JOURNAL OF FOREST SCIENCE, *56*, 2010 (11): 555–569

Health status of forest stands on permanent research plots in the Krkonoše Mts.

S. Vacek[1], K. Matějka[2]

[1]*Faculty of Forestry and Wood Sciences, Czech University of Life Sciences Prague, Prague, Czech Republic*
[2]*IDS, Prague, Czech Republic*

ABSTRACT: Damage to beech, mixed (beech with spruce to spruce with beech) and spruce stands in the Krkonoše Mts. is described on the basis of evaluation of transition matrices describing the probability of a change in the assessment of defoliation of particular trees in defoliation classes. The condition and development of health status were evaluated in the long run on PRP 1–32 in the Krkonoše Mts. by foliage and degrees of defoliation. Features describing the health status of the tree crown (damage by snow, frost, wood-decaying fungi, and insects) were also evaluated. Average defoliation, standard deviation of defoliation, estimation of minimum defoliation, and frequency of the tree number in defoliation classes were calculated for each plot, and each year. Three characteristic periods were distinguished according to different trend of foliage dynamics: period of the first symptoms of damage (1976–1980) – a decrease in foliage on average max. by 1% per year, period of great damage (1981–1988) – annual defoliation on average around 3–16%, period of damage abatement (1989–2009) – annual defoliation on average between 0% and 4%. The incomparably higher resistance of autochthonous stands to air pollution stress culminating in the eighties of the last century was demonstrated unambiguously.

Keywords: air pollution; beech, mixed and spruce stands; damage; defoliation; health status; Krkonoše Mts.; transition matrices

The first severe damage to spruce stands in the Krkonoše Mts. was apparent after climatic disruptions in March 1977 (Tesař et al. 1982). As a result of the air pollution impact accompanied by other negative factors (pathogenic organisms and extreme weather conditions) the forest suffered an extensive decline. Mainly allochthonous spruce stands, unsuitable for the sites concerned, were afflicted by such decline. Salvage felling due to air pollution was carried out on ca. 7,000 ha of forest stands (Vacek et al. 1994). On the contrary, autochthonous spruce stands, occurring mostly in protection forests, were substantially more resistant to air pollution. Mixed, beech and dwarf pine stands in ascending order showed high resistance to air pollutants.

In spite of the extant and further expected decrease in SO_2 emissions, the forest decline will continue in the Krkonoše Mts. in the years to come, although a certain stagnation of forest damage has been observed since 1988–1989 (Vacek 1995; Vacek et al. 2007). Particularly, great changes occurred in the soil environment while some ecological limits for the existence of ecologically stable and vital forest ecosystems were exceeded. For these reasons, research on the dynamics of forest stand damage was conducted in stand and site conditions. The broad knowledge of structural processes in forests exposed to air-pollution stress is essential for determination of specific principles of their management.

The result of forest dieback is a temporarily extremely increased volume of decaying wood as a substrate, in which natural decomposition processes take place, whereas decomposition prod-

Supported by the Ministry of Education, Youth and Sports of the Czech Republic, Project No. 2B06012.

ucts, important for the ecosystem regeneration, are released into the environment (Schwarz et al. 2007). Air pollution stress has a crucial impact on the microbiology of forest soils causing disorders of mycorrhizae while some species recede or disappear from the chemically influenced environment.

The objective of this paper is to provide an exact description of damage to beech, mixed (beech with spruce to spruce with beech) and spruce stands in the Krkonoše Mts. An emphasis is laid on the mathematical and statistical evaluation of acquired data. The evaluation of transition matrices describing the probability of a change in the assessment of defoliation of particular trees in defoliation classes was done. It is to note that damage to the tree layer of stands is generally understood as one element of a change in the forest ecosystem exposed to the impact of air pollution in synergism with other external environmental factors (cf. Vacek et al. 2007).

MATERIAL AND METHODS

Description of permanent research plots

Similarly like in the evaluation of the condition and development of soils the condition and development of health status of forest stands were evaluated in beech, mixed (spruce with beech to beech with spruce) and spruce stands on permanent research plots (PRP) 1–32 in the Krkonoše Mts.; their description was presented in a previous paper (Matějka et al. 2010) or earlier (Vacek et al. 2007).

Foliage evaluation

The ecological analysis of air pollution impacts on a forest ecosystem provided information about the changing the relations within the woody component, which constitutes the fundamental part of the forest ecosystems. The analysis of air pollution impacts was based on dendroecological reactions of particular trees within the stand texture.

The dynamics of the health status of beech, beech with spruce and spruce stands in the Czech part of the Krkonoše Mts. on 32 PRP has been evaluated in the long run by foliage and by degrees of defoliation using the following scale:

Degree of defoliation	Foliage (%)
0	91–100
1	71–90
2	51–70
3	31–50
4	1–30
5	0

In the period (1976) 1980 to 2009 the health status of forest stands was evaluated every year mainly by foliage. The classification of spruce foliage is based on Tesař and Temmlová (1971), of beech and other broadleaves on Vacek and Jurásek (1985). The evaluation comprised all dead or cut trees from the beginning of observation (cf. Vacek 2000; Vacek et al. 2007).

