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Results of monitoring the vegetative phenological phases of European beech (*Fagus sylvatica* L.) in 1991–2006

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Abstract

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There are presented results of a sixteen-year study of vegetative phenological phases in European beech (*Fagus sylvatica L.)* in the area of the Drahanská vrchovina Upland. The results of the monitoring show different starts and durations of phenological phases in individual years. A large range was noted in spring phenological phases. The start and duration of autumnal phenological phases has more regular character. The annual variability in the start and course of phenological phases in beech shows that in addition to genetic factors, also external conditions, particularly meteorological factors, participate in their start and duration. Relationships between the start of phenological phases and changing meteorological parameters are expressed with the sum of effective air temperatures higher than 5 °C. Also growth phases were evaluated in relation to vegetative phenological phases. On the basis of the results obtained it is evident that in recent years, the growth of the sum of effective air temperatures occurs, particularly in the autumnal season with extension of the growing season, which can result in the disturbance of physiological functions causing, in such a way, forest decline. Results of phenological monitoring can contribute to explain effects of climatic changes on the stability of forest stands.

Keywords

phenological phases, beech, air temperature, vegetative period, climate change

Introduction

In our country, forest phenology has a long tradition, but recently, in relation to expected changes in climate, its importance steadily increases. Long-term phenological studies can serve as the bioindicator of climatic changes. Phenology, as the integral part of climatology, encourages attention of climatologists but also botanists, zoologists, ecologists, foresters and farmers, both in our country and abroad.

Phenology is not a descriptive science anylonger, it also studies interrelationships between the development of climate and the start and duration of phenological phases in cultivated and natural species. Although the start and duration of individual phases are conditioned genetically, individual phases can shift also due to weather and disturb further development of the plants. Based on the results of phenological monitoring, climatic regions can be classified according to the average length of growing season corresponding to ecological properties of the tree species (Hofman, 1957; Luknárová, 2000). The start of phenological phases in the first half of the year is primarily controlled by the sum of so-called effective temperatures (exceeding certain temperature limits) preceding the phase. Phenological data within the second half of the year can be affected by all environmental conditions retarding or accelerating the process of maturation and ageing. Temperatures affecting the synthetic activity of plants is of the highest importance again. Other factors include reserves of nutrients, water, and especially effects of diurnal photoperiod (Larcher, 1988). Temperature requirements of plant species for the start of individual phenological phases are best expressed by the sum of effective temperatures (Havlíček, 1986). With respect to potential climatic changes, it is necessary to obtain further detailed information on growth processes in forest tree species, both present currently and those that were autochthonous for the given site. It is also necessary to monitor the stand´s microclimate with its contribution to explaining eco-physiological factors (Bagar et al., 2001). Expected climatic changes and related negative factors can affect the start and course of basic manifestations of life, particularly of forest ecosystems (Kramer, 1996).

Material and methods

Since 1991, phenological monitoring of European beech (*Fagus sylvatica* L.) is carried out in the immediate vicinity of the research site of the Institute of Forest Ecology, the Mendel University of Agriculture and Forestry in Brno. The area is situated in the geographical unit Drahanská vrchovina Upland, on a NE to E oriented slope of a watershed ridge, at an altitude of 625 m, below a short ridgy eluvium. The area has coordinates 16°41'30" E and 49°26'31" N. The climate is classified as slightly warm and slightly humid, with the long-term mean of annual temperatures 6.6 °C, and 683 mm annual precipitation (Collective, 1992).

For the purpose of phenological monitoring, there was used modified methodology developed by the Český hydrometeorologický ústav [Czech Hydrometeorological Institute – CHMI] (1987). Over the 16 years period of the study period, phenological phases were monitored in 10 beech sample trees of the same provenance. During the spring season, phenological monitoring was carried out 3 times a week. In the summer and autumnal season, phenological monitoring was carried out once a week. Basic meteorological parameters were measured directly in the area of the research plot and in the open area at a distance of 250 m. During the recent three years, also diameter increments of beech stems were measured with an automatic dendrometer (DR 22 of EMS Brno Co.) and tape dendrometers. There have been evaluated the following phenological phases: 0 – start of vegetation (buds in winter condition), 1–10% budbreak, 2 – beginning of foliage formation 10%, 3 – beginning of foliage formation 50%, 4 – beginning of foliage formation 100%, 5 – fully developed leaf area, 6 – 10% leaf colouring, 7–100% leaf colouring, 8–10% leaf fall, 9–100% leaf fall. The start of phenological phases was defined as the day when 50%-monitored trees had reached the given phase. For further processing, the ordinal number of this day in calendar was assigned to the individual phenological phases. The day when the mean daily air temperature exceeded 5 °C (Havlíček, 1986) in three subsequent days was determined as the beginning of the growing season. For the whole period of monitoring, there have been calculated cumulative sums of effective temperatures related to the individual phenological phases.

Results and discussion

The beginning and duration of phenological phases in beech differed considerably between the years. Together with genetic factors, air temperature and soil temperature are critical for the start of spring phenological phases (Bednářová and Kučera, 2002). Considerable variability between particular years at the beginning of phenological phases in beech (Fig. 1) becomes evident particularly in case of spring phenological phases, which also corresponds with the results of papers by Schieber (2006). Since a few years ago, the character of weather in the observed areas has been changed. Winter is longer and low temperatures in March are followed by a rapid onset of high temperatures already in the middle of April. This phenomenon leads to later budbreak and onset of leaf development. This phenomenon is evident in Fig. 1. On the other hand, higher temperatures and prolonged vegetative season with higher sums of effective temperatures are observed during autumn months. Fig. 2 characterizes the time course of spring phenological phases for the period 1991–2006. Results of monitoring the autumnal phenological phases are evident in Fig. 3. On the basis of data obtained, we can conclude that the average timing of 10% budbreak for the 16-year period was the 104th day from the beginning of the calendar year, at the sum of effective temperatures being 53.0 °C (Table 1 and Figs. 4 and 5). The earliest budbreak was found on the 84th day from the beginning of the year, at the minimum sum of effective temperatures 10.9 °C; and at the latest was on the 120th day with the sum of effective temperatures 135.6 °C. The beginning of 10% foliage was dated on average the 114th day from the beginning of the year with the mean sum of effective temperatures 80.1 °C. The shortest period from the beginning of year to the start of the phase was 106 days at the sum of temperatures 26.7 °C, and the longest period was 130 days connected with the sum of temperatures 173.0 °C. The beginning of 50% foliage occurred on average on the 118th day (105.8 °C), the shortest period for the beginning of the phase was 110 days (31.9 °C), the longest was 140 days (193.0 °C). The range of beginning of 100% foliage was the widest range from spring phenological phases over the whole period of monitoring (37 days). The phase occurred earliest on the 113th day (at the sum of temperatures 69.1 °C) and at latest on the 150th day (219.8 °C). On average, this phenological phase started on the 123rd day (138.8 °C). The start of this phase also controlled the next phenological phase, full foliage (fully developed leaf area), with an interval between maximum and minimum representing 36 days for the 16-year period. This phenological phase occurred earliest in 2000 when temperatures were the highest ones from within the whole evaluated period: at the beginning of May, already on the 127th day from the beginning of the year (330.8 °C); and the latest was the beginning of this period dated on the 163rd day (161.6 °C) in 1991. The average day of the beginning of this phase was obtained as the 138th day (246.0 °C) in the year.

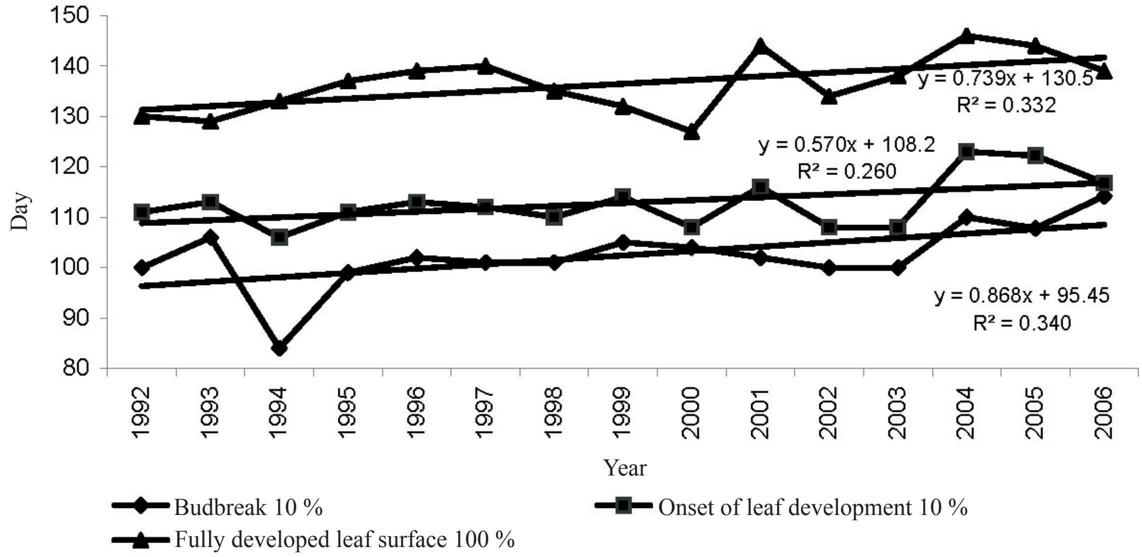

Fig. 1. The trend of onset spring phenological phases in the European beech in 1992–2006

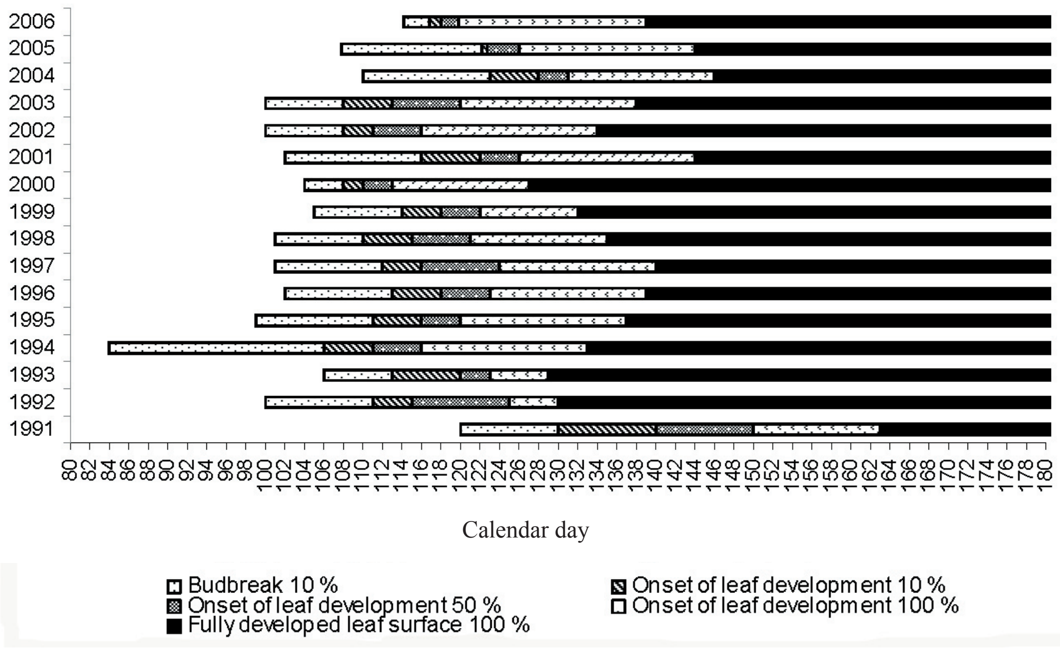

Fig. 2. Onset and duration spring phenological phases in the European beech in the years 1991–2006

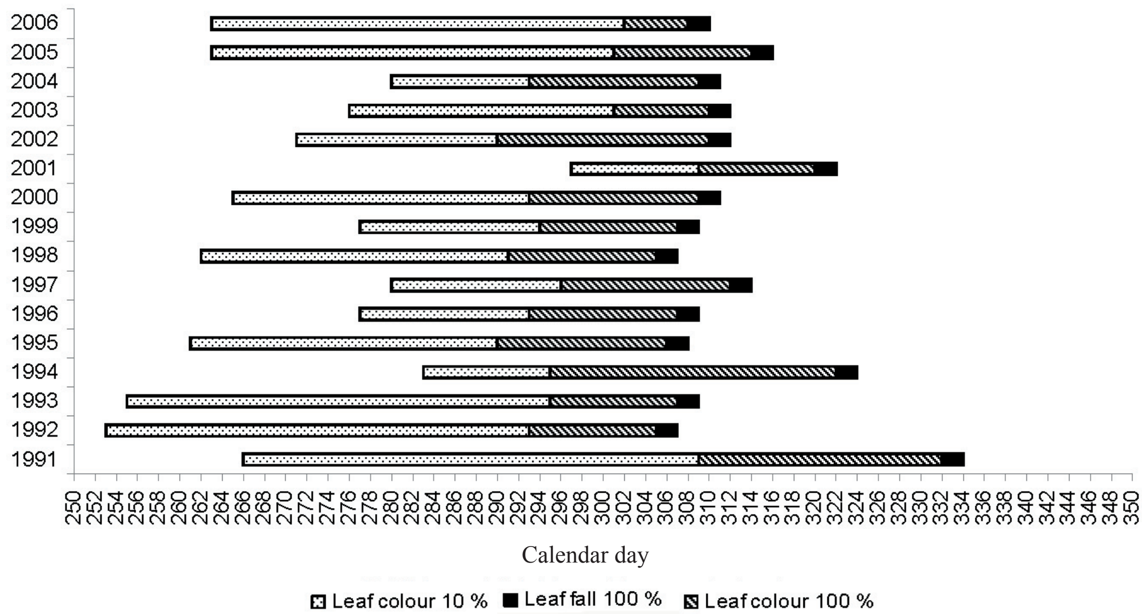

Fig. 3. Onset and duration autumnal phenological phases in the European beech in the years 1991–2006

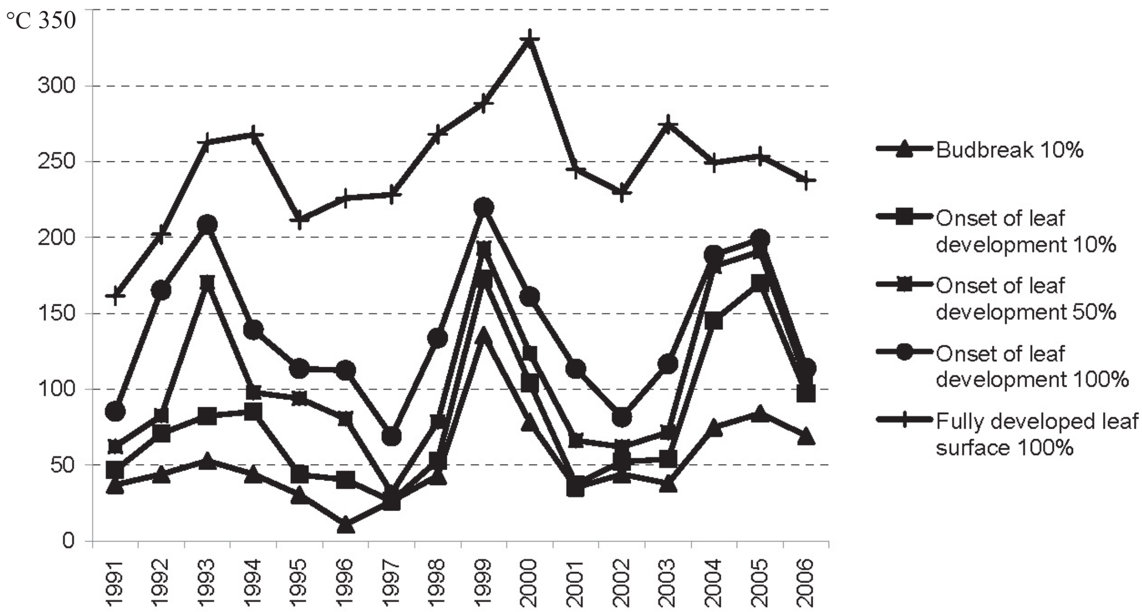

Fig. 4. Sums effective temperatures above 5 °C in the spring phenological phases in the European beech in the year 1991–2006

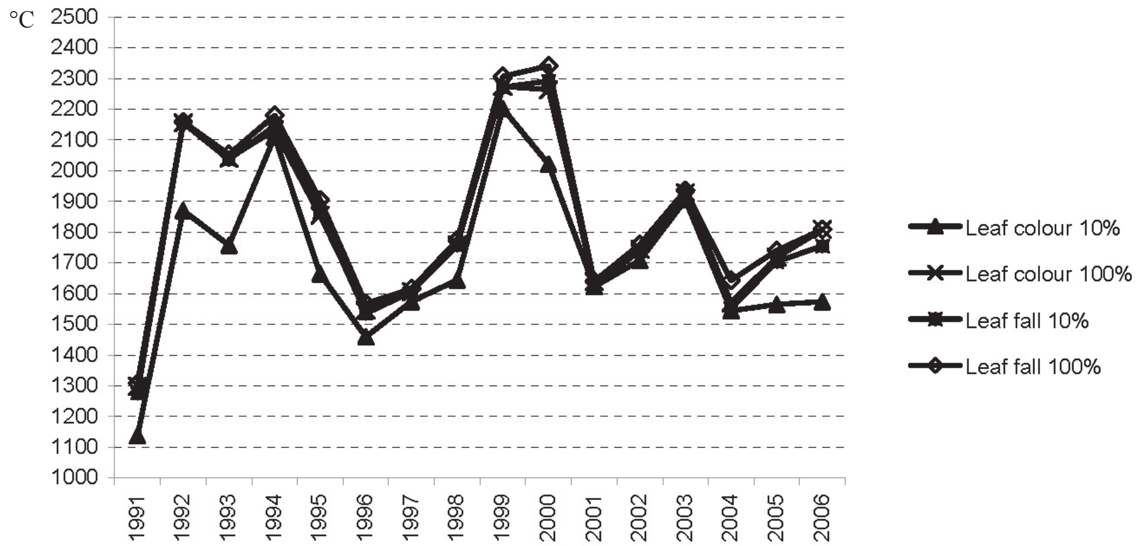

Fig. 5. Sums effective temperatures above 5 °C in the autumnal phenological phases in the European beech in the years 1991–2006

Table 1. Statistical characteristics of the onset of phenological phases and temperatures sums in European beech

Fagus sylvatica L.	Statistical characteristics									
1991–2006	Day of the years					Temperatures sums above 5 °C				
Phenophases	$\overline{x}$	sx	R	min	max	$\overline{x}$	sx	R	min	max
Budbreak 10 %	104	7.8	36	84	120	53.0	29.8	124.7	10.9	135.6
Onset of leaf development 10%	114	6.5	24	106	130	80.1	46.8	146.6	26.4	173.0
Onset of leaf development 50%	118	7.5	30	110	140	105.8	51.1	161.1	31.9	193.0
Onset of leaf development 100%	124	8.3	37	113	150	138.8	46.7	150.6	69.1	219.8
Fully developed leaf area 100%	138	8.6	36	127	163	246.0	38.7	169.2	161.6	330.8
Leaf colouring 10%	271	11.6	44	253	297	1709.8	265.3	1064.7	1137.4	2202.1
Leaf colouring 100%	297	6.1	19	290	309	1833.6	280.4	975.6	1298.4	2274.0
Leaf fall 10%	293	6.2	22	281	303	1827.7	290.3	1015.1	1276.3	2291.4
Leaf fall 100%	311	7.4	27	305	332	1858.4	288.3	1032.4	1308.1	2340.5

$\overline{x}$ – arithmetic mean, sx – standard deviation, R – variance range, min – minimal values, max – maxima

The character of winter termination and the start of spring warming dominantly determine the beginning and course of spring phenological phases. The character of weather in the spring season can be very variable in case when a warm period follows a very cold period and late budbreak occurs (Kurpelová, 1980; Larcher, 1988; Ditmar and Elling, 2006). The presented paper also comes to the same conclusions (see Figs. 6, 7).

Autumnal phenological phases mean the termination of the leaves´ photosynthetic activity. The interval of start and duration of these phases is very wide. The yellowing of leaves is a process taking several days, which is also mentioned by Chalupa (1969). At the locality studied by our team, the earliest 10% leaf yellowing (the start of autumnal yellowing) occurred on the 253rd day (1,137.4 °C) and at the latest on the 297th day (2,200 °C). The range for this phase was 44 days. On average, the start of the phase of the beginning of autumnal leaf yellowing occurred on the 271st day (1,709.8 °C). The interval of the phenological phase of 100% leaf yellowing was the shortest from all evaluated phenological phases, 19 days only. The phase started earliest on the 290th day from the beginning of the year (1,298.4 °C) and latest on the 309th day (the sum of effective temperatures 2.274.0 °C). On average, this phase started on the 297th day (1,833.6 °C). The phenological phase of 10% leaf fall started on average on the 293rd day (1,827.7 °C), also with a small range (22 days).

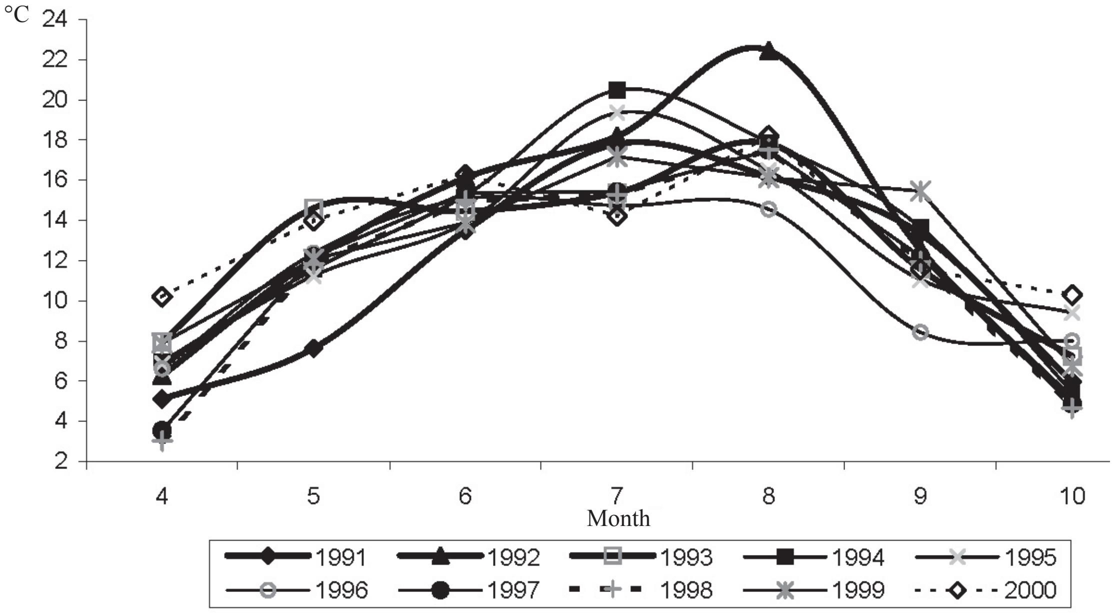

Fig. 6. Mean monthly temperature in the growing period in the years 1991–2000

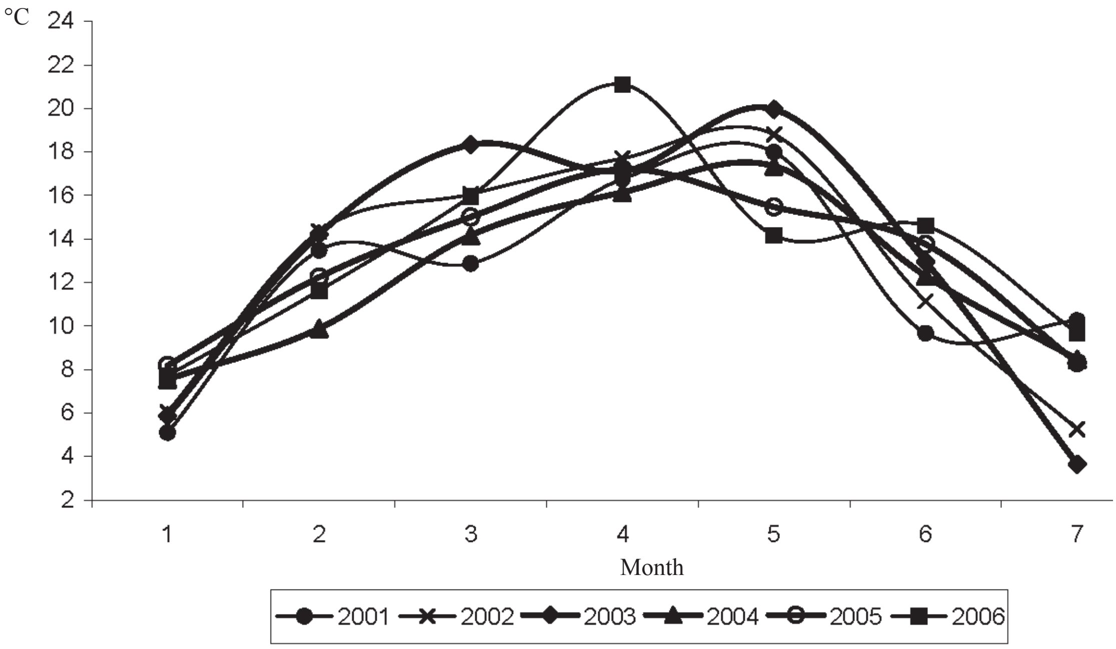

Fig. 7. Mean monthly temperature in the growing period in the years 2001–2006

The earliest beginning of leaf fall was observed on the 281st day (1,276.0 °C) and the latest on the 303rd day (2,291.4 °C). The stage of 100% leaf fall occurred in the studied area on average on the 311th day from the beginning of the year (the mean sum of temperatures was 1,858.4 °C). This finding corresponds also with the data provided by other authors. Chalupa (1969) mentions that in years when minimum temperatures do not fall below the freezing point and soil moisture is sufficient, considerable part of leaves maintain on trees until the first decade of November. In some years, smaller part of leaves remains on trees even until December. In the beech stand evaluated in this paper, the fall of leaves was noted as the latest on the 28th of November, which corresponded to the 332nd day, with the sum of temperatures 2,340.5 °C. The 100% fall of leaves occurred earliest on the 305th day (1,308.1 °C). A number of authors link the start of autumnal phenological phases with the previous rapid decline in temperatures and with a period of abundant precipitation (Haspelová-Horvátovičová, 1981; Priwitzer and Minďáš, 1998). These facts have also been confirmed for the locality monitored by our team.

The first diameter increment in beech stems occurred since the 130th day of the year. This date corresponded to the period between the start of 100% foliage and the phase of totally unfolded leaf area. An increment maximum was noted as late as the 208th day of the calendar year. The second phase of increment creation in beech occurred towards the beginning of August. The process ended after the 260th day, in the period corresponding to the phenological phase of 10% leaf yellowing. The obtained results show that in recent years, an increase in effective air temperatures occurred especially in the autumn season. This phenomenon can result in the extension of the growing season – and entail possible disturbances in physiological functions of the studied species. From the point of view of forestry, the length of a period when forest trees can produce new photosynthates is of considerable importance. However, the marked extension of the growing season due to the warming can induce reduction of the period of rest and winter dormancy. Premature yellowing (termination of assimilation) and possible disturbance of the endogenous dormancy of forest woody plants due to unfavourable climatic conditions could cause the reduction of vitality of trees. Expected climatic changes may cause impairment of growth conditions for forest woody plants and disturb their natural stability.

Conclusions

In the area of the Drahanská vrchovina Upland, spring and autumnal phenological characteristics in European beech (*Fagus sylvatica* L.) were monitored and evaluated from 1991 to 2006. There were considerable differences in start and duration of phenological phases between the individual years. In the phase of budbreak, the timing varied in an interval of 36 days, reflecting the dependence of spring phenological phases on air and soil temperatures. The sum of effective air temperatures preceding this phase can be considered to be crucial for timing the budbreak start. The lowest temperature for the phase start was 10.9 °C, the highest was 135.6 °C. A large variability over the 16-year monitoring was also found for the phase of 100% foliage (fully developed leaf area). Sums of effective temperatures related to this phase ranged from 161.6 to 330.8 °C. The autumnal phenological phase of 10% leaf yellowing had the widest variation range, with the start dated from the 253rd to the 297th day in the year and the interval of the sum of effective temperatures 1,137.4 °C to 2,200 °C. Other autumnal phenological phases appeared to be more balanced. The interval for the 100% fall of leaves was 27 days, with sums of temperatures from 1,308 to 2,341 °C. The start and duration of autumnal phenological phases is influenced not only by air temperatures before the beginning of the phase, but also by precipitation in the locality. The first increment of wood in beech was created in the period when the leaf area of the trees was nearly fully unfolded. The termination of wood increment was noted immediately after the phenological phase of 10% autumnal leaf yellowing. The study of the wood increment by means of the diameter increment measurements in relation to phenological phase can contribute to understanding eco-physiological properties of tree species and possibilities of their adaptability to potential changes in climatic conditions. The sum of effective temperatures at the start of autumnal phenological phases until the end of the growing season shows an increasing tendency in recent years, resulting from the gradual warming and thus prolongation of the growing season. This fact can affect physiological functions of trees. The long-term disturbances of physiological functions and prologation of the growing season after the start of the phenological phase of leaf yellowing can be a cause of forest decline.

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Výsledky sledování vegetativních fenologických fází u buku lesního (*Fagus sylvatica* L.) v letech 1991–2006

Souhrn

Lesnická fenologie má v našich zemích již dlouholetou tradici, ale v poslední době s očekávanými klimatickými změnami klimatu nabývá stále více na významu. Dlouhodobá fenologická sledování mohou posloužit jako bioindikátor klimatických změn. I když je počátek jednotlivých fenologických fází podmíněn genetickými vlastnostmi, vlivem počasí se mohou jednotlivé fenofáze posunout a tak narušit další vývoj rostlin. Z výsledků předkládané práce je patrno, že počátek a trvání jednotlivých fenofází se ve sledovaných letech velmi odlišoval. V práci jsou uváděny výsledky šestnáctiletého pozorování jarních a podzimních fenologických fází v období 1991 až 2006 u buku lesního (*Fagus sylvatica* L.). Výzkum byl realizovaný na výzkumné ploše ÚEL, LDF MZLU v Brně v oblasti Drahanská vrchovina. Sledované vzorníky buku lesního se nachází v nadmořské výšce 625 m. Klimaticky je tato oblast řazena jako mírně teplá a mírně vlhká s dlouhodobým průměrem roční teploty 6,6 °C a 683 mm ročních srážek. Za rozhodující charakteristiku při hodnocení počátku jarních fenologických fází lze považovat sumu efektivních teplot, která těmto fázím předchází. Jako efektivní teploty byly sumační metodou hodnoceny, ve vztahu k jednotlivým fenologickým fázím, teploty s prahovou hodnotou 5 °C. Počátek

a trvání vegetativních fenofází je ovlivněn nejen teplotou vzduchu, půdy ale i srážkovými poměry sledované lokality. Tento vliv se projevuje především u podzimních fenofází. V návaznosti na fenologické fáze byl sledován i nárůst dřevní hmoty pomocí měření tloušťkového přírůstu kmene. Zkoumaný vztah může rovněž přispět k objasnění ekofyziologických vlastností lesních dřevin v možnosti jejich adaptability k eventuálním měnícím se klimatickým podmínkám. K prvnímu přírůstu dřevní hmoty docházelo u buku lesního až ve fázi, kdy byla téměř zcela rozvinutá listová plocha. Ukončení dřevního přírůstu bylo zaznamenáno bezprostředně po podzimní fenofázi počátek žloutnutí listí. Suma efektivních teplot od nástupu podzimních fenofází do konce vegetačního období má v posledních letech zvyšující se charakter, což vyplývá z postupného oteplování ve sledované oblasti a tím prodlužování vegetační doby. Dlouhodobé narušování fyziologických funkcí a prodlužování vegetačního období po nástupu fenofáze – žloutnutí listí – může být příčinou chřadnutí lesů, zvláště pak u nepůvodních dřevin.

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Temporal and spatial variability of the most important phenological phases of birch in the Czech Republic

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Abstract

Hájková, L., Sedláček, V., Nekovář, J. 2007. Temporal and spatial variability of the most important phenological phases of birch in the Czech Republic. *Folia oecol*., 34: 86–96.

Phenology is the study of the times of recurring natural phenomena in plants and animals. The Czech Meteorological Service launched its phenological observations in 1940, with a whole data-providing network, including the archives from the year 1923. Today the Czech Hydrometeorological Institute (CHMI) operates with a network of phenological stations encompassing field crops, fruit trees and wild plants, according to the Methodical instructions number 2, 3, 10. There are also observed several very important allergenic species from which birch (*Betula verrucosa* Ehrh.) has been chosen for the subject of this case study – as one of the most frequent allergenic plants in Europe, including the Czech Republic. Its pollen grains are the most important allergen.

