Monitoring of defoliation in forest stands of the Czech Republic and its comparison with results of defoliation monitoring in other European countries

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ABSTRACT: As a part of International Cooperative Programme on Assessment and Monitoring of Air Pollution Effect on Forests (ICP Forests), defoliation of forest stands has been assessed in the Czech Republic since 1986. Defoliation is one of the principal parameters reflecting the health of forest stands that is assessed on monitoring plots within this programme. Monitoring plots are distributed evenly according to woodiness of the area in a regular schematic network all over the Czech Republic. Even though there has been a long-term reduction of air pollution in most European countries, forest ecosystems reflect these changes with some delay. In the Czech Republic the trend of total defoliation of coniferous and deciduous forest stands has been increasing very moderately in the last 10 years. This trend appears to be partially analogous with some neighbouring countries. Compared to the whole of Europe the trend of defoliation of broadleaves is very similar, but differences have occurred in conifers in the last 10 years. There are significant differences in defoliation levels among the particular countries; in this comparison the Czech Republic is classified as one of the worst. Differences in these levels are very evident especially among the neighbouring countries. To partly eliminate these differences, regular international calibration courses are organized.

Keywords: International Cooperative Programme on Assessment and Monitoring of Air Pollution Effect on Forests (ICP Forests); defoliation; monitoring; forest stands; forest species; air pollution; international comparison

The main cause of unsatisfactory changes in forest ecosystems is surely a long-term anthropogenic impact on the environment, and of course on forests. Due to the accumulation of harmful agents in forest stands caused by extreme long-term air pollution stress the upper soil horizons important for root nutrition have been acidified; physiological processes have been disturbed and the overall stability of forest ecosystems has been weakened. All that has resulted in the loss of the natural forest stand resistance to stress factors. This heavy damage to the forest stands has disturbed all the functions as well as the very character of the forest.

The early 1980's abrupt worsening of the health of forest stands in the European countries, which was a consequence of distinct stress effects of air pollution, initiated attempts to monitor the forest condition on the European level (UN-ECE 2010). On a European scale, one of the most important tools of monitoring is the programme of the European Economic Commission of the UNO denoted in short as ICP Forests (International Cooperative Programme on Assessment and Monitoring of Air Pollution Effects on Forests).

ICP Forests programme is based on the Convention on Long-Range Transboundary Air Pollution (CLRTAP) from 1979 (UN-ECE 1979) and the fulfilment of its goals is in accordance with the resolutions of Ministerial Conferences on Forest Protection in Europe. The basic principles of enforcement of the accepted obligations and accomplishment of the set objectives were laid down by Regulation No. 3528/86 of the Council (European Economic Community) on the Protection of the Forests of the Com-

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munity against the effects of air pollution (EEC 1986). Based on Regulation No. 2152/2003 of the European Parliament and Council from December 17, 2003, a new project of European cooperation, simultaneous to the ICP Forests, focused on forest monitoring and environmental influences in the Community forests, "Forest Focus", was adopted in 2003 (EC 2003). The follow-up project FutMon of the cooperation of European countries on monitoring of the forest condition, approved for the years 2009–2010, was targeted at the harmonization of methods of ICP Forests and National Forest Inventories and the subsequent conjoint use of monitoring plots.

Since the beginnings in 1986 nearly all the European countries, including former Czechoslovakia, have joined the ICP Forests programme. The importance of this programme lies in gathering information on spatial and temporal development of the forest condition within Europe and in furthering the understanding of the causes of current damage to the forests with special regard to air pollution levels.

MATERIAL AND METHODS

Each of the above-mentioned targets of ICP Forests programme needs a very different methodological approach to monitoring. They are implemented by means of monitoring systems varying in structure and in the intensity of measurement (Level I and II). Level I monitoring network is designed to gather widespread, systematic information on the forest health. Level II network includes monitoring plots with the higher intensity and range of examined parameters and therefore the number of these monitoring plots is significantly restricted. Their number is only approximately 5% of the total number of Level I plots.

In the Czech Republic, regular Level I ICP Forests monitoring is currently performed on monitoring plots of the basic 16 by 16 km network and on selected plots of the 8 by 8 km network, a total of 306 plots (Fabiánek 2005). These plots are evenly distributed throughout the Czech Republic according to woodiness of the area (Fig. 1). The plots are located within forest stands so as to sufficiently represent the conditions of the given site and stand. At the altitudes between 150 and 1,150 m above sea level, more than 11,000 trees that represent 28 forest tree species and various age classes are assessed every year. If a major part of the forest stand on the monitoring plot is in the stage of regeneration, either on account of planned economic measures or as a consequence of incidental felling, the monitoring is temporarily interrupted and is resumed only after the new stand is in the stage of established plantation. Therefore the actual number of the assessed plots per year is approximately 5–8% lower. The basic site and stand characteristics are determined for each plot. At regular intervals (every 1–5 years) the following expert investigations take place: assessment of crown condition (defoliation, discolouration, biotic and abiotic damage, etc.), detection of social status, measurement of dendrometric parameters. These investigations are complemented by analyses of leaves, soil and rings performed at irregular intervals. In recent years, monitoring plots have regularly been used for the investigation of biological diversity based on phytosociological relevés (processed usually at intervals of 5 years).