The former results from these research plots were summarized in many publications and were evaluated from different points of view, especially regarding the structure and development of stands, including reproduction and regeneration processes as well as site conditions (Tesař et al. 1982; Vacek 1981, 1983, 1984, 1986a, 1986b, 1987, 1988, 1989, 1990, 1992, 1993, 1995, 2001; Vacek et al. 1996, 1999, 2006, 2007, 2010; Vacek, Jurásek 1985; Vacek, Lepš 1987, 1991, 1995, 1996; Vacek, Matějka 1999; Vacek, Podrázský 1995, 1999, 2007; Lepš, Vacek 1986; Matějka et al. 1998).

Average foliage of forest stand according to tree species is expressed as the arithmetic mean of the values of foliage of all trees per plot. Defoliation (foliage complement to 100%) with special regard to the coenotic position and morphological type of crown was estimated to the nearest 5% and recorded as six defoliation classes that correspond to the degrees of tree damage:

Defoliation class	Defoliation interval (%)	Average defoliation (%)	Tree description
0	0–10	5	healthy
1	10–30	20	moderately-damaged
2	30–50	40	intermediately damaged
3	50–70	60	heavily damaged
4	70–100	85	declining
5	100	100	dead

The problems connected with the use of defoliation for a description of tree and forest stand damage were analysed in other papers by many authors (e.g. by Matějka 1993), and practically identical methodology was also used in ICP-Forests international project (Lorenz 1995).

Features describing the health status of the crown (damage caused by snow, frost, wood-decaying fungi and insects) were also evaluated.

The dynamics of tree defoliation and dieback on the particular plots was processed by the TDM (Tree Defoliation Modelling) programme of the IDS Company (Matějka 2009). Data on all trees were collected in one database table in dBase/FoxPro format, which is a source of data for the TDM programme.

The degrees were transformed to percentage values of defoliation for further calculations (average values for the defoliation class concerned). The evaluation of plots was based on development of the arithmetic mean of defoliation of all concurrently living trees per plot (mean for defoliation classes 0–4), standard deviations of defoliation and development of the number of dead trees (of totally defoliated trees, class 5). Each tree species was evaluated separately.

These characteristics were calculated for each plot and each year:

– average defoliation (AVG) as the arithmetic mean of the values of defoliation of all trees in percentage (as the class mark according to the classification of a respective tree);
– standard deviation of defoliation (STD) as the respective statistic of a statistical sampling set like in the preceding case;
– estimation of minimum defoliation (minDEFOL) as the value AVG + $u_{0.25}$ STD, where u_p is critical level of normal distribution for probability *P*;
– frequency of the tree number in defoliation classes.

Forest development prediction

Using the TDM programme the models (predictions) of defoliation development were also computed. The processes of changes in defoliation and dieback were investigated on the basis of the calculation of transition matrices (cf. Matějka et al. 1998) for the particular defoliation classes, always for two consecutive years. An attempt at the prediction of further forest development was done by the inclusion of particular trees in defoliation classes and by observation of changes in this classification during the observation. For two consecutive years it was possible to construct a transition matrix for each observed plot that indicates changes in the classification of evaluated trees. If the development in consecutive years shows a similar trend and if there are not any pronounced changes in environmental conditions, a similar structure of transition matrices is to be assumed. This is the reason why relatively homogeneous periods of forest condition development were distinguished and the "average transition matrices" were calculated as the matrices the elements of which are the arithmetic mean of the respective elements of original matrices. We assume that based on these matrices the expected stand development in a subsequent period can be calculated.

RESULTS AND DISCUSSION

After the occurrence of substantial air pollution in these mountains at the end of the seventies the synergism of air pollutants, climatic extremes and biotic pests resulted in high dynamics and destruction of forest ecosystems. The climatically exposed ridge parts of the Krkonoše Mts. at an elevation of approximately 900 m a.s.l. suffered the greatest damage (Schwarz 1997). However, influential anemo-orographic (A–O) systems allowed the penetration of air pollutants to leeward parts of glacial cirques and mountain valleys. It caused not only the damage or even decline of the woody component of these ecosystems but also pronounced changes in the herb and moss layer or in the soil environment (Vacek, Matějka 1999; Vacek et al. 2007).