Observing phenological phases (flower buttons visible, beginning and end of flowering) is important for identification of the pollen season. At wild plant stations, there are observed these phenophases in *Betula verrucosa* Ehrh: sprouting, first leaves, full leaves, flower buttons visible, beginning and end of flowering, bud creation, lignification of sprouts, yellowing of leaves, defoliation and ripening of fruits.

Temporal and spatial variability in the chosen phenophases (sprouting, first leaves, full leaves, flower buttons visible, beginning and end of flowering) was explored with using statistical (basic statistical characteristics) and GIS methods for the periods 1992–2006 and 1992–2007 with respect to allergenic importance of the phenophases.

Temporal variability was monitored at the phenological stations Lednice (48°48' N, 16°48' E, 165 m asl) and Pernink (50°22' N, 12°47' E, 860 m asl), the spatial variability at 44 stations with MASL (mean above sea level) ranging from 155 m (Doksany – Polabská nížina) to 1102 m (Filipova Huť – Šumava). The results are presented in form of tables and maps. In this case study we observed the following shifts in phenophases (lowland in comparison with mountain): sprouting (22.6 days), first leaves (19.8 days), full leaves (21.6 days), flower buttons visible (26.5 days), beginning of flowering (27.2 days), end of flowering (25.4 days).

Keywords

pollen, birch, phenophase, flowering, allergy season, GIS, sprouting

Introduction

The broadleved tree *Betula verrucosa* Ehrh. by another name *Betula pendula* Roth. is the most widespread species of the *Betula* (birch) genus in Europe. The main reason of its expansion from southern Europe far northwards, and also to higher altitudes in the Alps Mts, is its modesty and resistance against severe climate. The remarkably white bark has probably a very important role in reflecting back a substantial portion of incident solar radiation. The white pigment from the birch bark contains betulin – triterpenic pentacyclic steroid alcohol having an anti-inflammatory effect. This seems to be the ground of adaptability for survival at places with intensive and long-lasting sunshine. Birch tree is a quick growing species with low demands. It can reach a height of even 25 m and an age of 150 years. This tree is often introduced in restored regions or deforested territories. It's one of the typical pioneer tree species (expressing vigorous growth in youth, early fertility, short life), very active in colonisation of deserted land (abandoned fields, meadows, but above all places with bare soil and dumps). The birch can regenerate very well, especially in mineral soils (sandy and clayey soils) and every locality with sufficient supply of sunshine and at least minimum of moisture. Its seed production capability is high. The low weighing seeds can be wind-transported to long distances (up to 1 km from the parent tree), and therefore the birch invades free areas very easily. Together with pine, for example, birch trees build up the initial phase of forest ecosystems, but from the viewpoint of commercial forestry, there are mostly considered as mere weed. Birch wood is persistent, heating also in humid conditions, but low durable. The discussed species is very important in landscape engineering and it has a high aesthetical value. There have been grown several conspicuous, decorative forms of the species. For its resistance against unfavourable conditions, the birch is often used to create verdures in towns. *Betula verrucosa* is on one hand a decorative and useful species, but on the other, according to the pollen calendar it is a strong allergenic woody plant from March to May. We aimed our examinations especially at phenophases connected with pollen dispersal (flower buttons visible, beginning and end of flowering). The pollen dissemination in the atmosphere over these phenophases, represents a considerable stress for sensitive people. The normal size of pollen grain is 20–30 micrometers (it is about one third of human hair thickness). A number of specific proteins occurring on pollen grain surface can trigger an inadequate (exaggerated) response of the immune system (Fig. 1).

Material and methods

The CHMI operates with a phenological network of wild plants (Fig. 2.), following the concerned methodology (Český hydrometeorologický ústav, 1988). In birch, there are observed the following phenological phases: sprouting, first leaves (10, 50, 100%), full leaves, flower buttons visible, flowering (10, 50, 100%), end of flowering, formation of buds, yellowing of summer leaves, lignification of sprouts, discolouration (yellowing) of autumn leaves (10, 100%), defoliation (10, 100%), ripe fruits. We focus on the phenological phases associated with pollen production (flower buttons visible, flowering) and also on phenophases sprouting, first leaves (10%), full leaves (100%) and defoliation (10, 100%). At present, the birch is observed at 45 phenological stations.

We have subjected to basic statistic processing the data assembled over the period 1992–2007 at two stations situated at different altitudes. Birch is one of the most important allergenic species – that is why we also counted the number of days between the phenophases, especially between the phenophases flower buttons visible – beginning of flowering – end of flowering, which is very important for allergic sensitive person. For providing temporal and spatial pattern of phenophase entrance over the whole Czech Republic, the data have been converted to drawn maps (mean dates of phenophase entrance for period 1992–2006).

The detailed phenophase description represents instruction number 10 in the methodology (Český hydrometeorologický ústav, 1988). Patterns of phenophases are illustrated in the Phenological atlas (2004).

Description of the phenophase sprouting: the covering scales of the bud are partly opened. The tips of new leaves are visible at the bud tops. Only the terminal buds are observed. The date of the entrance of this phenophase is the first day when the number of

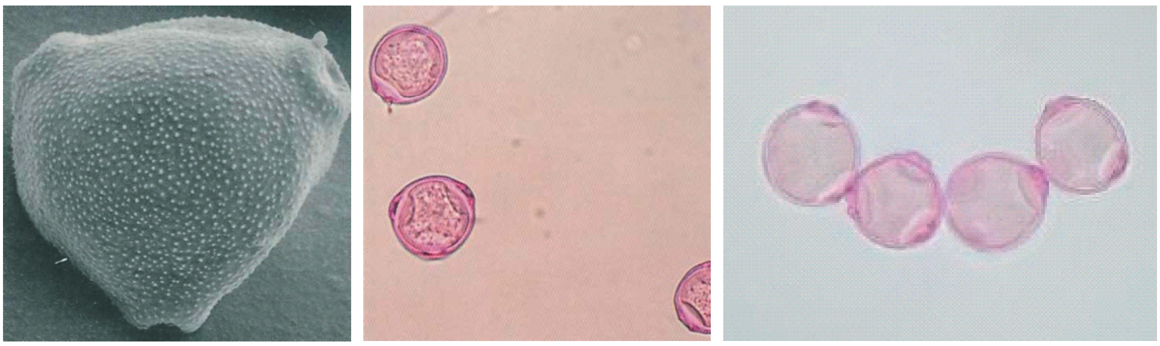

Fig. 1. Birch pollen grains

partly opened terminal buds is higher than 10 percent of the total.

Description of the phenophase first leaves: the whole leaf rib is just visible when examining the adaxial (upper) side of the leaf. The leaf blade is partly developed, but the precedent leaf folding in the bud is still recognisable.

Description of the phenophase full leaves: the leaf-blade is full opened; the whole leaf-stalk is distinctly visible. Form and size of the leaf are characteristic for mature leaf.

Description of the phenophase flower buttons visible: prolongation of catkins (male inflorescence) – the catkin is primarily rigid, with bractes pressed close one to other. Then the catkins most frequently release in the upper third, and bend downwards. In the flexural part, anthers protrude.

Description of the phenophase beginning of flowering: catkins are soft and already opened, anthers are full visible and some of them open and release pollen simultaneously. Entrance of this phenophase is associated with pollen release into the air.

Description of the phenophase end of flowering: the catkins are already empty, turn dark and dry, separate from the tree and fall on the ground.

The maps were processed with using geographic information systems (Application Clidata-GIS). As the input data, there were used the mean dates of phenophase entrance from the period 1992–2006. The maps use a horizontal resolution of 500 meters with reference to altitude (method of local linear regression between the measured or calculated value and the digital relief model). The regression coefficients were calculated for each station, based on the neighbouring stations and in accordance with the least squares method. The coefficients were subsequently interpolated into the space model, and the space distribution of the specific element was calculated by means of map algebra and linear equations.

In total, data from 44 stations with MASL (mean above sea level) ranging from 155 m (Doksany – Polabská nížina) to 1102 m (Filipova Huť – Šumava Mountains) were used for the maps creation. The stations Lednice (165 m) and Pernink (860 m) are described in details in the statistical results. The first station is situated in lowland, the second in mountains, the first in the south and the second in the north of the republic. Both stations have recorded complete time series, without interruption, for the period 1992–2007.

The station Lednice (48°48' N, 16°48' E, 165 m asl.) is situated in southern Moravia, the river basin Dyje, Lednice Castle Park. Birch trees are observed at the locality 1 (this station consists of 2 localities), vegetation unit – dispersed green vegetation, macro-relief – flat ground, geological substrate – clayey drift and combined soil, level of protection – the other categories of non-forest land. Birch locality conditions: micro-relief – flat ground, slope – up to 5 degrees, exposition – the phenological experiment is situated in the nearest parts of locality with given macro-relief, illumination of station – full illumination, humidity conditions – hygromesophyte, initial age – 40–60 years.

Station Pernink (50°22' N, 12°47' E, 860 m asl) is situated in the western part of the Krušné hory Mts, in the river basin Ohře. Birch trees are observed at the locality 1 (station has only one locality), vegetation unit – dispersed green vegetation, macro-relief – flat

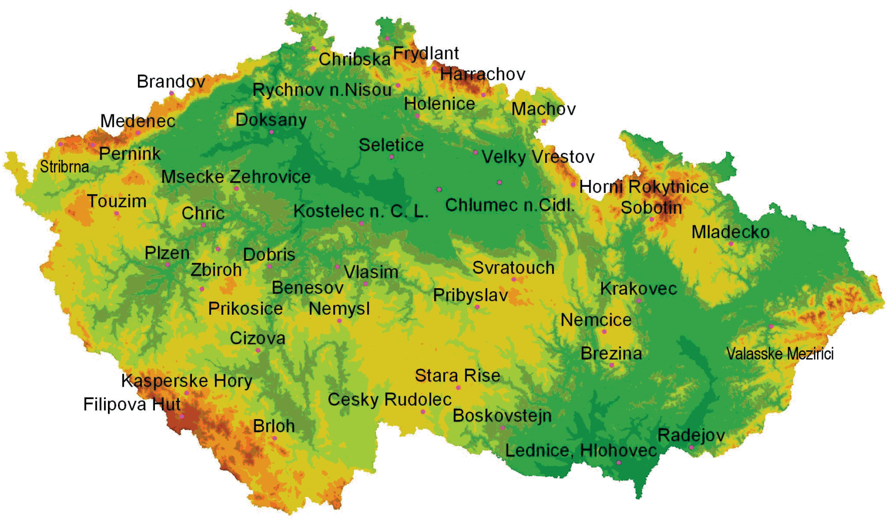

Fig. 2. Phenological network for wild plants

ground, geological substrate – plutonic rock, level of protection – the other categories of non-forest land. Birch locality conditions: micro-relief – flat ground, slope – up to 5 degrees, exposition – experiment is situated in the middle part of the locality with the given macro-relief, illumination of the station – full illumination, humidity conditions – mesophyte, initial age – 10–20 years.

Statistical results (stations Lednice and Pernink, period 1992–2007) in tables (Table 1–10), are given in form of Julian days.

Table 1. Phenophase – Sprouting *(statistical results)*

Station	Average	Standard deviation	Variance	Minimum	Maximum	Variation range	Average – median
Lednice	94.1	3.3	11.2	87 (28. 3.)	101 (11. 4.)	14	0.1
Pernink	116.7	6.4	41.0	102 (12. 4.)	127 (7. 5.)	25	–1.3

Table 2. Phenophase – First leaves *(statistical results)*

Station	Average	Standard deviation	Variance	Minimum	Maximum	Variation range	Average – median
Lednice	100.8	5.8	33.9	90 (31. 3.)	113 (23. 4.)	23	–0.2
Pernink	120.6	6.1	37.7	107 (17. 4.)	132 (12. 5.)	25	–0.4

Table 3. Phenophase – Full leaves *(statistical results)*

Station	Average	Standard deviation	Variance	Minimum	Maximum	Variation range	Average – median
Lednice	121.1	4.6	21.3	112 (22. 4.)	130 (10. 5.)	18	1.1
Pernink	142.7	7.7	60.0	129 (9. 5.)	161 (10. 6.)	32	1.7

Table 4. Phenophase – Flower buttons visible *(statistical results)*

Station	Average	Standard deviation	Variance	Minimum	Maximum	Variation range	Average – median
Lednice	94.2	4.4	19.2	90 (31. 3.)	105 (15. 4.)	15	2.2
Pernink	120.7	8.2	68.1	102 (12. 4.)	138 (18. 5.)	36	–0.3

Table 5. Phenophase – Beginning of flowering *(statistical results)*

Station	Average	Standard deviation	Variance	Minimum	Maximum	Variation range	Average – median
Lednice	97.9	4.3	18.9	93 (3. 4.)	107 (17. 4.)	14	1.9
Pernink	125.1	7.6	58.4	107 (17. 4.)	141 (21. 5.)	34	–0.9

Table 6. Phenophase – End of flowering *(statistical results)*

Station	Average	Standard deviation	Variance	Minimum	Maximum	Variation range	Average – median
Lednice	115.1	5.6	31.3	106 (16. 4.)	126 (6. 5.)	20	0.1
Pernink	140.5	9.0	80.6	122 (2. 5.)	158 (7. 6.)	36	–0.5

Table 7. Average number of days between phenophases *(difference between mean dates)*

Station	Beginning of flowering – flower buttons visible	End of flowering – beginning of flowering	End of flowering – flower buttons visible
Lednice	3.7	17.2	20.9
Pernink	4.4	15.4	19.8

Table 8. Beginning of flowering – flower buttons visible *(statistical results)*

Station	Average	Standard deviation	Variance	Variation range
Lednice	3.7	0.9	0.8	3.0
Pernink	4.4	2.1	4.4	6.0

Table 9. End of flowering – beginning of flowering *(statistical results)*

Station	Average	Standard deviation	Variance	Variation range
Lednice	17.2	4.0	15.7	15.0
Pernink	15.3	4.3	18.5	15.0

Table 10. End of flowering – flower buttons visible *(statistical results)*

Station	Average	Standard deviation	Variance	Variation range
Lednice	20.9	4.2	17.9	16.0
Pernink	19.7	4.9	24.3	18.0

Results

Phenophase: Sprouting

Phenophase entrance: In some localities, the first day of this phenophase is already dated in the period from March 30 to April 4; then, from April 5 to April 18, sprouting starts across the major part of the territory, and the latest entrance of this phenophase is in the mountain areas: from April 17 to April 22, in the highest situated mountain locations even after April 23 (Fig. 3).

Phenophase: First leaves

Phenophase entrance: over 85% of the Czech territory, the phenophase first leaves starts from April 10 to April 21, in the highest situated mountain areas (Krušné hory, Krkonoše, Orlické hory, Jeseníky, Beskydy and Šumava mountains) even after May 4 (Fig. 4).

Phenophase: Full leaves

Phenophase entrance: in lowlands and medium positions, birch is fully foliaged in average from April 29 to May 10, over 85% of the territory of the territory the fully is reached up to May 22. Only extreme mountain positions delay the beginning of this phase to May 23 and later (Fig. 5).

Phenophase: Flower buttons visible

Phenophase entrance: in lowlands and medium positions starts the phenophase flower buttons visible mostly from April 10 to April 20, but in the lowest and most-south situated localities it can be shifted before April 10 (it is the case of the Lednice station, where the mean date is shifted some days earlier, including year 2007). In medium situated areas, flower buttons become visible a few days later – from April 21 to April 25, in mountain positions from April 26 to April 30, and in the highest situated mountain positions starts this phenophase even later than on May 1 (Fig. 6).

Phenophase: Beginning of flowering

Phenophase entrance: for most of territory of the Czech Republic, the start is dated from April 13 to April 24 (at the southernmost located Lednice again few days earlier), at central and partly also at mountain positions from April 25 to May 6, in the highest situated mountain positions later than on May 7 (Fig. 7).

Phenophase: End of flowering

Phenophase entrance: *Betula verrucosa* first ends with blooming from April 25 to May 10 (across 75% of the territory), latest even after May 26 in the highest situated mountain locations (Fig. 8).

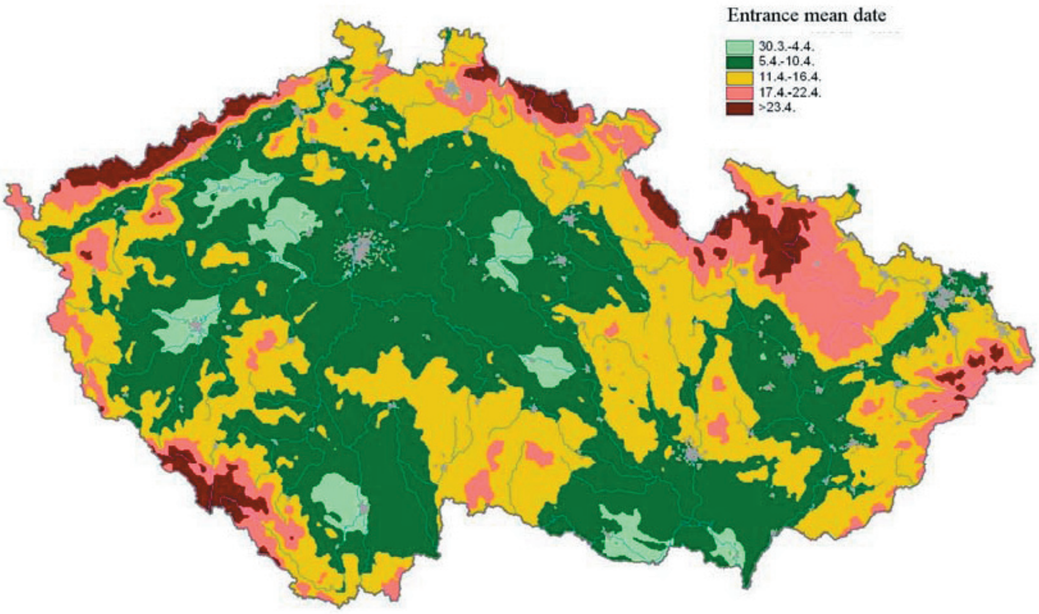

Fig. 3. Phenophase – sprouting, the mean dates for period 1992–2006

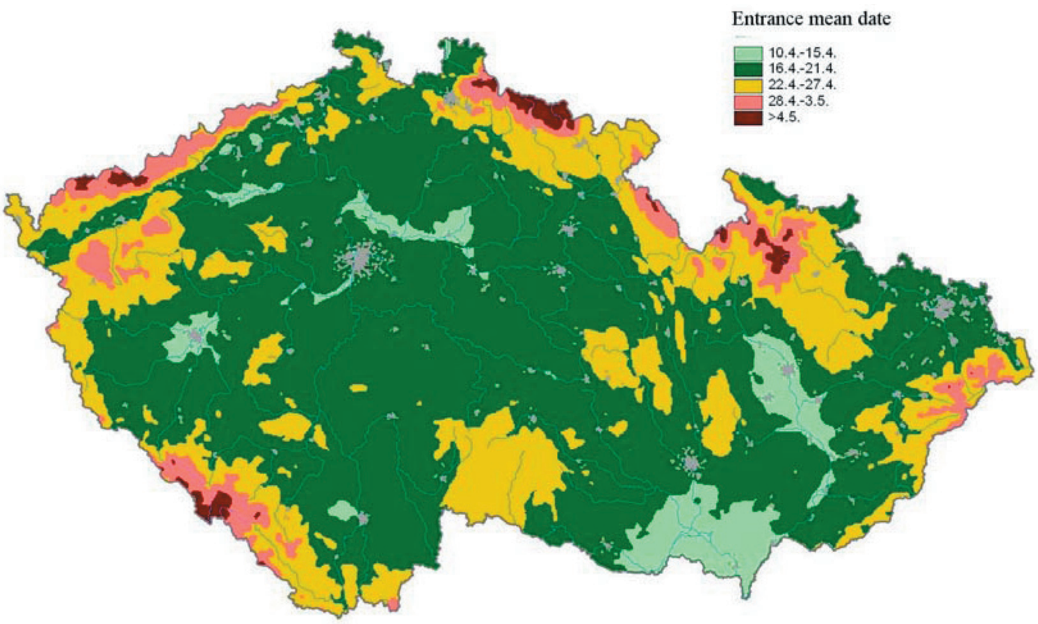

Fig. 4. Phenophase – first leaves (10%), the mean dates for period 1992–2006

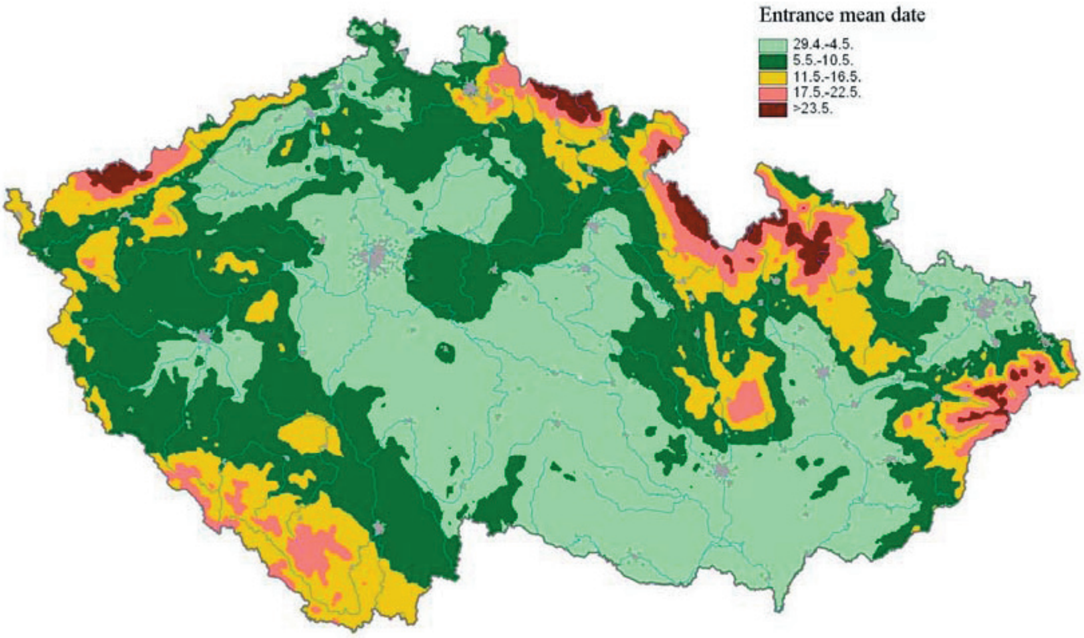

Fig. 5. Phenophase – full leaves, the mean dates for period 1992–2006

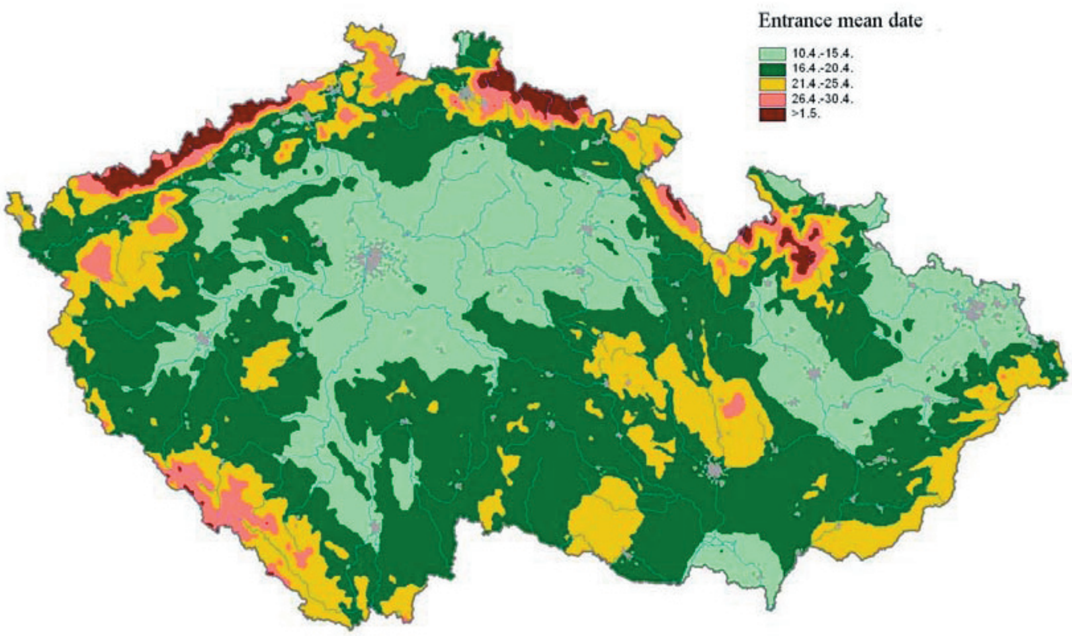

Fig. 6. Phenophase – flower buttons visible, the mean dates for period 1992–2006

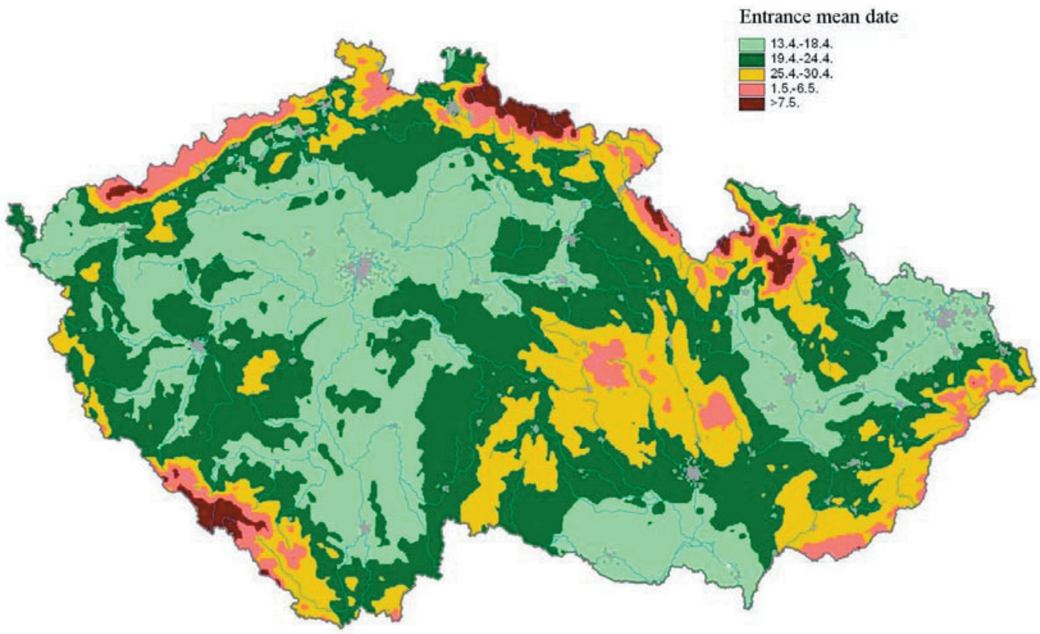

Fig. 7. Phenophase – beginning of flowering (10%), the mean dates for period 1992–2006

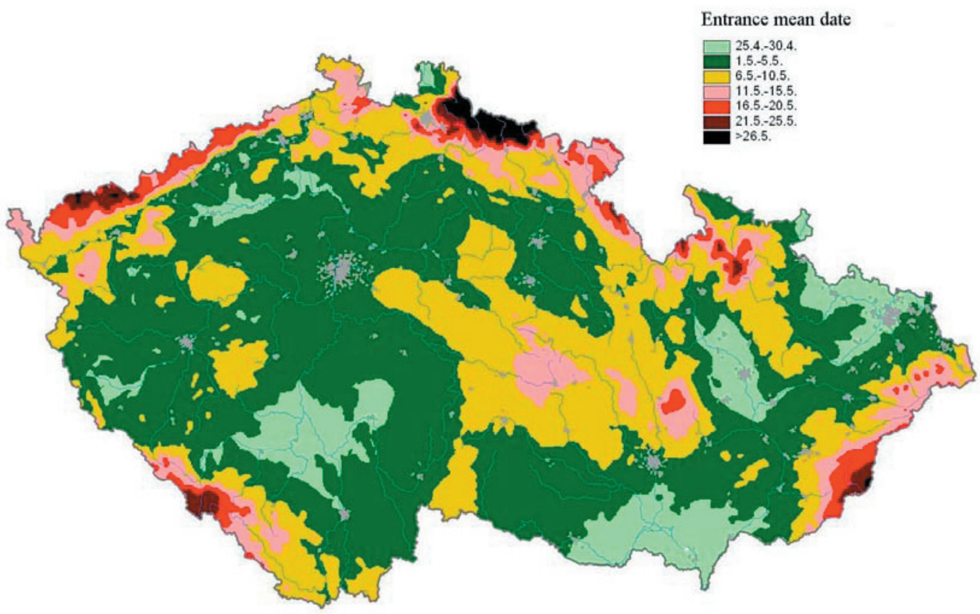

Fig. 8. Phenophase – end of flowering, the mean dates for period 1992–2006

Discussion

The two stations (lowland and mountain) were chosen for a detailed statistical processing of data on phenophases´ entrance. The station Lednice is situated in a lowland of the southern Moravia, the station Pernink is in the north-western part of the Czech Republic. The beginning and duration of phenological phases are influenced by many factors (air temperature, soil temperature, water conditions, position of locality, sunshine duration) together with genetic equipment of the plants. The dependence on altitude and also on aspect is documented in the results. The dating of phenophase entrance is in average earlier in lowlands: the sprouting about 22.6 days earlier, the first leaves about 19.8 days earlier, the full leaves about 21.6 days earlier, the flower buttons visible about 26.5 days earlier, the beginning of flowering about 27.2 days earlier and the end of flowering about 25.4 days earlier. Also for the period 1982–1999, it appears that spring came earlier and the growing season was longer in lowland regions of Fennoscandia, and along most part of the Norway coast (Hogda et al., 2001). Values of variance and also variation range are wider for higher altitudes. The highest variance was determined for the phenophase flower buttons visible (probably for the short time interval of distinguish this phenophase) and the end of flowering. The earliest and the latest phenophase entrance show a wide variance in years 1992–2007. The variation range was found expressively higher (nearly two times) at the mountain station Pernink than in lowland (the flower buttons visible 36 days, the beginning of flowering 34 days and the end of flowering 36 days). Deviation average – median, expressing whether lower or higher values are more important than the median, is in the case of lowland station mostly positive – so it means, that later phenophase entrance is more important. For the mountain station, the contrary was found. In case of phenophases connected with pollen season (the flower buttons visible, the beginning of flowering, the end of flowering), all average – median deviations are positive, by contrast to the mountain station when they were found negative. The pollen season is in average longer in lowland than in mountains. The average number of days between flower buttons visible and beginning of flowering is in its turn higher at the mountain station.

Conclusions

Phenological observations allow us to recognise the life cycle of plants in dependence on outside conditions, and they give us valuable information about duration of vegetation season in different climatic regions. This case study manifests the dependence of seasonal events in the examined birch species on altitude and aspect of the locality. The temporal variability of date of the first occurrence of phenophase in its annual cycle is considerable, and it depends on climatic conditions, locality and weather conditions in the current year. Duration of snow cover and variability of weather have influence on timing the phenophase entrance in mountain areas. We have compared the values of variance of average monthly air temperatures (December, January, February) between meteorological stations situated in comparable conditions as phenological stations (phenological station Pernink, 860 m asl – meteorological station Měděnec, 828 m asl; phenological station Lednice, 165 m asl – meteorological station Lednice, 176 m asl). For the studied period 1992–2007, there was found bigger variance for values obtained at the mountain station, what indirectly confirms the results of statistical processing of phenophases-related observation data. It is recommended to address the next case study to phenophase entrance in connection with air temperature, precipitation, sunshine duration and synoptic situation with the aim to enable forecasting the following phenophase entrance (especially flower buttons visible and beginning of flowering) in the current year. For example, Karlsson et al. (2003) found that a temperature increase of 1 °C causes bud burst in mountain birch to occur 3–8 days earlier, with the strongest influence in the elevated northern Sweden. The research will be extended with a detailed analysis performed at other phenological stations localised at different altitudes and having different topography and for other allergenic plants observed within the CHMI phenological network. We will compare our results with other European phenological networks – *Betula verrucosa*, especially the phenophases connected first leaves and flowering, is also observed in other countries – for example Slovakia, Finland, Germany, Norway, Poland (Nekovář, 1993). The results presented in this case study provide a basic outline of the temporal patterns of phenophase entrance in *Betula verrucosa* in the Czech Republic over the recent years, and also statistic comparison of localities situated at considerably different altitudes.