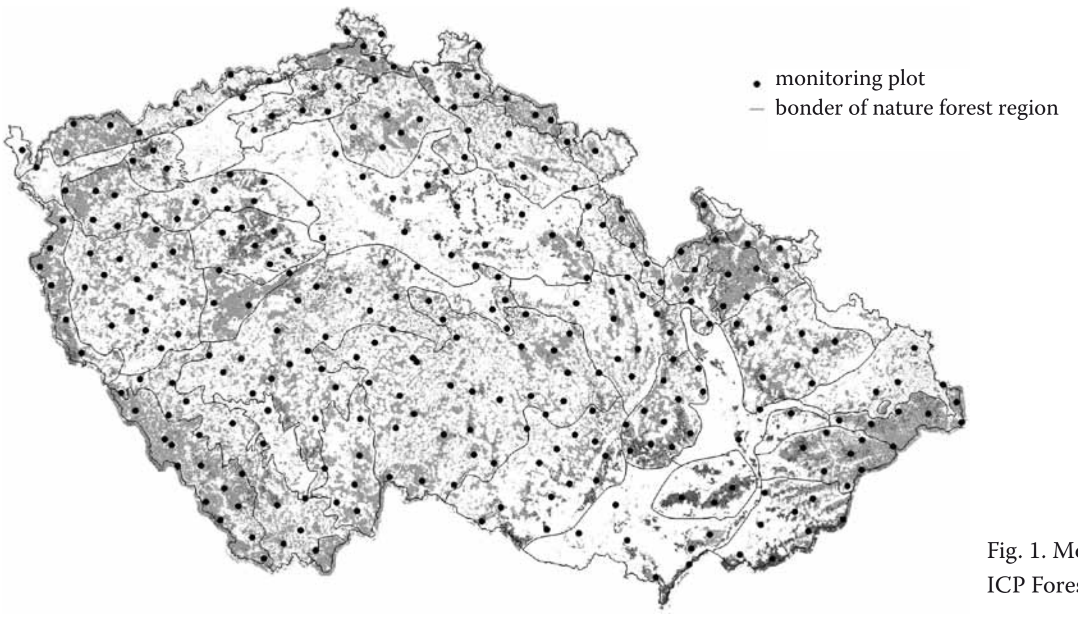

Fig. 1. Monitoring plots of ICP Forests – Level I

Defoliation is one of the most important parameters examined during forest monitoring. It is a non-specific symptom defined as the loss of assimilatory tissue in the tree crown compared to a healthy tree growing in the same stand and site conditions. Adverse changes in the forest ecosystem environment consequential to long-term, excessive air pollution as well as to inimical climatic development are the primary cause of this loss.

For the development of defoliation to be taken as an appropriate indicator of the forest health the state of the parameter observed in mature, mainly coniferous stands is a crucial feature. As the defoliation of an actual stand is changing in time due to natural development of the stand in question, it is very important that the stands on the monitoring plots will represent the age structure of forest stands of the whole assessed territory (i.e. of the whole of the Czech Republic) as closely as possible. In this comparison the extent of the approximation of two age structures takes precedence with little regard to the extent of the uniformity of the structures and their approximation to the norm (Fig. 2). The 5th and 6th age class dominates the age structure of the monitoring plots distinctly exceeding the representation of these classes throughout the Czech Republic (MZE 2010). This higher representation of older stands on the monitoring plots was caused by the intentional selection of these stands at the beginning of the programme in the 1980's which was motivated by the then existing practice and experience with the assessment of stand damage degrees and identification of pollution damage zones with the sole focus on mature spruce stands. The higher representation of stands in the 5th and 6th age class influences directly the increased defoliation value for the entire age category of stands older than 59 years. However, differences in the average defoliation values of stands in age classes 4, 5 and 6 equal units of percent. In total, the misrepresentation of the age structure on ICP Forests plots elevates the average defoliation value in the category of stands older than 59 years by less than 1% (Table 1).

Table 1. Defoliation according to age classes (ICP plots) and comparing of 4th to 6th age classes defoliation in the Czech Republic and in ICP plots

Age class	Mean defoliation in 2009 (%)
4	31.90
5	35.03
6	36.04
CR 4–6	34.05
ICP 4–6	34.73

The summary data on defoliation of tree species within a larger territory are distinctly influenced not only by natural conditions and climatic factors (especially precipitation and temperature) or their extremes, but also by the age and species structure of forest stands within the assessed territory. In the Czech Republic coniferous stands are dominant stands taking up 74.12% of forest land, while Norway spruce (*Picea abies* [L.] Karst.) is the most widely represented tree species, covering 52.16% of the stand area (MZE 2010). With regard to its increased sensitivity to air pollution in comparison with other species, Norway spruce is habitually taken as a perfect indicator of the impact of air pollution on forest stands.

