) (Tab. I) and in mineral soil 2578 kg ha\(^{-1}\).
  - Main transport processes are: litterfall 43 kg ha\(^{-1}\) y\(^{-1}\), input from atmosphere 16 kg, throughfall 33 kg, output by a stand 58 kg and leaching from forest floor to mineral soil 15 kg ha\(^{-1}\) y\(^{-1}\).

- The position of a spruce stand within the landscape shows considerable importance in the input of nitrogen into the ecosystem. Nitrogen is transported by wind into tree crowns and then washed out by precipitation water. Therefore, the relatively high value of throughfall occurs.

In 1977, a parallel plot with clear-felling regeneration was established in addition to the basic experimental plot.

Using the technology of whole-tree logging the significant output of carbon was noted:

\[ 142\,200\,\text{kg}\,\text{ha}^{-1} \]

This amount can be decreased by about 10% carbon included in needles and shoots, which fell off in the course of felling operations on the soil surface, ie:

\[ 1200\,\text{kg}\,\text{ha}^{-1} \text{needles} \]
\[ 530\,\text{kg}\,\text{ha}^{-1} \text{shoots} \]

Total 1730 kg ha\(^{-1}\),

that means that the total output of carbon caused by felling was about 140 500 kg ha\(^{-1}\) (Klimo, 2009) and nitrogen output was about 570 kg ha\(^{-1}\) (harvest thinning).

Considerable amounts of carbon remained accumulated in the surface humus layer. Due to logging operations, however, marked destruction of the surface humus natural stratification occurred, which could be characterized by 3 situations:

- areas where carbon accumulation increased to about 41 500 kg ha\(^{-1}\),
- areas with the maximum accumulation of carbon 36 400 kg ha\(^{-1}\),
- areas on skidding tracks where minimum stock occurred, viz. about 640 kg ha\(^{-1}\).

Thus, the average value of carbon accumulation on the soil surface in the first stage of clear felling increased as against the original spruce stand because the extraction track area occupied only a relatively small area. In the first stage after clear felling (1977–1980), carbon respiration from soil fluctuates about value 13.1 t CO\(_2\) ha\(^{-1}\), ie 3.57 t C ha\(^{-1}\) y\(^{-1}\).

Considering the use of means of mechanization (tractors) for the of felled biomass soil compaction occurred immediately in the first year after felling. With respect to the soil texture and the frequent occurrence of stones on the soil surface this compaction was not drastic and during the development of herb vegetation and a newly established spruce stand the gradual regeneration of physical properties took place (Tab. III).

In the second stage of clear-felling (1980–1986) a newly established spruce stand develops. The herb

<table>
<thead>
<tr>
<th>Forest stand</th>
<th>Layer/Horizon</th>
<th>pH</th>
<th>H</th>
<th>A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beech</td>
<td>H(_2)O</td>
<td>5.26</td>
<td>4.65</td>
<td></td>
</tr>
<tr>
<td></td>
<td>KCl</td>
<td>4.80</td>
<td>3.87</td>
<td></td>
</tr>
<tr>
<td>Spruce</td>
<td>H(_2)O</td>
<td>3.84</td>
<td>3.85</td>
<td></td>
</tr>
<tr>
<td></td>
<td>KCl</td>
<td>3.32</td>
<td>3.04</td>
<td></td>
</tr>
</tbody>
</table>
Vegetation of the clear-felling area is of considerable importance. The maximum production of a herb layer takes 4 years (1980–1983) and then, with the gradually originating canopy of a newly established spruce stand, the production declines each year by about 50%.

Carbon accumulates on a clear-felled area in the second stage of development

a) in a herb layer
b) in a newly planted spruce stand
c) in the layer of surface humus.

Carbon accumulation in the first three components changes dynamically depending on the biomass growth processes and decomposition processes in the surface humus.

Carbon accumulation in the organomineral layer is relatively stable.

Carbon in the layer of surface humus

Monitoring the process of the surface humus decomposition on the clear-felling area was difficult with respect to the high variability of its distribution on the soil surface. Therefore, a model area was established where changes were monitored in the accumulation of organic residues.

Decomposition took place particularly in L and F layers and values in the H-layer remained rather steady. The same situation occurred also in the case of the spruce stand transformation to a beech stand (Klimo, Kulhavý, 2006) where in a 40-year beech stand, the accumulation of organic residues amounted to 44 t in the H-layer and as against 52 t in a spruce monoculture. The L-layer decreased from 7.5 to 4.4 t and the F-layer from 30.1 to 6.1 t ha\(^{-1}\) DM.

Carbon in the herb layer and in the new planted spruce stand

In a mature spruce stand, only mosses created the herb layer. In the first years after felling (1977, 1978), the production was minimum and only in 1979, the accumulation of carbon in aboveground parts of herbs amounted to about 25 kg ha\(^{-1}\) and in next 4 years the production of herbs increased to about 81 kg ha\(^{-1}\), ie about 4000 kg ha\(^{-1}\) of C. With the growth of a newly established spruce stand and with the gradual crown canopy, carbon fixation in herbs decreased every year by about 50%. The experimental plot was reforested by spruce and the increase of carbon accumulation shows an opposite course as carbon in herbs. In the first years (1980–1981), carbon accumulation was low (24 and 77 kg ha\(^{-1}\)) and increased gradually more than 2 times between particular years: in 1982 it was 280 kg, 1983 850 kg, 1984 1800 kg, 1985 3580 kg and in 1986 7200 kg.