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Časová a prostorová variabilita nejvýznamnějších fenologických fáz břízy v Česku

Souhrn

V uvedené práci byly zpracovávány nástupy vybraných fenofází (rašení, první listy (10 %), plné olistění, butonizace, počátek a konec kvetení) u břízy bradavičnaté. Výsledky jsou uvedeny jak ve formě statistických tabulek se statistickými charakteristikami průměr, směrodatná odchylka, rozptyl, nejranější a nejpozdější datum nástupu, variační rozpětí (u dvou vybraných stanic – nížinné a horské za období 1992–2007), tak ve formě map za využití

geografických informačních systémů (aplikace Clidata – GIS s horizontálním rozlišením 500 m a se závislostí na nadmořské výšce) z celkem 44 fenologických stanic. Jako vstupní data byla použita průměrná data nástupů zvolených fenofází za období 1992–2006.

Vzhledem k tomu, že bříza bradavičnatá je velmi významný alergen, zaměřili jsme se v práci rovněž na statistické zhodnocení počtu dní mezi nástupy alergologicky významných fenofází, výsledky jsou rovněž uvedeny v tabulkové podobě.

Ve výsledcích srovnání nástupu fenofází v odlišných podmínkách byla prokázána závislost nástupu fenofází na nadmořské výšce i na poloze, vzhledem k orientaci ke světovým stranám.

Časová variabilita nástupu fenofází je velmi velká a závisí na klimatických podmínkách dané lokality a na průběhu počasí v daném roce. V horských polohách má na časový nástup fenofází vliv délka trvání sněhové pokrývky a variabilita počasí. V budoucnosti je vhodné věnovat se dalšímu studiu nástupu fenofází ve spojení s teplotou vzduchu, sumou srážek, slunečním svitem a synoptickými situacemi pro možnost prognózy nástupu fenofáze (zejména butonizace a počátku kvetení) v aktuálním roce. Výzkum rozšířit o další detailní rozbor fenologických stanic v jiných polohách a nadmořských výškách a další alergologicky významné rostlinné druhy sledované ve fenologické síti stanic ČHMÚ. Uvedené výsledky poskytují čtenáři základní představu o vývoji nástupu vybraných fenofází u břízy bradavičnaté v Česku v posledních letech a statistické porovnání lokalit s výrazně odlišnou nadmořskou výškou.

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Influence of snow damage on aerodynamic characteristics of a spruce stand

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Abstract

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Influence of snow damage on aerodynamic characteristics of a spruce stand was investigated during the growing seasons 2005 and 2006 before and after the winter 2005/2006 that caused damage to the forest. With this aim, the wind speed profiles measured in and above the investigated forest stand were analyzed. This forest is situated in the Experimental Ecological Study Site Bílý Kříž in the Moravian-Silesian Beskydy Mountains, the Czech Republic. The experimental site consists of two plots with Norway spruce monocultures with different stand densities. In the growing season 2005, the mean tree height was 11.9 m on the "dense" plot (Fd; a density of 2,044 trees/ha) and 11.0 m on the "sparse" one (Fs; a density of 1,652 trees/ha). The measurements of wind speed profile were realized at six levels on 26-m-high towers situated near the centre of each plot. The winter 2005/2006 was characterized by continuous snow cover (from November 2005 to April 2006) with a high water value in the investigated locality. The damage to the forest caused by this snow blanket was noticeable, mainly in Fd. The stand density decreased by about 29% on Fd and by about 14% on Fs plot. It witnesses entirely new airflow conditions within and over this forest stand and connected changes in its aerodynamic characteristics.

Key words

snow damage, spruce stand, wind speed, roughness length, zero plane displacement

Introduction

Forest damage caused by wind, snow, and frost is a serious economical problem in European forestry. The damaged forest, in its turn, influences the airflow and meteorological characteristics of the atmospheric layer affected by this stand. It has been recognised that a freshly thinned forest is more likely prone to damage than an intact dense forest stand. Low stand density seems to increase the probability of damage, especially from windstorms. Snow can cause damage to a forest also deep inside the stand (Pellikka and Järvenpää, 2003). The severity of snow damage depends on the tree characteristics. Stem taper and crown characteristics are the most important factors controlling the tree mechanical stability (Nykänen et al., 1997).

The majority of forest ecosystems in the Czech Republic consist of Norway spruce stands with a share exceeding 80%. The climate of Norway spruce monocultures is subject of an intensive research carried out at the Experimental Ecological Study Site (EESS) of the Institute of Systems Biology and Ecology (ISBE), AS CR, Bílý Kříž in the Moravian-Silesian Beskydy Mts (Kratochvílová et al., 1989). The research comprises:

measurements of solar radiation, measurements of soil temperature, profile measurements of the wind speed, air temperature and humidity inside and above the forest stand. The microclimate of the spruce stand at the site has been studied since the growing season 1997 (Rožnovský, 1998; Matejka et al., 2000). The winter 2005/2006 was characterized by a long period of continuous snow blanket with high water value, and it caused damage to the forest. The consequence was the changes in the microclimatic characteristics.

The aim of this contribution is to inform about our research on influence of snow damage on the airflow above and the aerodynamic characteristics of the examined spruce stand, particularly on the roughness length and zero plane displacement. These characteristics are very important in studying interactions between the vegetation cover and surface layer of the atmosphere. Therefore, growing seasons (May–October) 2005 (ie before damage) and 2006 (ie after damage) were compared from this point of view.

Experimental site and data

The experimental data for this study were provided by measurements within and over the spruce stand in the EESS. This experimental site is situated on a mild slope with SW orientation in the locality Bílý Kříž (49°30' 17" N, 18°32'28" E, 908 m asl; Janouš and Schulzová, 1995). The investigated forest consists of a Norway spruce monoculture (*Picea abies* [L.] Karst) established in 1981 with four-year-old seedlings.

To obtain two plots with different stand densities for further continual research, there were performed two thinning interventions in autumn 1996 and 1997. Each plot has an area of 0.25 ha. Later, in early May 2001, an additional thinning was carried out on Fs plot. In the growing season 2005, the density on Fd plot was 2,044 trees/ha and the mean tree height (h) was 11.9 m. Fs plot had the stand density 1,652 trees/ha and h = 11.0 m. Automatic measurements of wind speed profile within and above the plots started in 1997 (Fd) and 1998 (Fs).

The locality Bílý Kříž is classified as a cool and humid climatic region with abundant precipitation. The mean annual air temperature is 5–6 °C, the mean annual precipitation total is 1,000–1,200 mm, and the mean air humidity is 80–85%. The mean number of days with continuous snow blanket is 120–140 (Tolasz et al., 2007).

In general, north and west airflow predominates in the Beskydy Mountains, the south and south-southwest wind direction, however, is prevailing above the investigated spruce forest stand. It is a result of the highly diversified broken terrain (Havránková et al., 2001).

The wind speed and direction were measured continuously by an InSituFlux system (Sweden). The system enables us to measure the flux of energy and substances between the vegetative surfaces and boundary layer of the atmosphere, providing with the eddy-covariance method. At the same time, microclimatic profile measurements of the wind speed, air temperature and humidity inside and above the investigated forest stand were realized at six levels on a 26 m high tower in both experimental plots. The wind speed values were continually measured with an automatic measuring equipment with data logger (DL3000, Delta-T, U.K.) and anemometers (AN1, Delta-T, U.K.) at 10-minute intervals and recorded at 30-minute intervals.

Aerodynamic characteristics of vegetation cover can be described by the following parameters: roughness length z_0 and zero plane displacement d. The d values were determined by processing the results of measurements of the vertical wind speed profile at the neutral thermal stratification of the atmosphere (Brutsaert, 1982). The values of z_0 can be obtained from the analysis of the vertical wind speed profiles measurements above an active vegetation surface under different conditions of thermal stratification of the atmosphere (Monin and Obukhov, 1954; Matejka et al., 2000). According to the Monin-Obukhov similarity theory, each vertical wind speed profile $\overline{u}_k(z_i$ can be approximated by the relation:

$$u_k(z_i) = A_k (\gamma + \log z_i) + C_k z_i \qquad (1)$$

where k is the profile number. The values of A_k, γ, and C_k parameter are calculated using the least squares method for all profiles. Then the values of z_0 are obtained from the following relationship (Monin and Obukhov, 1954):

$$z_0 = 10^{-\gamma} \qquad (2)$$

Selected set of results was used for analysis of the vertical wind speed profiles. The analysed mean hourly values of measured wind speed complied with the condition: $u(h - 1) > 1.0$ m s^{-1}. This selection guaranteed that the wind speed profiles were measured in conditions of a turbulence development.

Results and discussion

The winter 2005/2006 in the investigated locality was characterized by a continuous snow blanket with high water value maintaining from the midst of November 2005 to the end of April 2006.

The mean monthly values of total snow blanket height and the mean monthly values of its water value are listed in Table 1 (data provided by the Czech Hydrometeorological Institute).

Forest damage from snow was noticeable, mainly on Fd plot. Many trees were seriously damaged and then removed. Towards the end of the growing season 2005 was the stand density 2,044 trees/ha on Fd and 1,652 trees/ha on Fs. In 2006, the stand density decreased to 1,444 trees/ha on Fd (ie about 29%) and 1,428 trees/ha on Fs (ie about 14%). Canopy openness, quantified through DIFN value ("by-product" of LAI-2000 Plant Canopy Analyser; Li-Cor, Nebraska, USA, during the leaf area index estimation as the visible proportion of sky), increased after the winter 2005/2006 by about 3.7% (ie from 1.1% to 4.8%) on Fd and by about 5.3% (ie from 2.2 to 7.5%) on Fs. Furthermore, some other trees had breaks in upper halves of their crowns. Tree height was measured on 514 exemplars on Fd and on 414 exemplars on Fs plot. On Fd plot, the mean tree height (h) in 2006 was 13.1 m and h value of broken trees was 5.5 m. The mean tree height including broken trees was h^* = 10.8 m. On Fs plot h = 11.9 m, h value of broken trees 4.0 m, and h^* = 10.9 m. This documents occurring of new conditions for airflow inside and above this forest stand, and also suggests about changes in its aerodynamic characteristics.

Table 1. Mean monthly values of total height of snow blanket (h_s) and of snow water value (SWV) in the locality Bílý Kříž during the winter 2005/2006

Year	Month	h_s [cm]	SWV [mm]
2005	November	31	75
	December	81	163
2006	January	140	313
	February	154	424
	March	140	468
	April	54	300

The analysed set, complying with the above mentioned conditions, consisted of 474 wind speed profiles obtained in the growing season (May–October) 2005 and 856 profiles obtained in 2006 on Fd plot. From the same growing seasons we analysed 1,899 profiles (2005) and 1,747 (2006) from plot Fs. We can see that there were differences in selection of profiles to be analysed between Fd and Fs plot in the same growing season. More wind speed profiles complying with the condition were analysed from Fs than from Fd plot also in all the investigated growing seasons (1997–2006). Consequently, the airflow above Fd plot is weaker than elsewhere in the surroundings. It can be explained by the influence of the local broken terrain on the airflow on these experimental plots (Havránková et al., 2001).

On Fd the wind speed was measured at six levels: 9, 11, 12, 14, 18, and 26 m above the ground during the growing season 2005 when the mean tree height h = 11.9 m and at 10, 12, 13, 14, 18, and 26 m during the season 2006 with h = 13.1 m. On Fs plot we measured at 8, 10, 11, 13, 18, and 26 m in 2005, h = 11.0 m and at 9, 10, 12, 13, 18, and 26 m in 2006 with mean tree height h = 11.9 m. These profiles were separated into the following range intervals:

$$\begin{array}{rl} \text{I} & 1.0 < u(z) < 2.0\ \text{m s}^{-1} \\ \text{II} & 2.0 \le u(z) < 3.0\ \text{m s}^{-1} \\ \text{III} & 3.0 \le u(z) < 4.0\ \text{m s}^{-1} \\ \text{IV} & 4.0 \le u(z) < 5.0\ \text{m s}^{-1} \\ \text{V} & 5.0 \le u(z) < 6.0\ \text{m s}^{-1} \\ \text{VI} & 6.0 \le u(z) < 7.0\ \text{m s}^{-1} \\ \text{VII} & 7.0 \le u(z) < 8.0\ \text{m s}^{-1} \\ \text{VIII} & 8.0 \le u(z) < 9.0\ \text{m s}^{-1} \end{array} \quad (3)$$

where $u(z)$ is the wind speed value measured at the level $z \approx h$, it means z = 12.0 m (2005) and 13.0 m (2006) on Fd plot, and 11.0 m (2005) and 12.0 m (2006) on Fs. Percent shares of the analysed wind speed profiles in these ranges are in Table 2.

Table 2. Percent representation of analysed wind speed profiles in ranges I–VIII according to Eq (3) measured on both plots in the locality Bílý Kříž during the growing seasons 2005 and 2006

Range	Fd		Fs	
	2005 [%]	2006 [%]	2005 [%]	2006 [%]
I	7.4	3.9	44.6	39.8
II	44.3	18.7	29.4	32.7
III	39.9	34.0	18.0	16.6
IV	8.4	24.2	7.4	8.4
V	–	13.4	0.7	2.3
VI	–	4.6	–	0.2
VII	–	1.1	–	–
VIII	–	0.2	–	–

From this analysis (Table 2) it follows that the airflow in the growing season 2006 was stronger on both plots, mainly on Fd, with more than 50% of the analysed profiles classified to intervals III and IV. On Fs plot, more than 70% of the analysed profiles were within lower wind speed intervals (I and II). It was caused by different conditions for airflow due to damage to forest on these plots.

The mean vertical wind speed profiles obtained according to Eqs (3) are graphically presented in Figs 1–2. Stronger airflow is also evident from the mean wind speed profile courses on both plots during the growing season 2006.

There were analysed the values of zero plane displacement (d) and dynamic roughness length (z_0). These characteristics of vegetation aerodynamic properties play an important role in the interaction between vegetation cover and lower layers of the atmosphere. The zero plane displacement increased with increasing stand density and increasing height of the centre of gravity of the vegetation. It can be expected that the penetration of airflow into the forest can be reduced as a result of gain of the biomass at this developmental stage of the forest (Jeager, 1984). Simultaneously, the ratio *d*/*h* varied during the investigated growing seasons in dependence on spruce stand characteristics (Table 3). Since 1997, the specific architecture of this spruce forest, being thin in the upper part and dense near the ground, started to appear more expressive. The values of *d* as well as of *d*/*h* ratio were quite high on both plots during the investigated growing seasons, except of 2006 (Table 3).

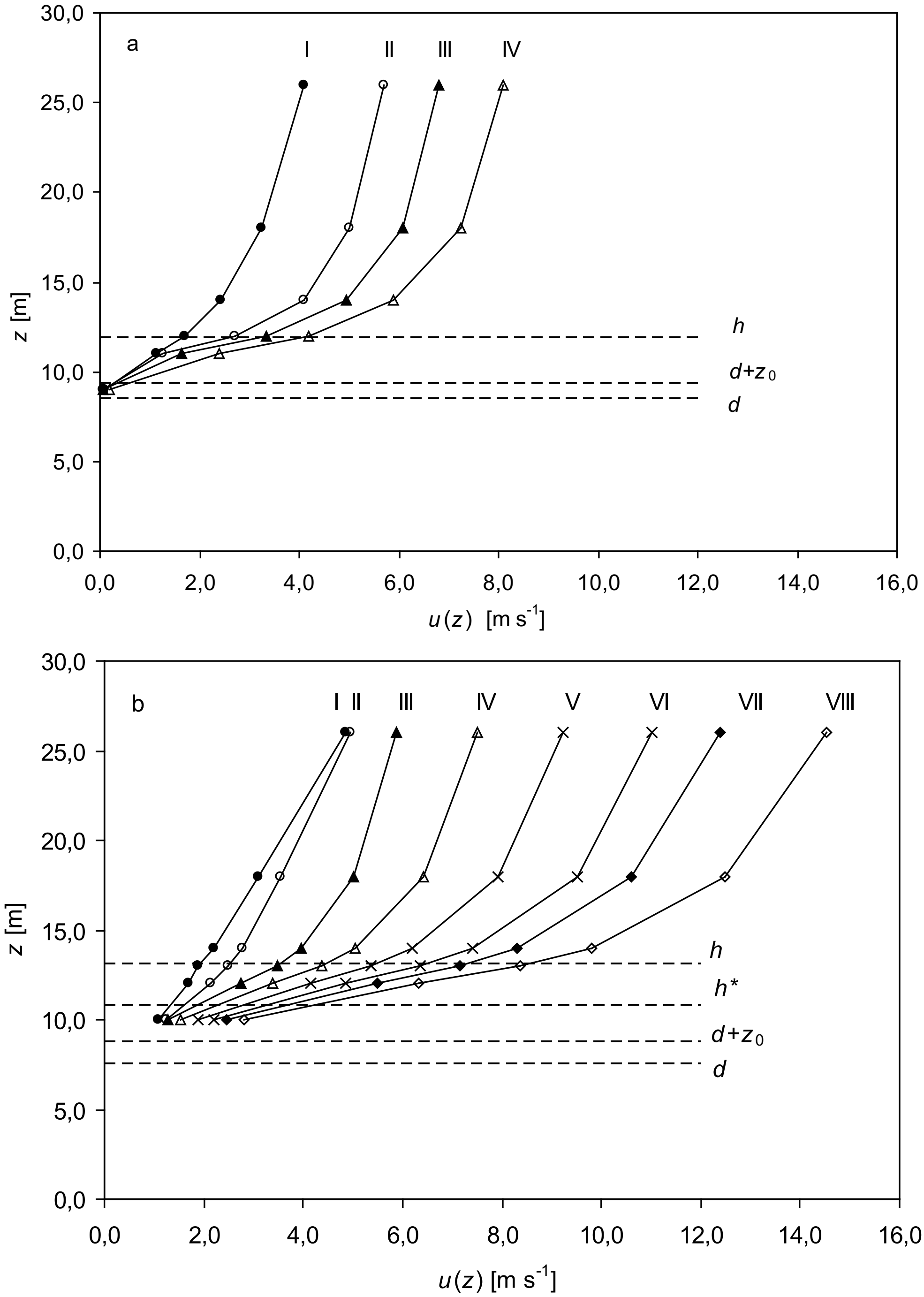

Fig. 1. Mean vertical wind speed profiles in and above spruce stand in Fd plot during growing season 2005 (a) and 2006 (b) *h* – mean tree height, *h** – mean tree height including broken trees, *d* – zero plane displacenemt, z_0 – dynamic roughness length, ranges I–VIII by Eqs (3)

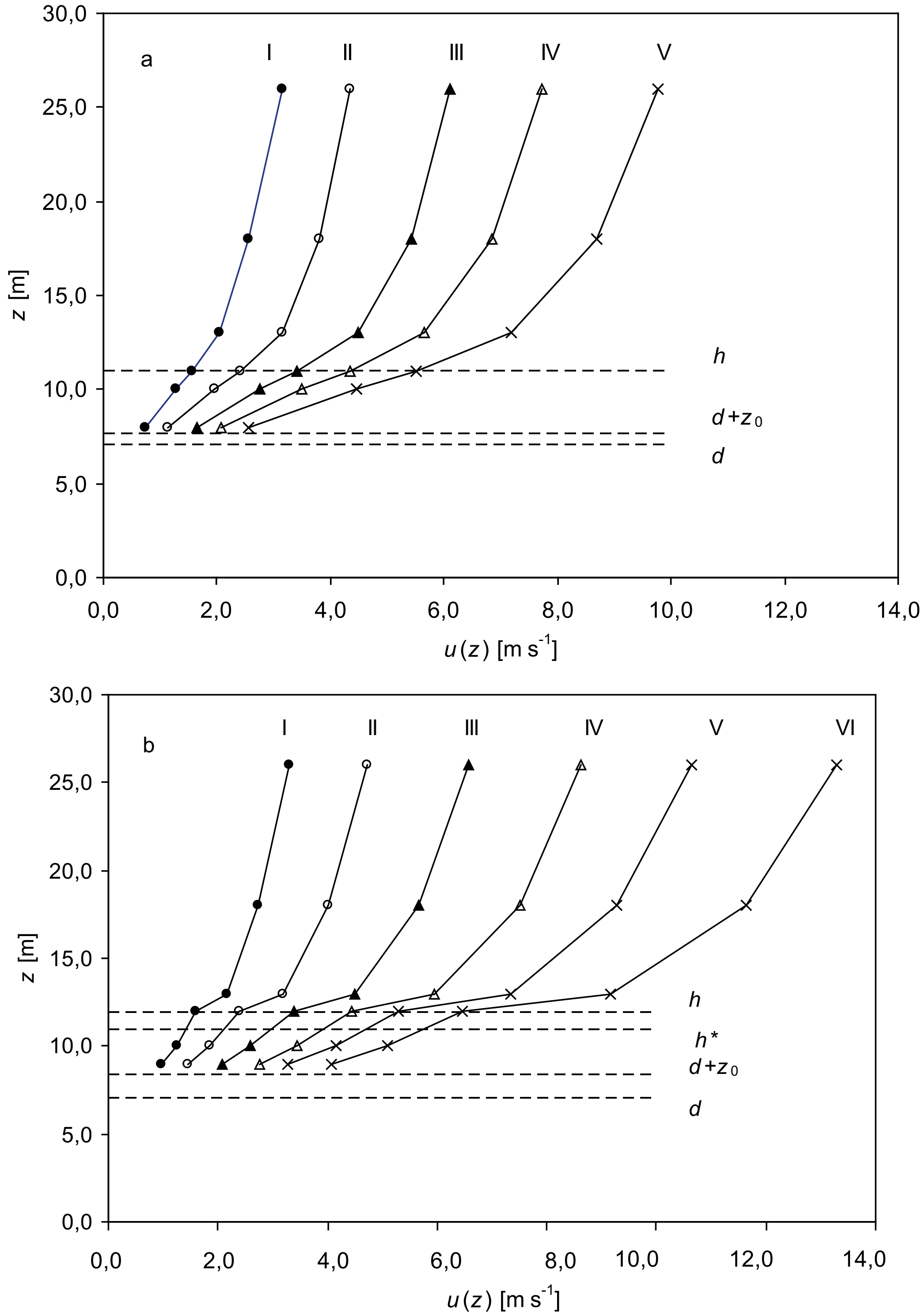

Fig. 2. Mean vertical wind speed profiles in and above spruce stand in Fs plot during growing season 2005 (a) and 2006 (b)
The symbols *h*, *h**, *d*, z_0 and ranges I–VI as in Fig. 1

Table 3. Values of ratio between zero plane displacement and mean tree height (d/h) averaged over nine growing seasons on the two experimental plots in the locality Bílý Kříž

	1998	1999	2000	2001	2002	2003	2004	2005	2006
Fd	0.75	0.76	0.76	0.76	0.74	0.76	0.77	0.72	0.59
Fs	0.69	0.70	0.76	0.60	0.70	0.70	0.68	0.64	0.62

The significant decrease in the d value on Fs during the growing season 2001 was obviously caused by the thinning performed on this plot in May 2001. The thinning has led to reduction of stand density from 2,400 trees/ha to 1,880 trees/ha. Different situation was in the growing season 2006. The strong forest damage from snow to Fd plot caused a significant fall of d values (d = 8.5 m in 2005 and d = 7.5 m in 2006). The forest damage on Fs plot was not so high and the d value was maintained stable (7.0 m) during the both investigated seasons.

In the case of a flexible vegetation cover, d and z_0 values vary with the wind speed (Hayashi, 1983; Hurtalová et al., 2004, 2006). The mean annual z_0 value of the damaged forest increased by about 0.9 m in 2005 and by about 1.3 m in 2006. Numerous authors cited by Nykänen et al. (1997) have proved that trees are especially susceptible to damage from 5 to 10 years after thinning. Snow accumulation is the highest during light winds (Pellikka and Järvenpää, 2003).

Conclusions

Airflow inside and above forest stands is dependent on aerodynamic properties of these stands. It means that a damaged forest with broken trees creates new conditions for the airflow. This was confirmed by the analysis of influence of snow damage on aerodynamic characteristics of a young spruce stand in the EESS of Bílý Kříž.

Forest damage caused by wind and snow depends on several factors: meteorological factors (wind speed and precipitation), topographical factors, forest stand characteristics, tree species and other factors related to landscape, especially openness of the crown layer (Nykänen et al., 1997). Synergic effects of these factors and continual snow cover with high water value maintaining from November 2005 to April 2006 in the locality Bílý Kříž caused considerable damage to the investigated spruce stand. This damage was found different on the dense (Fd) and the sparse (Fs) plots. The stand density decreased by about 29% on Fd and by about 14% on Fs plot. Furthermore, some other trees had breaks in upper halves of their crowns. These facts manifest occurring new conditions for airflow inside and above this forest stand and related changes in its aerodynamic characteristics.

It was shown, that the airflow in the growing season 2006 was stronger on both plots, mainly on the denser one, when more than 50% of the analysed wind speed profiles were found in intervals: $3.0 \leq u(z) < 4.0$ m s^{-1} (34.0%) and $4.0 \leq u(z) < 5.0$ m s^{-1} (24.2%). Furthermore, the strong forest damage on Fd caused a significant fall in the zero plane displacement value, from d = 8.5 m in 2005 to d = 7.5 m in 2006. The forest damage on Fs plot was not so strong, and the d value was 7.0 m in the both seasons 2005 and 2006. The annual mean value of z_0 for the damaged forest on Fd increased from 0.9 m in 2005 to 1.3 m in 2006 (Fig. 3).

To proceed with the continual research in the investigated spruce stand, there were established two plots with different stand densities by thinning performed at autumn 1996 and 1997. Another additional thinning was performed on Fs plot in May 2001. This silvicultural treatment reduced the stand density from 2,400 trees/ha to 1,880 trees/ha. From this follows that Fs plot had a higher susceptibility to the damage. In spite of this fact, the forest damage was more severe on Fd than on Fs plot. This can be explained by the diversified terrain with a broken topography. On the other hand, the snow accumulation is the highest during light winds. And as it follows from our analysis, more wind speed profiles complying with the condition $u(h - 1) > 1.0$ m s^{-1} were analysed on Fs than on Fd plot during all the investigated growing seasons.

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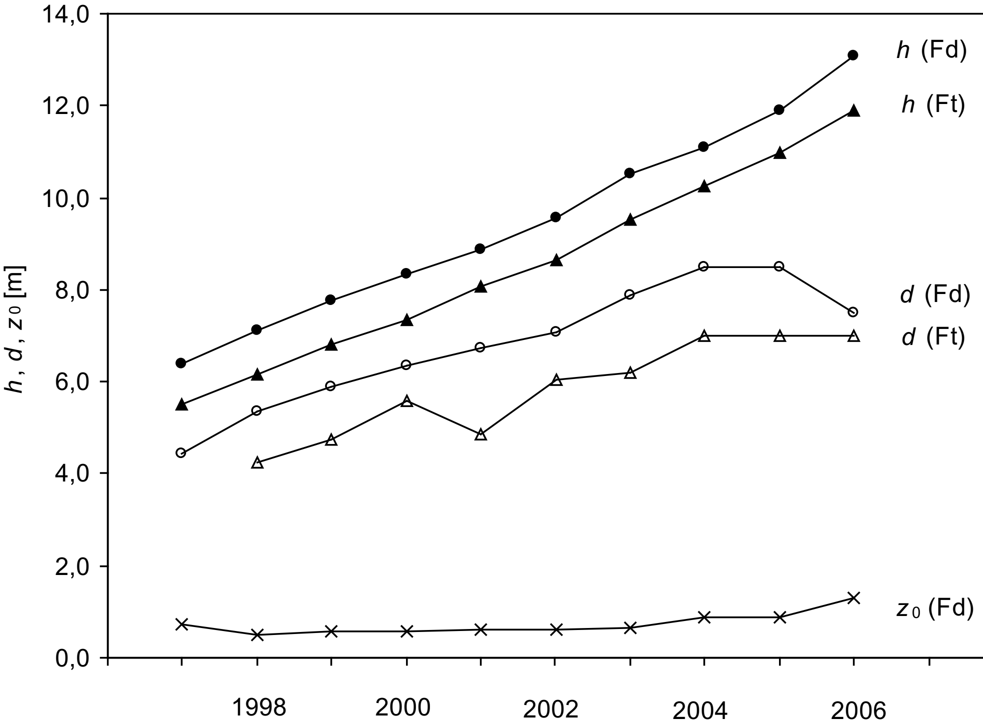

Fig. 3. Average seasonal values of the mean tree height (*h*), the zero plane displacement (*d*), and the roughness length (z_0) of investigated spruce stand during ten growing seasons

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Vplyv smrekového porastu poškodeného snehom na jeho aerodynamické charakteristiky

Súhrn

Vplyv porastu poškodeného snehom na aerodynamické charakteristiky sledovaného smrekového lesa bol analyzovaný počas rastových sezón 2005 a 2006 pred a po zime 2005/2006, kedy bol tento smrekový les významne poškodený snehom. Sledovaný smrekový porast sa nachádza v lokalite Bílý Kříž (49°30'17" N, 18°32'28" E) v lesnatej vrcholovej časti Moravsko-sliezskych Beskýd. V tejto oblasti celkove prevláda severné a západné prúdenie vzduchu, avšak priamo nad experimentálnou plochou sa často vyskytuje južný a juho-juhozápadný (SSW) vietor. Je to zapríčinené miestnou morfológiou terénu, pretože experimentálny porast smreku obyčajného (*Picea abies* (L.) Karst) sa nachádza na vo výške 898–908 m na miernom SSW svahu s maximálnym sklonom 13 %. Zima 2005/2006 v sledovanej lokalite bola charakterizovaná súvislou snehovou pokrývkou od polovice novembra 2005 do konca apríla 2006 s vysokou vodnou hodnotou, čo spôsobilo na poraste významné poškodenie, hlavne na ploche s vyššou hustotou stromov (Fd). Na tejto ploche s hustotou 2,044 stromov/ha, v dôsledku poškodenia, muselo byť 29 % stromov odstránených. Odstránené boli stromy, ktoré po poškodení mali výšku menšiu ako 2 m. Na ploche s nižšou hustotou (Fs), 1652 stromov/ha, bolo 14 % stromov odstránených. Mnohé stromy zostali poškodené (zlomené a ohnuté, cca 18,5 % na Fd a 7 % na Fs), ich priemerná výška na ploche Fd bola 5,5 m a na ploche Fs 4,0 m. S cieľom sledovať vplyv tohto poškodenia na aerodynamické charakteristiky porastu, dynamickú drsnosť povrchu (z_0) a efektívnu výšku porastu (d), bolo analyzované meranie profilov rýchlosti vetra vnútri a nad týmto smrekovým porastom. Ukázalo sa, že poškodený porast vytvoril podmienky pre silnejšie prúdenie vzduchu, keď v rastovej sezóne 2006 na ploche Fd viac ako 50 % analyzovaných profilov rýchlosti vetra bolo v intervale $3{,}0 \le u(h) < 5{,}0$ m s^{-1}. Poškodenie spôsobilo výrazný pokles priemernej hodnoty efektívnej výšky porastu (d) (hladina, kde dochádza k premene slnečnej energie na iné formy energie), z 8,5 m (2005) na 7,5 m (2006). Poškodený porast mal vyššiu priemernú hodnotu dynamickej drsnosti: z_0 = 0,9 m v r. 2005 a 1,3 m v r. 2006 (Fig. 3). Na ploche Fs vzhľadom k odlišným orografickým podmienkam a tým aj k menšiemu poškodeniu porastu bolo prúdenie vzduchu slabšie, viac ako 70 % analyzovaných profilov bolo v intervale $1{,}0 < u(h) < 3{,}0$ m s^{-1}. Priemerná hodnota d bola rovnaká v oboch sledovaných rastových obdobiach, d = 7,0 m. Z analýzy profilov rýchlosti vetra za celé sledované obdobie (1997–2006) vyplýva, že počet profilov, ktoré spĺňali podmienku $u(h - 1) > 1{,}0$ m s^{-1}, bol výrazne nižší na ploche Fd ako na Fs. To znamená, že prúdenie vzduchu vplyvom miestnej morfológie terénu je na ploche Fd slabšie. Podľa PELLIKKA a JÄRVENPÄÄ (2003) akumulácia snehu je najvyššia pri slabšom prúdení, čo vysvetľuje tiež vyšší stupeň poškodenia porastu snehom na tejto ploche.