RESULTS AND DISCUSSION

Development of defoliation for main species in the Czech Republic

A sharp increase in defoliation in the late 1980's is characteristic of the development of defoliation in older coniferous stands. In the subsequent period of the 1990's the dynamics of defoliation de-

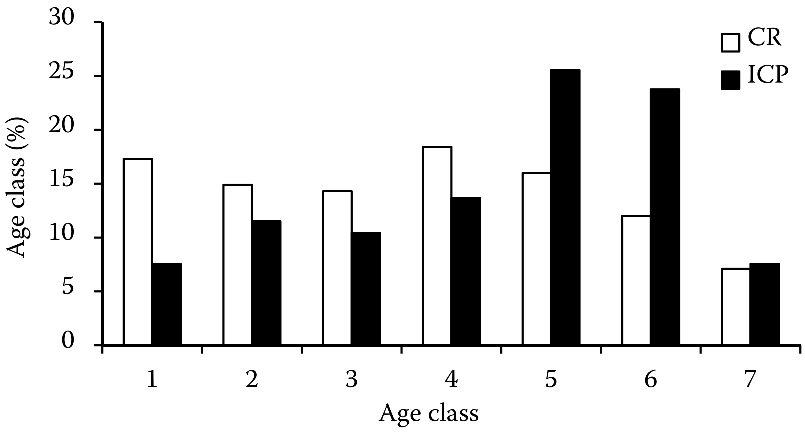

Fig. 2. Percentage of age-classes comparing on monitoring plots in the Czech Republic and ICP Forests

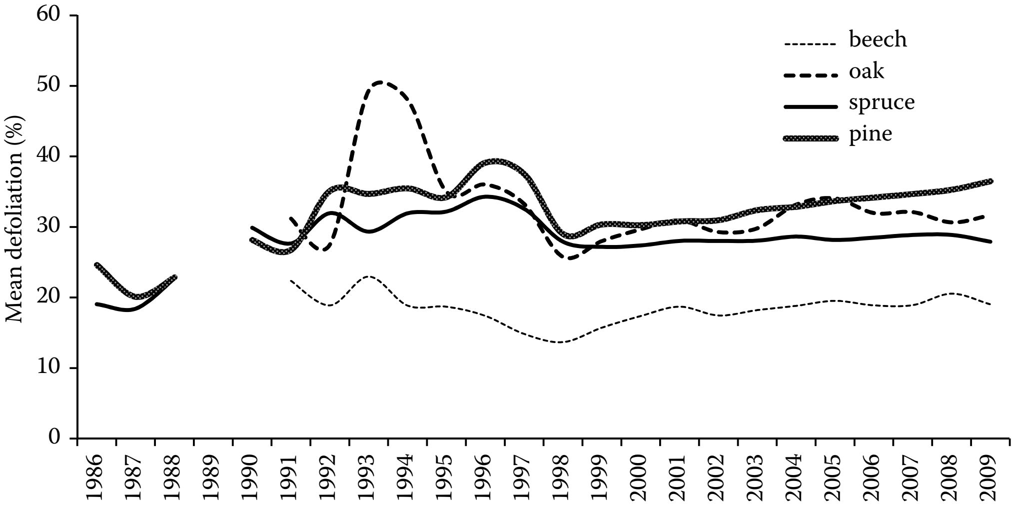

Fig. 3. Mean defoliation development of basic tree species in the Czech Republic

velopment in these stands decreased significantly and only moderate changes have occurred since 1999. The average value of defoliation of Norway spruce and Scots pine (*Pinus sylvestris* L.) during the monitored period of 1986–2009 reached the distinct culmination point in 1992. Other, less significant, changes followed and the average defoliation of these tree species increased in 1996 again and reached the maximum value (Norway spruce 34.3%, Scots pine 39.1%). This was followed by a decrease during the subsequent years, and the average defoliation has been increasing moderately since 1999, reaching around 30% (Fig. 3).

The long-term development of defoliation is slightly different for broadleaves of the same age category (stands older than 59 years). During the monitored period of 1991–2009 the defoliation of broadleaves reached the highest level in 1993 (average defoliation of oak sp. (*Quercus* L.) 43.0% and of European beech (*Fagus sylvatica* L.) 22.5%), in the next years the defoliation values decreased and reached their minimum in 1998 (average defoliation of the oak sp. 27.8% and European beech 14.6%). Then defoliation had been distinctly increasing until the year 2000 while in the subsequent period until 2009 the defoliation of older broadleaves was very moderately increasing with slight fluctuations. There are pronounced differences between the species. From the long-term perspective, for the oak sp., the values of defoliation show greater fluctuations and are overall higher than those of the European beech (Fig. 3). Despite the apparent differences in the development of defoliation between conifers and broadleaves this development is very similar among particular species for each of these categories of species.