The herb layer on a clear-felled area, particularly in the period of its maximum production, i.e. in 1980–1983, shows a highly significant proportion also in the nitrogen accumulation and cycling. The mean value of nitrogen reached 164 kg ha\(^{-1}\) y\(^{-1}\) in the herb biomass in this period. The succession of herbs on a clear-felled area showed also a positive effect on the decrease of transport of nitrates into water sources.

The last stage of the spruce stand clear-felling regeneration consists in reaching the full crown clo-

### IV: Changes in carbon accumulation in the surface humus layer on a clear-felling area

<table>
<thead>
<tr>
<th>Layer</th>
<th>1979 kg ha(^{-1})</th>
<th>%</th>
<th>1980 kg ha(^{-1})</th>
<th>%</th>
<th>1981 kg ha(^{-1})</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>L, F, H</td>
<td>24600</td>
<td>100</td>
<td>22500</td>
<td>91</td>
<td>18800</td>
<td>80</td>
</tr>
</tbody>
</table>

From the aspect of assessing the effect of thinning on the surface humus accumulation and thus also carbon stock, we had to take into account the high variability of this accumulation due to the extraction of trees using the whole-tree technology of logging and, therefore, we did not use this comparison.
The high coefficient of variation was noted particularly at the H-layer, viz. 54% in the stand free of thinning and 66% in the stand with thinning. The lowest coefficient of variation was noted at the L-layer (26%) in both variants where the layer of litterfall was created.

In the process of growth of the newly established spruce stand, differences occurred in the content of nitrogen in needles of trees growing at the edge of the plot and inside the plot in the period 14, 15 and 16 years after clear-cutting regeneration. Significant differences occurred also in the weight of needles (Tab. V).

<table>
<thead>
<tr>
<th>Plot</th>
<th>Year</th>
<th>N%</th>
<th>Weight of 1000 needles in g DM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Trees on plot margin</td>
<td>1990</td>
<td>2.12</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1991</td>
<td>1.03</td>
<td>2.34</td>
</tr>
<tr>
<td></td>
<td>1992</td>
<td>1.32</td>
<td>1.92</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1.49</td>
<td>2.13</td>
</tr>
<tr>
<td>Trees inside the plot</td>
<td>1990</td>
<td>0.94</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1991</td>
<td>0.96</td>
<td>1.72</td>
</tr>
<tr>
<td></td>
<td>1992</td>
<td>0.91</td>
<td>1.51</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>1.60</td>
</tr>
</tbody>
</table>

Concentration of nitrogen in one-year-old spruce needles in trees growing at the edge of the plot and inside the plot did not balance due to thinning. Thus, 23 years after regeneration, nitrogen concentration was: at margin trees 1.11%; at trees inside the plot after thinning 1.12%.

At the conclusion, it is possible to note:

Due to artificially established monocultures of spruce stands, retardation of decomposition processes occurred and thus, the accumulation of surface humus, carbon and nutrients on the soil surface.

The clear-felling method and trends to increase the industrial use of tree biomass mean the marked output of organic matter and biogenic elements from a forest ecosystem.

Thus, through the actual technology of clear-felling, considerable destruction of surface humus or even surface mineral layers of soil occur.

Using means of mechanizations (transport) a change in physical soil properties occurred. Due to ingoing clear-cut area vegetation gradual regeneration of physical properties of soil occurred. There is a possibility that soil will regenerate during 8–10 years.

The development of herb vegetation on a clear-felled area is of great importance for the site development on the clearing, which obtains biogenic elements into cycling. It became evident in the 3rd year after felling.

In the next development of the 2nd generation spruce stand, cleaning showed positive effects as compared with a spruce stand left to its spontaneous development.

About 10 years after the growth of a new plantation on a clear-felled area, the actual symptoms of N deficit occurred (proved by the analysis of needles). The reason of this situation consists in blocking nitrogen in the organic matter of surface humus and in the considerable competition of the dense spruce thicket (planting + self-seeding). This deficit is gradually balanced due to silvicultural measures (thinning).

MOISTURE REGIME OF SOILS AND THE WATER BALANCE IN A SPRUCE STAND

Soil moisture dynamics

Increased attention was paid to values of the forest soil moisture of modal Cambisol and its annual balance. Measurements were carried out continuously, virtually once a week, by a capacity probe on prepared measuring places being completed by occasional gravimetric determinations. The moisture of the mineral soil profile was measured from 6 to 90 cm. The surface layer of forest floor was not separately evaluated as for the moisture content. In the profile balance, it was included into the layer of 0–10 cm and evaluated according to measurements carried out in 7 and 10 cm, ie in the mineral horizon with the admixture of humus. This simplification was necessary because the reliable measurement of moisture in this complicated layer of forest floor has not been worked out yet.

Soil moisture measurements at the monitored locality were started already in 1976, which was extreme as for moisture conditions. After abundant precipitation activities in May and at the beginning of June, the soil profile was saturated nearly to the value of full water capacity. Then, nearly a seven-week rainless period occurred and the soil moisture decreased throughout the profile to the wilting point soil-moisture constant.
Measurements of the soil moisture dynamics are graphically demonstrated in the form of chronoisoplets (Fig. 3) in a climatically average year 1980 together with the amount of precipitation during the years. The figure also shows considerable fluctuation in the content of soil moisture depending on the course of climatic factors as well as actual evapotranspiration of the spruce stand. Conditions of the profile higher saturation are evident, viz. generally at the end of the winter season and also after abundant precipitation. The periodical short-term stagnation of ground water was also found at the turn of April and May at a depth below 50 cm owing to the low permeability of subsoil. Moisture minimum at the turn of September and October is almost a characteristic feature of these soils. The most marked moisture decline was found in the soil layer from 20 to 40 cm where soil moisture decreased below 20% (in volume). It concerns a layer where considerable part of the spruce root system occurs.