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Intraseasonal stem circumference oscilations: their connection to weather course

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Abstract

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The diameter (circumference, radial) growth of trees is primarily connected with activity of secondary lateral meristematic tissues – cambium and phellogen. Their activity is linked with the basic physiological processes running in trees, the influence of which can be either direct or indirect. This process is also influenced by climate and weather fluctuations. At the same time, the tree stem with its tissues (bark, phloem, xylem) serves as a water reservoir for transpiration, and the short-time oscilations in the stem magnitude reflect the water balance and water potential of these tissues. The study ran in the vegetation period 2006. We measured short-time stem circumference changes on 1 beech and 3 spruce individuals in a primeval spruce forest in locality Predná Poľana (1360 m asl). In this contribution we deal mainly with inter-daily circumference changes and their connection to the seasonal weather course. A strong weather signal, affecting the circumference changes, was observed both on spruce and beech.

Key words

circumference changes, growth, spruce, beech, climatic signal

Introduction

The circumference (diameter, radial) growth of trees is primarily connected with activity of secondary lateral meristematic tissues-cambium and phellogen. According to Požgaj et al. (1997) wood creation is much more intensive than the creation of phloem. The sensitivity of tree ring formation to external factors has provided a background for new wood science branches – dendrochronology and dendroclimatology (Fritts (1976), Cook and Kairiukstis (1990)). Kozlowski et al. (1991) and Larcher (2001) suggest that activity of these meristematic tissues is linked with the basic physiological processes running in trees, the influence of which can be either direct or indirect – through metabolites and hormonal growth stimulators. This process is also linked with climate and weather fluctuations. There exist several works dealing with diameter growth, its seasonal trends and relation to physiological processes, climate factors, weather fluctuations and tree health status. (eg. Deslauriers et al. (2003), Ďurský and Mozoľová (2001), Ježík and Voško (2002), Knott (2004), Kramer (1982), Tardif et al. (2001), Tatarinov and Čermák (1999), Zweifel et al. (2000)). Short-time (over a day or a few days) fluctuations in woody plant circumference is also strongly influenced by water balance of the woody plant. In this case, the tree stem with its tissues (bark, phloem, xylem) serves as a water reservoir for transpiration, and deviation in the stem diameter (caused by shrinkage and swelling) reflect the water balance and water potential of these tissues as mention eg Offenthaller et al. (2001), Zweifel and Häsler (2001), Zweifel et al. (2001, 2006). The study ran in the vegetation period 2006. We measured short-time stem circumference changes on 1 beech and 3 spruce individuals in a primeval spruce forest in locality Predná Poľana. Here, in conditions of Slovakia, beech reaches its upper distribution limit and spruce is on its own altitudinal vegetation zone. In this contribution we deal mainly with inter-daily circumference changes and their connection to the seasonal weather course. To detect this linkage, we applied mainly modified methods widely used in dendrochronology and dendroclimatology.

Material and methods

Examined experimental material was acquired from the research site located on the Predná Poľana (PP) (48°37' N, 19°27' E, 1360 m asl) during the growing season 2006. The site is a part of the Poľana Biospheric reserve and the Zadná Poľana Nature reserve. The research plot is situated near the top of a south-west oriented slope with an inclination 5–25°.

The parent rock material is volcanic (andesite), the soil type has been classified as a Dystric Cambisol.

The studied forest stand belongs to the seventh forest altitudinal vegetation zone, the group of forest types Sorbeto–Piceetum, Acereto-Piceetum. The dominant tree species is spruce (*Picea abies*, (L.)) (93%) mixed with beech (*Fagus sylvatica*, (L.)) (4%) and European rowan (*Sorbus aucuparia*, (L.)). It is an uneven-aged primeval forest with spruce stands having up to 150–190 years and reaching an average height of 25 m. The stand structure is mosaic, clump, highly differentiated in thickness and height, the stocking value is about 0.6. In conditions of Slovakia the beech trees growing in this locality reach the upper distribution limit. Their growth forms are either shrubs suppressed under the main spruce layer or trees, mainly on sites where the main spruce layer is more opened. We measured stem circumference in three spruce and one beech individuals. The selected spruce trees were 19.0–21.5 m high and 26–39 cm in dbh. Their age was estimated (wood cores) between 85–100 years. The selected beech was a tree-formed individual, 14.5 m high and 25 cm in dbh. The age of tree-formed beech trees estimated from wood cores varied between 55–80 years.

The area belongs to cold mountain climate type, with mean annual temperature ranging from 3.5–4.0 °C and mean annual precipitation total reaching 900–1,100 mm over the last decade. For better comparison of seasonal climate with the long-term average, we used climatic data from the station of the Slovak Hydrometeorological Institute (SHI) Sliač. The meteorological station Sliač is situated in Zvolen basin, 23 km west from the PP, at 315 m asl.

The values of meteorological variables were measured at a meteorological station belonging the Slovak Hydro-meteorological Institute, situated at an altitude of 1260 m asl, by the mountain hotel Poľana, at about a 500 m distance from the studied forest stand. The information about the monthly temperatures and precipitation amounts was provided by the SHI.

From May 31 up to the end of September (September 28) or October (October 26) we carried out parallel measurements of temperature and relative humidity of air, intensity of global radiation and daily precipitation totals. The scanning ran continually, at 10 min intervals. The data were stored into the memory of a digital measuring MINICUBE 32 central (EMS Brno, Cz). In the first days of August, the equipment measuring global radiation intensity was damaged, and therefore the data about global radiation could not be used in analysis of influence of meteorological variables on changes in the stem circumference. Soil temperature and soil water potential (plaster bricks) were measured at a depth of 0.3 m, and the values were stored into the memory of a MICROLOG central (EMS Brno, Cz) in situ in the studied forest stand.

The changes in stem circumference were measured with an automatic band dendrometer – Dendrometer increment sensor DR 22 (EMS Brno, Cz). Circumferential band was made from stainless steel 12 mm wide and 0.2 mm thick, with a small thermal expansion – contraction factor. The data were therefore not corrected for thermal expansion. The tension strength of dendrometers was 10–15 N. The dendrometers were installed at 2.5 m above ground. The measured circumference data were stored at 10 min intervals into the data-loggers. We performed our circumference measurements from May 13, 2006 to October 26, 2006. For comparison with climatic data we used a segment from May 31.

For our analysis, we used daily average circumference values and climatic data. Because no growth occurs until the end of May, to ease comparison, May 31 was arbitrarily set to the zero value for all band dendrometers.

The circumference increments (CI) were calculated using the difference between mean values of two successive days. The obtained values of CI were filtered through "low-pass" and "high-pass" digital filters. It was done for the purpose of studying the variance at particular frequencies related to different processes running in tree stems. These filters are based on moving averages weights presented in Fritts (1976). They are reciprocal filters, designed to pass variance at opposite extremes of the frequency spectrum. Thus we obtained a "low-frequency" and "high frequency" signal.

For detailed climatic response analysis we used a segment from June 5 to September 28 (116 days). We analysed the values of CI and their corresponding signals in relation to the photoperiod (DL – day length) and to the daily values of climatic variables (SP – soil water potential, ST – soil temperature, AT – air temperature, AH – relative air humidity, PR – precipitation) their one-day delay (L1 – lag 1 day before the current day) and some longer-period averages (or in case of precipitation sums) values (4d – preceding four days for all climatic variables, 14d, 28d, 35d – preceding 14, 28, and 35 days for air temperature and precipitation). In total, we used 22 independent variables. Due to high values of correlations between independent variables, we used partially modified (without autocorrelation but including photoperiod) method of "response function analysis", detailed described in Fritts et al. (1971), Fritts (1976), Cook and Kairiukstis (1990), which has found an extensive use in area of dendroclimatology. Predictor variables were transformed into a new set of orthogonal or uncorrelated variables called principal components or eigenvectors and then standardized. Thus we obtained the factor scores matrix. We used 17 standardized eigenvectors, which represented 99.9% of original variability, as predictors in stepwise multiple-regression analysis. Further, we only used significant ($P < 0.05$) partial multiple regression coefficients for model construction, and insignificant regression coefficients were provided with a value of zero. Then the regression coefficients of eigenvectors were mathematically transformed (using eigenvectors amplitude matrix) into a new set of coefficients corresponding to the original set of variables. In a similar way, the standard errors of regression coefficients were transformed and the statistical significance of transformed regression coefficients of original climatic variables was calculated.

Results

Fig. 1 illustrates the climate history in the locality Predná Poľana across the individual months 2006. In summary, the year 2006 was characterised by a cold winter with high accumulated snow cover. The examined locality had a coherent 40–50 cm thick snow cover in forest even towards the end of April (April 29, 2006), and patches of this cover were present even at the installation of the dendrometers (May 13, 2006). Evidently the highest temperature was recorded in July, with the values in Sliač exceeding the long time average by 3.6 °C. Then there followed August-average in temperature and a sunny autumn period with temperature above the average. As for the precipitation totals, the period from January to April was normal. The most abundant precipitation total was recorded in June, followed by August. The autumn period up to the end of year can be characterised as warm and deficient in precipitation. The total precipitation amount over the growing season (April–September) was 642 mm at a mean temperature of 10.7 °C. The summer total (June–August) was 397 mm at an average temperature of 13.5 °C.

Fig. 2 (a, b, c) illustrates the course of daily climate variables: water potential of soil, length of astronomic day, mean daily values of air and soil temperature, mean daily relative air humidity, and daily precipitation totals over the growing season 2006 – during the measurements of stem circumference. In context of influence of weather on changes in stem circumference, it is necessary to keep in mind some anomalies in the weather history, especially the cold first decade of June, the highest daily precipitation totals recorded from June 27 to June 28 with occurrence of torrent rains (52 and 54 mm over some tens of minutes). The last decade period of July was very warm as a result of penetration of very warm air from west. In this air, lines of instability arose several times, associated with storms. Towards the end of the first decade of August, an occlusive front was progressing from west towards the interior of the continent. In the following days, central Europe was under influence of an extensive area of low atmospheric pressure. The associated frontal system was influencing the weather with frequent precipitation. At the end of the second decade of August, warm south-western airflow was dominant. The third decade, after a cold front transition, there dominated cold weather up to the end of the month.

Measuring values of soil water potential reflecting the strength of bonds between soil and water enabled us to assess soil water accessibility. In spite of the fact that the studied period was in precipitation below the reference long-term mean, we did not record a significant moisture deficit in summer months (June, July, August, Fig. 2a), thanks to frequent occurrence of storms in studied area.

Relative air humidity strongly varied between the days. In summary, the lowest values of air humidity were recorded in July.

After the cold first decade of June, the mean daily air temperature has exceeded a value of 10 °C, and the soil temperature a value of 5 °C. Up to the end of September, the soil temperature did not sink below this limit. The air temperature manifested a steep increase in the second half of June when we also for the first time recorded continual increasing stem perimeters (Fig. 2d) both in spruce (demonstrated on spruce No. 10) and in beech. The beginning of this process can be dated exactly between 16. and 20. June for spruce, and between 20. and 24. June for beech. In case of spruce, the increase was very steep while beech started slowly and manifested a conspicuous acceleration after June 25. The arrows in Fig. 2d point out some notable changes (slowing down) in rate of stem perimeter growth that are easy to identify optically. Comparing these changes with the course of mean air temperature, we can see their correlation with remarkable decreases at the beginning of July (below 13 °C for three days), and similarly on July 15, 16 and 17 (on 16 even under 10 °C). In August, the temperature sunk below 13 °C from 2. to 16., and for four days it kept under 10 °C. After August 7, we did not recorded a remarkable increase in perimeter in spruce trees, with exception of cases when a preliminary decrease in perimeter (caused by shrinkage) was followed by precipitation event. On August 7, spruce reached 97% of its maximum circumference. On August 14, beech reached 93% of its maximum circumference. On September 1, spruce reached 100% and beech 99% of their maximum circumferences.

On Fig. 3 (a, b, c) we can see that course of daily growth curves and course of monthly increment and growth curves of individual spruce trees were synchronised and different from curves for beech. The spruce trees created major parts of their increments already during the last two weeks of June (from 49 to 53%), in July from 34 to 35% and in August from 12 to 17%. In September, the perimeters were diminished by 7 to 8% of the annual increment, and then followed an increase in October, again. By the end of July, there had been created from 83 to 88% of the annual increment, with maximum (100%) recorded towards the end of August. On the other hand, the beech tree created only 14% of its annual increment in June. The highest proportion, up to 60% was created in July, in August it was 24%. Summarising, by the end of July it had been created 74% and by the end of August 99% of the total annual increment.

Fig. 4a illustrates the course of daily increments in spruce (s10) and beech (b2) trees over the time period that we subjected to a thorough analysis in context with climatic variables. We can see that the increment values varied substantially between the days, and in case of spruce we also recorded conspicuous drops into negative values indicating diminishing stem circumference between the individual days. This phenomenon was especially evident after the termination of major circumference growth, after the mentioned August 7.

The increment time series can be treated similar to image or sound signal with a certain frequency. Consequently, the increment signals of individual trees were processed using the method of digital filtering following the works by Fritts (1976) and Cook and Kairiukstis (1990). In such a way, we obtained a low-frequency (LF) and high-frequency (HF) signal presented in Fig. 4b. Summarising the values for individual days, we obtained growth curves for both low and high frequencies (Fig. 4c). Comparing these curves with the measured growth curves we can see that the low-frequency signal very well corresponds to the growth process of the trees. On the other hand, the high-frequency signal does not indicate a growth trend. Consequently, it corresponds to the reversible day-to-day changes. Re-examining the Fig 4b we find that the growth process expressed with the low-frequency signal was different in spruce and beech, according to the facts just mentioned in the analysis of the growth curves.

The obtained multiple-regression relations between the increments, their frequencies and individual eigenvectors or principal components of the independent climatic variables were explanatory for major part of the variability. In case of spruce we could explain through these relations from 76 to 80% of increment variability, in beech it was possible to explain 67%. The highest proportion of the explained variability was obtained with the low-frequency signal: from 93 to 95% for spruce trees and 89% for beech. In case of the high-frequency signal, the share of explained variability was lowest: 43–48% in spruce and 28% in beech. The

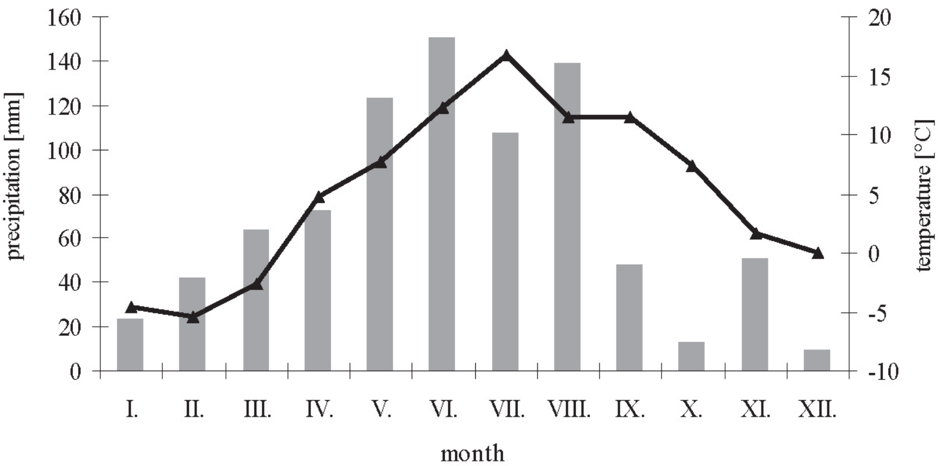

Fig. 1. Mean monthly temperatures (line) and precipitation totals (bars) at Predná Poľana in 2006

climate signal alone (without influence of photoperiod) represented in spruce increment from 65 to 69%, in beech 66% of variability. In case of low frequencies, the climate signal in spruce represented from 62 to

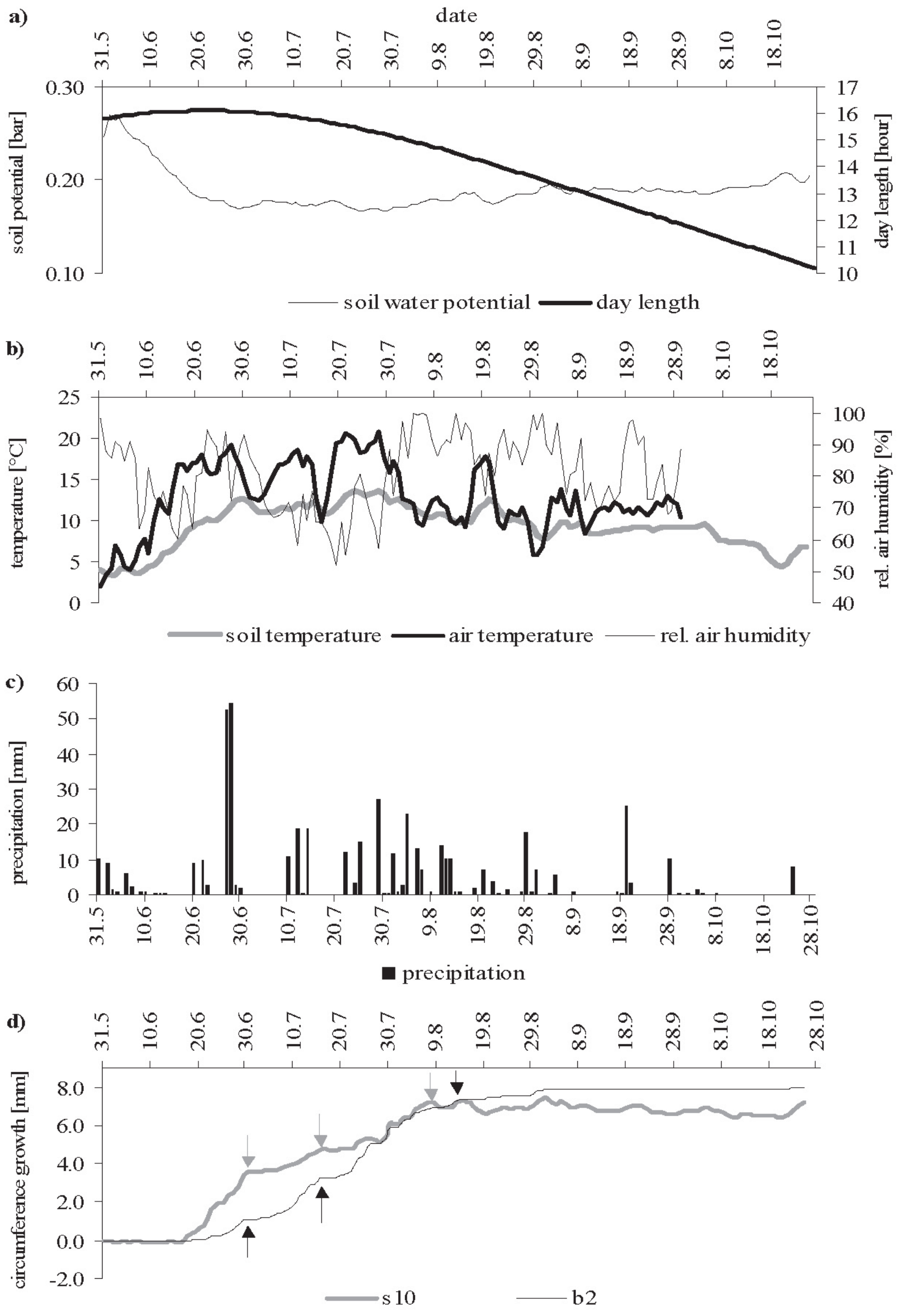

Fig. 2. Seasonal course of mean daily soil water potential and day lengt (**a**), soil temperature, air temperature and relative air humidity (**b**), precipitation (**c**) and circumference growth (**d**) of spruce (s10) and beech (b2) individuals

70% in beech up to 83%. In case of high frequencies was the influence of photoperiod insignificant and the climate signal represented from 43 to 47% of the total variability for spruce trees and 28 % for beech.

The influence of individual factors is illustrated in Fig. 5a, b, c. Noticeable are primarily the highest values of regression coefficients-having the strongest influence on the analysed signals. The responses of all the examined spruce trees were very similar. As for the increment itself (Fig. 5a), spruce responded in positive way, especially to the day length, relative air humidity in the given day, precipitation in the preceding day and mean air temperature over the preceding 4 days. The response was negative in case of air humidity over the preceding four days. The temperature over the last 14 days influenced the increment creation less strongly and in positive way, similar to the precipitation in the given day and in the preceding four days. In case of beech, the influence of photoperiod was found considerably weaker. The most positive was the influence of temperature and especially precipitation in the preceding day, temperature in the preceding four and fourteen days and, different from spruce, also the mean temperature over the preceding 28 and 35 days. Similar to spruce, the increment was negatively influenced by air humidity in the preceding four days.

In the low-frequency signal, the influence of photoperiod increased, and in spruce it was the dominant factor influencing the signal strength. The second most important factor with positive influence was temperature in the preceding four and also fourteen days. The positive influence of precipitation in the given day, preceding day and in preceding four days was weaker and rather uniform, as well as temperature in the given and the preceding day. In case of beech, the dominant factor was positive influence of temperature in the preceding 4, 14, 28 and 35 days. The influence of temperature was also found positive in the given and the preceding day. The influence of photoperiod was similar. Unlike in spruce, influence of long term temperature was found

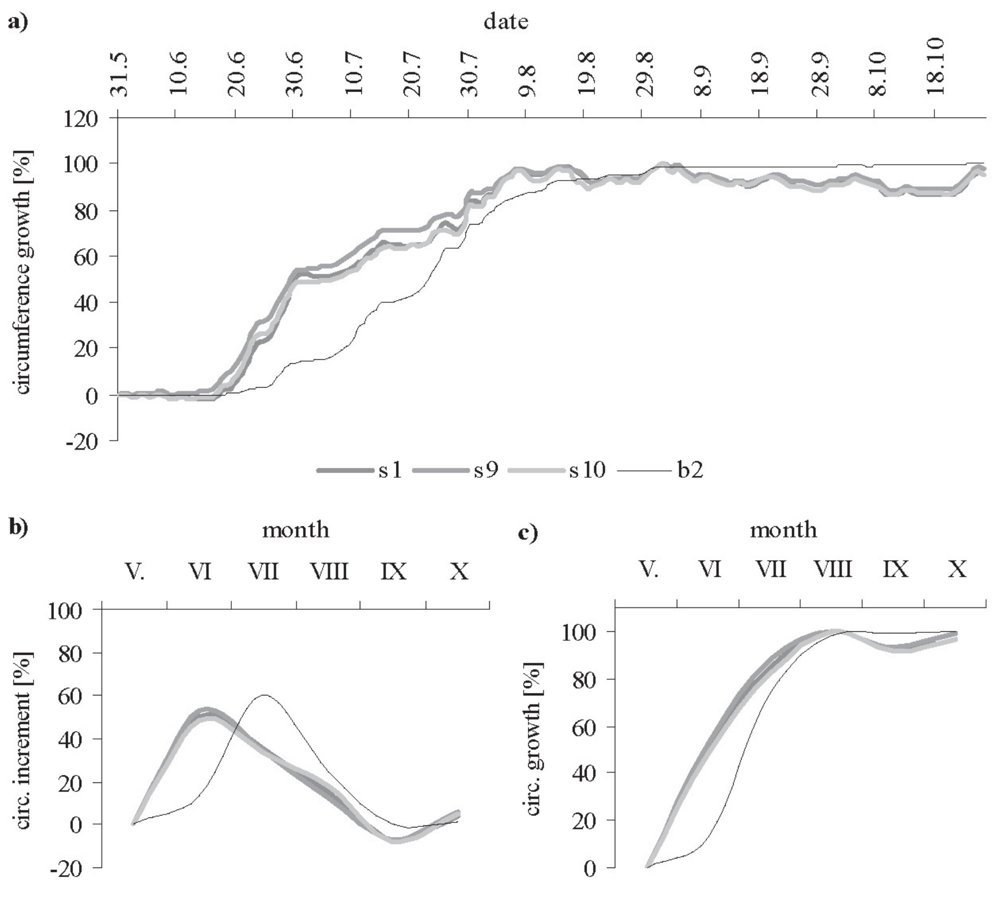

Fig. 3. Relative seasonal growth curves of measured trees (**a**) and their relative monthly increment (**b**) and growth (**c**) curves

positive. The most remarkable negative relation was recorded for air humidity in the preceding four days.

In case of high-frequency signal, the influence of photoperiod was negligible. For spruce, influence

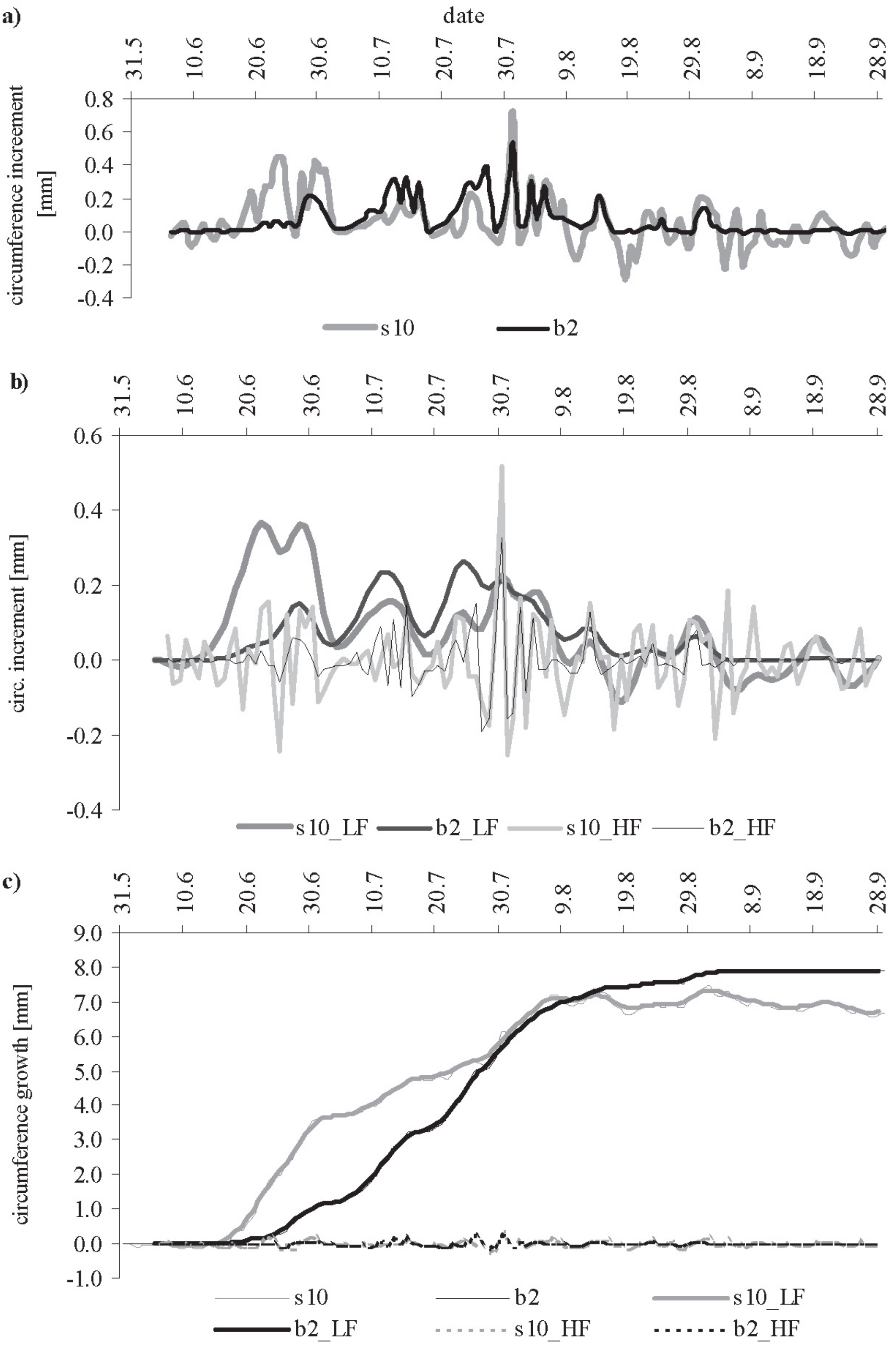

Fig. 4. Seasonal daily increment curves of spruce (s10) and beech (b2) individuals (**a**), their low (LF) and high-frequency (HF) components (**b**) and corresponding increment, low-frequency and high-frequency growth curves (**c**)

of air humidity in the given day and precipitation in the preceding day were found equally high significant. Influence of air humidity over the previous four days was found negative and weaker. In beech, the most important factor was precipitation in the preceding day. Influence of air humidity in the given day and negative influence of humidity in the preceding four days were substantially weaker than in spruce.

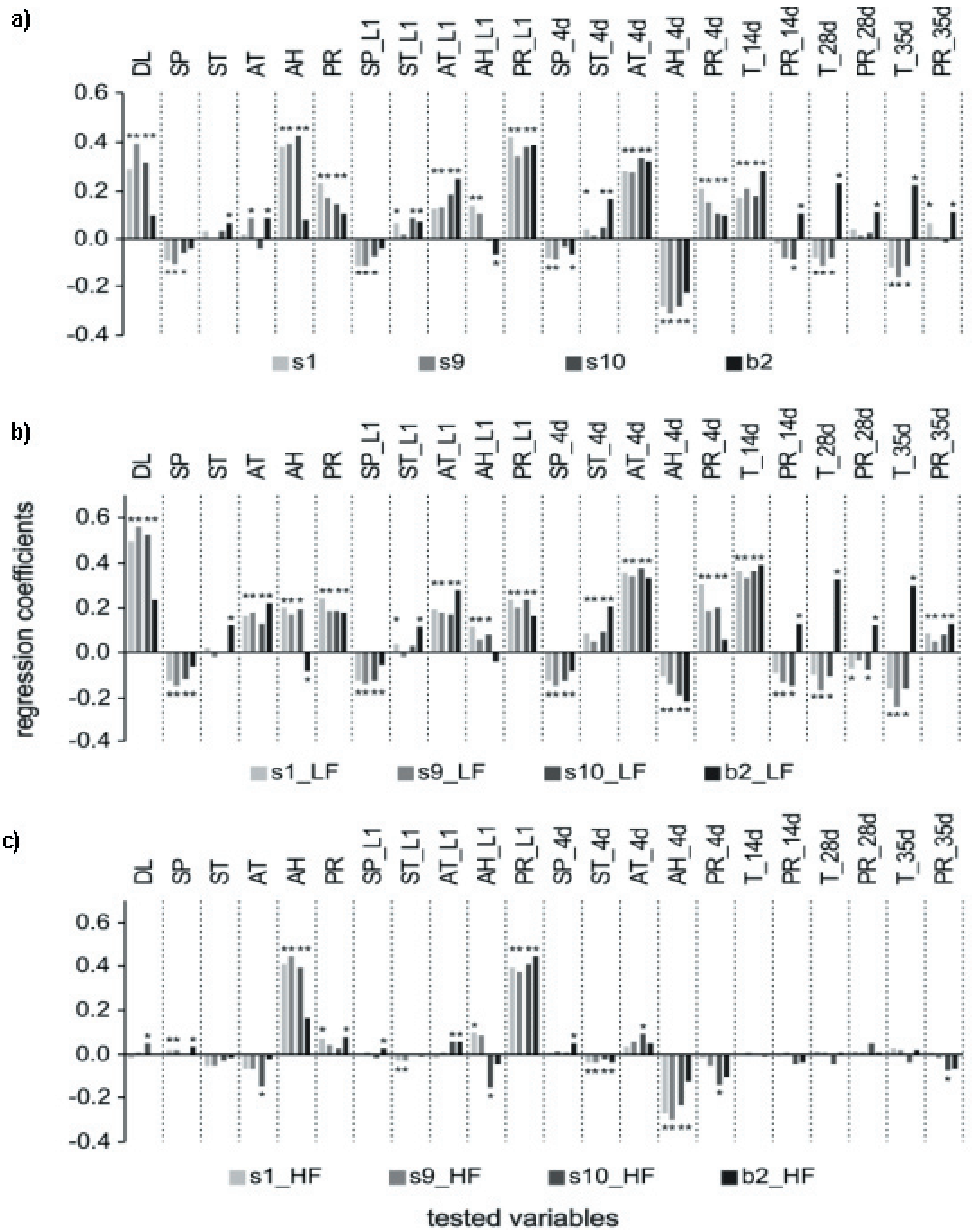

Fig. 5. Results of response function analysis (standardized regression coefficients) between measured increments (**a**) their low-frequency signals (**b**), high-frequency signals (**c**) and tested independent variables, where: DL – day length, SP – soil water potential, ST– soil temperature, AT (T) – air temperature, AH – relative air humidity, PR – precipitation, L1 means previous day, 4d – previous 4 days, and 14d, 28d, 35d – previous 14, 28 and 35days.
***** – marked statistically significant coefficients at $P < 0.05$

Discussion

In connection with seasonal dynamics of diameter growth in woody plants is commonly recognised that the onset of growth is primarily dependent on temperature, and the growth process is stopped in dependence on the day length. It seems to be evident because towards the end of August and in the first days of September, most woody plants in temperate zone stop their diameter increment creation (Šmelko et al. (1992)). In our case, both the beginning and sudden damping of the growth process, first of all the low-frequency signal, were distinctly synchronised with temperature. The important role of temperature in launching and keeping active performance of cambium and in production of xylem and phloem has also been confirmed by Gričar et al. (2006). Miller (in Šmelko et al. (1992)) reports 5.0 °C as a threshold value impeding growth in spruce, larch and mountain pine. Rossi et al. (2006a) suggest for a threshold value of air temperature necessary for spruce xylogenesis an interval of 6.5–10.0 °C and soil temperature between 3.0–7.5 °C. In our case, after the cold first ten-day period of June, the mean air temperature exceeded the limit of 8 °C for the first time on June 11, and the soil temperature was for the first time over 5 °C on June 12. The onset of growth started expressly after June 16 in spruce and after June 20 in beech following an abrupt rise of temperatures.