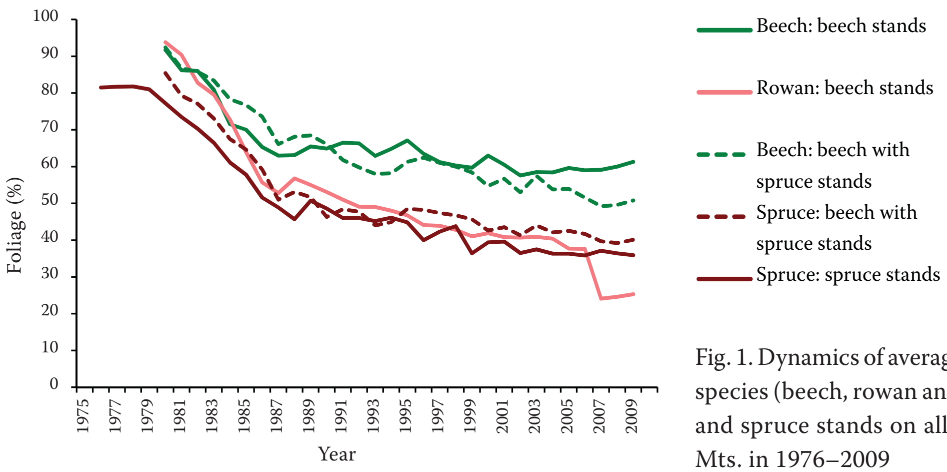


Fig. 1. Dynamics of average foliage of particular tree species (beech, rowan and spruce) in beech, mixed and spruce stands on all 32 PRP in the Krkonoše Mts. in 1976–2009

Table 1. Mean values of foliation (%) of beech in beech stands of PRP 27–32, and of beech and spruce in mixed stands of PRP 1,2, 6–9 in the period 1980–2009. Plots are grouped according to defoliation

PRP	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
Beech in beech stands																														
27	86.2	80.2	78.1	75.3	64.5	62.9	55.6	50.9	48.4	57.7	51.3	54.3	55.7	49.5	52.5	61.0	53.9	48.9	50.9	51.8	54.8	55.0	51.4	52.9	53.4	54.7	53.4	53.0	52.4	54.7
28	92.7	88.3	86.5	81.8	70.2	69.1	64.2	62.4	62.4	66.7	61.4	66.4	66.8	64.0	58.8	67.7	60.6	56.0	58.7	56.8	62.2	61.7	57.2	58.4	57.3	59.3	58.9	59.8	59.5	60.8
29	97.2	94.0	93.9	87.7	82.5	81.2	77.8	76.7	77.8	78.5	78.2	78.0	78.8	77.6	84.2	77.7	71.9	74.1	70.8	74.4	73.1	70.3	68.0	69.2	69.4	69.1	68.1	65.4	68.3	69.6
30	91.9	86.7	87.0	82.2	73.2	71.6	69.4	68.1	65.6	67.2	69.6	67.8	66.7	64.7	68.9	67.8	70.2	67.7	66.1	65.4	68.0	62.9	63.2	62.4	62.0	63.8	64.3	64.8	63.8	65.6
31	92.3	85.8	87.4	81.7	72.0	69.4	65.0	61.2	62.9	61.1	64.4	66.1	64.4	63.2	61.5	64.8	64.0	62.2	61.3	57.4	62.7	57.3	52.8	53.9	54.0	55.0	54.7	56.4	58.3	58.8
32	89.6	82.1	82.8	76.5	66.5	65.7	60.1	58.8	61.3	61.9	64.4	66.4	65.3	58.6	62.6	63.3	60.3	58.1	53.9	52.6	56.9	55.8	53.0	54.2	54.2	55.9	54.4	55.6	57.6	58.5
AVG	91.7	86.2	86.0	80.9	71.5	70.0	65.3	63.0	63.1	65.5	64.9	66.5	66.3	62.9	64.8	67.1	63.5	61.2	60.3	59.7	63.0	60.5	57.6	58.5	58.4	59.6	59.0	59.1	60.0	61.3
Beech in mixed (beech-spruce and spruce-beech) stands																														
8	93.4	88.9	88.7	82.4	74.6	74.3	72.4	65.6	63.9	66.6	61.3	62.1	62.6	59.8	59.5	66.1	69.2	63.5	57.6	55.5	49.3	49.6	45.5	49.9	44.6	46.0	42.2	39.6	41.0	42.9
2	95.2	90.2	91.1	90.2	90.2	87.2	84.6	81.1	81.9	80.4	80.7	77.5	71.8	72.7	74.1	73.0	76.4	80.9	78.5	73.6	66.2	75.3	69.6	78.2	69.8	73.0	71.9	65.2	63.6	65.3
7	92.5	87.8	86.3	84.3	79.4	76.6	72.7	64.3	74.0	74.8	72.4	71.6	72.0	66.1	69.6	74.1	74.2	72.2	71.5	70.9	62.2	66.5	61.5	65.2	67.0	67.4	65.0	64.4	66.3	66.9
9	93.6	84.9	82.3	81.5	77.2	78.6	75.6	66.4	63.6	67.7	62.6	63.7	60.6	58.2	57.8	59.5	64.2	61.8	58.7	57.9	59.8	57.0	53.5	59.3	50.7	51.8	48.3	44.9	45.5	46.6
6	91.3	86.5	85.3	82.4	73.5	69.6	66.4	56.5	58.2	55.8	57.7	59.5	58.5	53.8	52.5	56.5	54.9	47.9	53.2	54.4	52.1	52.8	48.5	49.9	52.2	52.4	51.6	51.0	51.3	52.0
1	88.3	81.9	81.0	79.6	74.6	74.1	69.7	62.5	66.9	65.5	62.0	36.6	33.0	37.4	35.8	38.7	35.5	39.4	40.8	38.3	38.7	38.7	39.2	42.8	38.8	32.8	30.9	30.1	30.1	31.2
AVG	92.4	86.7	85.8	83.4	78.3	76.7	73.6	66.1	68.1	68.5	66.1	61.8	59.8	58.0	58.2	61.3	62.4	61.0	60.0	58.4	54.7	56.7	53.0	57.5	53.8	53.9	51.6	49.2	49.6	50.8
Spruce in mixed (beech-spruce and spruce-beech) stands																														
8	70.8	57.5	57.5	58.1	58.1	55.0	53.3	36.1	36.1	43.6	34.4	45.6	43.9	32.8	37.2	46.1	46.1	41.4	36.9	34.7	30.3	30.0	27.8	34.4	30.0	30.0	30.0	28.6	31.1	33.9
2	91.0	85.8	84.9	81.3	78.0	73.6	68.3	64.6	65.2	69.6	65.4	66.2	63.7	59.4	61.0	61.6	61.6	64.8	66.0	62.3	59.0	60.9	57.0	60.4	59.3	58.4	57.3	51.5	51.5	48.5
7	94.0	93.0	88.2	80.6	74.9	73.6	66.0	66.0	71.8	69.1	68.4	66.8	69.5	69.5	70.2	74.0	74.0	73.3	71.8	76.8	65.7	69.0	67.0	68.8	70.5	72.5	71.0	67.7	32.3	67.7
9	87.2	79.0	74.7	70.6	64.4	64.4	63.0	52.5	55.9	54.6	51.1	56.5	57.0	52.7	51.9	58.3	56.1	55.4	55.5	56.0	55.8	55.4	52.6	55.9	55.4	55.8	53.3	52.5	47.5	52.5
6	87.9	85.2	80.8	73.5	58.2	54.2	41.3	36.8	39.0	34.0	32.2	35.6	33.3	31.7	31.3	35.9	37.4	37.0	36.6	32.0	33.1	33.5	31.6	31.2	32.4	33.1	33.1	32.8	67.2	32.8
1	81.7	75.2	76.5	74.6	71.5	66.9	63.1	50.2	50.5	39.5	25.9	19.4	18.8	18.1	18.1	15.3	14.0	12.7	13.2	12.7	12.0	12.0	12.0	13.3	5.3	5.3	5.3	5.3	5.3	5.3
AVG	85.4	79.3	77.1	73.1	67.5	64.6	59.2	51.0	53.1	51.7	46.3	48.4	47.7	44.0	44.9	48.5	48.2	47.4	46.7	45.7	42.6	43.5	41.3	44.0	42.1	42.5	41.7	39.7	39.2	40.1