Saturation of this layer by water either from precipitation or from soil water supplies is mostly insufficient. This phenomenon is documented by intensive manifestations of actual evapotranspiration, ie considerable consumption of soil water by the spruce root system in summer months. A period at the beginning of July 1980, when after intensive precipitation, the short-term saturation of the soil profile by water occurred even in subsoil, can be evaluated as an exception. Advantages of this capacity method of measurements consist in a fact that the method notes the whole moisture scale, ie from saturated soil profiles up to profiles dried to the wilting point. A calibration line determining the dependence of measured values (μA) on the volume soil moisture shows virtually a linear course.

At the water balance in the growing season, profile values of the water supply were taken into consideration at the beginning and at the end of the balanced period. Based on the difference of these values, the amount of water, which is supplied by the soil profile to the total water balance, is calculated. These data differ considerably in particular years as shown by the following table.

<table>
<thead>
<tr>
<th>Year</th>
<th>mm</th>
<th>% (of total precipitation)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td>52</td>
<td>11</td>
</tr>
<tr>
<td>1978</td>
<td>70</td>
<td>16</td>
</tr>
<tr>
<td>1979</td>
<td>37</td>
<td>9</td>
</tr>
<tr>
<td>1980</td>
<td>25</td>
<td>6</td>
</tr>
<tr>
<td>1981</td>
<td>14</td>
<td>3</td>
</tr>
<tr>
<td>1982</td>
<td>56</td>
<td>13</td>
</tr>
<tr>
<td>1983</td>
<td>45</td>
<td>10</td>
</tr>
<tr>
<td>1984</td>
<td>88</td>
<td>20</td>
</tr>
<tr>
<td>1977–1984</td>
<td>48.4</td>
<td>11.1</td>
</tr>
</tbody>
</table>

It follows that the soil profile contributes to the water cycle in the growing season on average by 48.4 mm, ie 11.1% open area precipitation in the growing season.

### Water supplies and the retention capacity of forest soil

The detailed knowledge of physical conditions of soils, moisture retention lines and soil-moisture constants in particular soil horizons and, finally, detailed data on the soil moisture condition made possible to calculate supplies of soil water (mm) and their changes within the monitored period. Water supplies were assessed partly for the soil layer 0–40 cm where predominant part of the spruce root system occurred and partly for the soil layer
0–90 cm, which virtually represented the physiological depth of soil because from about 90 cm, soil-forming substrate appeared and root penetration of this layer was minimal at the given locality.

An example of the water supply and its dynamics in the course of 1981 including the value of the water retention capacity and the wilting point is demonstrated in Fig. 4. The moisture range of these two soil-moisture constants is illustrated by cross-hatching.

This graphic demonstration proves that the water supply at the given site is sufficient for the major part of the growing season. Regular but not critical decline of the soil moisture occurs at the end of the growing season in August and September. During the winter season, the content of soil water is mostly saturated up to the value of water retention capacity. A marked increase in the soil water supply occurs only in connection with spring snow-melt roughly in March and April. Thus, in the monitored period from 1977, a marked decline in the soil moisture below the wilting point value never occurred. Frequent precipitation sufficed to complete soil water supplies for the need of evapotranspiration. Following table documents periods free of atmospheric precipitation.

This finding has to be taken carefully because in 1976, ie one year before the start of regular measurements of particular parameters of the water balance, a long-term period (49 days) free of precipitation occurred in summer (from 3 June to 23 July). Within this period, supplies of soil water in the profile under evaluation decreased from 281 to 126 mm, ie by 155 mm. It means that the mean value of daily evapotranspiration amounted to 3.16 mm. These values can be considered to be outer limits of the soil profile retention capacity of the local modal Cambisol detected under natural conditions. Similar data determined on the basis of physical parameters in the laboratory, ie differences between the maximum saturation of undisturbed soil samples and the wilting point, amounted to 151 mm.

The water balance in a spruce ecosystem

Precipitation and evapotranspiration are most important in the spruce stand water balance. These values were rather equal in 1977, 1979, 1980, 1981 and 1982. All measured data prove that the studied locality shows rather equal water balance, which is deficit in precipitation-below-average years. It means that the actual evapotranspiration exceeds precipitation totals. An occasional moisture deficit is balanced by the supply of water in the soil profile. For example in 1978, soil water supplies reached nearly 40% precipitation fallen to the soil surface. Surface and slope inflow and runoff participate in the water balance only slightly. For the water cycle balance at the measured locality, a following simple balance equation was used:

\[ W1 + P + K + q1 + q2 = Et + O1 + O2 + W2 \] [mm]

After the substitution of actually measured values of particular averaged elements for the balance period 1977–1984, the equation looks as follows:

