Changes in air quality in different phases of forest management process in a sub-mountain beech ecosystem (West Carpathian Mts.)

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ABSTRACT: We studied air quality in a sub-mountain beech ecosystem in the Kremnické vrchy Mts., Central Slovakia. We chose the method of passive sampling. The amounts of airborne pollutants (H^+ and O_3) were determined at regular time intervals, covering the whole vegetation period, on four plots with different stocking. The original stand was subjected to two cuts with a purpose to simulate the phases of a common silvicultural process. The first research period (1999–2003) started 10 years after the first cutting, the second (2004–2006) was launched immediately after the second cut. Ten years after applying the first cut, the differences in the proton load input were getting smaller – with the dynamically changing crown canopy. The largest difference in proton load (H^+) was found between plots C and I after the second intervention, when the correlation coefficient value was 0.15. The differences in proton load input between the plots were influenced by the cut, especially in the first three years after its application. No significant differences in ground level ozone concentrations between plots I (intensive cut), Me (medium intensive), Mo (moderate) and C (control) were revealed either after the first or after the second cutting intervention. Differences in ozone concentrations are not significant, and they indicate that the stocking density does not play an important role in association with ozone affecting the stands. The increase in ozone concentrations after the second intervention was evident on all plots – indicating the absence of connection with the individual phases of forest management process, but at the same time indicating the presence of climate change. In the studied sub-mountain beech ecosystem in the Kremnické vrchy Mts., an important role of episodes with high ozone concentrations is evident.

Keywords: ground level ozone; hydrogen ion; cutting phases; sub-mountain beech stands; passive samplers

Forest ecosystems are damaged by a range of harmful agents acting synergically. Among the anthropogenic ones, airborne pollutants (immissions) are considered the most important.

In the first half of the 1990s, the developmental trends in emission and immission conditions in Slovakia were positive, then a stagnation followed – up to the end of the century (Spišáková et al. 2003). Towards the beginning of the new millennium, the situation began to change – with certain indicators manifesting an increase again. The contemporary causes, however, are different from those in the past. Today it is nitrogen dioxide, particulate matter and ozone (Váňa, Smrčková 2000; SHMÚ 2006). The decrease in NO_x was not as steep as in SO_2 emissions (Fleischer et al. 2005), which is associated with an increasing number of mobile sources. Stagnation or worsening in the case of ozone is due to long-range transport of airborne pollutants (Hrouzková et al. 2004), and due to the meteorological situation,

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especially high temperatures in the case of anti-cyclones with many sunny days without precipitation (Šec et al. 2007).

The intensity of direct impact of airborne pollutants on forest stands is getting lower, forest soil acidification is, however, still present. There also persist consequences of the climate change. The resulting persistent damage to forests requires devoting more attention to research. In this context, our research on the studied sub-mountain beech ecosystem was focussed on effects of pollutants in the particular phases of forest management process. The research was conducted at the Beech Ecological Experimental Site (BEES) Kremnické vrchy Mts., West Carpathian Mts. The individual phases of silvicultural process were simulated through regeneration cutting interventions.

MATERIAL AND METHODS

The basic idea of our research was to find out differences in amounts of airborne pollutants entering the stands with very similar growth conditions but different stocking densities. The density was changed according to the common forest management practice. The first cut was applied in February 1989 (Greguš 1987) with the aim to obtain the required stocking density. The original forest cover at the site was a mixed stand consisting of beech (76%), fir (15%), oak (4%), and hornbeam (5%). Applying a series of cuts with scaled intensities, four plots were obtained: I with intensive intervention, Me with medium-intensive intervention, Mo with moderate intervention and control C, representing the original stand without intervention. After the regeneration cut done in spring 1989, the dominant woody plant was beech (94.7% on plot C). At the time of the first cutting intervention, the stand age was 80–90 years. In the following years, the stand density was adjusted by Barna (2000). The second cut was applied in spring 2004 (Barna 2004). The stand density values after the first and the second intervention are shown in Table 1.

The research locality, the Beech Ecological Experimental Site (BEES), is situated in Central Slovakia, in the SE territory of the Kremnické vrchy Mts., at altitudes ranging from 470 to 510 m (φ = 48°38'N, λ = 19°04'E). The slope is west-oriented, from 30% to 36%.