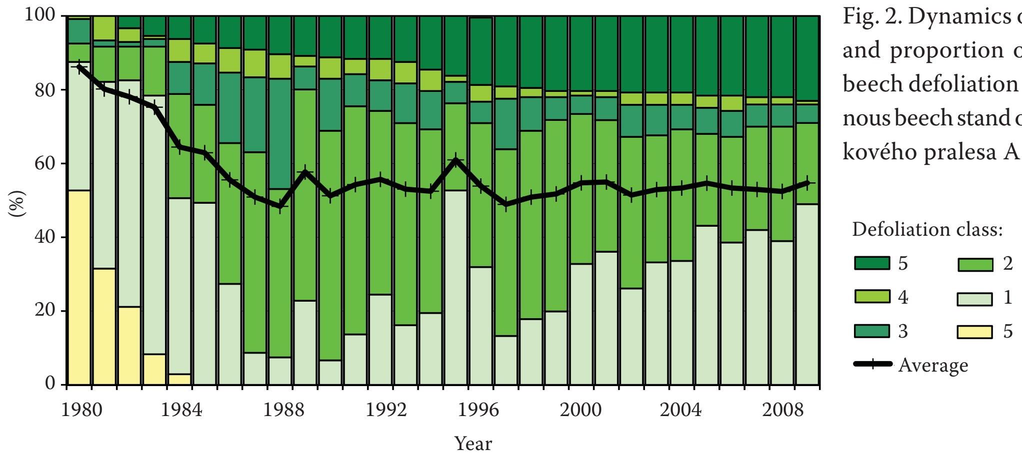
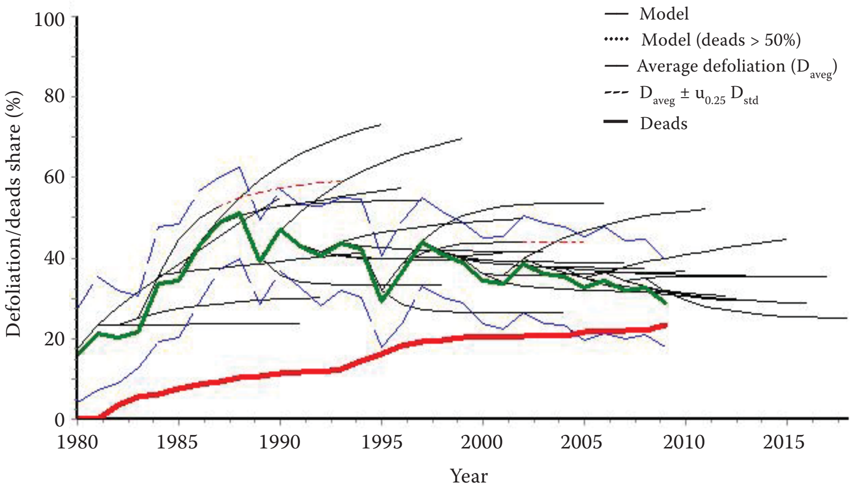