Our results also confirm strong influence of photoperiod on increment creation, especially in the studied spruce trees in which the major part of increment was being created over the short fortnight period in June following a temperature increase. The considerable influence of photoperiod on increment has also been confirmed by Rossi et al. (2006b), observing conifers in a cold environment and having found out that the maximum growth performance was synchronised with the day length. On the other hand, the growth performance of the studied beech reached its maximum in the second and the third decade of July and in the first days of August, because the species has at the locality the upper limit of its range and, evidently, requires bigger amounts of accumulated heat and necessary supply of assimilates. The increment dynamics in beech was in accord with the results obtained by Ježík et al. (2007), who found based on the data recorded with mechanical dendrometers installed on the same plot in growing seasons 2003–2005, that the beech increment was mostly dependent on temperature and reached its maximum mainly in July. Following the extreme hot period May-June 2003, the beech trees had created considerable high increments already by the end of June. In case of substantially colder weather in the year 2004, the increment created in June was significantly lower and it showed a steep peak, together with the temperature between August 5 and 19.

Kamlerová and Schejbalová (2006), performing their observations at 620 m asl, found that the increment creation in spruce started in the first half of May and reached its peak in July, after June exceedingly above-average in temperature and in precipitation. Krammer (1982) measured beech trees in the region of Lower Saxony (Germany, 500 m asl). He found out that the diameter increment creation started towards the end of April to the mid-May and finished about the end of August. Some fluctuations in diameter values, however, were observed up to the end of October. The highest increment rate was created in June and July. At the site with high precipitation, the fortnight increments were influenced heavily by the amount of global radiation and air temperature. Ďurský and Mozoľová (2001) studied diameter creation in trees close to our experimental site PP (5 km apart), at 850 m asl. The diameter increment of spruce and beech started to create since the mid-May and was finished towards the beginning or end of September. Knott (2004) found in a stand in the Czech Republic (460 m asl), that during the humid vegetation period 2001, precipitation and mainly temperatures showed positive effects on weekly diameter increment in fir and beech.

While in conditions of colder climate is the diameter growth of trees mostly influenced by temperature, in lower altitudes, especially in summer, precipitation turns more important. Ježík et al. (2007) recorded expressive shrinkage of beech stems measured at fortnight intervals in the extremely hot and dry summer 2003 on the plot situated in the 3rd forest altitudinal vegetation zone. The highest proportion of increment was in the case of 2003 created in May, in other years in June, followed by July. The similar effect of shrinking was observed by Zweifel et al. (2006) in oak, pine and spruce trees during the extreme drought in the year 2003 in the central valley in Switzerland.

Shrinkage and subsequent swelling of tree stems are not possible to distinguish fully from the growth process based on the measurements carried out with dendrometers. This phenomenon has also been pointed out by eg Krammer (1982), Zweifel et al. (2006), and it is also well-known from the observations of daily diameter dynamics (Deslauriers et al. (2003), Goldhamer and Fereres (2004), Herzog et al. (1995), Offenthaller et al. (2001), Ortuño et al. (2006), Tardif et al. (2001), Zweifel et al. (2001), Zweifel and Häsler (2001)). We observed shrinking of stems, mainly of spruce after cessation of growth after August 7.

In our approach, we filtered the original signal for obtaining its low-frequency and high-frequency component. The second is very close connected with reversible changes especially. It showed strongly positive responses to the precipitation in the preceding day and in case of spruce also to the changes in air humidity (rise in air humidity comparing to previous 4 days). As for moisture conditions, the low-frequency signal responded less positively to precipitation in the preceding day. The influence of air humidity variability on spruce trees was less less strong as for high-frequencies, too. It manifested closer correlation with the precipitation in the current day, with longer precipitation history and mainly for spruce with soil water potential.

Conclusions

In summary we can conclude, that we found a strong climatic signal in inter-daily circumference increment of spruce and beech in 2006 at the studied locality.

The circumference increment of spruce trees primarily associated with their cambium activity (low-frequency signal) was in the growing season 2006 mostly influenced by photoperiod, followed by mean air temperature over the preceding four and fourteen days. In case of reversible changes (high-frequency signal), there were primarily changes in air humidity and precipitation amount in the preceding day.

In case of beech, for the low-frequency signal, determining factors were mean temperatures, over the preceding four, fourteen, as well as 28 and 35 days. For the given, for beech extreme, locality, this fact points out necessity of temperature accumulation and evidently also accumulation of sufficient amounts of assimilates necessary for the cambium performance. The decisive factor in the high-frequency signal was influence of precipitation amount in the preceding day. Influence of changes in air humidity was less strong than that observed in spruce.

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Sezónne kolísanie obvodu kmeňov: ich spojitosť s priebehom počasia

Súhrn

Počas vegetačnej sezóny 2006 sme pomocou automatických dendrometrov zaznamenávali krátkodobé zmeny obvodu troch smrekov a jedného buka v prírodnom horskom lese v lokalite Predná Poľana. Podrobne sme analyzovali zmeny obvodu kmeňov medzi jednotlivými dňami, ktoré súvisia predovšetkým so sezónnym rastom (aktivita sekundárnych meristematických pletív) drevín ako aj ich vodnou bilanciou, a ich spojitosť s priebehom počasia. Po dlhej zime a chladnej prvej dekáde júna sme zaznamenali počiatok rastu kmeňov smrekov koncom druhej júnovej dekády, jeho následnú prudkú akceleráciu a vyvrcholenie v tretej júnovej dekáde. Rastový proces buka začínal mierne v tretej júnovej dekáde a vrcholil až v tretej júlovej dekáde. Do konca augusta sa vytvoril celý sezónny prírastok, pri jedincoch smreka prakticky už do konca prvej augustovej dekády. Použitím analýzy „response function“ sme zistili existenciu silného klimatického signálu ovplyvňujúceho zmeny obvodu kmeňov smrekov aj buka, ktorý bol rôzny pri jednotlivých frekvenčných komponentoch prírastkovej krivky. Pri jedincoch smreka, ktoré reagovali veľmi podobne, nízkofrekvenčná zložka prírastkovej krivky (ktorá súvisela predovšetkým s rastom stromov) závisela pozitívne hlavne od fotoperiódy a teploty počas predchádzajúcich 4 a 14-tich dní. Pri buku bola nízkofrekvenčná zložka prírastkovej krivky ovplyvnená najmä teplotou a jej akumuláciou za dlhšie obdobie (až 35 dní). Vplyv zrážok bol u obidvoch drevín slabší a prevažne pozitívny. Vysokofrekvenčnú zložku prírastkovej krivky (reverzibilné zoschýnanie a napúčanie) ovplyvňovali u obidvoch drevín najmä zrážkové pomery predchádzajúceho dňa a pri smrekoch silne aj zmeny vo vlhkosti vzduchu.

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Decomposition dynamics and biological activity in a floodplain forest

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Abstract

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The submitted work presents preliminary results of study evaluating the values of humus ratio in a hardwood floodplain forest situated near Lednice na Moravě, Forest Enterprise Židlochovice. The basic characteristics of surface humus layer in the mixed growth of the examined forest are assessed. The research locality is situated at an altitude of 151–153 m. The average of annual temperature is approximately 9–10 °C, average of annual rainfall is 500–550 mm. In samples of litter fall (oak, ash), the contents of carbon, nitrogen, dry matter and C/N ratio were determined and the microscopic pictures of foliage decomposition were made.

Key words

floodplain forests, humus, litter fall

Introduction

Floodplain forests of Central Europe represent exceptional forest geobiocoenoses. In the Czech Republic, floodplain forests occupy only a small percentage (1.4%) of the total area. From the aspect of production, there represent sporadic plant formations, the remnants of which is worth of total protection and conservation. Floodplain forests are unique ecosystems ranking among the richest-in-species ecosystems in our country.

Water is undoubtedly the most important factor affecting the biome of floodplain forests (Klimo, 2001). The first turnover in the hydrological regime of the Morava and Dyje rivers was caused by the extensive colonization of the landscape entailing gradual deforestation of the whole basin area. The runoff conditions were disturbed, there followed soil erosion, and the soil from higher locations was transported downwards and deposed in lower situated ones. This process was repeated in several waves related to the development of pasturage and agriculture from the Middle Ages up to the present time (Prax, 2004). In the 70s and 80s of the 20th century, other marked changes occurred there, namely the construction of dikes and integrated water-management measures. The aim of these measures was to protect the land, villages and towns from floods (Veselý, 2004). Changes in the water regime resulted in particular changes in the dynamics of available water and air in soil. In course of recent years, the project of floodplain forest revitalization was gradually implemented in southern Moravia, through artificial flooding with water from the Nové Mlýny reservoirs (Klimo, 2001). In this study we present preliminary results of evaluation of values of C/N ratio in a hardwood floodplain forest in Lednice na Moravě. The basic characteristics of surface humus in mixed growth of the studied forest are assessed.

Material and methods

At the experimental locality, a research plot was established in autumn 2005. On the plot, there was sampled only oak and ash litter for determining the content of carbon, nitrogen and C/N ratio. Apart from this, the content of carbon, nitrogen and C/N ratio as well as soil reaction were determined in soil samples taken from various depths of soil (soil pit). Moreover, the course of decomposition in randomly selected leaf samples was documented with photo-records.

The next year and in the same season, samples of litter were taken, using a sampling plate 50 × 50 cm in size, with the aim to determine the reserves of humus and nutrients per one hectare, namely in L1, L2 and F layers. These samples were not separated any more, that means that all the litter occurring on the plot was involved in the sample = mixed sample (containing, in addition to oak and ash, also hornbeam, maple and lime).

Description of the study area

The locality is situated in Lednice na Moravě, Forest Enterprise Židlochovice. The most part of the floodplain above the confluence of Dyje and Morava Rivers is covered with forest representing about 4,200 ha, which is 84% of the total territory. The research plot was established in the part called "Horní les" in autumn. The wide floodplain of the Dyje and Morava rivers is situated at an altitude of 151–153 m. The mean annual temperature ranges between 9–10 °C, mean annual precipitation is about 500–550 mm (Danihelka, 2002). The whole area belongs to the Dolnomoravský úval (the Low Morava river valley basin) (Collective, 1996) ranking among the Pannonian basins (Demek et al., 1987). From aspect of geology and morphology, it refers to the youngest formation of the rivers consisting of sediments gradually deposited in course of particular stages of flooding (Činčura et. al., 1983). Here soils of these locations are arenic Fluvisols (Němeček, 2001) with a high-quality layer of mull humus. The locality ranks among the geobiocoene type group *Ulmi-fraxineta carpini* belonging to the driest hardwood floodplain forest with groundwater table below 150 cm. The geobiocoene type group is characterized by a considerable presence of grove species in its undergrowth. In the tree layer occur *Carpinus betulus, Tilia cordata* and *Acer campestre* (Maděra, 2004).

Determination of the content of C, N and C/N ratio in samples of forest floor

The content of C and N was determined in finely ground samples of litter in a LECO CNS-2000 (MI USA) automatic analyser. To determine C, the standard of LECO Co., viz. sulfamethazine (502–298, Lot No. 1032) with the declared carbon content of 51.78% was used. To determine nitrogen, the standard of LECO Co., viz. Alfalfa (502-273, Lot No. 1008) with the declared nitrogen content of 3.29% was used. The temperature of sample combustion was 1,100 °C. Particular charges amounted to about 0.2 g.

Evaluation of the soil reaction

For determining the soil reaction we used samples dried with ventilation. From the dried soil, larger parts of soil skeleton, plant and animal residues were removed and the pulverized earth sieved though a sieve with a mesh size of 2 mm to separate soil skeleton particles > 2 mm. An average amount of 5 g was taken from the soil sample, pulverized in an agate and passed through a sieve with a mesh size of 0.25 mm. The values of actual and exchangeable soil acidity were determined using potentiometry according to Zbíral (1995).

Determination of the content of C, N and C/N ratio in the soil profile

The content of C and N was determined in finely ground soil samples using a LECO CNS-2000 (MI USA) automatic analyser. To determine C, the standard of LECO Co. viz. sulfamethazine (502-209, Lot No. 1032) with the declared carbon content of 51.78% was used. To determine nitrogen, the standard of LECO Co, viz. Tobacco (502-082, Lot No. 1008) with the declared nitrogen content of 2.45% was used. The temperature of sample combustion was 1,000 °C. Results are the arithmetic mean of two or three parallel determinations. Particular charges amounted to about 0.5–1.0 g.

Humus reserves per one ha

To determine the mean reserve of humus, a sampling plate 50 × 50 cm in size was used. The plate was placed on the soil surface and trimmed with a knife, surrounding litter and humus was removed aside to prevent contamination (mixture). All determinations were carried out in 5 repetitions. The litter under the plate was collected into bags and transported to the laboratory where the samples were weighed and subsequently dried in an oven at 60 °C to a constant weight. After the drying, the samples were weighed again, and the mean dry weight was determined. Based on the obtained value, the weight reserves of the forest floor per one ha were calculated.

Nutrient reserves per one ha

To determine the content of nutrients, the samples were sent to an external laboratory (EKOLA s.r.o. Bruzovice) where the nutrients were determined using wet mineralization. The results obtained were consequently converted to the reserves of nutrients per one ha.

Photo-documentation of the course of decomposition

Across the research area, leaves were sampled randomly from litter and the rate of decomposition was monitored in them. In the biometric laboratory of the Department of Forest Management Planning, Faculty of Forestry and Wood Technology, Mendel University of Agriculture and Forestry in Brno, microscopic images were taken by means of the Hitachi HV – C20 camera and a Navitar microobjective. Morphometric characteristics were processed with Lucia G program that provides the computer-based image analysis.

Release of CO_2 by the soil in natural conditions

Production of CO_2 was determined using the absorbing method provided with Sodasorpu (new title for "Natrokalcit"). The experiment was carried out in full summer weather (end June, beginning July). Sodasorp granules were filled to Petri dishes in quantities 15 g per one vessel, and before exposition, the desiccation run for one-and-half hour at a temperature of 105 °C. Thereafter, the dishes were closed, cooled and weighted on an analytical scale.

The studied soil surface was cleared of the leaf litter and green herbal cover. Open Petri dishes with absorbers were placed on soil surface, together with soil sensors (on surface and in depth of 5 cm) for monitoring changes in temperature. Each set was covered with a metal basket (diameter 23 cm, height 31 cm), with margins inserted into the soil (5 cm deep). Surface of the baskets was covered with aluminium folia, to avoid superheating the inner space. The experiment ran in five repetitions. To enable comparison of temperature inside and outside the baskets, there were installed outside sensors too. Because the production of CO_2 also depends on soil moisture, soil samples were taken for moisture assessment with the help of Kopeckého roller, in 6 repetitions. Sodasorp granules placed for 24 hours on the soil surface absorbed CO_2 released by the soil. From the differences between the weight before and after the exposition we can calculate the quantity of released CO_2.

Results and discussion

Determination of the content of C, N and C/N ratio in forest floor samples

C/N ratio is the tool for evaluation of decomposition rate of organic matter. The higher is C/N ratio, the slower is organic matter decomposition. In the oak litter, the C/N ratio was found 42.7, in ash litter 24.4 (Fig. 1). At slow decomposition of organic matter, the latter is accumulated on the soil surface, which results in lowering the rates of mineralization and humification processes and slowing down also the nutrient cycle. Litter rich in nitrogen (C/N ratio < 30) is decomposed usually fast (Klimo, 2001). In both variants of the stand (oak and ash), the content of carbon ranged about 50%, unlike the content of nitrogen, which was almost double (2.05%) in ash litter compared to the oak litter (1.18%).

Evaluation of the soil reaction

Soil reaction affects forest stands, because it influences biochemical processes in their soils as well as processes of the nutrients uptake by particular autotrophic organisms. The soil reaction in the studied area changed from medium acid to neutral in potentially exchangeable soil reaction, and from slightly acid to slightly alkaline in actual soil reaction (Fig. 2). The pH values increased with the increasing soil depth.

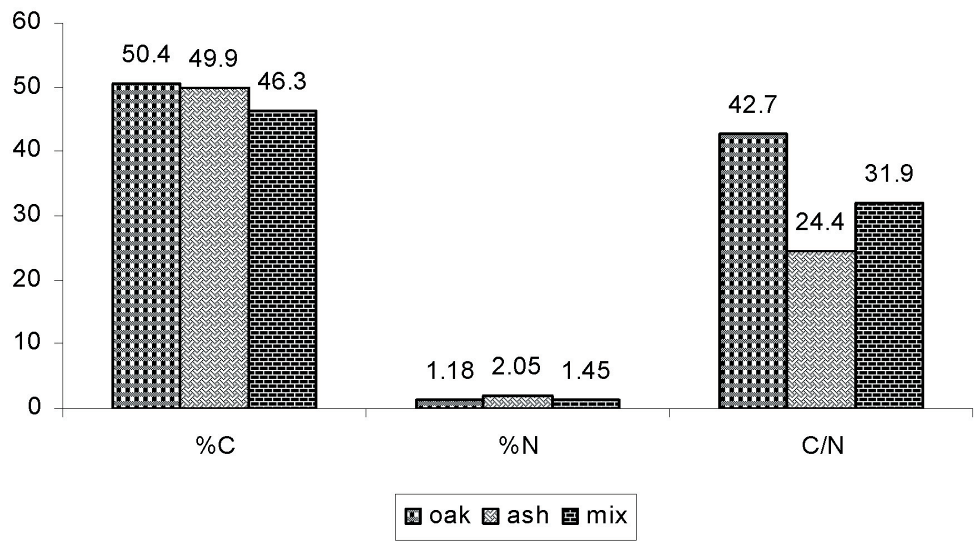


Fig. 1. Determination of the content of C, N and C/N ratio in samples of forest floor

Determination of the content of C, N and of C/N ratio in the soil profile

Nitrogen occurs predominantly in organic soil constituents. Soil organic matter is the main reservoir of nitrogen for plants and soil micro-organisms. The results obtained show that the content of carbon and nitrogen decreased with the soil depth (Fig. 3). The highest values were determined at depths of 5 and 10 cm. On the contrary, the lowest values were determined at a depth of 100 cm below the soil surface. The most marked drop in the content of carbon and nitrogen was noted only at a depth of 10–30 cm where the values decreased by half, elsewhere their content decreased more slowly. Quantity of carbon and nitrogen in the soil is influenced above all by two factors – temperature and moisture. At higher temperatures, decomposition of organic matter is faster, and thereby there is also lower content of organic soil matter. Higher soil moisture content is associated with higher organic matter content in soil.

Humus reserves per one hectare

Humus layers have a different function and also different character Therefore, it is possible to differentiate between the litter L (in our case L1 = the current year's litter without signs of decomposition, L2 = last year's litter subjected to slight decomposition) and horizon F (in which the decomposition of organic matter is evident, but with remnants still keeping their original form and structure). Conversion of organic matter to soil is associated with creation of humus – in process that is an important dynamic component of floodplain forests´ environment. The concern is about the mull type that is characteristic with distinct changes in its nutrient concentration over the year (Gartner and Cardon, 2004). Litter decomposition is "vital to nutrient cycling and the productivity of forests"(Didham, 1998) and "is an important component of the global carbon budget"' (Aerts, 1997). The biggest reserves of humus are in the humic layer F.

Nutrient reserves per one hectare

Soil-forming and biological processes influence the course of bio-geochemical cycles in ecosystems. Biogenic elements, as carbon, nitrogen, sulphur and phosphorus, are the main building stones of cells and tissues of organisms. In process of cells necrotising, organic compounds are decomposed; inorganic nutrients are released and can again be received by other organisms (Šimek, 2003). From above diagrams follows, that the highest reserve of all nutriments we can find in layer F and last year's litter L2 (Figs 5, 6).

Photo-documentation of the course of decomposition

On the surface of oak leaves, pupated damaged (dead) eggs of small butterflies (Microlepidoptera, Tineidae)

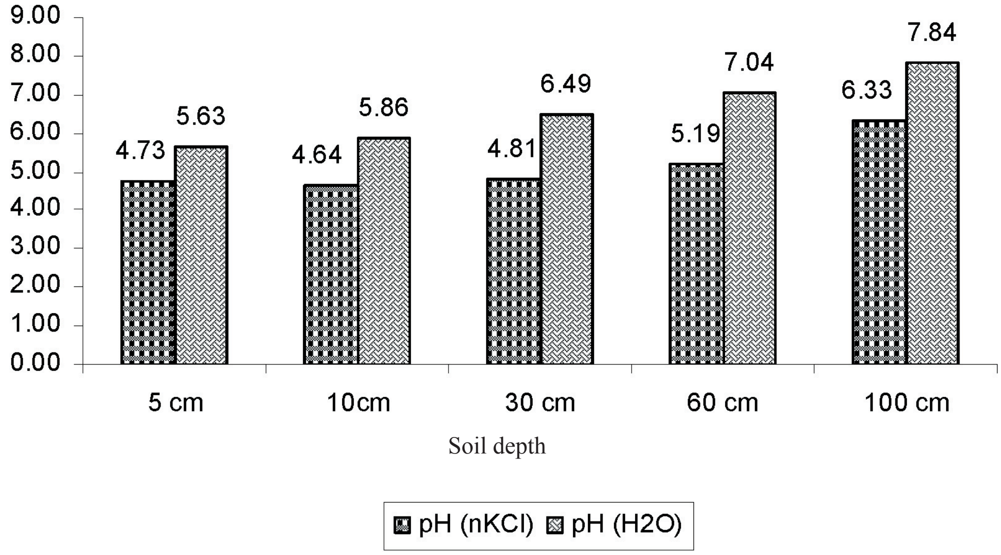


Fig. 2. Evaluation of the soil reaction in various soil depths

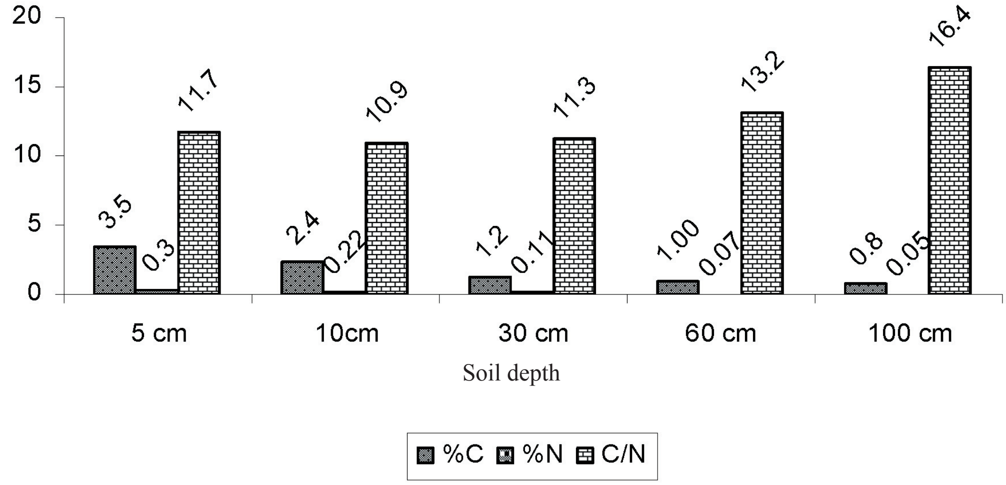


Fig. 3. Determination of the content of C, N and C/N ratio in the soil profile

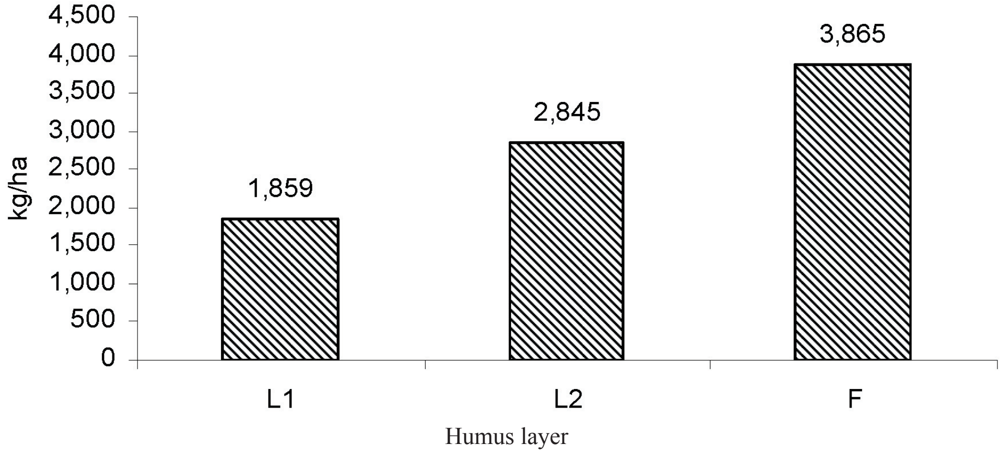


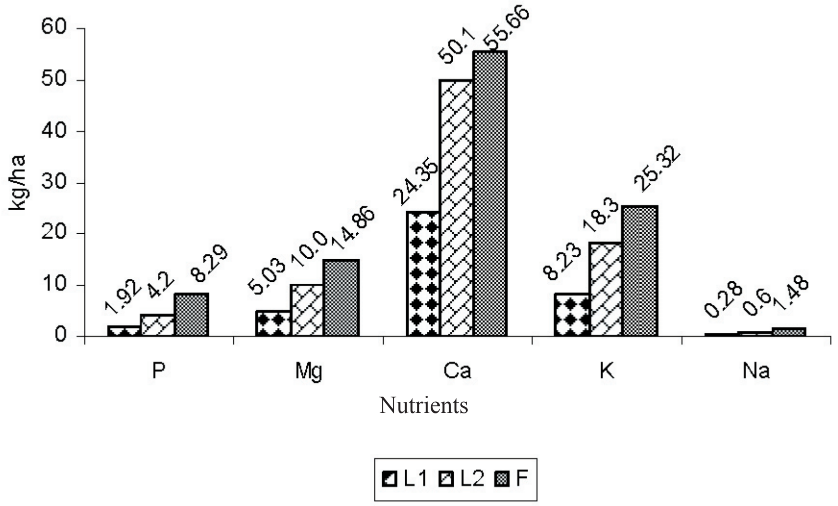
Fig. 4. Humus reserves per one hectare in different humus layers

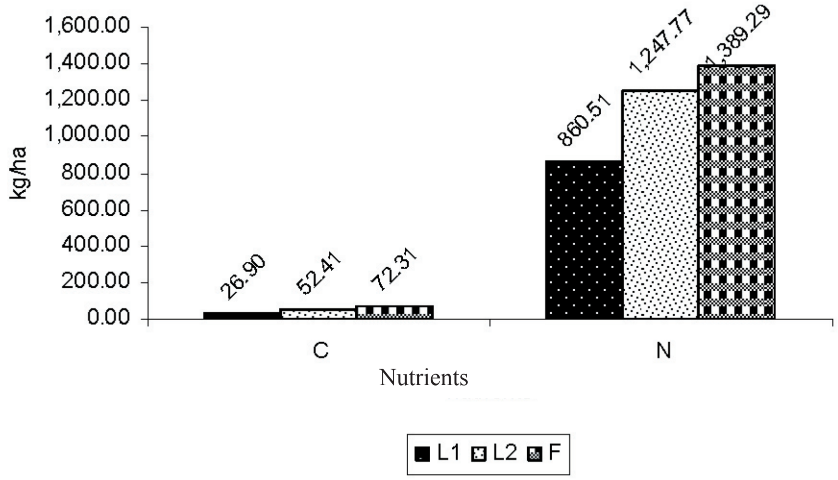
were found. Pupae (Fig. 7) occurred only on the leaf surface, consequently, they do not seem to have any effect on the rate of leaf decomposition. Also a gall of *Neuropterus numismalis* was observed (Figs 8, 9).

The examined ash leaves were in more advanced phase of decomposition than oak leaves. On the abaxial leaf side, there was found white dusty spongy growth with surface scattered with tiny yellow to black-coloured fruiting bodies – cleistothecia – *Phyllactinia guttata* (Figs 10, 11).

Release of CO_2 by the soil in natural conditions

Soil respiration together with respiration of the plant cover represent the main way of releasing carbon from ecosystems. Average quantities of CO_2 released from soil surface ranged in intervals 0.46–0.57 g CO_2 m^{-2} per day. The specific soil moisture content was found to be 38.7%. The data obtained with sensors manifest that during the exposition time, there were no expressive changes in temperature of the inner





Figs. 5, 6. Nutrients reserves per one hectare in different humus layers

Fig. 7. Microscopic photo of oak leaf. Pupa with dead eggs of small buterflies (*Microlepidoptera, Teneidae*) were found. The surface of pupa is 3.07 mm^2.

environment. The differences between the temperature measured inside the closed baskets, both on soil surface and in a depth of 5 cm, and the temperatures recorded by outside sensors were max. about 1 °C, mainly during the night.

Region of floodplain biotopes of Dyje and Morava Rivers is significant in such degree that it has been assigned to the category of wetland ecosystems of international importance: RS 9 – Wetland Ecosystem of lower Podyjí (Heteša, 2004).

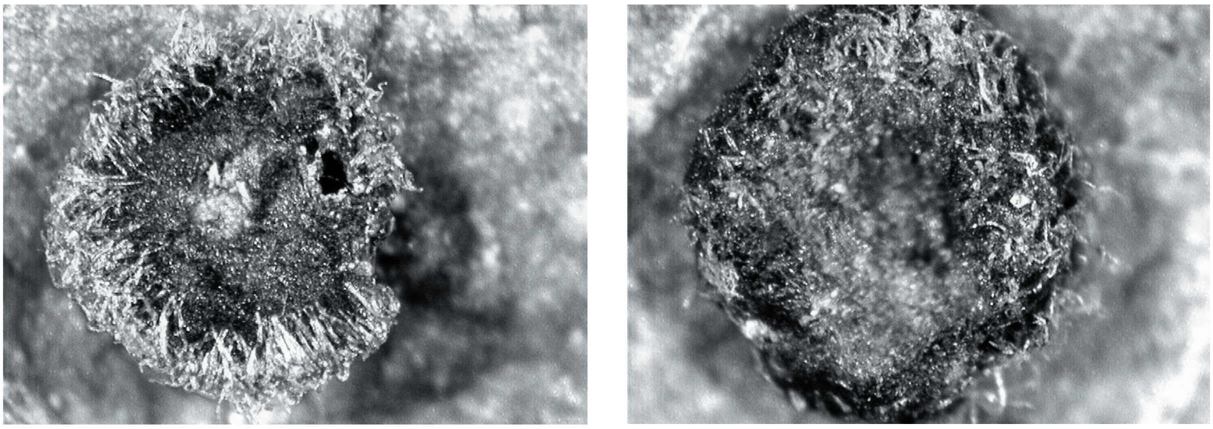


Fig. 8, 9. Microscopic photo of oak leaf. A gall of *Neuropterus numismalis* was found.