As for the climate, the territory of BEES belongs to the moderate warm and moderate wet region. The long-term annual mean of air temperature is 8.2°C, in vegetation period 14.9°C. The annual precipitation totals vary from 510 mm to 1,040 mm (annual), in vegetation period 160–530 mm (Kellerová, Dubová 2002; Janík 2006).

As for airborne pollutants, the research plots are situated in a locality outside the direct impact of polluting materials and outside the extreme influence of long-range pollution transport. The nearby Zvolenská kotlina basin, however, with three stationary power units, dense network of motorways and large railway junction can influence the situation on plots under "favourable" meteorological conditions.

Our research on air quality was oriented locally. We monitored pollution in the ground layer in the forested territory sufficiently distant from the local and urban sources. At elevations where we carried out our research, the industrial pollutants were dispersed throughout the environment and their levels were in general lower than in industrial agglomerations.

The possibilities of monitoring airborne pollutants in sub-mountain conditions are limited, the data are supplemented with figures obtained by statistical processing or with information obtained by using passive samplers. The equipment is neither cost-demanding nor does it require the presence of a power source, and it is easy to operate. The passive samplers

Table 1. Stand density at the BEES Kremnické vrchy Mts. (West Carpathians)

Phase of management process	I intensive intervention	Me medium intervention	Mo moderate intervention	C control
1989 (after the first intervention)	0.3	0.5	0.7	0.9
1996	0.4	0.6	0.8	0.9
2004 (before the second intervention)	0.5	0.7	0.9	1.0
2004 (after the second intervention)	0.0*	0.3	0.5	1.0

*From the viewpoint of the original parent stand, the plot I (intensive intervention) is not a clear-cut any more, at present it is covered with a natural thin-pole stand