Comparison of defoliation with development of emissions of principal air pollutants

In the Czech Republic the total emissions of principal air pollutants (solid particles, SO_2) have been gradually decreasing since the mid-1980's, and the emissions of NO_x since the late 1980's (ČHMÚ 2002, 2005, 2008, 2010). Until 1999 the decrease

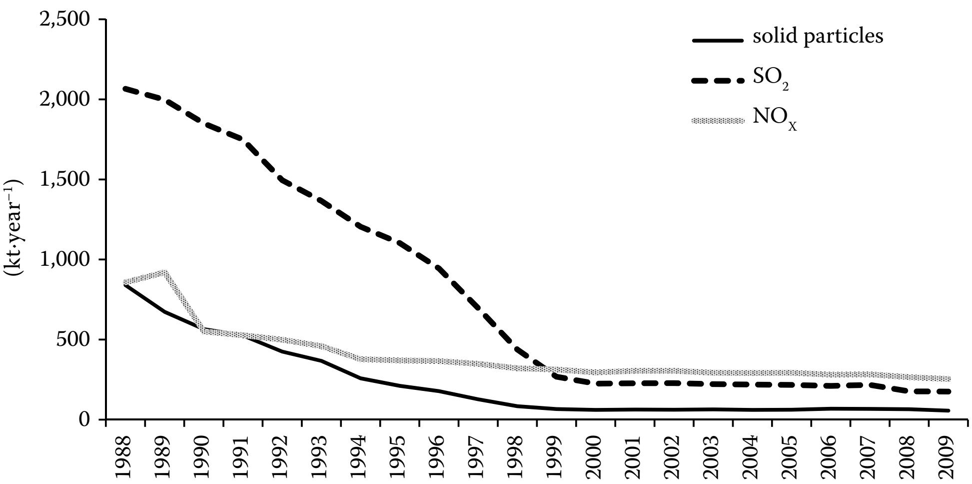

Fig. 4. Total emissions of principal pollutants in the Czech Republic

had been quite rapid, interannually in the order of 100,000 kt, whereas since 2000 the intensity of the decrease in emissions was diminished and until 2009 the interannual decrease was in the order of 1,000 kt (Fig. 4). While the emissions of principal air pollutants were decreasing sharply until 1999, the average defoliation of the older stands of Norway spruce and Scots pine was sharply increasing with significant interannual fluctuations until 1996, and only in the subsequent years 1997 and 1998 both these species showed a distinct decrease. In the broadleaves, the defoliation of oak sp. and European beech also rose during the significant emission decrease with its decline beginning in 1994, three years before the conifers. The decrease was more intensive for the oak sp. than for European beech and more fluctuating. There are two important breaking points in the development of emissions and defoliation that are very close to each other. It is the year 1999, when a long period of a moderate increase in defoliation started in all the main tree species, and the year 2000 for the air pollution development, when on the contrary a long period of a very moderate decrease in the emissions of principal air pollutants began.

Defoliation and its development in the Czech Republic compared to European average

However, the relatively high proportion of Norway spruce in forests of the Czech Republic is reflected in quite high total values of defoliation in comparison with the other European countries. The frequency distribution of the assessed samples of all the species according to defoliation in the Czech Republic is of a different structure than the European average. Frequency distribution is left-sided in both cases, but for the Czech Republic it is less distinct, drawing nearer to the central (higher) value. Whilst the conifers are slightly more numerous than the broadleaves on European average (Fischer et al. 2010), this disparity is in multiples in the Czech Republic (Figs. 5 and 6).

The results from 2009 show once more the decisive influence of conifers on the total average defoliation level in the Czech Republic that is caused both by the dominant proportion of conifers in the species structure as well as by their defoliation level, which is significantly higher than that of broadleaves. Compared to the European average, the representation of higher levels of defolia-

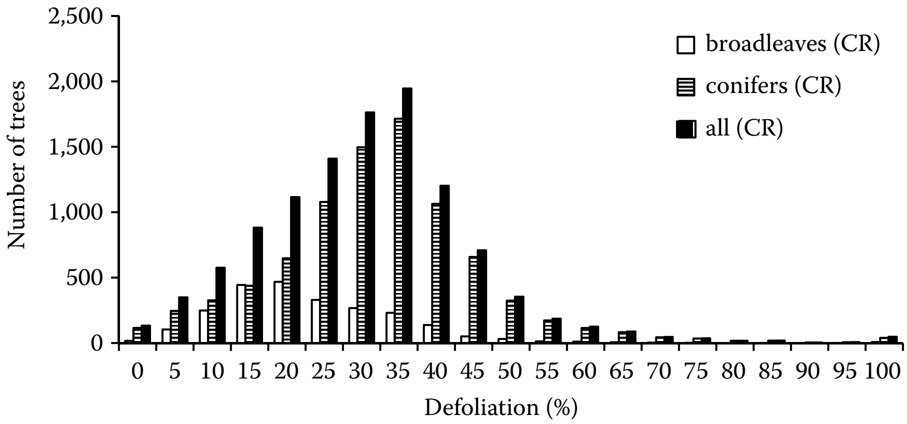

Fig. 5. Frequency distribution of all tress assessed in the Czech Republic in 2009