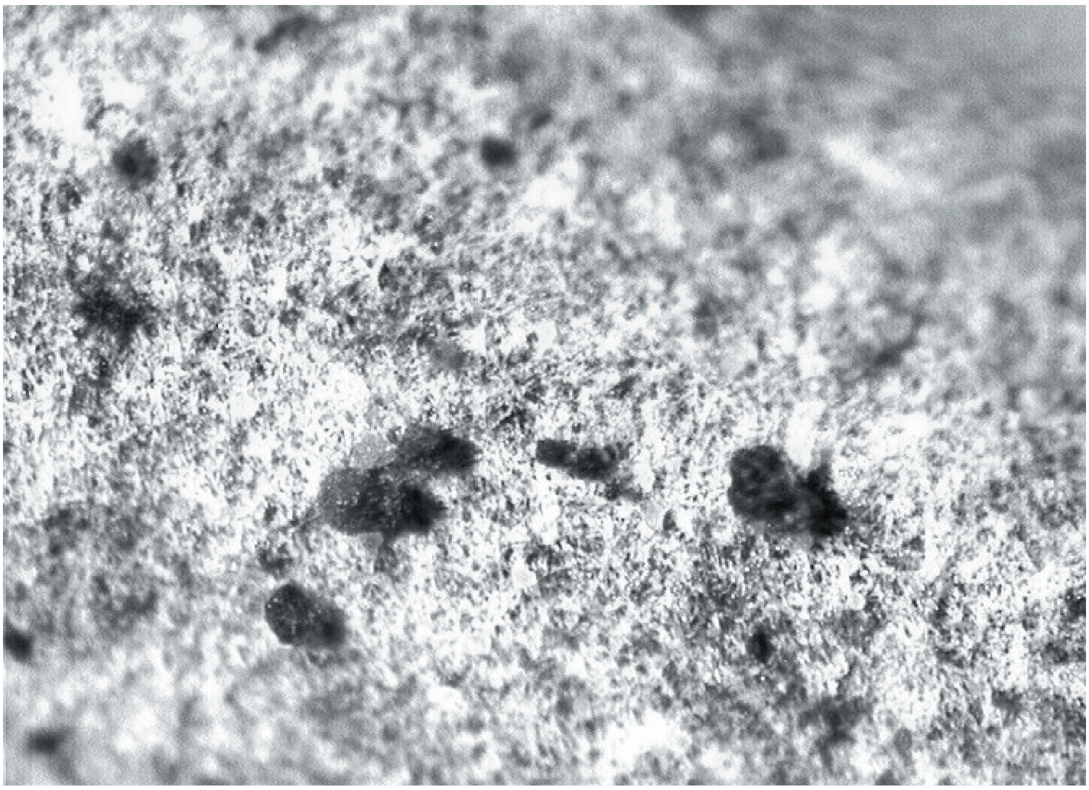


Fig. 10. Microscopic photo of ash leaf. The back side of leaf with white dusty growth, with yellow to black fruiting bodies (cleistothecia) of *Phyllactinia guttata*

Fig. 11. Microscopic photo of ash leaf with cleistothecium of *Phyllactinia guttata*.
The diameter of this cleistothecium is 0.17 mm.

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Humusové poměry a biologická aktivita lužních lesů

Souhrn

Lužní lesy střední Evropy představují vyjímečné lesní geobiocenózy. Lužní lesy zaujímají v České republice zanedbatelné procento (1,4%) z celkové lesní plochy Během 70. a 80. let 20. století došlo k výstavbám hrází a dalším vodohospodářským úpravám, jejichž cílem byla protipovodňová ochrana pozemků a obcí. Lužní les byl však na povrchové rozlivy záplavových vod adaptován a díky těmto změnám začal les vysychat a měnit svůj charakter.

Předkládaná studie přináší předběžné výsledky hodnocení humusových poměrů v lužním lese v Lednici na Moravě. Konkrétně jsou zde hodnoceny základní charakteristiky povrchového humusu ve smíšeném porostu tvrdého luhu, které budou později doplněny o charakteristiky mikrobiální aktivity půd.

U dubového opadu byl poměr C/N 42,7 a u jasanového opadu 24,4. U smíšeného vzorku se hodnota C/N pohybuje někde uprostřed dvou předešlých výsledků, což je způsobeno příměsí opadu dalších druhů dřevin. Je zřejmé, že opad jasanu je nejbohatší na dusík, proto zde rozklad probíhá nejrychleji a dusík, který je nevyužitý mikroorganismy je uvolňován do prostředí. Na zkoumaných plochách se půdní reakce mění od středně kyselé po neutrální, u půdní reakce potenciální výměnné, a od mírně kyselé až po mírně alkalickou u půdní reakce aktuální. Hodnoty pH stoupají spolu s rostoucí hloubkou půdy. Z výsledků vyplývá, že obsah uhlíku i dusíku klesá s rostoucí hloubkou půdy. Nejvyšší hodnoty byly zjištěny v 5 a 10 cm hloubce. Největší zásoba humusu se nachází v humusové vrstvě F. Z výsledků také vyplývá, že nejvyšší zásoba všech živin se nachází ve vrstvě F a loňském opadu L2. Z pořízené fotodokumentace byla na povrchu dubového listu nalezena zakuklená poškozená (odumřelá) vajíčka drobných motýlů (Microlepidoptera) – molovití (Tineidae). List jasanu byl v pokročilejší fázi rozkladu než list dubu. Na zadní straně listu byl nalezen bílý prachový houbovitý růst, na němž byly zachyceny žluté až černé pohlavní plodící struktury-cleistothécia čeledi padlí – *Phyllactinia guttata*.

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On the possibility of usage of GIS for ecological damage evaluation, demonstrated on example of the wind calamity in the High Tatra National Park

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Abstract

Melicharová, A., Schneider, J., Mikita, T., Celer, S., Kupec, P., Vyskot, I. 2007. On the possibility of usage of GIS (Geographic Information System) for ecological damage evaluation, demonstrated on example of the wind calamity in the High Tatra National Park. *Folia oecol.*, 34: 125–145.

The article presents methodology and results of ecological damage evaluation carried out with using the Geographic Information System (GIS). The concerned ecological damage was caused by the wind calamity impacted the most part of the High Tatra National Park (TANAP) in November 2004. The ecological damage to mountain forests has been evaluated by the ecosystem method called Quantification and Evaluation of Forest Functions (Vyskot, 2003) as empowering (reduction) of the ecosystem functions resulting from the wind calamity having caused the damage. There have also been determined the damage categories and their presence in the forest stands. The GIS was used in the first step for the extensive data set processing; in the second step for some special analyses. The GIS software special analyses were applied in multi criteria evaluation of forest stands resistance to wind ecological damage, where different parameters of forest stand biotic and abiotic conditions were combined. The results presented in the article show evidence of powerful usage of GIS software for analyses connected with ecological damage evaluation.

Key words

GIS, functional analysis, damage to forest functions

Introduction

The modern science supplies us with different possible approaches to ecological damage evaluation. One of the leading scientific practices in this area is so called ecological evaluation. This approach evaluates the ecological damage as the empowering (reduction) of the ecosystem functions resulting from effect of the phenomenon causing the damage. The quantification and evaluation of ecosystem functions before and after the ecological damage provides the background for this approach to ecological damage evaluation.

The method Quantification and Evaluation of Forest Functions (Vyskot et al., 2003) is widely used for forest ecosystem evaluation in the Czech Republic. This method is based on determining ecological criteria and parameters of forest ecosystem functions for objective quantification of forest functions. Forest ecosystems are usually evaluated in frame of their spatial organization units.

In case when this method is used in evaluation of larger forest areas, there are usually present a lot of different forest units and the use of Geographic Information Systems (GIS) development provides us with new tools and possibilities for the method application.

Our article presents the methodology and results of ecological damage evaluation with using the Geographic Information System (GIS). There was examined the ecological damage caused by the wind calamity impacted the most part of the High Tatra National Park High Tatras (TANAP) in November 2004.

The method Quantification and Evaluation of Forest Functions (Vyskot et al., 2003) is used for evaluation of forest functions, and the ArcGIS software is used for the basic data processing and the presentation of the results.

The article deals with the extensive research and evaluation of the ecological damage resulting from the wind calamity in the TANAP. The research was concentrated to localities with the highest level of nature protection (Tichá and Kôprová valleys); localities with interesting recreational forests adjacent to the town of Vysoké Tatry (Štrbské pleso, Tatranská Lomnica, Starý Smokovec) and a locality with amenity forests around the health resort Vyšné Hágy. In this article we present the results obtained at the model locality Tatranská Lomnica.

The issues presented in this article (analyse of geomorphologic surveys regarding the influence of terrain segmentation on stability of forest stands and on their functional potential) was intended as preparation of theme for Area 6.1.3.2. – Vulnerability assessment and societal impacts (7th Framework Programme of the European Community for Research, Technological Development and Demonstration). The other parts were processed within a study of ecological detriment to the TANAP forests.

Materials and methods

Locality

The presented results are divided into two groups. The first ones (results of methodological character) are general results taken across the whole above mentioned area (Tichá and Kôprová valleys, forests adjacent to the town of Vysoké Tatry and forests around Vyšné Hágy). The second group (results of GIS application in ecological damage evaluation process) consists of the concrete results obtained at the model locality Tatranská Lomnica.

The High Tatra National Park (TANAP) is situated in the northern part of the Slovak Republic. It was established by the Act SNR No. 11/1948 Zb. Its area is nearly 73,800 ha, and it can be characterized as a mountain area consisting of the main ridge with a system of side peaks and valleys. The natural conditions in the area especially result from its geomorphology; the High Tatra Mts are the highest mountain group in the so called Carpathian Arc. The climate of the locality is cold and very cold with high humidity. The contemporary vegetation cover comprises different types of mountain forests, mountain meadows and so called forestless areas above the upper tree line.

The locality Tatranská Lomnica is situated in the central part of the TANAP. The average altitude is 850 m above sea level; average slope orientation is south and southwest. The prevailing tree species in forest stands is Norway spruce (*Picea abies* (L.) Karst). The area of the stands is nearly 800 ha.

Working procedure

As it has been mentioned above; the main goal of the research discussed in this article was evaluation of ecological damage caused by the wind calamity in forest stands in the TANAP, November 2004. For solving this problem, the method Quantification and Evaluation of Forest Functions (Vyskot et al., 2003) (in the following text only the Method) was used; the data processing was done using the ArcGis software.

The working process can be divided into five steps:

1. Transformation of typological units and their comparison with natural conditions in the Czech highland forests as a base for verification of correct usage of the chosen Method
2. Forest stands damage class evaluation realised through analysis of the ortho-photographs
3. Analysis of geomorphologic surveys regarding the influence of terrain segmentation on forest stands´ stability and their functional potential
4. Real functional potential and topical functional effect of forest stands estimated from the GIS-created layouts
5. Assessment of the degree of naturalness of the forest stands.

Application of the Method in Slovak (High Tatra) conditions

Because the Method has been created for conditions in forests of the Czech Republic, the first step was verification of its applicability in conditions of Slovakia, especially the High Tatra Mts. Conversion of the Slovak typological units – groups of forest types – to units used in Czech forest management planning was based on similarity in stand and biocenological conditions, adequate for specification of particular management groups of stands (MGS). MGS comprises associated groups of forest types based on similar site and production conditions. The map of the Tatra’s MGS was elaborated and compared with the analogous

Czech mountain forests conditions (Ještěd – Jeseníky Mts and Plešný – Šumava Mts) with respect to the differences between Hercynicum and Carpathians. This analysis confirmed the correctness of using the Method in Slovak conditions.

Damage class establishment and evaluation

The damage to the stands was first evaluated through analysis of the orthophotographs (made after the wind calamity in December 2004) and individual stand damage classes were established. The classification was then verified directly in field. Our evaluation is presented in Table 1 and Figs 1–4. The damage classes were determined on the base of the forest stand status immediately after the wind calamity in 2004.

Relationship between geomorphology and damage class of forest stands (Analysis of geomorphologic surveys with regard on influence of terrain segmentation on forest stand's stability and on its functional potential)

This problem was solved at the model locality – forest stands in wide surroundings of Tatranská Lomnica. The whole study area is a rectangle 5 × 6 km in size. The analyses were processed using the ArcGIS 9.2 software with the Spatial Analyser and 3D Analyser extensions. The input data for analysis were vector contours having a 10 m contour interval, vector forest stand maps, mapping server of the Slovak Agency for Nature Protection.

The initial data for geomorphological analysis consisted of a digital elevation model calculated from vector contours (received in shape file format) with using the TopoToRaster tool of ArcGIS Spatial Analyst extension with a final resolution of 10 × 10 m. In spite of the fact that the contour interval of 10 m did not enable a higher resolution in this DEM, there are visible some innaccuracies resulting from the relief curvature between the contours. On the basis of DEM, there were processed maps of Aspect, Slope and Curvature. The aspect map was reclassified into 8 categories according to the main orientations, Slope map was reclassified into 9 categories each consisting of 4 classes and Curvature map into 5 categories.

The initial data for forest naturalness evaluation were vector forest stand layers. Having compared the tree species composition and potential vegetation for every stand, we divided all forest stands into several categories expressing their naturalness. On the basis of these values were the whole layers converted from vector to raster format and the result was a map of forest stands naturalness.

Real functional potential and creation of GIS layouts for topical functional effect of forest stands (incl a brief description of the basic Method terms and definitions)

General functions of forest mean all effects of this natural ecosystem which are independent of human influence. The ecosystem method of quantification and evaluation of forest functions is, therefore, based on the quantification and evaluation of elements and parameters of forest ecosystems determining their functional effects.

The principle of indirect parameter quantification is used for all systemized implemented ecosystem functions of the forests. The elements and segments of the ecosystem are aggregated to so-called functional criteria specifying the functional effects under evaluation.

To quantify a forest ecosystem it is necessary to define its condition entering the evaluation procedure.

Each of the forest functions (effectiveness of the functional group) is quantified through quantities of functions of the determining parameters (determination criteria). The compatible (value) classification of parameters (criterion elements and segments) also expresses the extent of functional effectiveness of functional determination criteria through the hierarchy of value degrees (rate of quantity).

Table 1. Characteristics of damage classes

Class	Damage class characteristics
A	Forest stands or their parts totally damaged by the calamity. Area has got a character of a clear-cut area, or with solitary, predominantly extremely damaged trees (damage degree IV, IIIb).
B	Seriously damaged forest stands or their parts (stocking 2–4). Remaining trees are predominantly heavy or medium damaged (damage degree IIIa, II).
C	Forest stands or their parts influenced by wind calamity (stocking 5–7). Slightly or medium damaged trees (damage degree II, I) predominate.
D	Forest stands or their parts not affected or only slightly disturbed by the calamity. Stocking maintains without change or is slightly decreased (8 +). Health condition of stand is good (damage degree 0, 0/I, I).

The procedure is implemented at the following levels:

- o Real potential of forest functions RP_{FF} – quantified functional potential of forests (values of produced functions) under optimum ecosystem conditions
- o Real topical effect of forest functions RE_{FF} – topical quantified functional effects of forests (values of produced functions) under topical ecosystem conditions.

Method works with six groups of forest functions: bioproduction, ecological – stabilization, hydric – water management, edaphic – soil conservation, social – recreation, health – hygienic.

The real potential of forests functions is determined for certain forest ecosystem units corresponding to the so called stand types within the functional management groups. The stand type specification is described in the Method references (Vyskot et al, 2003) in detail; here we only specify the stand type coding in terms of tree species composition. Stand type is labelled with an Arabic number (coding the group of tree species) and a capital letter (coding its proportion in the evaluated forest ecosystem). Functional management groups summarise forest sites (forest habitats) with functionally similar conditions. Real potential of forest functions is graded according a 7 value scale (0–6), where 0 means functionally unsuitable real potential, 6 means extraordinary real potential of forest functions (see Table 2). There is also presented so called total real potential of functions, which is defined as the sum of potentials of the particular functions. The value of the total real potential of functions varies from 5 to 36, and it is classified in classes I–VI of total real potential of functions.

Table 2. Value classification of real potentials of forest functions

Degree	Classification of actual potential of forest functions (RP_{FF})
0	functionally unsuitable
1	very low
2	low
3	average
4	high
5	very high
6	extraordinary

The real effect represents the topical function effectiveness of a forest ecosystem resulting from its topical condition. It expresses the rate of a produced function with respect to its potential capacities in percentage values (value classification of real effect of forest functions – see Table 3). Real effect of forest functions is derived from real potential of forest function with using the parameters characterising the actual status of forest ecosystems – so called function-reducing criteria – age (forest ecosystem development phase), stocking and health conditions.

Table 3. Value classification of real effects of forest functions RE_{FF}

Degree	Classification of actual effect of forest functions (RE_{FF}) – % of RP_{FF}
0	≤ 10
1	11–30
2	31–45
3	46–55
4	56–70
5	71–90
6	≥ 91

The general formula for calculation of the real effect of forest functions is the following:

$$RE_{FF} = v_T * T + v_Z * Z + v_{ZS} * ZS\ (\%)$$

where:

T – value of the partial real effect of a given function in relation to *age* (stand development phase)

Z – value of the partial real effect of a given function in relation to *stocking* (stand development stage)

ZS – value of the partial real effect of a given function in relation to *health condition* (stand development stage)

v_T – weight of *age* for a given function in the stand development stage

v_Z – weight of *stocking* for a given function in the stand development stage

v_Z – weight of *health condition* for a given function in the stand development stage

Calculation of the value of real topical effects of functions is realised for the whole group of forest functions.

Evaluation of degree of naturalness of forest stands

The degree of naturalness according to Vyskot (Vyskot et al., 2003) is the parameter used for evaluation of the natural tree species composition of forest stands. It is closely associated with the tree species composition – it mainly reflects the tree composition of stands. The spatial structure of stands is reflected only marginally and tree diversity is not included. (See Table 4).

Degree of naturalness according to Vyskot (dependent only on tree species composition) gives somewhat overestimated results (higher degree). Therefore, there was created a new approach for individual naturalness evaluation. It is based on degrees of naturalness according to Vyskot, and it takes into account both vertical spatial structure of the stand and modifications to the tree biodiversity – simplification or "arborisation". Vertical spatial structure of the stand is presented on particular levels. In case of species composition, it shows a considerable simplification (thanks to the trees profitable for natural species composition) or on the contrary the extreme (unnatural) biodiversity. The modification of tree composition reduces the degree of naturalness. Characteristics of these degrees are summarised in Table 5.

Table 4. Degree of naturalness (Vyskot et al., 2003)

Code Degree specification	Degree of naturalness
0 unsuitable	paraclimax – ecotope change (e.g. locust forest), tree species representation of natural composition < 10%
1 very low	exotic species, tree species representation of natural composition 11–30%
2 low	monocultures endangered by air pollution and damaged by game, allochthonous tree species, substitute stands corresponding to air pollution stages A and B, genetically unsuitable stands, tree sp. representation of natural composition 11–30%
3 average	monocultures, cultivated biocoenoses, unsuitable species composition, tree species representation of natural composition < 50%
4 high	semi-cultivated forest, poor species composition, tree species representation of natural composition 51–70%
5 very high	close-to-nature forest differentiated from species and spatial aspects, tree species representation of natural composition 71–90%
6 exceptional	natural species composition corresponding to natural conditions, > 90%

Table 5. Characteristics of new modified degrees of naturalness

DOF 2	DOF 1	Characteristic
3	3	Monocultures, unsuitable species composition, tree species representation of natural composition < 50%. Simplified spatial stand structure
	4	Monocultures, unsuitable species composition, tree species representation of natural composition < 50%. Two- or three-storey spatial stand structure
4	3	Semi-cultivated forest, simplified or unnaturally adjusted composition, tree species representation of natural composition 51–70%. Simplified spatial stand structure.
	4	Semi-cultivated forest, tree species representation of natural composition 51–70%. Close-to-nature tree species diversity. One- or two-storey spatial structure
	5	Semi-cultivated forest, tree species representation of natural composition 51–70%. Close-to-nature tree species diversity. Two- or three-storey spatial structure
5	4	Close-to-nature forest differentiated in species and spatial aspects, tree species representation of natural composition 71– 90%. Partially simplified or unnaturally adjusted composition. Large-area stands with simplified spatial structure
	5	Close-to-nature forest differentiated in species composition, representation of natural composition 71–90%. Close-to-nature tree species diversity. One- or two-storey spatial structure
	6	Close-to-nature forest differentiated in species and spatial aspects, tree species representation of natural composition 71–90%. Close-to-nature tree species diversity. Two- or three-storey spatial structure
6	5	Natural species composition corresponding to natural conditions, > 90% but monocultures of autochtonous tree species. Wide area stands with simplified spatial structure
	6	Natural species composition corresponding to natural conditions, > 90%. Two- or three-storey spatial structure

DOF 1 – Degree of naturalness – (Vyskot et al., 2003); DOF 2 – Degree of naturalness – modified

Results

Comparison of the Czech and Slovak (High Tatra) mountain forests conditions (verification of correctness of usage of the chosen Method)

As it was mentioned above, the Method was elaborated for conditions in the Czech Republic. The first step was verification of its applicability for conditions in the Slovak Republic, especially the High Tatra Mts. Having compared the criteria determining particular forest function, we could conclude that ecosystem conditions in forest complexes in the forest zone at the foothill of the High Tatra Mts correspond to the conditions in the management group of stands (MGS) 71, 73, 75, 77, 79, 1, 2, 3. The Slovak typological units (SSLT – sets of forest types groups) were converted to the Czech MGS. Example of conversion of SSLT to MGS presents Table 6. Conversion of SSLT to MGS was accomplished on base of analogical stand and biocenological conditions according to the particular MGS characteristics. The forest type groups similar in site conditions and production were associated into corresponding management groups of similar stands.

Forest stands damage degrees determination

Figure 1 illustrates distribution of damage to selected forest stands surrounding the town of Tatranská Lomnica, according to particular damage classes.

Real functional potential and topical functional effect of forest stands (GIS records) – on example of social-recreational function

These maps (Figs 2, 3 and 4) present real potentials of forest functions in the model locality Tatranská Lomnica, and the differences in real functional effects of forests stands before and after the wind calamity. Decrease in functional capacity of the forests is evident.

Determination of close-to-nature degree

Confrontation of both types of close-to-nature degree is presented with diagram in Figure 5. This parameter was determined based on the original state of stands before the wind calamity in year 2004.

Relationship between topography (geomorphologic parameters) and damage classes of forest stands

Almost all forest stands in area with smooth topography (very shallow ragged hillside with a mild slope, south-east aspect with only a few gullies and small valleys were extensively damaged (only few small islands of trees have been preserved). All the stands situated under influence of the High Tatra´s peaks (especially Lomnický štít), located on a steep hillside below glacial moraine of Skalnaté pleso have been preserved. The GIS analysis was used to examine the relation between the degree of the stand damage and the damaged stand's location and topography. The following figures (Figs 6–8) present the GIS layers of geomorphological characteristics of the model locality.

The impact of the glacial moraine on the wind flowing was theoretically deduced based on viewshed analysis. A line perpendicular to the wind direction (oriented from south-west to north-east) was created through digitalization of maps in the location of the highest peak in the surroundings (Lomnický štít, 2,655 meters above sea level). The created DEM was converted to TIN (so called Triangulated Irregular Network) and the line representing mountain rocks was added to this TIN. Then this model was divided into 9 regular segments 1,000 meters wide in the windflow direction. In each segment, a central point representing the observation point was located at the middle of the line. The final Viewshed map was created with using viewshed analysis performed from each point to the

Table 6. Example of conversion of SSLT to MGS

SSLT	Nomenclature	MGS	
6111	Extrémna borovicová smrečina vst	1	extremely unfavorable sites
6112	Svieža borovicová smrečina vst	73	acidophilous sites of highlands
6113	Čučoriedková borovicová smrečina vst	73	acidophilous sites of highlands
6121	Sutinová rašelinlková smrečina s jedlou vst	71	exposed sites of highlands
6143	Smlzová smrekovcová smrečina nst	73	acidophilous sites of highlands
6144	Balvanovitá smrekovcová smrečina nst	73	acidophilous sites of highlands
6145	Živná smrekovcová smrečina nst	75	nutritive sites of highlands

SSLT – sets of forest types groups, MGS – management group of stands relevant partial segment and after that by combining of all these rasters together. (See Figs 9 and 10). All the preserved forest stands located on the steep slope below the glacial moraine were determined as hidden – in accordance with our suppositions.

In the next step, all the damaged and preserved forest stands had to be distinguished. The allocation of these stands was specified based on supervised classification of the colored airborne images from the year 2006 with a half-meter resolution. Firstly all pixels were divided into 10 spectral classes and then each class was classified according to its value determined from airborne images (using Iso Cluster and Maximum Likelihood Classification tools of ArcGIS Spatial Analyst extension) (see Fig. 11).

Thanks to classification of the airborne images, there was created binary raster expressing forest stand damage in two categories: 0 – damaged forest stands, 1 – preserved forest stands. Because the analysed area contained also some parts of the town Tatranská Lomnica, where all objects inside the town like buildings and roads were classified wrongly and outside our interest, finally it was necessary to convert all the final maps with a vector layer of forest stands to shapefile format, and then with the visibility layer to exclude the hidden parts. The final grid of the forest stand damage was adjusted into the resulting resolution 10 × 10 meters and all the subsequent analyses cover only this area.

Combining of all the created rasters (Aspect, Slope, Curvature and Forest Naturalness) to the final raster, each pixel received values from all layers. Selection by attribute enables us to explore the data and draw conclusions about the damaged and protected forests such as dominant aspect, dominant

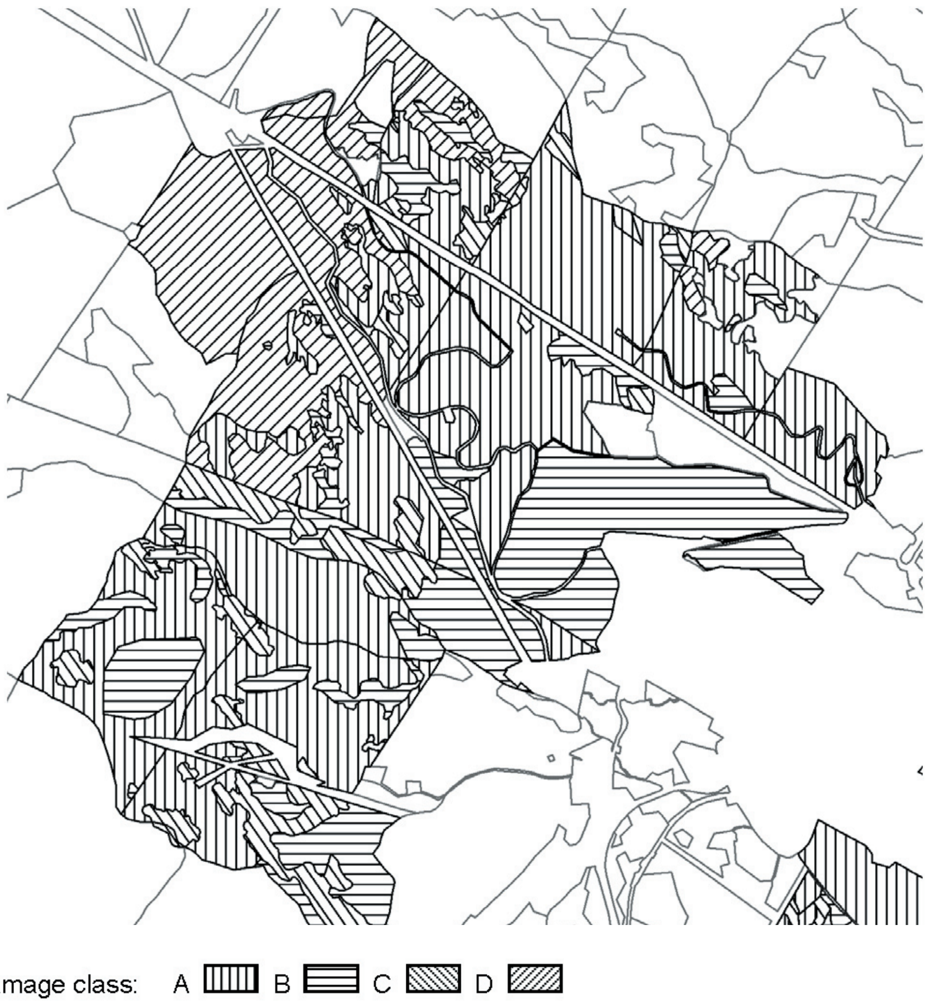

Fig. 1. Damage to selected stands surrounding Tatranská Lomnica (north-western part), according to particular damage classes

slope, curvature and close-to-nature status (see Figure 12 and 13).

The following graphs (Figs 14–17) illustrate terrain characteristics and close-to-nature degree, expressed from the analyzed raster maps in terms of pixel distribution.

Discussion

The GIS software provides with a wide range of possible use in functional evaluation and prediction of ecological detriment (caused by biotic or abiotic factors) to forest stands. However, accuracy of these tools primarily depends on precision of the research method used. The degree of naturalness is a typical example. This parameter is very different in dependence on the author and evaluated element. Another important aspect is the research locality. Final results of analysis are highly influenced by location and characteristics of the research area. Most intensive damage to forest stands was visible in pictures of flat places with south-east aspect, small slope and closest-to-nature forest. This is probably caused by the mentioned location and also with high naturalness of the forest.

Nevertheless, there was elaborated a good methodology for evaluation of forest sustainability. The visibility map shows quite precisely the influence of topography, but for obtaining more precise results it would be necessary to digitize all High Tatra peaks and to create real observation lines. For more precise results, it is necessary to test this method in assessment across a larger area with different geomorfological conditions.