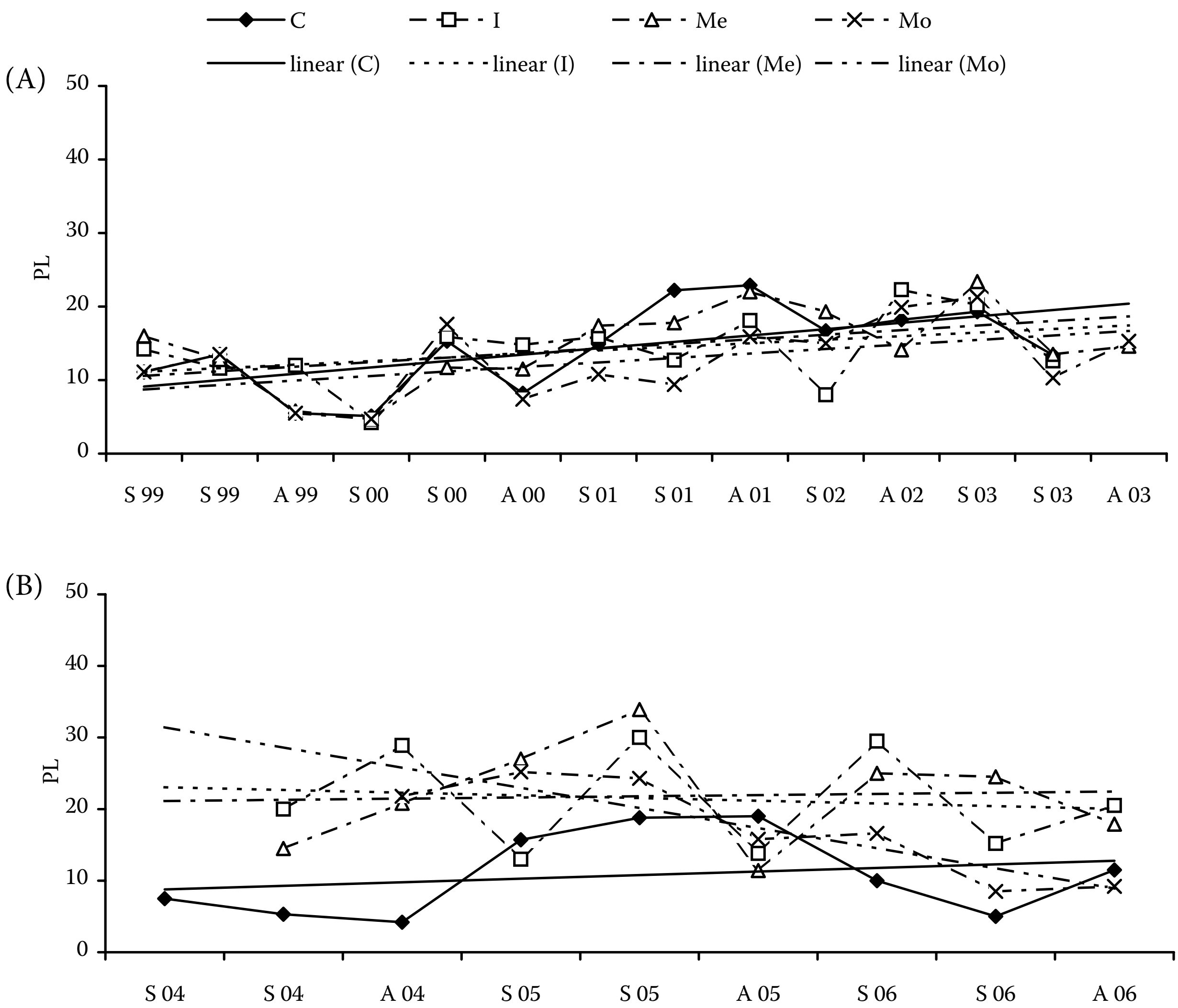

Fig. 1. Variability and trends of proton load (PL) in mmol H^+ day/m^2 (warm half of the year: spring, summer, autumn) on plots C (control), I (intensive cut), Me (medium intensive), Mo (moderate) at the BEES Kremnické vrchy Mts.: A – after the first cutting intervention (1999–2003), B – after the second cut (2004–2006)

enable to precisely delineate the risk territories from the viewpoint of potential damage to ecosystems as well as to measure pollution levels in the individual phases of forest management process. They are used not only in Slovakia (Šablatúrová, Bičárová 1995; Varšavová, Barančok 1999; Molnárová 2000) but also abroad (Hangartner et al. 1989; Cox 2003; Bytnerowicz et al. 2004). The methods are progressively improved, getting simpler, and the obtained results can be compared with the results obtained with continual analyzers (Gerosa et al. 2001). Their shortcoming is that they do not enable to monitor the circadian concentration dynamics.

To measure the long-term influence of pollutant load on forest ecosystems and the differences between seasonal and inter-annual concentrations it is recommended to use the method determining the proton load (H^+) according to Obr (1989) and determining the ground level ozone (O_3) concentrations by the sorption-accumulation method (Werner 1991). The amounts of airborne substances were determined at regular time intervals over the whole growing season (April–September). A more detailed description of the method is in Kellerová et al. (1997) and Kellerová (2002).

The results were evaluated by mathematical and statistical methods provided by the software MS Excel 2007 in MS Windows XP. In our study Pearson's correlation coefficient (*r*) was used measuring the linear dependence between two random variables.

RESULTS AND DISCUSSION

In 1999, ten years after the first cut, resulting on four plots in the required phases of the forest man-