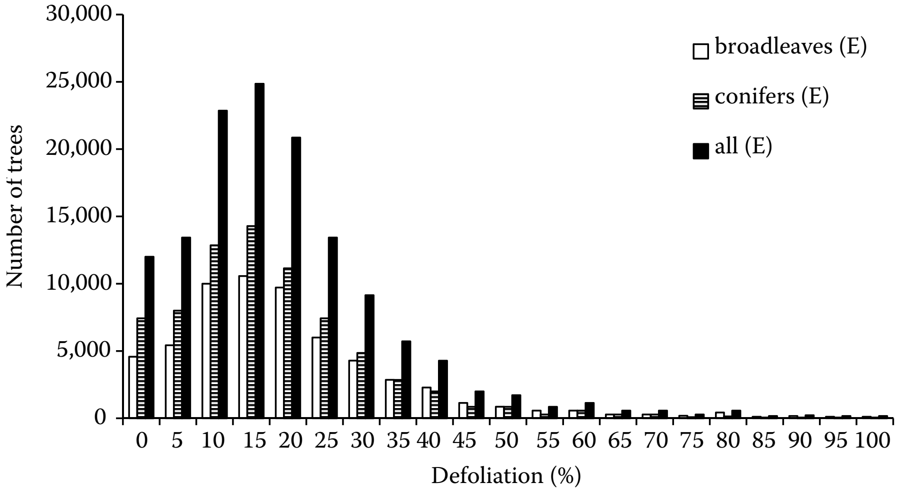

Fig. 6. Frequency distribution of all tress assessed in Europe in 2009

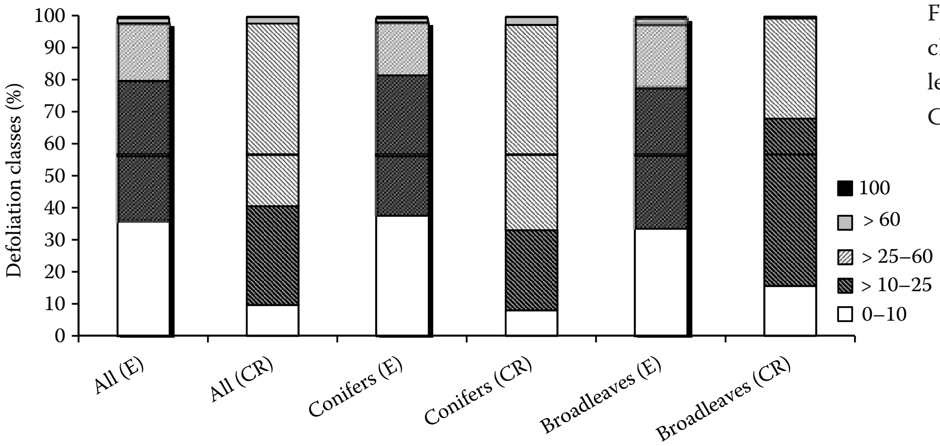

Fig. 7. Distribution of defoliation classes of conifers and broadleaves in 2009 (Europe and the Czech Republic)

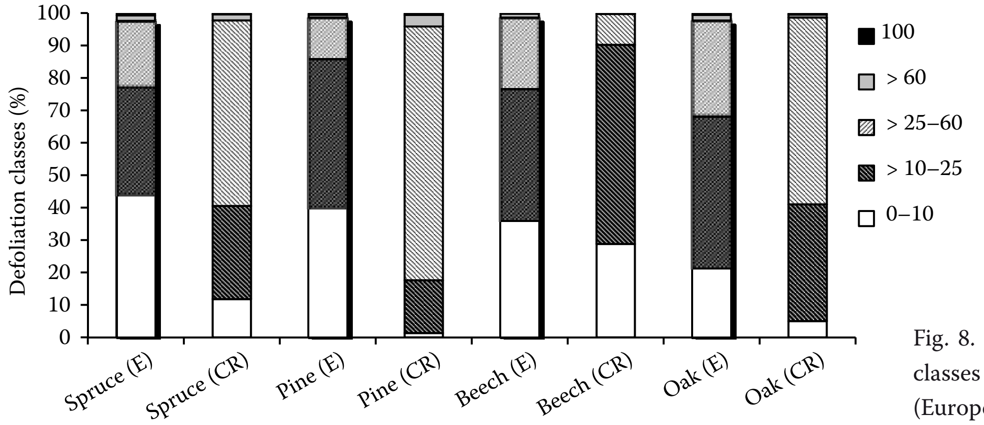

Fig. 8. Distribution of defoliation classes in the main species in 2009 (Europe and the Czech Republic)

tion at the expense of lower levels is higher in the Czech Republic for both the categories, conifers and broadleaves, but it is the most distinct in the coniferous stands (Fig. 7). Of the particular species this difference is the largest for Scots pine where the representation of defoliation classes 2–4 (> 25–100%) reaches the value of 14% on European average whereas in the Czech Republic it is up to 82.4% (Fig. 8). The difference is less distinct in Norway spruce and oak sp., and for European beech the representation of defoliation classes 2–4 is even lower in the Czech Republic than in Europe, CR – 9.7%, Europe – 23.2% (Fischer et al. 2010).