### VII: Periods free of precipitation in the growing seasons at the locality

<table>
<thead>
<tr>
<th>Year</th>
<th>The longest period free of precipitation in the growing season (days)</th>
<th>Date</th>
</tr>
</thead>
<tbody>
<tr>
<td>1977</td>
<td>34</td>
<td>24/9 to 7/10</td>
</tr>
<tr>
<td>1978</td>
<td>12</td>
<td>6/10 to 17/10</td>
</tr>
<tr>
<td>1979</td>
<td>22</td>
<td>25/9 to 16/10</td>
</tr>
<tr>
<td>1980</td>
<td>12</td>
<td>27/7 to 7/8</td>
</tr>
<tr>
<td>1981</td>
<td>12</td>
<td>28/7 to 8/8</td>
</tr>
<tr>
<td>1982</td>
<td>16</td>
<td>7/9 to 22/9</td>
</tr>
<tr>
<td>1983</td>
<td>27</td>
<td>7/8 to 6/9</td>
</tr>
<tr>
<td>1984</td>
<td>22</td>
<td>4/10 to 25/10</td>
</tr>
</tbody>
</table>
48.4 + 274 + 0 + 10.2 = 295.0 + 10.2 + 27.4 + 0

Explanatory notes:

W1 – Soil moisture at the beginning of the growing season was calculated as a difference of the soil water supply at the beginning and at the end of the growing season. In this case, W2 = 0

P – The sum of stand precipitation and stemflow

K – Permanent ground water table was not found at the monitored locality. Therefore, a value = 0 was substituted in the equation

q1 and q2 – Surface and subsurface inflow is given only by one value, which is equal to the value of runoff O1

Et – The value of actual evapotranspiration is the only value, which is calculated from the balance equation, however, it is not directly measured

O1 – Surface and slope runoff

O2 – Subsurface runoff

It is necessary to mention that presented balance elements are affected by a certain fluctuation in particular years. For example, stand precipitation amounted only 55% open area precipitation in 1978 while maximum precipitation occurred in 1977, viz. 343.4 mm, ie 73%. From the viewpoint of the selection of methodical procedures values of evapotranspiration can be affected by a relatively higher error (determined by calculation) as well as the value of subsurface runoff (dependent on the selected lysimeter system).

In conclusion, it is possible to say that the selected period and carried out balance measurements characterize concisely and in detail the water balance of an artificially regenerated fully closed mature spruce stand growing on modal Cambisol in the forest type group of silver fir-oak beech forest. The monitored spruce monoculture is a typical element of commercial forests of the CR upland regions although spruce shows its optimum distribution at higher vegetation zones.

Soil moisture and surface erosion events on a clear-felled area

In 1979–1986, the moisture regime of forest soils was monitored (modal Cambisol on the granodiorite weathered rock) on a newly forested clear-felled area (Forest Enterprise Rájec-Jestřebí) in a research area of the Institute of Forest Ecology, Mendel University of Agriculture and Forestry in Brno. An old stand was harvested by means of a technology using whole-tree logging (including crowns). Reforestation was carried out by a disk-type planting machine PH 4-010. Through this technology, shallow furrows/rills originated on a moderate slope of SE aspect situated virtually perpendicular to the slope. The dynamics of soil moisture was monitored using the capacity method partly in the rill (soil pit 2) and partly between rills in an undisturbed soil profile (soil pit 1). The moisture regime was evaluated in the form of the soil water supply in 0–40 and 0–100 cm profiles. It was found that soil water supplies ranged mostly within the limits of soil moisture constants of the retention water capacity and wilting point, ie mostly in the physiologically available form for plants (Figs. 5 and 6). Only precipitation-deficit year 1983 was unfavourable. Then, soil moisture fluctuated in soil pit 1 between the rills about the wilting point value from August to November. Thus, based on the evaluation of the whole monitored period, supplies of soil water in a profile disturbed by a rill after the planting machine operation were mostly slightly higher as against the undisturbed soil profile between the rills.

Further, erosion activities of water were monitored on a clear-felled area. Air photographs (made out using the aircraft model) of the whole clear-felled area document a fact that disturbed soil surface in the place of a skidding track was virtually stabilized after three years and also minute erosion events originated immediately after felling disappeared during two or three years due to a newly originated

| VIII: Resulting values of water balance after evaluating and averaging particular balance elements for the monitored eight-year period |
|---------------------------------|-------|-------|
| mm %                           |       |       |
| Total annual precipitation of the open area | 674.6 | -     |
| Total precipitation of the open area in the growing season | 422.7 | 100   |
| Stand precipitation            | 269.7 | 64    |
| Stemflow                       | 4.1   | 1     |
| Sum of stand precipitation and stemflow | 273.8 | 65    |
| Interception                   | 149.6 | 35    |
| Surface and slope runoff in a layer 90 cm thick | 10.2  | 2     |
| Subsurface runoff              | 27.4  | 7     |
| Water supplies in the soil profile | 48.4  | 11    |
| Potential evapotranspiration   | 450.7 | 107   |
| Actual evapotranspiration (calculation) | 295.0 | 69    |
| Actual evaporation from soil   | 83.1  | 20    |
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The mechanized planting of spruce was evidently of great importance. At the planting, rills created perpendicular to the slope functioned as infiltration belts for storm surface waters.