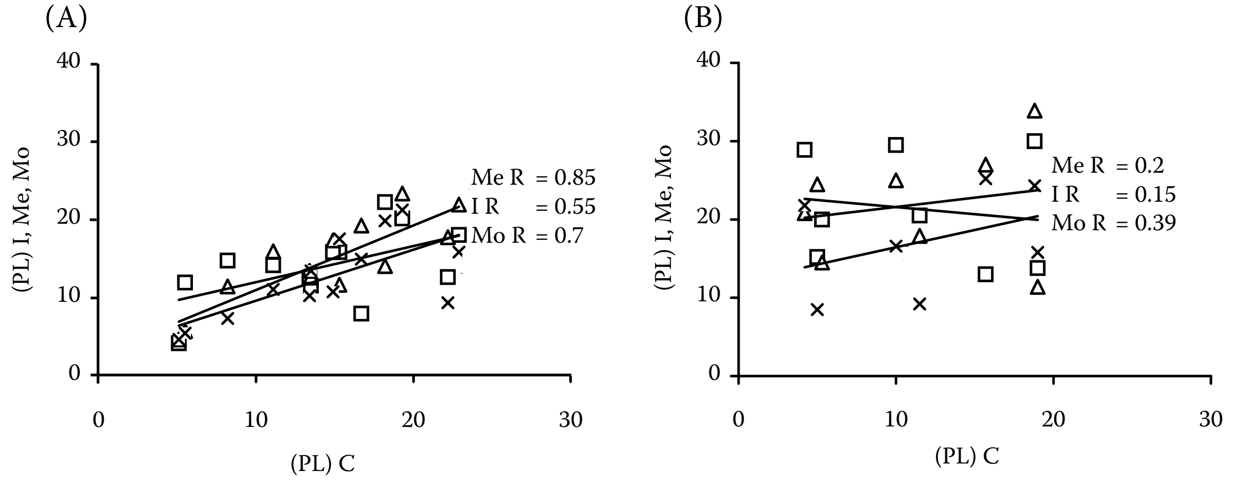

Fig. 2. Average values of proton load (PL) in mmol H^+ day/m^2 on control plot (C) related to plots □ I, Δ Me, × Mo, and their linear dependence: A – after the first cut, B – after the second cut

agement process, all the plots (I – intensive intervention, Me – medium-intensive intervention and Mo – moderate intensive intervention) were covered with a natural forest stand in the phase of thin pole. The control plot (C) has maintained its former character – without understorey.

In 1999–2003, the quantity of proton load was relatively uniform on all the plots (Fig. 1A). The most pronounced difference was detected between plots C and I, which is also documented by the correlation coefficient value of 0.6 (Fig. 2A). These facts corresponded to the natural and supposed proton flow in forest stands. The protons are intercepted by tree crowns fulfilling their role of filters for precipitation and for gases (Bublinec, Dubová 2003; Dubová, Bublinec 2006), depending on the stand and canopy density. In comparison with plot I, the stand density values on Me and Mo were more similar to the control plot (Table 1). Higher similarity between plots C-Me (0.9) and C-Mo (0.7) is also evident on the related correlation coefficients.

The second cut was done in 2004, when all the remaining trees were removed from plot I. The stand density values were also changed on plots Me and Mo (Table 1), and so also the crown structure and canopy on these plots. This cut resulted in enhanced differences in proton load amounts between the plots (Fig. 1B). The largest difference was between plots C and I again, with the correlation coefficient value being 0.15 only (Fig. 2B). The value of correlation coefficient between plots C and Me after the second cut was 0.2, in the case of plots C and Mo it was 0.4. It follows that the different amounts of proton load of the particular plots were influenced by the cutting, the differences were, however, most pronounced in the first three years following the cut.

Besides the spatial trends, we also evaluated temporal trends and input dynamics of the proton load. Evaluating the annual means we can see (Fig. 1) that the trend of proton load (H^+) was increasing on all the studied plots. It is probably associated, apart from other factors, with nitrogen oxides (NO_x), the decrease of which does not reach the rate of sulphur dioxide. At present the study area is noticeably influenced by developing industry and more and more dense traffic. In this context, the research on ground-level ozone is evidently important.

No significant differences in ground-level ozone concentrations were identified among plots I, S, M, C – either after the first or after the second cutting intervention (Fig. 3).

The correlation coefficients between plots C-I, C-Me and C-Mo ranged from 0.7 to 0.9 (Figs. 4A,B). The largest difference was detected between control plot and plot I again, both after the first and the second intervention when the calculated correlation coefficient was 0.7. We can see that the differences in ozone concentrations are not significant – which manifests that the role of stand density is not important in this case.

The Central-European sub-mountain areas are, however, similar to the high-mountain ones characterized by two concentration maxima per year. The first maximum is usually reached in spring (April), the second in summer (August). There are mostly short-lasting episodes with high concentrations that are in general considered more harmful to woody plants than long-term exposures to lower concentrations (Mortensen et al. 1995). In events of high concen-