Fig. 2. Dynamics of average foliage and proportion of the degrees of beech defoliation in an autochthonous beech stand on PRP 27 – U Bukového pralesa A



Stand foliage condition and development, stand development prediction

Development of the average foliage of particular tree species (beech, rowan and spruce) on PRP 1–32 in the Krkonoše Mts. in 1976–2009 is briefly summarised with regard to the specific situation on plots in beech, mixed and spruce stands (Fig. 1). The evaluation of development on each plot is based not only on the description of the proportions of trees included in defoliation classes but also on the observation of average defoliation (it was always calculated as the average value of defoliation of all living trees) and/or average foliage (calculated for all trees on PRP). From the aspect of further stand development so called average minimum defoliation is important (the value minDEFOL, which expresses the average defoliation of 25% of trees with the lowest defoliation on PRP) which indicates the outlook of further stand development in the case that there is a sufficient number of living trees per plot. The represented models of development describe the trend of development in a satisfactory way (changes in defoliation from year to year).

Beech stands

Dynamics of mean foliation of beech in beech stands on PRP 27–32 in the years 1980–2009 is documented in the Table 1.

The development of average foliage and of the proportion of defoliation degrees in a beech stand on PRP 27 – U Bukového pralesa A shows severe defoliation of European beech (Fig. 2) in 1980–1988. The foliage apparently stabilized after 1988 but some oscillations were observed mainly in 1989–1997. A marked increase in rowan defoliation was recorded in 1980–1987. In subsequent years the defoliation continued to increase with larger or smaller oscillations. In 1999–2004 the trend of defoliation stabilized and a pronounced decrease in defoliation as a result of climatic fluctuations was observed again in 2005 while in subsequent years (2006–2009) the trend of defoliation stabilized again (Fig. 3). The relatively accelerated dynamics of the health status development mainly in rowan and also in beech is markedly influenced, besides the air-pollution stress, by the proceeding stage of disintegration of this stand.

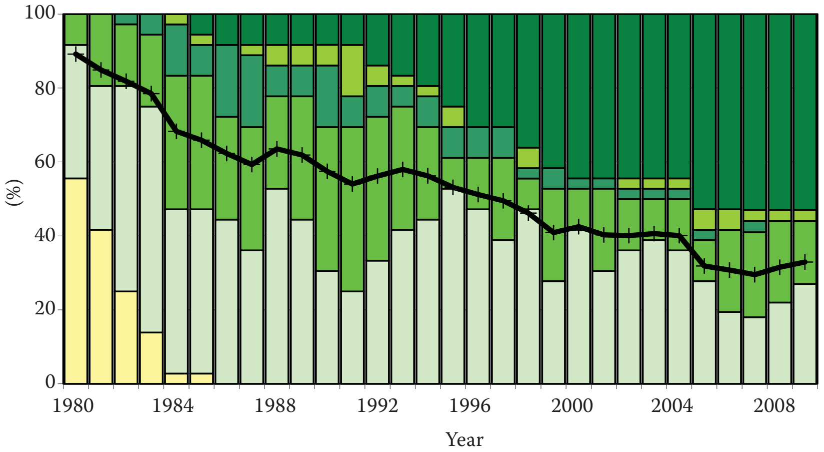
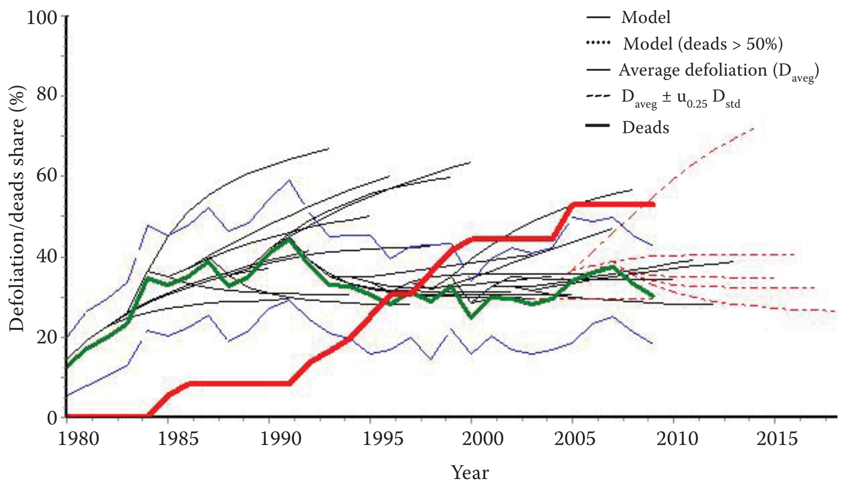