Conclusion

The water balance of forest soils was monitored in ecosystem of spruce stand on modal Cambisol. Runoff conditions were monitored and subsurface runoff was carried out on the basis of monitoring and calculating the dependence of intensity of spring runoff on the amount of precipitation. Measurements of the soil moisture dynamics show fluctuation in the content of soil moisture depending on the course of climatic factors as well as actual evapotranspiration of the spruce stand. The most marked moisture decline was found in the soil layer from 20 to 40 cm, where great part of the spruce root system occurs. Decline of the soil moisture occurs at the end of the growing season. During the winter season, the content of soil water is mostly saturated. Marked decline in the soil moisture below the wilting point value never occurred. The soil water supplies ranged mostly within the retention water capacity and wilting point, in the physiologically available form for plants. Erosion activities of water were monitored on a clear-felled area. Disturbed soil surface in the place of a skidding track was stable af-

5a: Rájec, soil pit 1. Period 1979–1986. Values of maximum and minimum supplies of soil water (in mm) for the profile 0–100 cm.

5b: Rájec, soil pit 1. Period 1979–1986. Values of maximum and minimum supplies of soil water (in mm) for the profile 0–40 cm.
After three years due to a new herb cover. At the planting, rills served as infiltration belts for storm surface water.

**CHRONOSEQUENCE OF ECOSYSTEM DEVELOPMENTAL STAGES FROM BIODIVERSITY POINT OF VIEW**

A climax community indicating the whole biocoene (*sensu* Zlatník, 1978) is in typified form the *Fagetalia abietino-quercina* group of geobiocoene types (according to Buček et Lacina, 2002). Geobiocoene denotes not only the climax community and its developmental stages but also the altered and derived communities occurring within the same (essentially unchanged) frameworks of abiotic environment. In this work, we call this developmental continuity a chronosequence.

The area of interest belongs in the climatic-vegetation zone of nemoral broadleaved deciduous forests (zonobiome VI), climatic-vegetation region of transitional climate with elements of climate affected by the Mediterranean Sea in the vicinity of region with elements of climate affected by the Baltic and the North Sea. The territory is situated on the boundary between regions with normal and be-
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Due to the absence of thermophilous species and only a rare occurrence of piedmont species on the research plots and in their broader environment, the research plots can be in agreement with Vašíček (1978) classified in Vegetation tier 4 - Beech. Ambros (1987) informs however that a mild prevalence of species exists there, which are descending in terms of vegetation zonality. This would point to the upper boundary of this vegetation tier. As to moisture regime, prevailing are the species of mesophyte character; the representation of species tolerant to temporary drying of rhizosphere is considerable though. Therefore, we can speak of a normal hydric subseries within the basic hydric (i.e. leader) series, which is oligo-mesotrophic in terms of trophicity.

The used research plots are of both analogical character (/1) developmental stage of natural beech forest/ and parallel character (/2) developmental stage of the non-close-to-nature spruce forest of the 1st generation/ or of permanent plot character (3) developmental stage of even-aged vegetation after clear cutting of the spruce stand, (4) developmental stage of the regeneration non-close-to-nature spruce forest of the 2nd generation, (5) developmental stage of the growing-up non-close-to-nature spruce forest of the 2nd generation with tending measures, or with the spontaneous development (6) – developmental stage of the growing-up non-close-to-nature spruce forest of the 2nd generation without tending measures.

These frameworks then can become a comparative basis of data on biotic and/or abiotic constituents of ecosystems.

The above-mentioned climax community can be classified in the Luzulo-Fagion alliance of the phytocoenological system (Moravec, 1994).

**CHRONOSEQUENCE OF ECOSYSTEM DEVELOPMENTAL STAGES ON SITE OF THE POTENTIAL GEOBIOCOENOSES OF THE FAGETA ABietetino-Quercina GROUP OF GEBIOCOENE TYPES**

1. Developmental stage of natural beech forest

Synusia of woody species consists of 9 tree species with the main layer being entirely dominated by European beech (*Fagus sylvatica* L.). Sessile oak (*Quercus petraea* (Mattuschka) Liebl.) is interspersed. Other species occur only in the lower layers (namely in the shrub and advance regeneration layers) and their degree of coverage is low. They include silver fir (*Abies alba* Mill.), hornbeam (*Carpinus betulus* L.), silver birch (*Betula pendula* Roth), European mountain ash (*Sorbus aucuparia* L.), red-berried elder (*Sambucus racemosa* L.), but also Norway spruce (*Picea abies* (L.) Karst.) and European larch (*Larix decidua* Mill.).

Total cover of the main layers is 75%.

Synusia of non-woody undergrowth consists of 30 species. Predominant are 2 species: *Luzula luzuloides* (Lam.) Dandy et Wilmott (with a degree of coverage +2) and *Calamagrostis epigeios* (L.) Roth (with a degree of coverage -2). Degree of coverage 1 is reached by 5 species: *Athyrium filix-femina* (L.) Roth, *Galium rotundifolium* L., *Maianthemum bifolium* (L.) F. W. Schmidt, *Mycelis muralis* (L.) and *Oxalis acetosella* L. Other species are of lower degrees: 13 species reach the degree of coverage + and 10 species reach the degree of coverage – (Annex 1a). Total cover of the main layers is 75%.

Synusia of terrestrial mosses consists of 4 species (Annex 1b) and reaches a total cover of 3%.

**Graph 1:** Representation of ecoelements in relation to light

Legend:

- **SS** = deep shade species
- **S** = sciophytes
- (S) = semi-sciophytes
- **O/S** = semi-heliophytes
- **O** = heliophytes
- * = unclassified species
- **d** = humicolous and humiproducent species
- **h** = humicolest and humicolestuent species

Graph 1: Representation of ecoelements in relation to light

Legend:

**SS** = deep shade species, **S** = sciophytes, (S) = semi-sciophytes, O/S = semi-heliophytes, **O** = heliophytes, * = unclassified species, **d** = humicolous species, **h** = humicolest and humiproducent species.
Species diversity index is 3.169 and equitability index is 0.646.