In the Czech Republic, compared to the neighbouring countries the representation of defoliation classes 2–4 for conifers was on the highest level during the period 1998–2009 (Fig. 9). In the Czech Republic these values were on average approximately 20% higher than in Slovak Republic, 40% higher than in Germany and nearly 50% higher than in Austria. However, all the above-mentioned countries showed a similar trend in the represen-

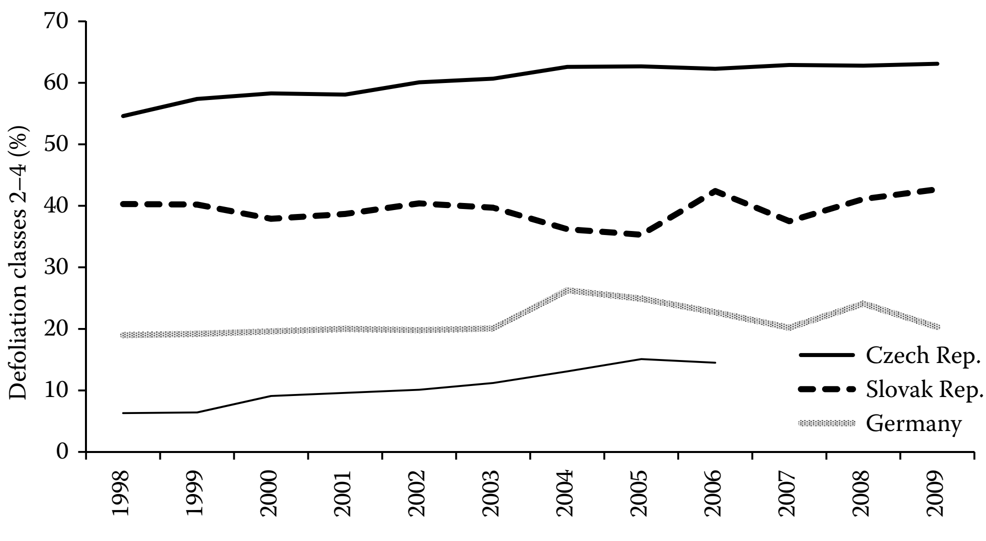

Fig. 9. Percentage of defoliation classes 2–4 of conifers in Central European countries

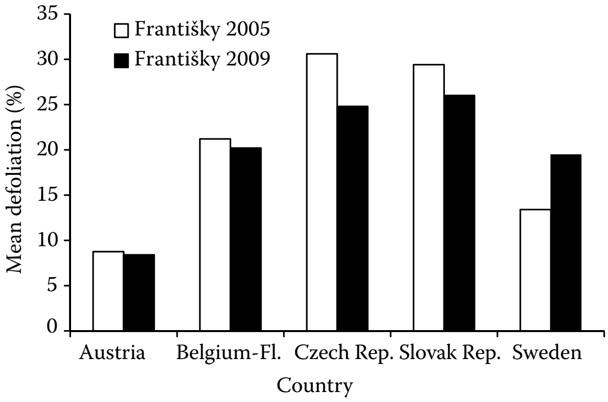

Fig. 10. International Cross-Calibration Course on Crown Condition, Czech Republic 2005 and 2009, Františky locality, mean defoliation of spruce, selected countries

tation of these defoliation classes during the monitored period. For the Czech Republic, Germany and Austria the trend was slightly increasing; in Slovak Republic it was stagnant with minor fluctuations. Of course, the relatively large differences in the representation of defoliation classes 2–4 in conifers among the neighbouring countries do not necessarily reflect equally large differences in the defoliation level. The difference of no more than 5% in the assessment of defoliation of a particular tree (which is the presented accuracy of assessment) can put this tree into a different defoliation class and thus increase its frequency.

Differences in the assessment of defoliation levels in particular countries are eliminated in part by regular International Cross-Calibration Courses on Crown Condition. If these courses are attended by a stable team of experienced assessors representing the particular countries, then a reciprocal relationship can be defined among these assessors on the basis of a statistical analysis. Consequently it is possible to generate a correction coefficient for statistical compensation of systemic differences in assessment among the particular countries and to eliminate thereby, to a certain extent, the subjective influence on defoliation assessment in each country. A comparison of the results of defoliation assessment, carried out by the chosen representatives