Fig. 3. Dynamics of average foliage and proportion of the degrees of interspersed rowan defoliation in an autochthonous beech stand on PRP 27 – U Bukového pralesa A



On PRP 28 – U Bukového pralesa C severe defoliation of European beech was observed in 1980–1984. In two subsequent years the trend of defoliation decelerated and since 1987 the foliage apparently stabilized but some oscillations occurred in 1989–2002. In 2005–2009 the beech showed foliage equalisation. Pronouncedly accelerated dynamics of the health status development as indicated by foliage in 1981–1984 was undoubtedly caused by high air pollution of the environment and by a heavy attack of the beech scale (*Cryptococcus fagi*) on this stand.

On PRP 29 – U Bukového pralesa B marked defoliation of European beech occurred only in 1983 and 1984 and also in 1995 and 1996. In the other years the trend of foliage was apparently stabilized but some oscillations were observed particularly in 1996–1999. The situation in 2007 was similar. A pronounced increase in rowan defoliation was recorded in 1981–1985, and besides the high air pollution stress it was caused by the heavy browsing of rowan by red deer. In subsequent years (1987 to 1996) there was a further increase in defoliation with larger or smaller oscillations. After 1996 the trend of defoliation stabilized and a marked decrease in defoliation was observed in 2007 as a result of the proceeding stage of disintegration. The relatively accelerated dynamics of the health status development in rowan and also in beech is largely influenced, besides the air pollution stress, by the proceeding stage of disintegration of this stand; the impact of red deer was also substantial on this plot in the eighties of the 20th century.

On PRP 30 – U Hadí cesty D the defoliation of European beech was severe in 1983 and 1984. After 1985 the foliage apparently stabilized but some oscillations were recorded mainly in 1988–2001. The occurrence of healthy trees and moderate increase in their number were observed since 2003.

On PRP 31 – U Hadí cesty F the defoliation of European beech in 1983–1987 was severe. The situation was similar in 2001 and 2002. After 1987 the foliage apparently stabilized but some oscillations were recorded mainly in 1994–2000. Since 2002 the foliage showed a very balanced and moderately upward trend. It was also a result of an increasing proportion of healthy trees since 2006.

On PRP 32 – U Hadí cesty E, the defoliation of European beech was obviously pronounced in 1981, 1983 and 1984. After 1986 the foliage apparently stabilized but some oscillations were recorded mainly in 1992–2000. Since 2002 the foliage showed a very balanced and moderately upward trend. It was also a result of the increasing proportion of healthy trees since 2007. The highly accelerated dynamics of the health status development in beech was substantially influenced by the air-pollution stress in 1981–1986.

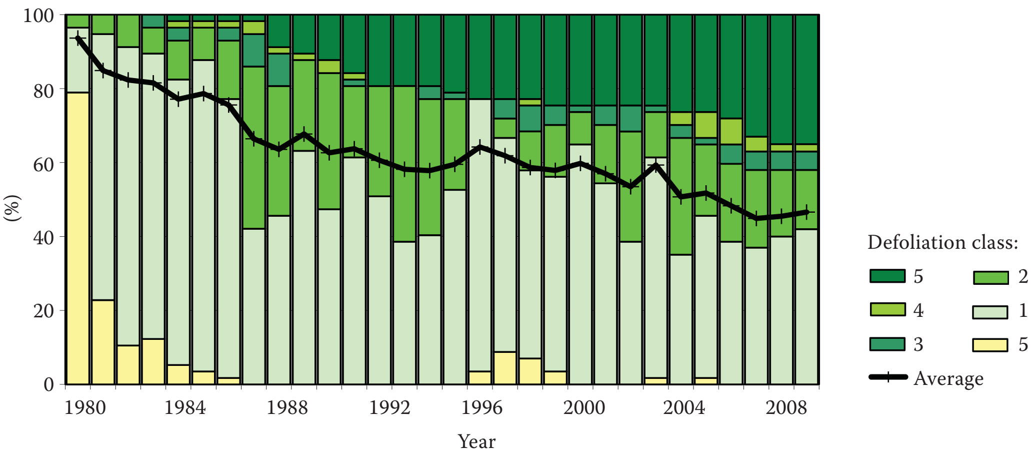
Mixed stands

Dynamics of mean foliation of beech and spruce in the mixed stands on PRP 1, 2, 6–9 in the years 1980–2009 is demonstrated in the Table 1.