**Annex 1a:**

**Annex 1b:**

2. Developmental stage of the non-close-to-nature spruce forest of the 1st generation

Synusia of woody species consists of 8 tree species with the main layer being dominated only by 1 species – Norway spruce (*Picea abies* (L.) Karst.). Other species are either only interspersed in the spruce or find place in the lower layers, namely in the shrub layer and in the layer of advance regeneration. Their degree of coverage is very low and they include – silver birch (*Betula pendula* Roth), wild cherry (*Cerasus avium* (L.) Moench), European hazel (*Corylus avellana* L.), European beech (*Fagus sylvatica* L.), sessile oak (*Quercus petraea* (Mattuschka) Liebl.), European mountain ash (*Sorbus aucuparia* L.) and red-berried elder (*Sambucus racemosa* L.). Total cover of the main layers is 95%.

Synusia of non-woody undergrowth consists of 29 grass, herb and fern species. Most represented are 4 species with the degree of coverage 1 of Zlatník's scale, namely *Maianthemum bifolium* (L.) F. W. Schmidt, *Hieracium lachenalii* C.C.Gmelin, *Vaccinium myrtillus* L. and *Oxalis acetosella* L. Other species are of lower degrees – 5 species reach the degree of coverage + and 20 species reach the degree of coverage − (Annex 2a). Total cover is 8%.

Synusia of terrestrial mosses consists of 12 species (Annex 2b) and reaches a total cover of 25%.

Species diversity index is 3.263 a equitability index is 0.665.

**Annex 2a:**
Species with the + degree of coverage: *Chamerion angustifolium* (L.) Holub, *Deschampsia flexuosa* (L.) Trin., *Gallium rotundifolium* L., *Myctis muralis* (L.) Dumort., *Rubus idaeus* L.

**Annex 2b:**
3. Developmental stage of even-aged vegetation after clear cutting of the spruce stand

All layers of the synusia of woody species were totally destroyed by felling. The layer of advance growth (layer V) was destroyed by felling too, but this is the stage when its regeneration starts through both natural and artificial way. This developmental stage at the beginning of which the woody species play no role at all ends by their development (Annex 3b).

There were 89 plant species changing in the synusia of non-woody undergrowth, of which only 9 species occupied a dominant or sub-dominant position (Agrostis stolonifera L., Calamagrostis epigeios (L.) Roth, Carex ovelis Good., Carex pallescens L., Carex pilulifera L., Chamerion angustifolium (L.) Holub, Juncus conglomeratus L., Rubus idaeus L., Veronica officinalis L.) - (Annex 3a). Total cover is 88%.

Although the synusia of terrestrial mosses was not surveyed in details, some small remainders of its components were presumably left behind after the felling and extraction of trees.

Species diversity index is 2.461 and equitability index is 0.380.

Graph 3: Representation of ecoelements in relation to light
Legend:
SS = deep shade species, S = sciophytes, (S) = semi-sciophytes, O/S = semi-heliophytes, O = heliophytes, * = unclassified species, d = humidestruent species, h = humicolous and humiproducent species.

Graph 4: Representation of ecoelements in relation to available nitrogen
Legend:
1 = kinds of soils poor in nitrogen, 2 = kinds of soils with mild nitrogen supply, 3 = kinds of soils with medium nitrogen supply, 4 = kinds of soils rich in nitrogen, 5 = kinds of soils very rich in nitrogen, * = unclassified soil kinds.


Annex 3b: The following 5 tree or shrub species took eventually the dominant or sub-dominant position in the synusia of woody species (Betula pendula Roth, Picea abies (L.) Karsten, Populus tremula L., Salix caprea L., Sambucus racemosa L.).
4. Developmental stage of the regeneration non-close-to-nature spruce forest of the 2nd generation

The synusia of woody species intensively increases its total cover and rapidly suppresses the synusia of non-woody undergrowth (herbs, grasses). The forest is dominated by the population of Norway spruce (*Picea abies* (L.) Karst.), which was planted artificially. Spruce individuals originating from the self-seeding of spruce stand adjacent to the clearcut occurred spontaneously; however, their significance was only complementary as to the degree of coverage. Total cover is 65%, number of tree species is 9 and other occurring tree species are: *Betula pendula* Roth, *Cerasus avium* (L.) Moench, *Larix decidua* Miller, *Pinus sylvestris* L., *Populus tremula* L., *Pseudotsuga menziesii* (Mirbel) Franco, *Salix caprea* L., *Sambucus racemosa* L.

Synusia of non-woody undergrowth shows a characteristic encroachment of one powerful dominant – *Calamagrostis epigeios* (L.) Roth; other species are withdrawing, even co-dominants such as *Rubus idaeus* L., *Chamerion angustifolium* (L.) Holub or *Juncus conglomeratus* L. (Annex 4a).

Synusia of terrestrial mosses consists of 4 species (Annex 4b) and its total cover is 4%.

Species diversity index is 1.637 and equitability index is 0.280.


Annex 4b:
Dianella heteromalla (Hedw.) Schimp., Dianera scoparium Hedw., Pohlia nutans (Hedw.) Lindb., Polytrichum formosum Hedw.