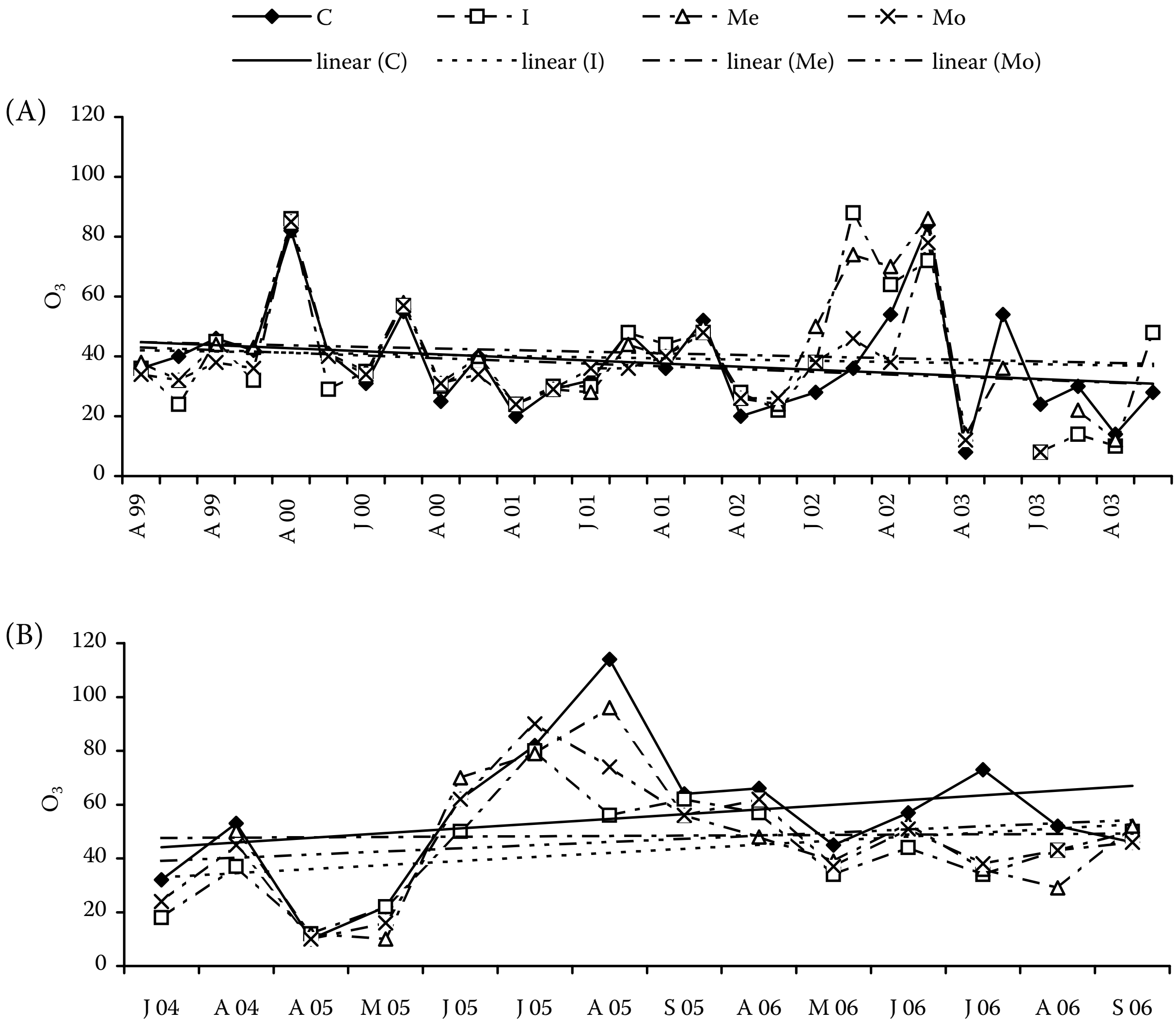

Fig. 3. Variability and trends of ozone concentrations (μg/m^3) (warm half of the year: April – September) on plots C, I, Me, Mo at the BEES Kremnické vrchy Mts.: A – after the first cutting intervention (1999–2003), B – after the second cut (2004–2006)

trations, the vegetation can be damaged within a few hours. During the episodes, the former established threshold value for ozone concentration – 65 μg/m^3 (32.5 ppb) is exceeded. The immission level for forest ecosystems and vegetation (92/72/EC) was set by the European Union in 1992 as the 24-hour mean value. The ozone concentration values measured on the plots in the Kremnické vrchy Mts. were calculated for one day; consequently, the comparison with the above-mentioned limit is possible. On the experimental plots, the daily critical limit of 65 μg/m^3 was exceeded 11 times in 1999–2003 and 10 times in 2004–2006 (see Figs. 3A,B). In contradiction with the fact that recently the number of ozone episodes in Central Europe has been decreasing (Váňa, Smrčková 2000); their adverse impact is still effective. The impact of episodes is in general extensive; consequently, the differences between the plots are not noticeable.