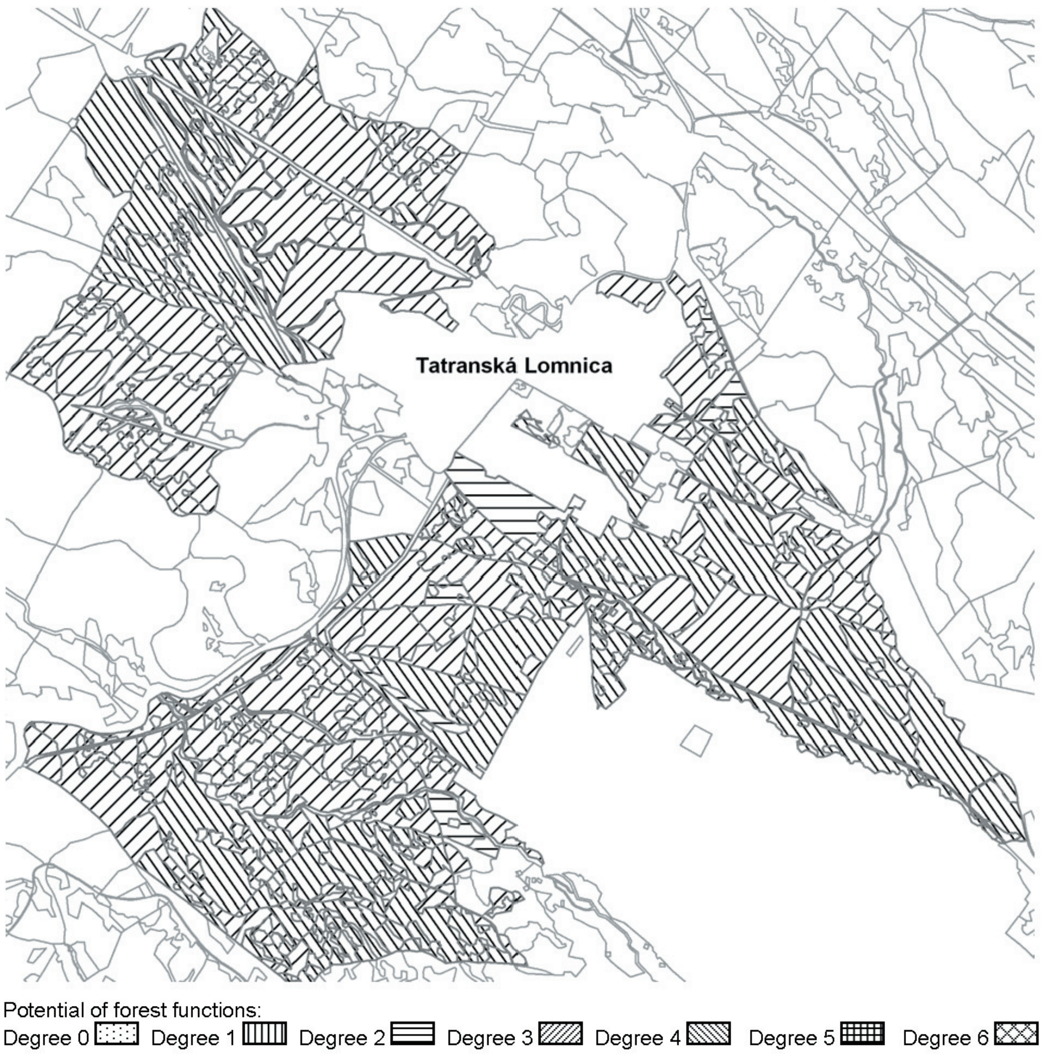

Fig. 2. Real potential of social-recreational function in the model locality Tatranská Lomnica

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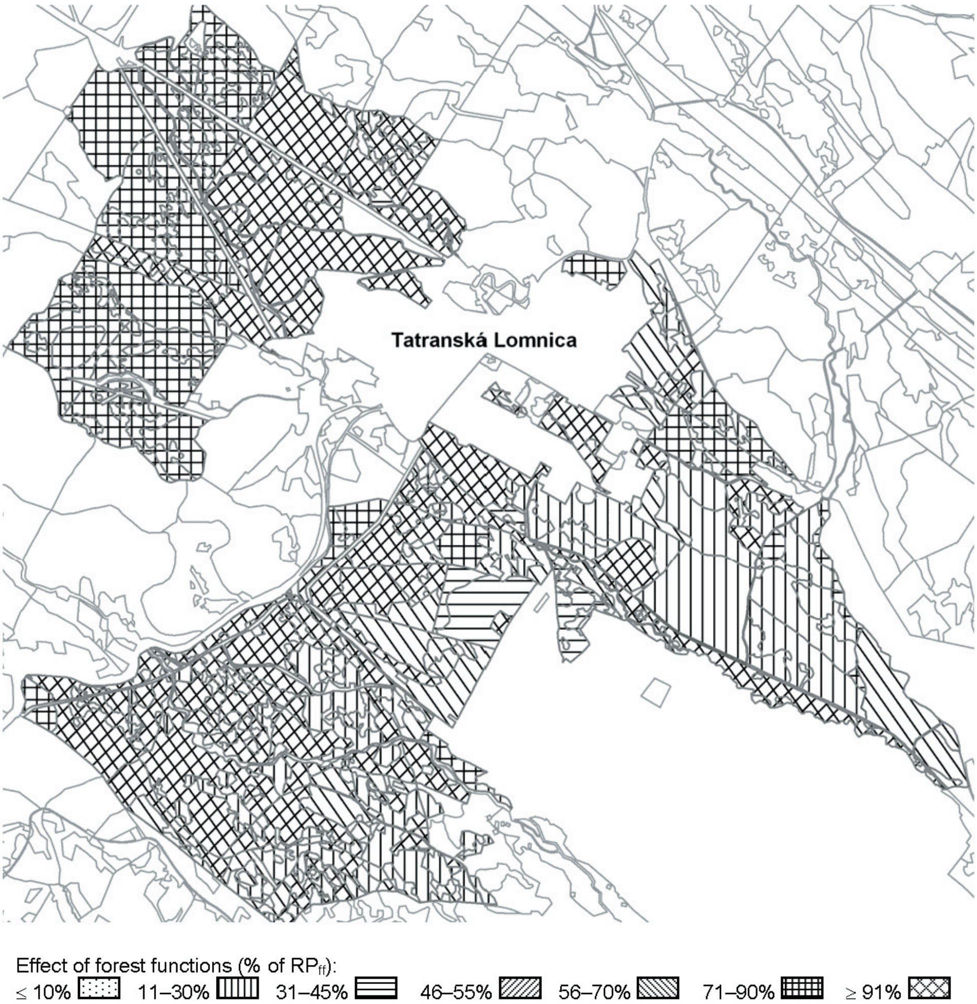


Fig. 3. Real effects of social-recreational function in the model locality Tatranská Lomnica before wind calamity

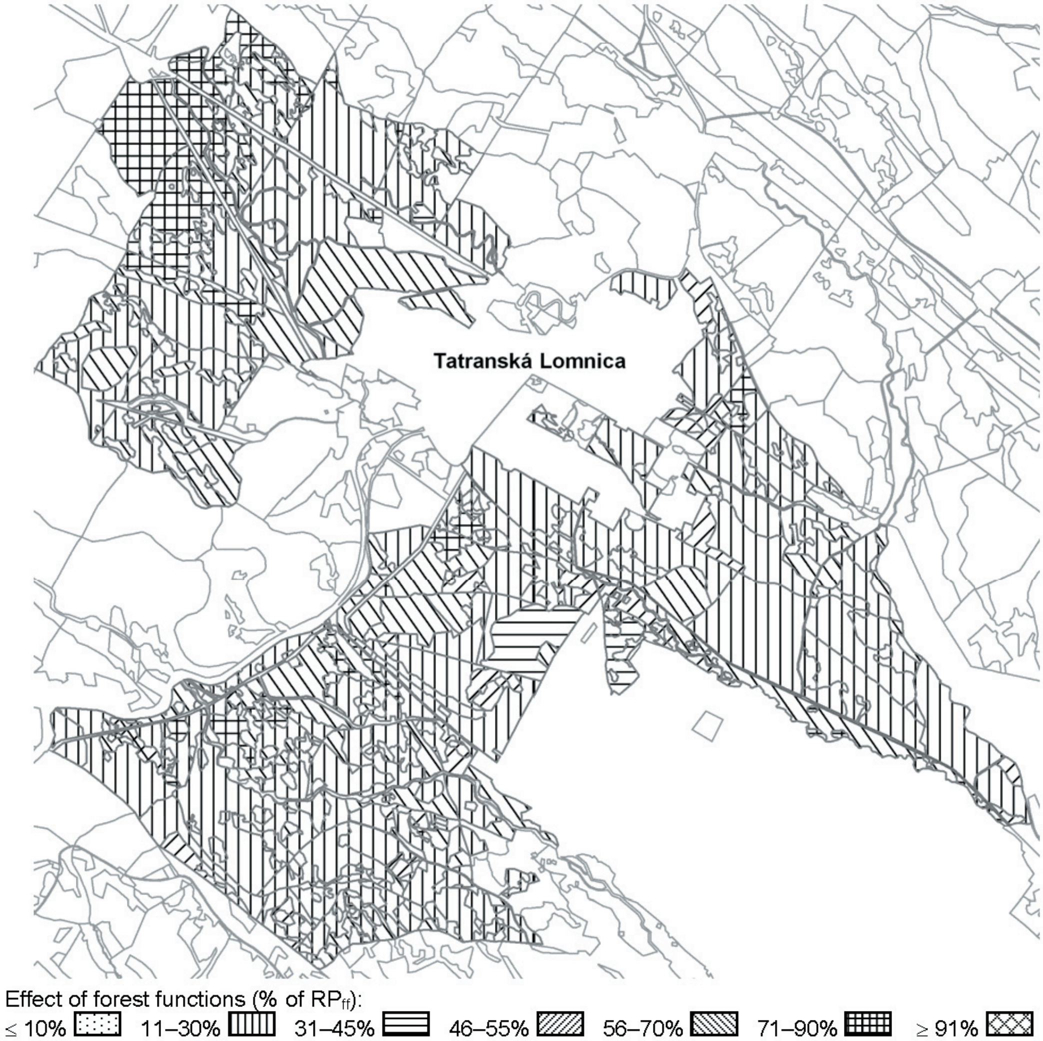


Fig. 4. Real effects of social-recreational function in the model locality Tatranská Lomnica after wind calamity

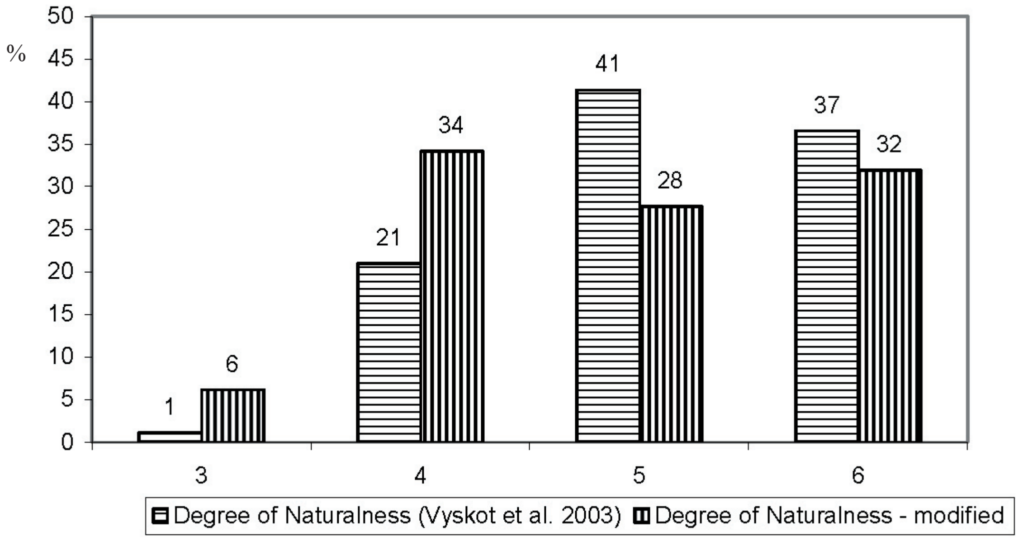


Fig. 5. Distribution of degrees of naturalness according to Vyskot and modified in %

Fig. 6. Aspect (exposition) map of the model locality Tatranská Lomnica

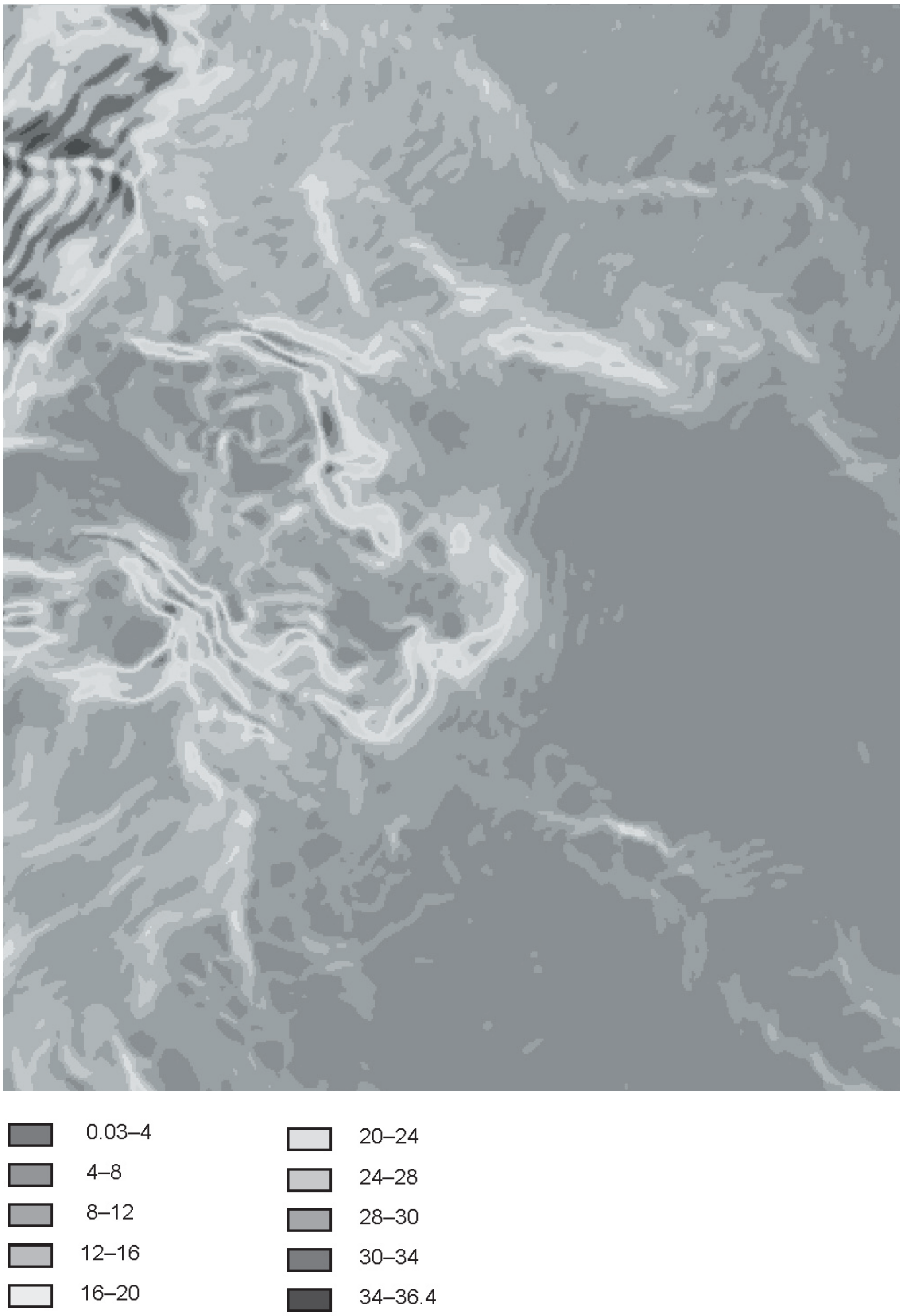


Fig. 7. Slope map in degrees of the model locality Tatranská Lomnica

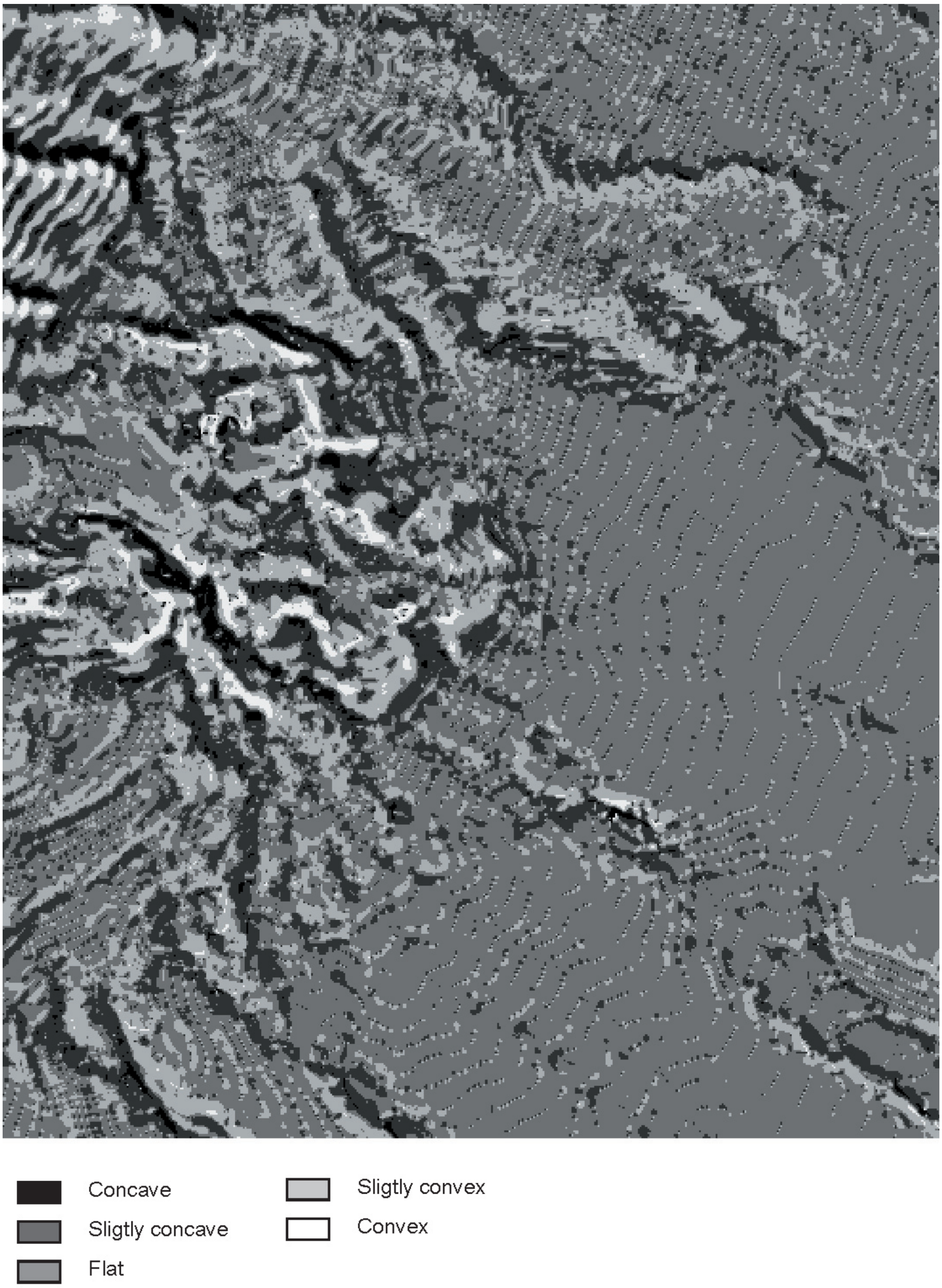


Fig. 8. Curvature map of the model locality Tatranská Lomnica

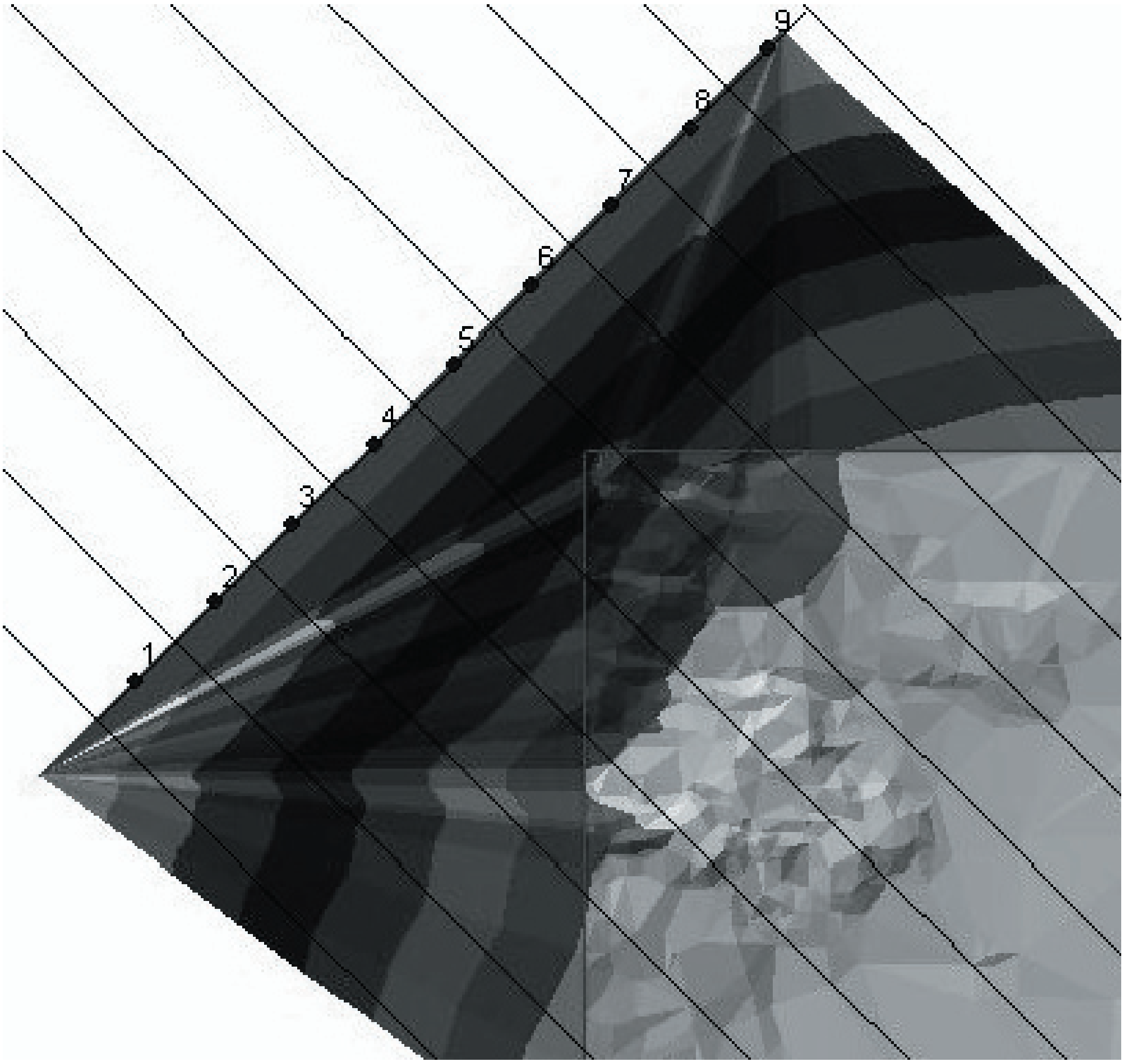


Fig. 9. Creation of Wiewshed Map

Fig. 10. Final Wiewshed Map

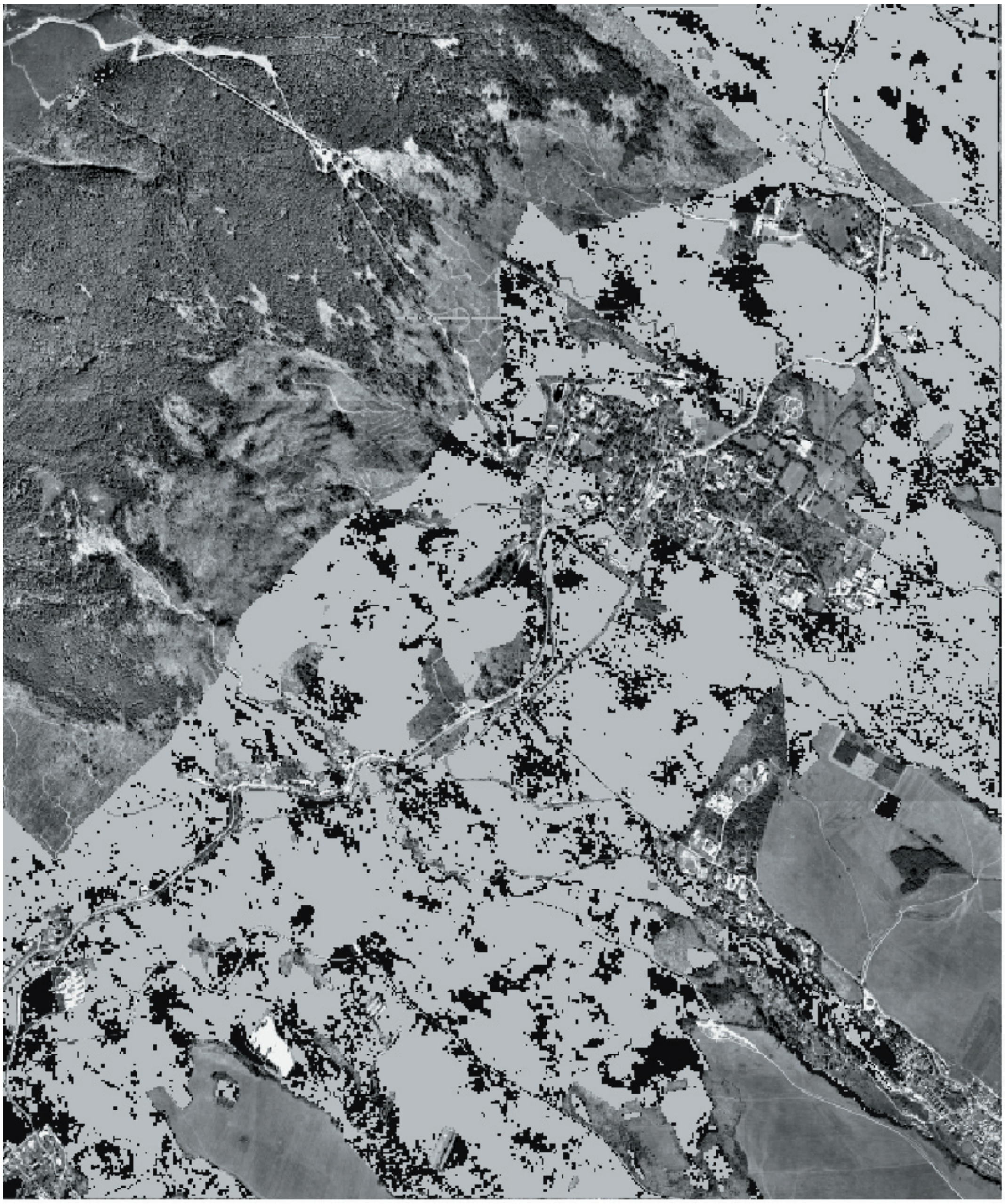


Fig. 11. Map of damage to forest stands

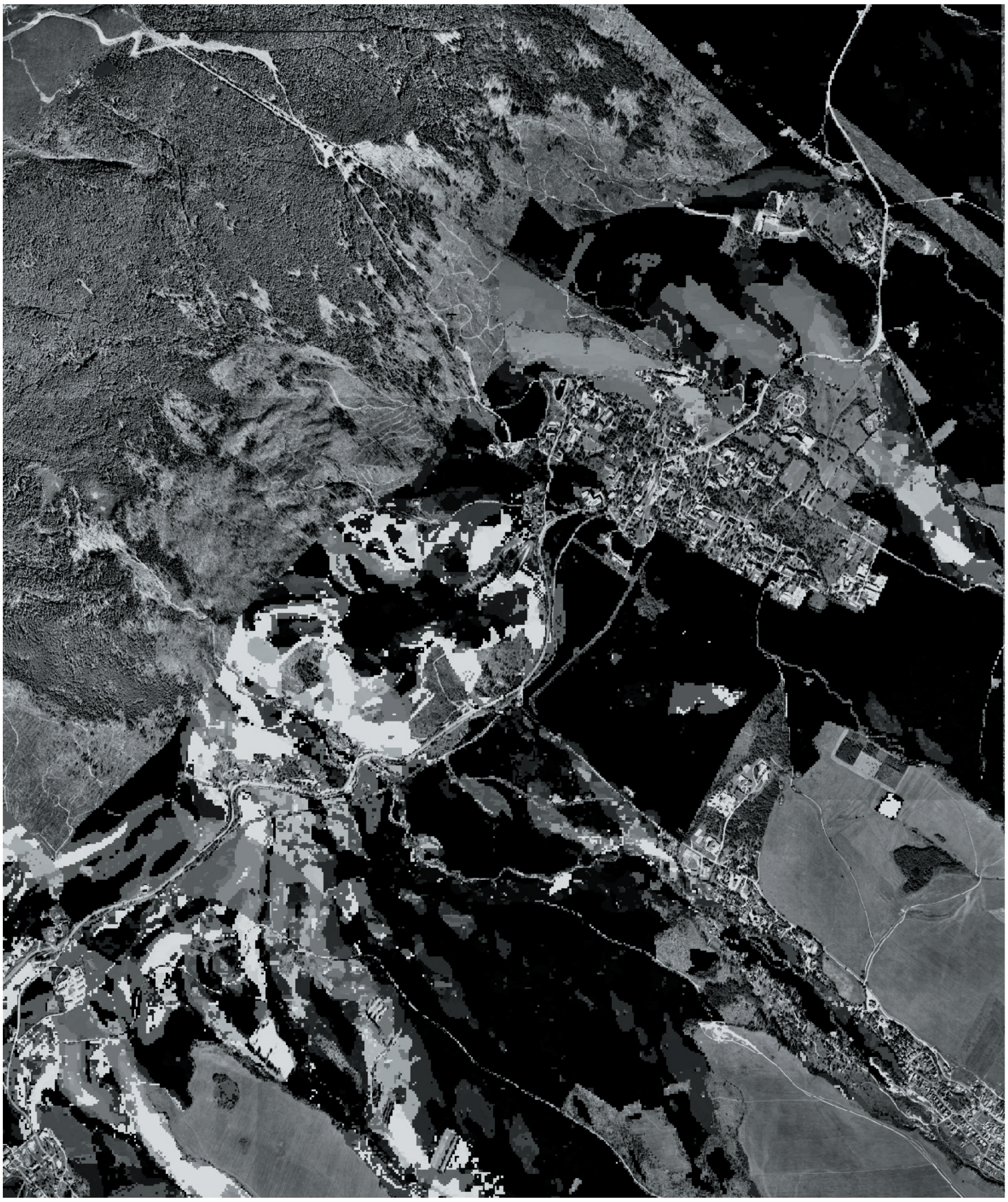
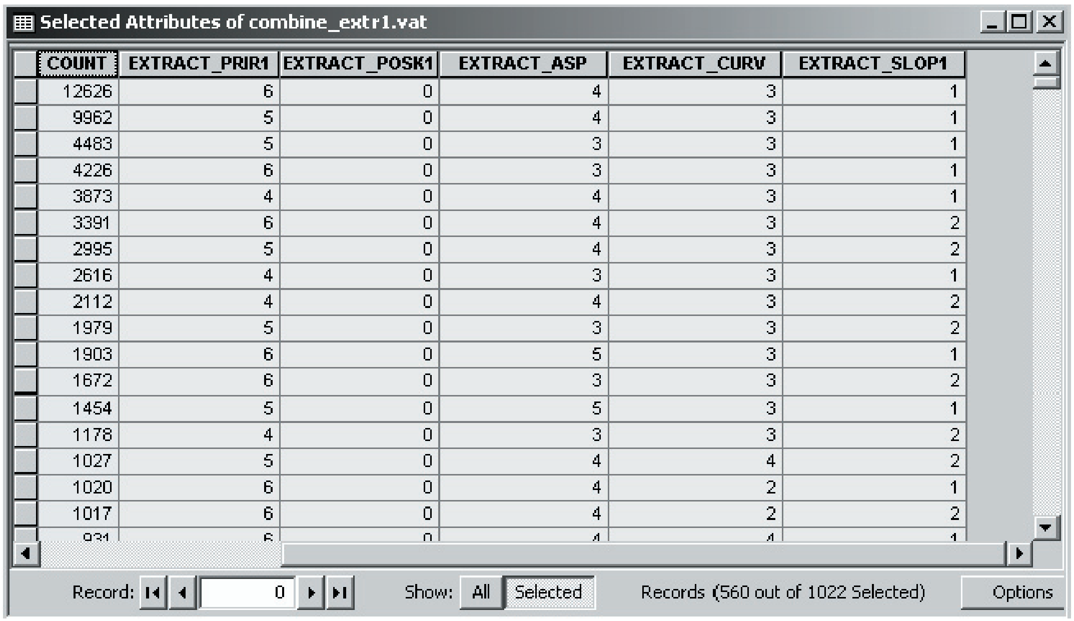


Fig. 12. Combinations of all layers

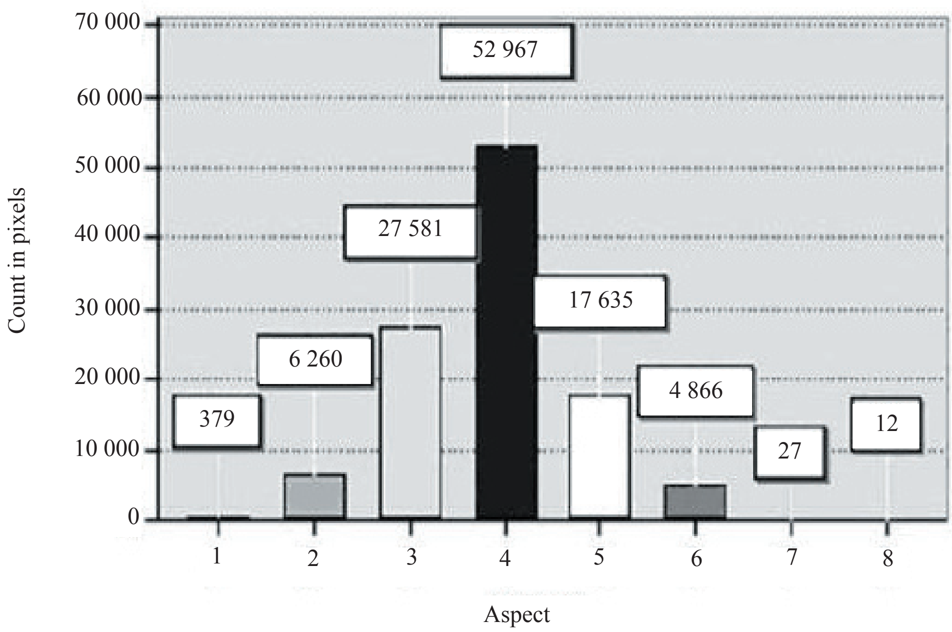


Selected Attributes of combine_extr1.vat

COUNT	EXTRACT_PRIR1	EXTRACT_POSK1	EXTRACT_ASP	EXTRACT_CURV	EXTRACT_SLOP1
12626	6	0	4	3	1
9962	5	0	4	3	1
4483	5	0	3	3	1
4226	6	0	3	3	1
3873	4	0	4	3	1
3391	6	0	4	3	2
2995	5	0	4	3	2
2616	4	0	3	3	1
2112	4	0	4	3	2
1979	5	0	3	3	2
1903	6	0	5	3	1
1672	6	0	3	3	2
1454	5	0	5	3	1
1178	4	0	3	3	2
1027	5	0	4	4	2
1020	6	0	4	2	1
1017	6	0	4	2	2