5. Developmental stage of the growing-up non-close-to-nature spruce forest of the 2nd generation with tending measures

Synusia of woody species consists of dominant Norway spruce (Picea abies (L.) Karst.) and admixed European larch (Larix decidua Miller) and Scots pine (Pinus sylvestris L.). Other tree species are sparse — silver birch (Betula pendula Roth), alder buckthorn (Frangula alnus L.), European aspen (Populus tremula L.), goat willow (Salix caprea L.); other tree species occurred only in the lowest layer — sessile oak (Quercus petraea (Mattuschka) Liebl.), red-berried elder (Sambucus racemosa L.) and European mountain ash (Sorbus aucuparia L.). Total number of tree species is 10, total cover reaches 90%.

Density of the young spruce stand does not allow development of other tree, herb or grass species which penetrate only sporadically. Self-thinning
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of the spruce population discards individuals without disrupting the canopy closure. Total number of tree species is 5, total cover reaches 100%. Except for the Norway spruce (Picea abies L.), other tree species found were – silver birch (Betula pendula Roth), European aspen (Populus tremula L.), goat willow (Salix caprea L.) and sessile oak (Quercus petraea (Mattuschka) Liebl.). The last mentioned species was found in a few small specimens that took roots even under the fully closed spruce stand, at all times however with at least some light penetrating from the side.

Relative irradiation of this layer is already so low that the synusia of non-woody undergrowth practically does not exist – sparsely occurring are individuals of 5 species (Annex 6a), total cover is below 1%.

A nearly total lack of light neither allows development of the synusia terrestrial mosses whose total cover is 5% and the number of species amounts to 8 (Annex 6b).

Soil surface cover characteristically consists only of coniferous litterfall; advance regeneration of tree species, herbs, grasses, lerns or mosses cannot gain ground due to deficient light and probably also due to lacking moisture because precipitation often cannot penetrate through the dense crown canopy of the spruce stand to the ground surface.

Species diversity index is 1.971 and equitability index is 0.849.

Graph 10: Representation of ecoelements in relation to available nitrogen
Legend:
1 = kinds of soils poor in nitrogen, 2 = kinds of soils with mild nitrogen supply, 3 = kinds of soils with medium nitrogen supply, 4 = kinds of soils rich in nitrogen, 5 = kinds of soils very rich in nitrogen, * = unclassified soil kinds.

Graph 11: Representation of ecoelements in relation to light
Legend:
SS = deep shade species, S = sciophytes, (S) = semi-sciophytes, O/S = semi-heliophytes, O = heliophytes, * = unclassified species, d = humidestruent species, h = humicolous and humiproducent species.
Annex 6a:

Athyrium filix-femina (L.) Roth, Carex pilulifera L., Dryopteris carthusiana (Will.) H. P. Fuchs, Lycopodium annotinum L., Vaccinium myrtillus L.

Graph 12: Representation of ecoelements in relation to available nitrogen
Legend:
1 = kinds of soils poor in nitrogen, 2 = kinds of soils with mild nitrogen supply, 3 = kinds of soils with medium nitrogen supply, 4 = kinds of soils rich in nitrogen, 5 = kinds of soils very rich in nitrogen, * = unclassified soil kinds.

Annex 6b:

Brachythecium oedipodium (Mitt.) A. Jaeger, Dicranum scoparium Hedw., Isothecium mysurosoides (Hedw.) Brid., Plagiothecium cursifolium Schliep., Neoreozium schreberi (Brid.) Mitt., Pohlia nutans (Hedw.) Lindb., Polytrichum formosum Hedw., Thuidium tamariscifolium (Hedw.) Lindb.

Total cover of the synusia of woody species determines the amount of light penetrating to lower layers of the biocoenosis – synusia of non-woody undergrowth and synusia of terrestrial mosses.

Graph 13: Total cover of the respective synusias
Legend:
Σts = total cover of the synusia of woody species
Σhs = total cover of the synusia of non-woody undergrowth
Σtms = total cover of the synusia of terrestrial mosses
Developmental stages are plotted on axis X.

Thus, the development of these synusias is conditioned (Graph 13) with the determining synusia of woody-species (in our case spruce or beech) decisive for their mutual ratio. The more compact is the spruce canopy, the greater is the development of the synusia of terrestrial mosses with the synusia of non-woody undergrowth withdrawing.

This we can see not only on the basis of total cover but also based on the number of species (Graph 14) and it holds true unless the relative irradiation of lower storeys falls under critical level – see a young spruce forest without tending measures, in which deep shade above the ground surface does not al-
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low even the development of such life forms like mosses.

Indication by means of ecoelements in relation to light of the non-woody undergrowth synusia can be for the respective developmental stages seen in Graphs 15 and 16. There let us mention a similar situation in the mature spruce stand (2) and in the young spruce stand with thinnings (5) – the small variance consisting in the fact that the young tended spruce forest has only patches with light penetrating after thinning while in the mature stand with several thinnings, semi-sciophyte species persist on the opened plots. The stage of even-aged vegetation after clear cutting is characterized by a blend of various ecoelements; the stage of regeneration exhibits dominance of adaptable species winning a greater part of the ground – these are typically grasses. At the stage of clearcut (3) and regeneration (4), the synusia of non-woody undergrowth is entirely governed by humidestruent species; the species of raw
humus have practically become extinct. As soon as a closed spruce canopy develops (5, 6), the ratio of indicators will change completely. In contrast, a mature commercial spruce forest is characterized by the occurrence of both indicators with the representation of raw humus species similar as in the young tended spruce forest (5) and with a markedly lower representation of humus-consuming species.