On PRP 8 – Nad Benzínou 2 severe defoliation of European beech was observed in 1981–1987. The foliage stabilized in 1988–1994, and in two subsequent years (1995–1996) there was a more marked increase in defoliation. In 1997–2002 gradual moderate defoliation occurred again while from 2003 to 2009 the trend of defoliation stabilized again in spite of some oscillations.

On PRP 2 – Vilémov the defoliation of European beech was relatively moderate in 1981–1992. After 1992 the foliage apparently stabilized, but mainly in 1997, 2000, 2002, and 2004 greater oscillations by climatic extremes were recorded. The most severe defoliation occurred in 2000, probably as a result of great damage by ozone to the assimilatory apparatus (necroses, chloroses, spoon leaf). A pronounced increase in Norway spruce defoliation was observed in 1981–1987. The trend of foliage more or less stabilized in subsequent years with the existence of larger or smaller oscillations due to climatic fluctuations.

On PRP 7 – Bažinky 1 marked defoliation occurred in European beech in 1981–1987. Since 1988 the trend of foliage relatively stabilized but there were some oscillations mainly in 1993, 2000–2002. A pronounced increase in Norway spruce defoliation was recorded in 1981, in the year with extreme air pollution, and in 1987 as a result of the infestation with the eight-toothed spruce bark beetle. In the other years there was only a moderate increase in defoliation followed by the stabilized trend of foliage with



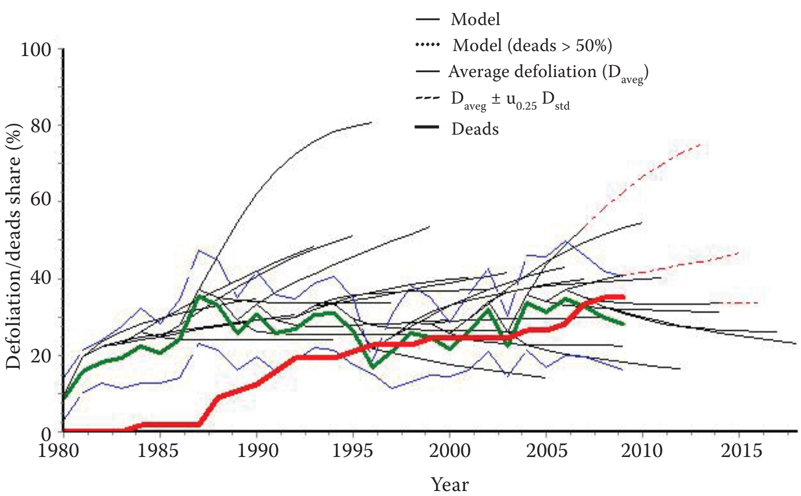


Fig. 4. Dynamics of average foliage and the proportion of defoliation degrees in beech in the autochthonous beech with spruce stand on PRP 9 – Nad Benzínou 1

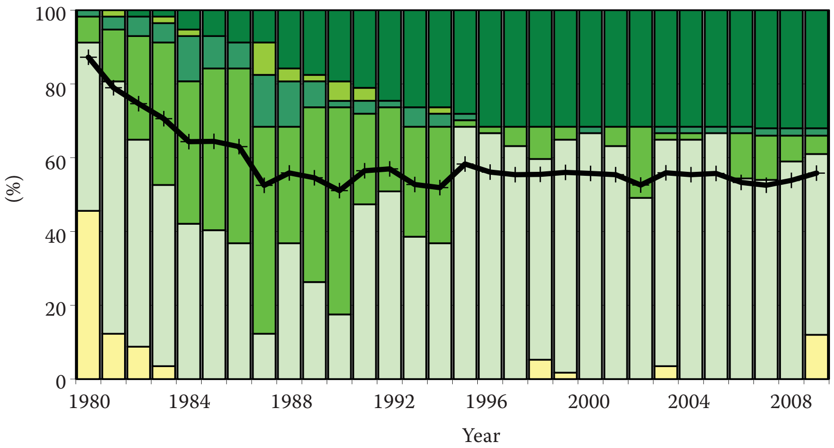
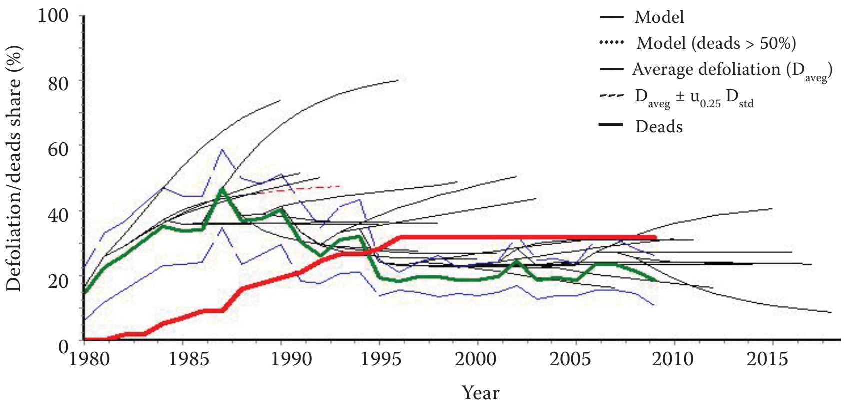


Fig. 5. Dynamics of average foliage and the proportion of defoliation degrees in spruce in the autochthonous beech with spruce stand on PRP 9 – Nad Benzínou 1



the existence of larger or smaller oscillations. The relatively accelerated dynamics of the health status development mainly in spruce is markedly influenced, besides the air-pollution stress, by the periodic feeding of the eight-toothed spruce bark beetle.