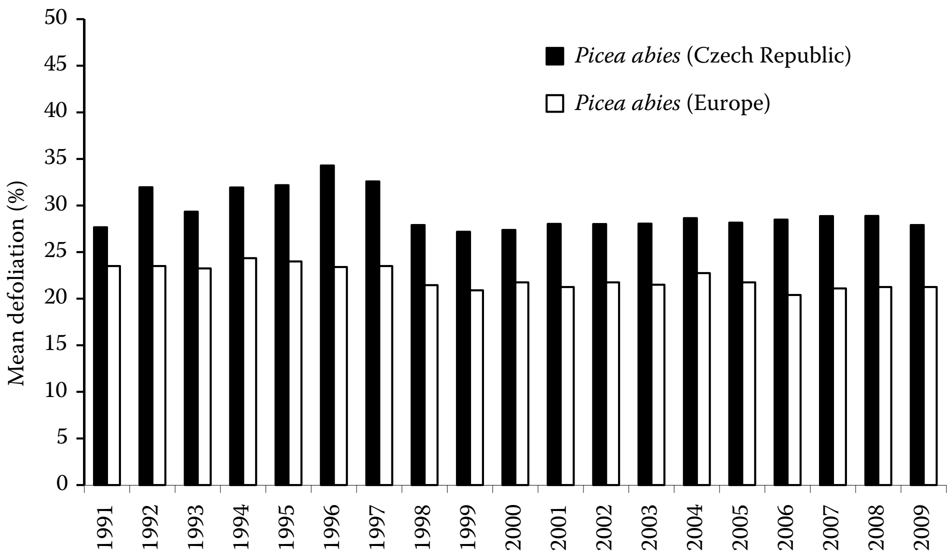

Fig. 11. Mean defoliation development of *Picea abies* (L.) Karst.

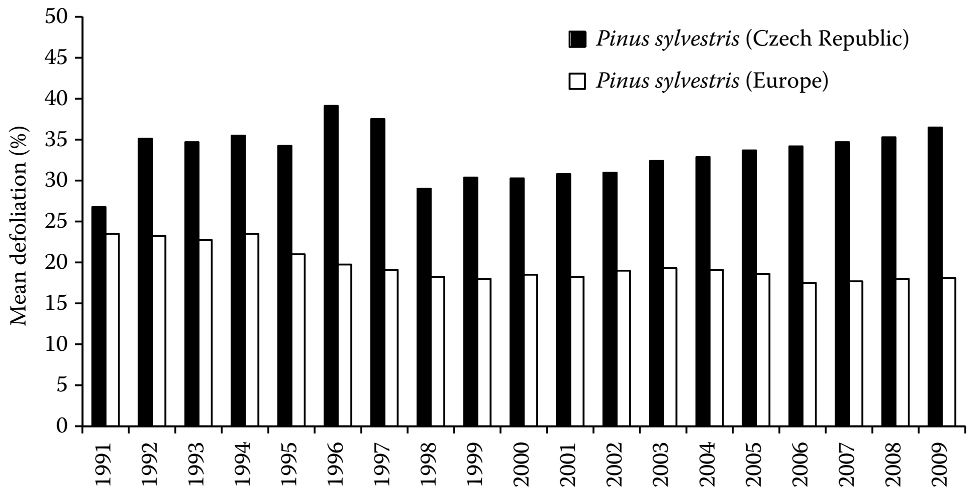

Fig. 12. Mean defoliation development of *Pinus sylvestris* L.

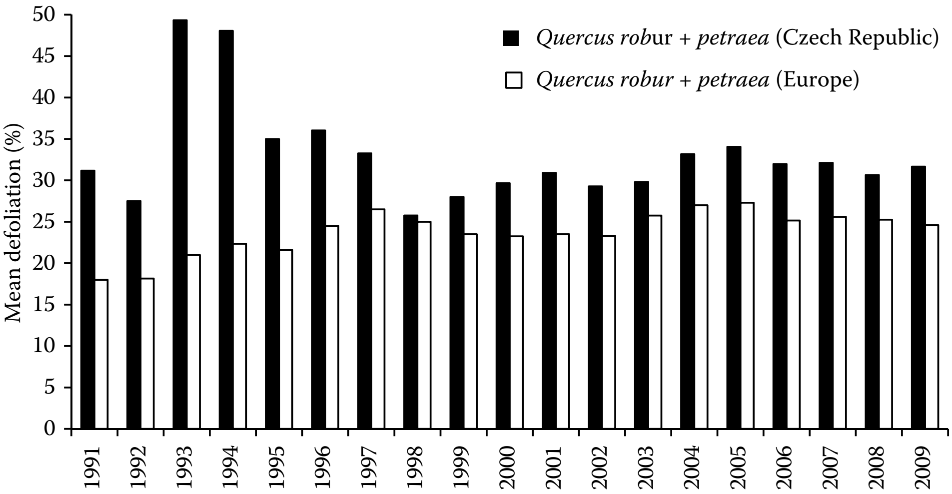

Fig. 13. Mean defoliation development of *Quercus robur* L. and *Quercus petraea* (Mattuschka) Liebl.

of several countries during the calibration course in the spruce stand in the Bohemian-Moravian Highlands, shows a relationship between different levels of assessment in the particular countries (Fig. 10). Austria with its defoliation assessment (especially for spruce) occupies the lowest position among the participating countries in the long run. Different levels of assessment among the particular countries are not caused solely by the assessor's subjective influence; they reflect in the first place the knowledge of different specific environmental conditions of forest ecosystems in the given country and different standard of a relatively healthy tree resulting from them. Moreover, a different level in defoliation assessment is influenced by different approaches to defining the natural and artificial (caused by anthropic activities) defoliation.