The indication in relation to available nitrogen points to a small amount of the element in young spruce stand (5, 6). Differences between the stage of natural beech forest (1) and substitute spruce stand (2) are apparent from Graph 17, in which we can also see the absence of ecoelement designated with symbol 4.

The individual developmental stages can be generally characterized as follows:

Graph 16: Representation of humus-consuming indicators and raw humus indicators
Legend:
d – humus-consuming species (humidestruents), increasing the degree of coverage after canopy opening (clearcut heliophytes)
h – species of raw humus or species contributing to raw humus formation (humiproducents)

Graph 17: Representation of ecoelements in relation to available nitrogen
Legend: 1 – species with the occurrence centre on soils with low nitrogen supply; 2 – species with the occurrence centre on soils with mild nitrogen supply; 3 – species with the occurrence centre on soils with medium nitrogen supply; 4 – species with the occurrence centre on soils with high nitrogen supply; 5 – species with the occurrence centre on soils with very high nitrogen supply; * – unclassified species
1. Developmental stage of natural beech forest: markedly dominant are the plants of forest shade but we can also find adaptable species here and to a lesser extent even semi-heliophytes. Penetrating light facilitates the development of humidestruents (ca ¼ of the synusia cover) while the species of raw humus are practically absent. Although the kinds of soils with low and very high nitrogen supply occur in the natural beech forest, predominant are the kinds of soils with mild and medium nitrogen supply.

2. Developmental stage of the non-close-to-nature spruce forest of the 1st generation: as to the shade-loving species, its composition is similar as that of developmental stage (1) but the spruce stand canopy is more compact with light penetrating through patches only, which creates conditions favourable for semi-heliophytes that join the shade-loving species. Present are both the humus-consuming species and the species of raw humus that are much more abundant. In contrast to the stage of natural beech forest, the kinds of soils appear with low nitrogen supply and the kinds of soils with very high nitrogen supply have a greater representation too.

3. Developmental stage of even-aged vegetation after clear cutting of the spruce stand: the species of raw humus are missing in the composition, which is in contrast dominated by humidestruent species. The kinds of soils with very high nitrogen supply occupy about a half of total cover while the degree of coverage of soil kinds with low nitrogen supply is negligible.

4. Developmental stage of the regeneration non-close-to-nature spruce forest of the 2nd generation: the absence of raw humus species and the dominance of humidestruent species are retained; the soil kinds with very high nitrogen supply rapidly decrease their degree of coverage and the cover of soil kinds with low nitrogen supply remains very low.

5. Developmental stage of the growing-up non-close-to-nature spruce forest of the 2nd generation with tending measures: although this developmental stage is similar to that of the mature spruce forest with respect to ecoelements in relation to light, the ecological range of the species representation in relation to nitrogen is different; dominant are soil kinds with low nitrogen supply, the raw humus species have the same representation but the humus-consuming species are absent.

6. Developmental stage of the growing-up non-close-to-nature spruce forest of the 2nd generation without tending measures: the characteristics are very similar to those of Developmental stage (5) with the existence of ground-floor synusias being severely hampered.

**Conclusion**

Moss synusia development is very significant for the spruce stands of all developmental stages together with the non-woody undergrowth synusia suppression. On the other hand the clear cutting is a reason why the moss synusia disappears. The lowest value of the non-woody undergrowth synusia diversity index is recorded for developmental stage of the regeneration non-close-to-nature spruce forest of the 2nd generation. The coverage of the non-woody undergrowth synusia is very low in spruce stands, especially in young canopy-closed stages. The spruce stand of the 1st generation is comparable to natural beech forest concerning the number of species and diversity index of the non-woody undergrowth synusia.

Species with the occurrence centre on soils with low nitrogen supply appear only in the spruce stages – in mature stand less than in young stand where these species are nearly prevailing. They have no occurrence in the other developmental stages. On the contrary humus-consuming species which increasing the degree of coverage after canopy opening do not occur at all in the young spruce developmental stage.

Phytoindication method shows that unavailable nitrogen accumulation proceeds in spruce forest stands of all developmental stages particularly in young ones. Biodiversity is various and varies according to age stand and tree canopy. Relationship and proportion of the non-woody undergrowth synusia and the terrestrial moss synusia are changed in moss synusia favour due to non-close-to-nature spruce stand.

**SOUHRN**

Změny prostředí lesa a biodiverzity v ekosystému smrku s holosečnou obnovou na původním stanovišti buku

Předmětem dlouhodobého ekologického projektu Ústavu ekologie lesa, lesnické a dřevařské fakulty „Rájec“ (Drahanská vrchovina) byla analýza ekologických důsledků intenzivního hospodaření v monokulturách smrku na původním stanovišti buku. Studium bylo zaměřeno zejména na stav prostředí lesa po holosečné obnově a stav smrkové monokultury 2. generace. Práce obsahuje data o akumulaci uhlíku a dusíku v jednotlivých částech porostu a jejich transportní procesy, stejně jako změny ve vodním režimu a biodiverzitě. Rovněž byla zkoumána funkce bylinné vegetace, jejíž hlavní produkce
byla zjištěna ve 4. až 7. roce po těžbě. Sledovaná smrková monokultura se nachází mimo přírodní areál smrku v nadmořské výšce 625 m.

holosečná obnova smrkového lesa, akumulace uhlíku, vodní bilance, biodiversita

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