The episodes of high ozone concentrations primarily depend on locally and regionally emitted ozone precursors, on meteorological conditions, and in our case also on long-range transported pollution (Závodský et al. 2001; Liu et al. 2006; Zapletal, Chroust 2007). The local ozone production represents about 10% of the total amount; the major part is associated with advection. The main local sources are transport, solid fuel heating of houses and agriculture.

The trend of ozone concentrations in 1999–2003 showed a moderate decrease, which was reasonable to expect in the context of an overall decrease in human-produced airborne pollutants in the Slovak territory. After the second cut, however, the trend of ozone concentrations showed an increase (Fig. 3B). The mean ozone concentration (56 μg/m^3) in 2005 was one and a half times higher than the value ob-

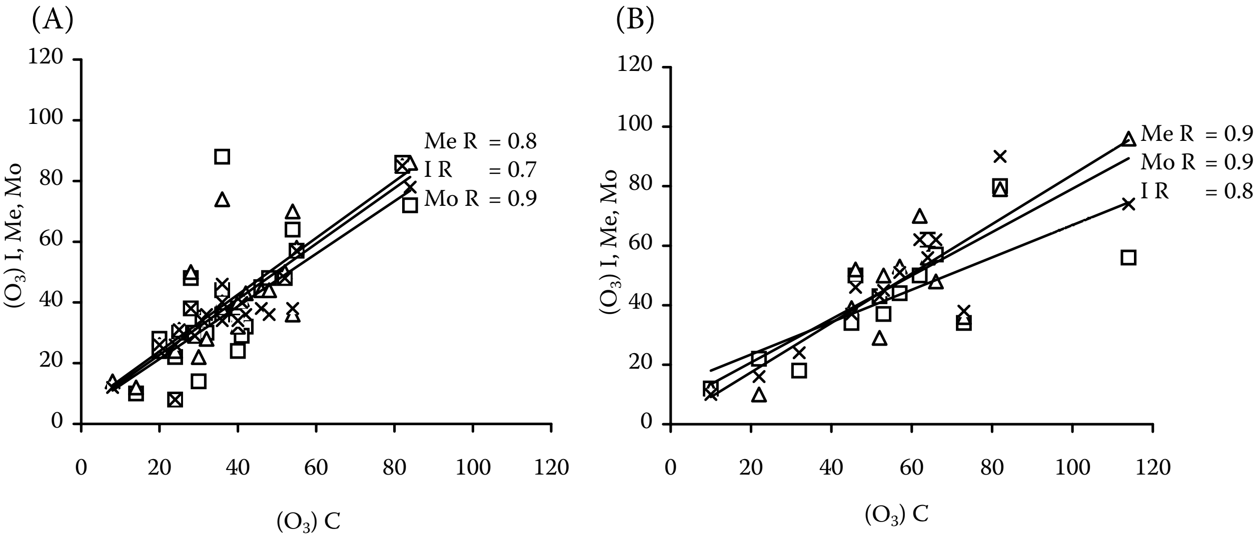

Fig. 4. Average values of ozone (O_3) concentration (μg/m^3) on control plot (C) related to plots □ I, Δ Me, × Mo, and their linear dependence: A – after the first cut, B – after the second cut

tained in 2004 (38 μg/m^3). The year 2005 was very warm and dry at the same time. The mean temperature in the growing season in the Zvolenská kotlina basin is 14.8°C (1961–1990), in 2004 it was 14.3°C, but in 2005 it was 15.1°C. The increase in ozone concentration after the second cutting intervention was evident on all plots – manifesting the independence of conditions associated with the individual phases of silvicultural process, on the other hand, pointing out the presence of climate change.

In the case of small areal units, passive sampling is a method well-fitted for evaluating the data in terms of potential damage to forest stands by pollutants, and for definition of the risk area boundaries. Parallelly we used the same method in a beech stand (stand density 0.7) in the surroundings of the aluminium plant in Žiar nad Hronom, and we compared the two localities. The average value of proton load on all plots in the Kremnické vrchy Mts. 10 years after the first cut was 13.9, after the second cut it was 17.9 mmol H^+ day/m^2. The average value over the years 1999–2003 was 12.9, over the period 2004–2006 it was 13.1 mmol H^+ day/m^2. The beech stand Žiar nad Hronom was not subjected to cutting, consequently, the amounts of pollutants entering the stand were lower.