In the long-term development of average defoliation in 1991–2009, Norway spruce showed a similar trend in the Czech Republic like on European average but the values were 4–10% higher during the entire monitored period. In the last decade, the development of defoliation for this tree species could be described as stagnating within Europe and very moderately increasing in the Czech Republic (Fig. 11). The values of average defoliation for Scots pine were 3–20% higher during the above-mentioned period in the Czech Republic in comparison with the European average. In 1998 the development of average defoliation for Scots pine showed a distinct decrease in both cases, while in the next period until 2009, the defoliation development for this tree species in the Czech Republic differed from the European trend, which could be described as stagnating with slight fluctuations during the said period; by its strong increasing trend (Fig. 12).

The long-term development of average defoliation of the oak sp. in the period 1991–2009 was among the most fluctuating and at the same time most strikingly different when the values for the Czech Republic are compared with the European average; defoliation values in the Czech Republic exceed the European average by 1–28%. The development of this species in the Czech Republic in the last decade can be considered very similar to the development of the European average (Fig. 13). The long-term development of average defoliation of European beech during the above-mentioned

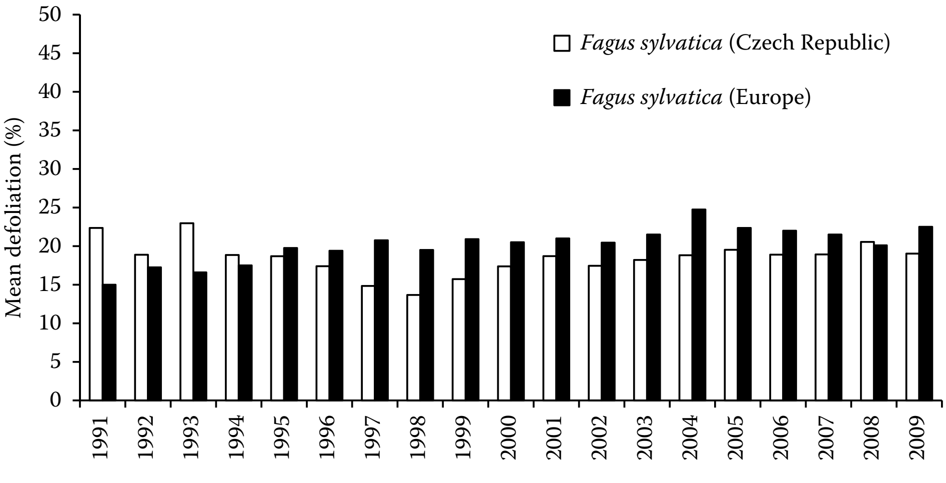

Fig. 14. Mean defoliation development of *Fagus sylvatica* L.

monitored period (1991–2009) can be described as slightly increasing within the European average, while in the Czech Republic the defoliation was in a significant decrease until 1998 and only in the next years the average defoliation started to increase gradually. In the years 1991–2009 the values of average defoliation for European beech in the Czech Republic differed from the European average in the range of 0.5–7%. In the last decade the defoliation values for European beech in the Czech Republic were 2–6% lower in comparison with the European average, the only exception being the year 2008, when the average defoliation of European beech in the Czech Republic was 0.5% higher than the European average (Fig. 14) (Fischer et al. 2010).

CONCLUSION

The unsatisfying forest condition in Europe, and especially in Central Europe, is a problem that transcends frontiers and directly concerns all the European countries. The cooperation of these countries in finding a solution to the common problem seems to be natural, with the inevitable part of this cooperation being the use of unified methodology as a prerequisite to the comparability of information acquired in different countries under different conditions. It is not possible to adopt effective remedial measures needed to ensure sustainable forest management without analyzing the causes of the adverse forest condition and monitoring their development. ICP Forests is the only programme covering the whole territory of the Czech Republic in its activities and providing information on the forest condition in accordance with the unified European methodology. With regard to the long-term character of the monitored problem and its all-European implications this is of paramount importance. Not less important is, however, the significance of such information for the verification of the reliability of data on the forest condition acquired by remote reconnaissance. The information assessed from satellite images can be verified only by data collected by ground monitoring in a wide range of stand and site conditions which is performed methodically in the same unified way.

The significant reduction of air pollution in the Czech Republic in recent years has undoubtedly been beneficial to the health of forest stands, even though the positive changes in the environment exert an effect on them with some delay. Yet still the forest stands of the Czech Republic show a high level of defoliation which is among the highest in Europe and, despite certain fluctuations, defoliation shows a very moderately increasing trend, as it is obvious from the long-term observations. This high level of defoliation is caused by the lower yet persistent negative influence of air pollution on the one hand, and on the other hand by the fact that the stability of forest ecosystems has long been disturbed by the excessive air pollution of previous years. A high level of defoliation is, of course, affected by other negative factors of biotic and abiotic origin, some of which have been increasing in importance in recent years (climatic extremes, wood-destroying insects, etc.).

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