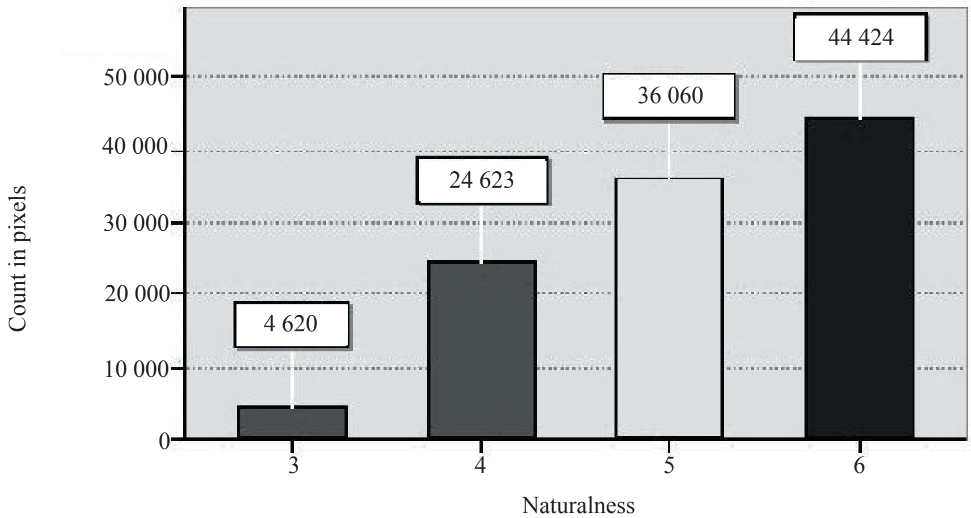
Record: 0 Show: All Selected Records (560 out of 1022 Selected) Options

Fig. 13. Final attribute table of combined data ordered descending by count of pixels expressing the damage class to the forests



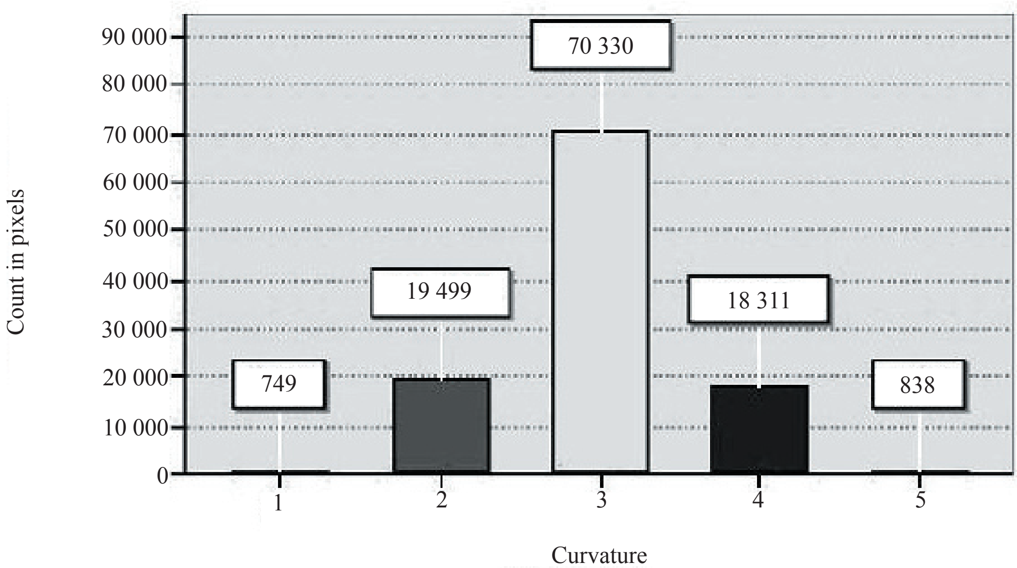
1 – North, 2 – Northeast, 3 – East, 4 – Southeast, 5 – South, 6 – Southwest, 7 – West, 8 – Northwest

Fig. 14. Aspect (exposition) of damaged forest stands in the model locality Tatranská Lomnica



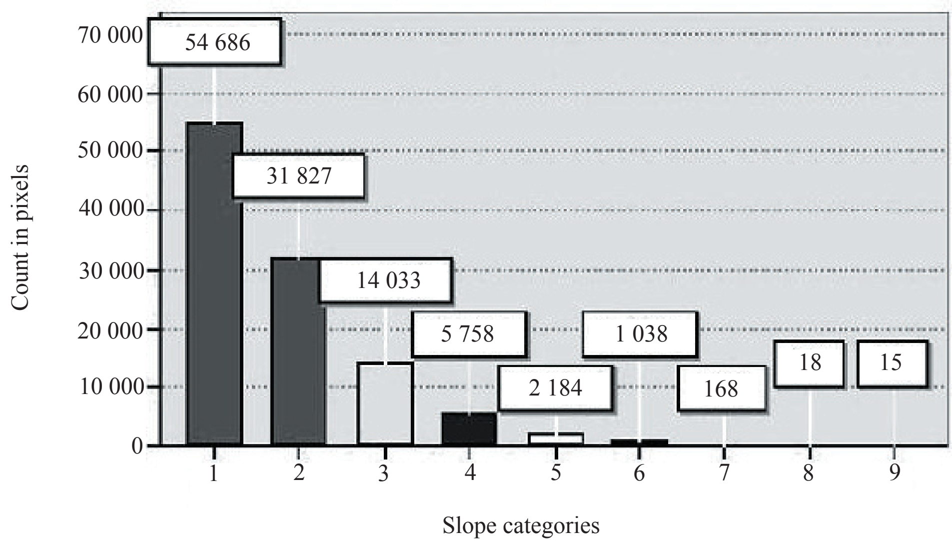
3 – Average, 4 – High, 5 – Very high, 6 – Extraordinary

Fig. 15. Naturalness of damaged forest stands in the model locality Tatranská Lomnica



1 – Concave, 2 – Slightly concave, 3 – Flat, 4 – Slightly convex, 5 – Convex

Fig. 16. Curvature of damaged forest stands in the model locality Tatranská Lomnica



1 – 0 to 4 deg, 2 – 4 to 8 deg, 3 – 8 to 12 deg, 4 – 12 to 16 deg, 5 – 16 to 20 deg, 6 – 20 to 24 deg, 7 – 24 to 28 deg, 8 – 28 to 30 deg, 9 – 30 to 32 deg

Fig. 17. Slope analysis of damaged forest stands in the model locality Tatranská Lomnica

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Možnosti využití GIS pro hodnocení ekologických škod na příkladě větrné kalamity, která proběhla v Národním parku Vysoké Tatry

Souhrn

Článek prezentuje jednu z možností využití geografických informačních systémů (GIS) při hodnocení ekologických škod na příkladě větrné kalamity, která proběhla v Národním parku Vysoké Tatry v listopadu 2004. Do hodnocení byly zahrnuty poškozené lesní porosty v okolí Tiché and Kôprové doliny a obcí Vysoké Tatry a Vyšné Hágy. Poškození lesních porostů bylo kvantifikováno prostřednictvím hodnocení újmy na funkcích lesů metodou Kvantifikace a hodnocení funkcí lesů (Vyskot, I. a kol., 2003), kdy byly jednotlivé lesní porosty zařazovány do tzv. tříd poškození. Prostředí GIS ArcView bylo využito pro parametrizaci vztahu míry poškození lesních porostů větrnou kalamitou a geomorfologických podmínek jejich stanovišť.

Hodnocením stavu lesních porostů a GIS analýzou vztahu mezi geomorfologickými parametry a třídami poškození před a po větrné kalamitě bylo zjištěno:

- zcela poškozeny byly porosty lokalizované na svazích bez výrazných terénních nerovností, jihovýchodní expozice s mírným sklonem 0–8 %,
- na území v okolí Tatranské Lomnice byl prokázán vliv horských štítů a terénních zlomů Vysokých Tater (konkrétně Lomnického štítu a Skalnatého plesa); na prudkých svazích se sklonem nad 20 % pod Skalnatým plesem porosty nebyly významně poškozeny,
- nebyla prokázána přímá závislost mezi stupněm přirozenosti porostů a rozsahem poškození.

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Prediction of medium- and long-term changes in soil reaction in a beech forest based on observations in the beech stemflow zone

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Abstract

Pichler, V., Gregor, J., Homolák, M., Capuliak, J. Bebej, J., Váľka, J. 2007. Prediction of medium- and long-term changes in soil reaction in a beech forest based on observations in the beech stemflow zone. *Folia oecol*., 34: 146–152.

The active soil reaction in a mature beech forest subjected to alkaline dust deposition reflected parallel influence of both alkaline and acid deposition. As a result, the active soil reaction within the stemflow zone at the depth of 5–10 cm decreased from 7.4 and 6.5 to 5.9 and 4.7, respectively. Outside the stemflow zone, the soil pH values were reduced from 7.9 to 6.6. This phenomenon occurred due to the long-range acid air pollution transport. Stechiometric calculations showed that the amount of acid deposition was amplified through the stemflow effect in beech trees that in their turn partly offset the alkaline deposition. Thus, the active reaction of the topsoil subjected to stemflow moved from moderately alkaline to moderately acid range during the period 1990–2006, while a similar shift from moderately alkaline towards neutral values occurred outside the stemflow zone. The pH decrease was correlated with a more than 90% reduction in alkaline dust emissions from magnesite works. In the stemflow zone, the active soil reaction at the depth of 5–10 cm is supposed to remain in the related intervals up to about 2030. Outside the stemflow zone, the active soil reaction at the same depth should persist in the neutral range until 2015. Subsequently, the active soil reaction will move towards the moderately acid range even outside the stemflow zone. Standard forest management will probably cause the active soil reaction to converge to the original soil pH value of 5 in the course of approximately 200 years.

Keywords

forest soils, beech forests, stemflow, alkaline deposition, acid deposition, soil reaction prognosis

Introduction

Acidification or alkalization of soils occurs through H^+ transfer processes across vegetation cover, soil solutions and soil minerals (Bremen et al., 1983). Important determining factors are: composition and development of vegetation, soil-forming parent material, woody species composition, air pollution and variability of soil properties. On one hand, the Slovak Republic has an unfavorable position, being heavy influenced with long-range air pollution transport. Prevailing western and northwestern winds displace airborne pollutants towards the Central Europe. Therefore, inputs of sulphates, nitrates and other acid components into forest ecosystems remain high, despite a considerable drop in domestic emissions (Pichler and Bublinec, 2006).

Along with the acidification of forest soils, however, their alkalization took place across certain localities, such as the Muráň Valley, as well. It features a high concentration of magnesite industry whose products play an important role in exports of the Slovak Republic. The production is based on the magnesite deposits in the Carboniferous rocks. Currently, two major plants in Jelšava and Lubeník are functioning within the area of interest, but their recent impact on the surrounding environment has been limited due to the introduction of efficient separation facilities. In the past, mainly between 1970 and 1990, that situation was different due to the continuous release of polydisperse emissions containing solid particles of magnesium and calcium oxide, making several thousand metric tons a year. This fact has resulted in a considerable degradation of the adjacent areas, where the Mg content in soils exceeded 2,000 mg kg^{-1} (Bobro et. al., 2000; Hančuľák and Bobro, 2004). According to these authors, soils of some monitoring plots have already begun to lose their Mg surpluses due to improved situation in airborne pollutant load, ie in places where the Mg input does not exceed the natural Mg losses of 23–34 kg ha^{-1} $year^{-1}$ any longer. The alkaline reaction in the local soils has been caused by presence of low soluble minerals such as periclase, magnesite, calcite and amorphous MgO. The magnesium losses thus occur mainly owing to the secondary minerals such as hydromagnesite, nesquehonite, brucite and others that are able to migrate as a part of the soil solution (Bobro et al., 2000).

The main adverse effect of the strongly increased alkalinity consists in the nutrients immobilisation, because the optimum reaction varies between pH 5.0–6.5. Among the elements whose intake by plants is affected, phosphorus, potassium, nitrogen and trace elements rank comparatively high (Bublinec, 1971).

In this context, it is important to note that conclusions on the impact of natural or anthropogenic depositions are often made based on their isolated effects. In reality, however, combined effects of various depositions are rather a rule than an exception, and they depend on their concentrations and variable exposure times. Thus, the result may be additive, synergic or even antagonistic (Anonymus). Neither assessments nor predictions of airborne pollution impact on soils should therefore be made without a proper attention paid to their mutual interactions. The interaction processes in respect to their transport mechanisms, deposition, chemical reactions, kinetics and spatial heterogeneity of the environmental patterns manifest a high variability both in space and time. To identify the trends means to investigate processes on appropriate time scales and choose suitable validation procedures.

In our study, we leaned on the amplification of airborne pollutants input through stemflow. Stemflow is typical of various beech species due to the specific habitat of the genus *Fagus* (Gersper, 1970; Gersper and Holowaychuk 1970), as different from other species such as oak (Tužinský and Soroková, 2002). Jochheim and Schäfer (1988) established that the stemflow zone received eight times more water enriched by particles and dissolved chemical compounds in comparison with areas only exposed to throughfall. Such processes led to formation of spots in which soil was significantly acidified due to higher amount of acid deposition from coal-fired power plant and remote pollution sources (Šály and Pichler, 1993). Their existence influenced the spatial variability of soil microbiological activity (Gömoryová, 2004a, 2004b). The stemflow-impacted zone was also used by Werner (1988) to study the processes of heavy metals accumulation in forest soils. In a broader sense, it has been the application of geobiocenotic fields concept as defined by Zinke (1962) and Karpachevsky (1977). It relies on the fact that trees, as the main edificators in forest ecosystems, modify the effects of environmental factors in a predominantly circular or radial pattern.

Our approach aimed at the description, interpretation and prediction of soil reaction changes under the influence of past alkaline deposition and continuing acid deposition in the Muráň Valley. The study goals consisted in establishing how the soil pH changes under the European beech trees (*Fagus sylvatica* L.) in the area of interest are likely to be influenced by the stem flow under the current load by airborne pollutants.

Material and methods

We based our investigations on several assumptions:

- The increase in hydrogen protons in the buffer intervals of carbonates (pH 6.2–8.6), silicates (pH 5.0–6.2) and sorbents (pH 4.2–5.0) as defined by Ulrich (1983) can be considered approximately as a linear process.
- An n-fold increase in the acid deposition causes an n-fold acceleration of a soil acidification (Sparks, 2003).

Site description

The soil sampling was carried along a transect in hills of the Revúcka Vrchovina Mts, on the northern slope of Tri Peniažky (583 m asl), 2.5 km SSW of the Jelšava Magnesite Plant, at an elevation of 490 m asl. (Fig. 1). The area is built by black and grey schists and white crystalline limestones from the carboniferous period. The yearly precipitation amount reaches 800 mm. In 1990 when the first sampling was performed, the 95-year-old beech stand had 0.8 stocking and 90% canopy closure. It belongs to the Fagetum pauper forest association with scarce herb layer of *Hedera helix*. The original soil type was Dystric Cambisol whose reaction was around pH 5.0, but it increased to 7.5–8.0 by 1990 due to magnesite pollution. In spite of the alkaline airborne pollution load, the beech forest did not show signs of physiological damage.

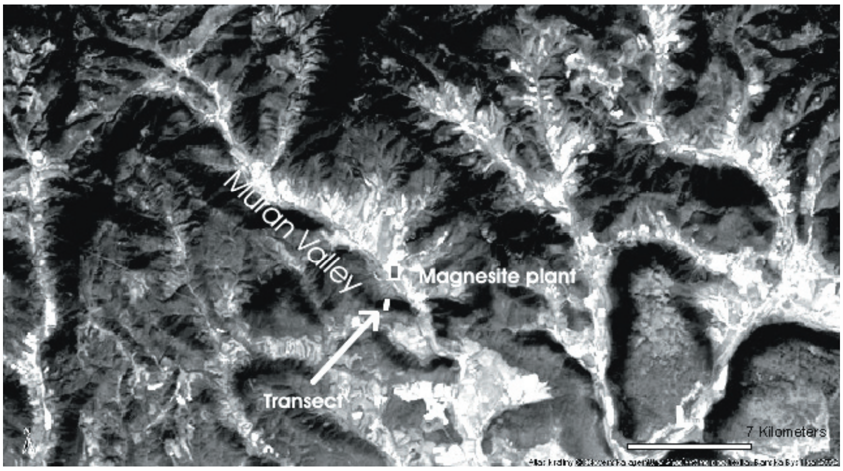

Fig. 1. Tri Peniažky beech transect and Jelšava Magnesite Plant in the Muráň Valley

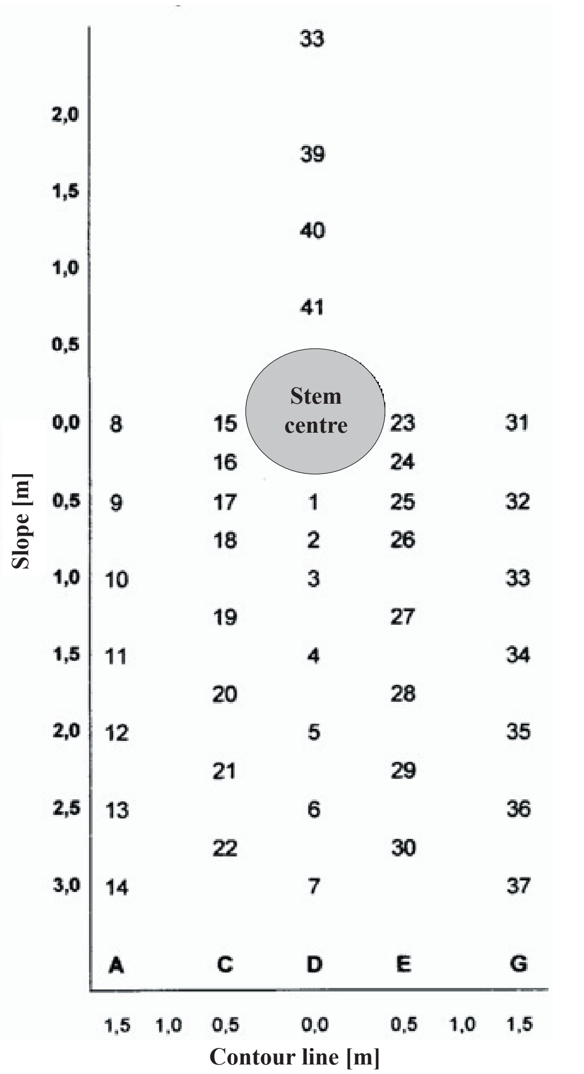

Fig. 2. Soil sampling scheme at Tri Peniažky beech transect

Soil samples

The soil sampling was carried out under five beech trees from the main canopy, ie tree classes 1 and 2 according to Kraft (1884), in October 1990 and 2006. Samples weighing 250 g were taken from the depth of 5–10 cm, according to the sampling scheme given in Fig. 2. The active soil reaction in samples was measured in the laboratory, using a glass ion-sensitive electrode referenced with a standard calomel electrode and a meter (Schofield and Taylor, 1955).

Data analysis

Spatial interpolation among the discrete pH values was performed to identify the stemflow zone defined as a circular or elliptical continuous area with comparatively low pH around the stem. Subsequently, the area-wise ratio between the stem flow zone and the rest of the scheme was calculated. The ratio was used as a percentile dividing the set of measured soil pH values into two classes – affected by either stemflow or throughfall. The pH values were then recast as hydrogen protons concentrations, according to the relation pH = $-\log[H^+]$ and $C_{(H+)} = 10^{(-pH)}$. Regression and correlation analysis was applied to the hydrogen protons activities. Extrapolated trends in both active and exchange reactions were projected, using regression lines. To assess the prediction, the $C_{(H+)}$ increase in soil subjected to stemflow from 1990 to 2006 was compared with the corresponding values in soil exposed to the througfall only. We then established whether the result would fell into the same order of magnitude as the stemflow/throughfall ratio, ie 6–12, as given by Tužinský (2004) and Johnson and Lehmann (2006).

Results and discussion

Interpolated contours of the active soil reaction at the 5–10 cm depth under the beech trees based on values measured in 1990 are given in Fig. 3. Similar contours based on samples taken from the same depth in 2006 are graphed in Fig. 4. A simple ocular inspection of the graphs shows a considerably increased soil reaction span in 2006 when compared to 1990. Also the spatial variability of soil reaction increased by 2006 due to heterogeneity of throughfall, as indicated by an increased number of circular patterns of pH contours. The comparatively lower spatial variability in soil reaction as recorded in 1990 apparently occurred due to distinctive processes connected with acid and alkaline deposition. The deposition of alkaline dust on the soil surface is spatially more uniform. During the winter season, it settles on the snow cover surface that releases it during the snowmelt. At the same time, acid airborne pollutants are much less captured by the snow particles. Their maximum input occurs in the spring when they are dissolved in the raindrops that must penetrate the foliated tree canopies that cause a considerable spatial variability of throughfall (Krečmer and Fojt, 1981). It is the liquid precipitation that has the highest capacity to capture and dissolve the sulfate emissions (Pichler and Bublinec, 2006). Finally, only these take part in the stemflow process. The observed increase in the active soil reaction across the entire soil surface developed owing to the highly active MgO and better soluble CaO, along with the products of their reaction with the air and soil CO_2, or with the air and soil moisture, ie $MgCO_3$, $Mg(OH)_2$ (Novák 1981) and $Ca(OH)_2$.

In spite of the full area soil pH increase, the process of the planar differentiation had already begun by 1990, because the initial stage of stemflow zone formation could be detected at that time (Fig. 3). Data in Table 1 show the 10th and 90th percentiles for the measured soil pH values. All the data bellow the 10th percentiles fall into the zone subjected to stemflow that had an average planar area of 0.16 m², as seen from Table 2. From these tables, a 10th percentile decrease and a stemflow zone planar increase are evident.

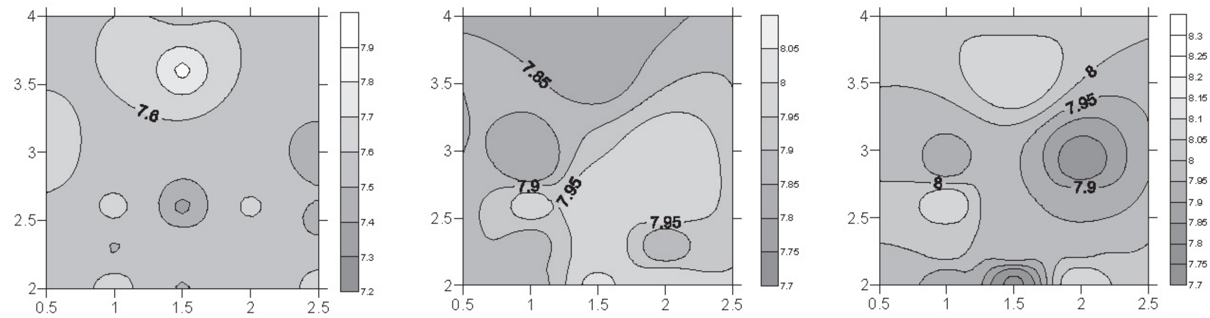

Fig. 3. Active soil reaction contours at Tri Peniažky beech transect, measured in 1990
Beech stem centres have co-ordinates [1.5, 1.5].

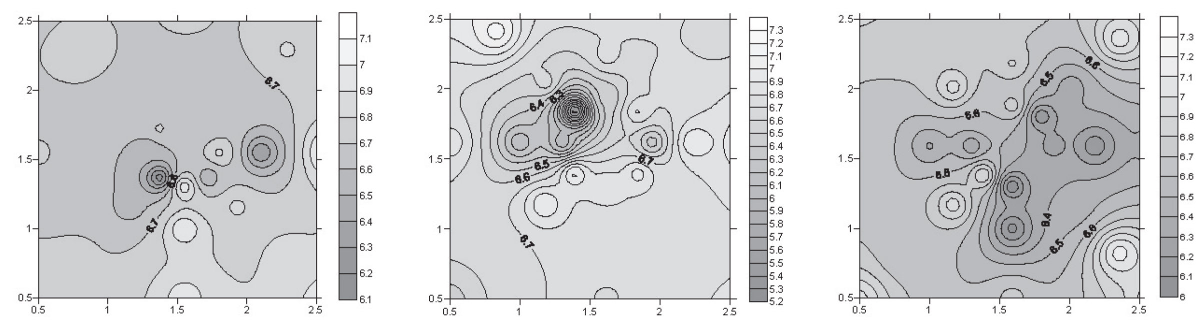

Fig. 4. Active soil reaction contours at Tri Peniažky beech transect, measured in 2006
Beech stem centres have co-ordinates [1.5, 1.5].

Table 1. Basic statistical characteristics of the active soil reaction values, measured at the Tri Peniažky beech transect

Year	Valid N	Mean	Minimum	Maximum	10^{th} percentile	90^{th} percentile	Std. dev.
1990	227	7.80	7.22	7.84	7.50	8.01	0.23
2000	127	6.72	5.25	7.30	6.34	7.06	0.30

Table 2. Planar areas of zones impacted by stemflow and throughfall at the Tri Peniažky beech transect

Zones	Planar Area [m^2]	
	1990	2006
Stemflow zone	0.16	0.28
Througfall-affected zone	3.84	3.72
Total area	4.00	4.00

That resulted from an antagonistic effect of the acid deposition containing H_2SO_4 and HNO_3 along with H_2CO_3 on one side, and the aforementioned alkaline dust on the other side. If the S and N deposition within the area of interest, amounting to 2.0 g m^{-2} $year^{-1}$ S and 1.5 g m^{-2} $year^{-1}$ N (Závodský, 2002a, b), is considered, it corresponds stoichiometrically to approximately 2.8 g m^{-2} $year^{-1}$ Mg that enters chemical reactions with both elements. According to the measurements from the margins of the area of interest, the total deposition of Mg in 1998 varied around 2.1 g m^{-2} $year^{-1}$ (Hančuľák and Bobro, 2004). The literature gives 3.0 g m^{-2} $year^{-1}$ of Mg as a natural loss from soils (Hronec, 1996; Indrikson and Zalitis, 2004). From this point of view, secondary minerals originating in an airborne-pollution-loaded environment such as hydromagnesite, nesquehonite, brucite and others play an important role, while they are able to migrate at least partially with the soil solution (Bobro et al., 2000), similar to easy-soluble $Mg(NO_3)_2$ that forms deposition during reactions with $(NO_3)^-$. In this rough approximation, we did not consider the natural loss of magnesium from soil due to retention in the tree biomass as sulphur too was retained in that pool. Moreover, we assumed that the nutrients intake occurred from the original mineral part of the soil.

Further development of active soil reaction at 5–10 cm between 1990 and 2006 showed that the magnesium loss from the soil under investigation prevailed over the alkaline dust deposition. During the 15 study years, the active reaction dropped from 7.4 to 5.9 within the stemflow zone. In the throughfall zone, such drop was much less pronounced, from 7.9 down to 6.6 (Fig. 5). Based on Fig. 5, we can conclude that the active soil reaction in the stemflow zone decreased from the moderately alkaline interval into moderately acid interval. In the throughfall zone, the soil reaction changed from the moderately alkaline interval into neutral. The reaction is supposed to remain in these intervals till 2030 and 2015 respectively.

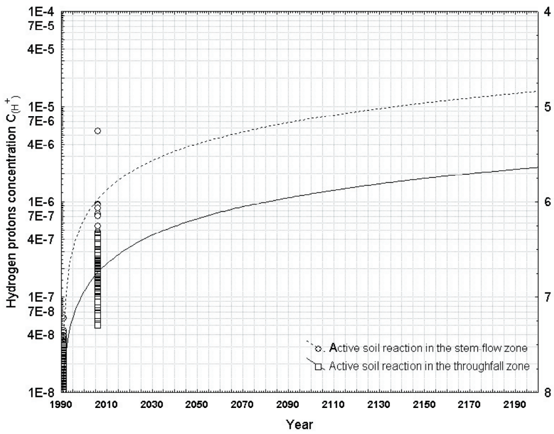

Fig. 5. Regression lines of the active soil reaction in the stemflow and throughfall zones at the Tri Peniažky beech transect

These predictions are consistent with the generally observed six- to twelve-times-higher rainwater input into the stemflow zone compared to the throughfall, which means that such an increase in water percolation linked with the corresponding immission load speeds up proportionally the soil acidification processes in the stemflow zone compared to the throughfall-impacted zone. Indeed, according to Fig. 5, the soil pH values in the throughfall zone will decrease to levels measured in the stemflow zone in 2006 by 2080 so that the process will take six times longer than in the stemflow zone. That is also in compliance with the assumption of increased acidification resulting from higher acid airborne pollution load according to Sparks (2003).

Conclusions

The measurement and evaluation of both active and exchangeable soil reaction under a mature beech forest growing within an area under alkaline dust deposition from the Magnesite Works, Inc., Jelšava, showed an antagonistic influence of the alkaline pollution and acid deposition from both local and remote sources. The resulting pattern was co-determined by the stemflow water percolation through the topsoil.

Thus in 1990, the soil pH values measured in H_2O unexpectedly did not indicated any increase compared to the values measured in samples taken outside the stemflow zone. Instead, there was found an overall increase in the actual reaction to 7.5–8.0 over the whole area, irrespective of the sampling point position.

Stoichiometric calculations showed that the amount of acid deposition amplified by the stemflow effect of beech trees has mitigated the alkaline deposition. By 2006, such trends in the relevant forest stand prevailed in general. In the stemflow zone, the active soil reaction at the depth of 5–10 cm decreased from 7.4 and 6.5 to 5.9 and 4.7, respectively. Outside the stemflow zone, the pH reduction was less dramatic, from 7.9 to 6.6. So, during the period 1990–2006, the active reaction of the topsoil subjected to stemflow moved from moderately alkaline to moderately acid while a similar shift from moderately alkaline range towards neutral values occurred outside the stemflow zone. The pH decrease was correlated with a more than 90% reduction in alkaline dust emissions from the magnesite plant.

The active soil reaction at the 5–10 cm depth in the stemflow zone is supposed to remain in the respective intervals until 2030. Outside the stemflow zone, the active soil reaction at the 5–10 cm depth will probably persist in the neutral range until 2015. Subsequently, the active soil reaction will move towards the moderately acid range even outside the stemflow zone. Under the standard forest management, the active soil reaction is to converge to the original approximate soil pH 5 in the course of approximately 200 years.

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Stredno- a dlhodobá predpoveď pôdnej reakcie v bučine na základe pozorovaní zóny stoku po kmeni buka

Súhrn

Meraním a vyhodnotením aktívnej a výmennej pôdnej reakcie v bukovom poraste v okrajovej časti oblasti zasiahnutej alkalickým prašným spadom zo Slovenských magnezitových závodov, a. s., Jelšava, bol preukázaný vzájomne protismerný účinok alkalického prašného spadu na jednej strane, a kyslých imisií z diaľkového prenosu v kombinácii s intenzívnou perkoláciou vody v pôde zóny stoku po kmeni bukov. V zóne stoku po kmeni buka, kde sa účinky oboch depozícií prejavili v podobe zosilnenej účinkom jedincov buka ako edifikátorov geobiocenotických polí, t. j. pôsobením stoku po kmeni, dosiahla už v roku 1990 výmenná reakcia pôdy v hĺbke 5 cm hodnoty pH 6,2–6,6 z mierne kyslého intervalu, hoci aktuálna aj výmenná reakcia pôdy celoplošne vzrástla až na úroveň pH_{H_2O} 7,56–8,00 a pH_{KCl} 7,0–7,2.

Ďalší vývoj aktívnej reakcie pôdy v hĺbke 5–10 cm v období rokov 1990 a 2006 preukázal odbúranie antropogénnej alkalinity pôdy. Počas 15-tich rokov poklesla aktívna pôdna reakcia v hĺbke 5–10 cm v zóne stoku po kmeni zo 7,4 na úroveň 5,9. V medzikmeňovom priestore bol pokles aktívnej reakcie v tejto hĺbke menej prenikavý, z hladiny 7,9 na 6,6. V medzikmeňovom priestore nastal pokles aktívnej reakcie zo 7,7 na 6,8. Aktívna reakcia pôdy vystavenej pôsobeniu stoku po kmeni bukov tak poklesla za obdobie od roku 1990 do roku 2006 z mierne alkalického pásma do mierne kyslého pásma, v medzikmeňovom priestore z mierne alkalického pásma do neutrálneho pásma.

Predpokladaná doba ďalšieho zotrvania aktívnej pôdnej reakcie v uvedených pásmach bude v zóne stoku po kmeni v hĺbke 5–10 cm do r. 2030. V medzikmeňovom priestore zotrvá aktívna pôdna reakcia podľa použitého modelu v neutrálnom pásme v hĺbke 5–10 cm iba do roku 2015. Následne sa aktívna reakcia pôdy v medzikmeňovom priestore posunie do mierne kyslého pásma. Viac ráz opakované vyťaženie a opätovná obnova porastu povedú k postupnej konvergencii aktívnej reakcie pôdy v zóne stoku a v medzikmeňovom priestore na pôvodnú úroveň pH_{H_2O} 5.

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