The average value of ozone concentration on Kremnické vrchy Mts. plots after the first cut was 42, after the second cut it was 49 μg/m^3. The mean value calculated for growing periods 1999–2003 in Žiar nad Hronom (urban environment) was 84 μg/m^3 (Hrouzková et al. 2004).

Our research results reveal that the direct impact of polluted air on the forest stands in the Kremnické vrchy Mts. is not getting weaker. On the other hand, the buffering capacity of soils in this area is good, and the soil is fairly resistant to the changing acidity. The increasing ozone concentration is a serious risk factor in this sub-mountain area, in spite of the fact that it does not reach the extreme values measured in the surroundings of Žiar nad Hronom. The consequences of the persistent negative impact of ozone may impair the health of forest stands; in some cases they may even initialize their decomposition, which could have a significant influence on the ecosystem stability.

CONCLUSIONS

Our research, conducted in the growing seasons 1999–2006, was focussed on the identification and analysis of the impact of proton load (H^+) and ground level ozone (O_3) on beech stands differentiated by the intensity of the applied cut. The modelled phases corresponded to the phases of a common silvicultural process.

Ten years after the first cut, the crown canopy was changing dynamically, and the differences in proton load input between the plots were getting smaller. It was evident that the closed stand canopy performed as a filter for precipitation and gases, and through their retention capacity, the stands favourably influenced the air quality in their interior. Significant differences in the values of proton load were observed between beech stands I (intensive), Me (medium intensive), Mo (moderate) and C (control plot) after the second intervention, especially in the first years following the cut: 2004–2006.

No significant differences were found in ground level ozone concentrations between the plots with different stocking values. This fact reveals that the stocking value has no influence. Conditions necessary for ozone creation are dependent on the meteorological situation – governing over large areas if it is an anticyclone and if other synergically acting agents are present. An important risk factor has been recognized in increasing ozone concentrations in sub-mountain beech forests, especially in the case of extreme ozone episodes.

The obtained information on the air quality and on pollutants entering the environment provides a contribution for defining conditions for natural regeneration in beech ecosystems and for applying regeneration cuts, including the system of forest management methods in contemporary unfavourable ecological conditions.

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Zmeny kvality ovzdušia v rozličných fázach obhospodarovacieho procesu v podhorskej bučine (Západné Karpaty)

ABSTRAKT: Kvalitu ovzdušia sme skúmali v podhorskej bučine v Kremnických vrchoch na strednom Slovensku. Zvolili sme metódu pasívnych zberačov. Kvantita imisných látok (H^+ a O_3) sa zisťovala v pravidelných časových intervaloch na plochách s rozličným zakmenením počas vegetačných období. V pôvodnom poraste boli dvakrát zámerne nasimulované fázy obhospodarovacieho procesu lesa. Prvá výskumná perióda (1999–2003) začala 10 rokov po prvom zásahu, druhá (2004–2006) bezprostredne po druhom zásahu. Desať rokov po prvej ťažbe sa rozdiely inputu protónovej záťaže medzi plochami vyrovnávali s dynamicky sa meniacim zápojom korún. Najväčší rozdiel protónovej záťaže (H^+) bol medzi plochami C a I po druhom zásahu, kedy bola hodnota korelačného koeficientu 0,15. Diferencie vstupu protónovej záťaže na jednotlivé plochy boli ovplyvnené ťažbovým zásahom prevažne v prvých troch rokoch po ťažbe. Podstatné rozdiely v koncentrácii prízemného ozónu medzi výskumnými plochami I (intenzívny zásah), Me (stredne intenzívny), Mo (mierny zásah) a C (kontrolná plocha) sa nepreukázali ani po prvom, ani po druhom ťažbovom zásahu. Diferencie v koncentráciách ozónu sú nevýrazné, z čoho vyplýva, že rozličné zakmenenie, v prípade pôsobenia ozónu na porasty, nezohráva významnú úlohu. Nárast koncentrácií ozónu po druhom zásahu bol na všetkých plochách, čo nepoukazuje na súvislosť s ťažbovými fázami obhospodarovacieho procesu, ale na zmenu klimatických podmienok. V podhorskej bučine Kremnických vrchov zohrávajú významnú úlohu epizódy s vysokými koncentráciami ozónu.

Kľúčové slová: prízemný ozón; vodíkový ión; fázy obhospodarovania; podhorská bučina; pasívne zberače

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