The development of average foliage and of the proportion of defoliation degrees in the beech stand on PRP 9 – Nad Benzínou 1 documents severe defoliation of European beech in 1981–1987 (Fig. 4). The trend of foliage relatively stabilized in 1988–1996 while in 1997–2000 defoliation was rather pronounced again; the foliage stabilized since 2000. A marked increase in Norway spruce defoliation was observed in 1981–1987 due to the extreme air pollution stress in synergism with the attack by the eight-toothed spruce bark beetle. Since 1988 the trend of foliage stabilized with the existence of smaller oscillations (Fig. 5).

On PRP 6 – Bažinky 2 the defoliation of European beech was obviously severe in 1981–1987. After 1988 the trend of foliage relatively stabilized but larger oscillations were recorded mainly in 1997 and 2000. A pronounced increase in Norway spruce defoliation was observed also in 1981–1987 due to great air pollution stress and the infestation with the eight-toothed spruce bark beetle. After 1988 the trend of foliage more or less stabilized with the existence of inconsiderable oscillations. The relatively accelerated dynamics of the health status development mainly in spruce is markedly influenced, besides the air-pollution stress, by the periodic feeding of the eight-toothed spruce bark beetle.

On PRP 1 – U Tunelu the defoliation of European beech was severe in 1981–1991 while the most pronounced decrease in foliage was recorded in 1991 as a result of acute damage to the assimilatory apparatus by air pollutants in synergism with the intensive sucking of the beech scale. The trend of foliage stabilized in 1992–2003 while defoliation markedly increased again in 2004 and 2005. The trend of defoliation stabilized after 2005. A pronounced increase in Norway spruce defoliation was recorded in 1981–1991 due to heavy air pollution and infestation with the eight-toothed spruce bark beetle. In 1992–2003 the trend of foliage stabilized again. In 2004 there was another increase in defoliation as a result of the eight-toothed spruce bark beetle feeding and since 2005 the trend of foliage stabilized again. The considerably accelerated dynamics of the health status development mainly in spruce was largely influenced in the past by the eight-toothed spruce bark beetle feeding, besides the heavy air pollution stress.

Table 2. Mean values of foliation (%) of spruce in spruce stands on PRP 3–5; 10–26 in the period 1976–2009. Plots are grouped according to defoliation in the year 2006

PRP	1976	1977	1978	1979	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009
4					77.6	76.2	73.7	68.0	61.4	58.2	49.6	43.6	46.0	46.4	44.3	41.8	45.9	42.8	45.0	43.6	43.4	41.8	41.8	40.9	37.7	42.1	40.0	41.5	41.5	40.9	40.7	36.8	37.2	37.2
5					80.6	79.6	75.9	71.2	65.8	62.5	55.6	47.3	50.9	56.6	51.0	47.1	54.1	56.4	61.1	57.7	55.1	55.5	56.3	56.8	54.7	57.6	51.8	57.6	55.7	55.5	52.5	51.9	54.0	56.8
21					68.9	67.7	69.4	65.5	62.0	60.3	54.4	52.4	48.7	57.1	57.3	57.0	52.1	56.4	57.6	56.8	58.8	58.6	59.3	59.0	58.0	56.9	56.3	56.4	54.5	56.2	56.5	55.8	58.2	59.7
22					77.7	76.5	74.0	70.5	65.6	63.9	57.1	54.3	51.6	58.9	58.2	54.4	54.8	58.4	55.5	58.7	56.9	60.9	60.4	54.1	57.3	54.9	52.1	56.0	51.8	51.5	50.5	49.6	49.5	52.8
23					70.3	69.4	66.5	62.4	56.0	52.6	44.8	42.8	37.1	42.5	42.6	42.4	42.1	39.9	46.7	46.1	48.1	46.5	46.4	38.7	43.6	43.5	40.3	39.8	37.5	39.1	38.3	36.8	38.1	40.8
24					80.7	79.5	77.1	73.1	70.4	69.7	62.7	61.6	58.4	63.5	64.5	65.0	61.7	59.9	62.2	63.3	58.3	63.0	60.4	58.6	60.5	60.7	54.5	58.6	57.5	55.3	55.3	54.1	51.6	32.4
10					70.1	69.1	67.3	64.5	59.3	55.0	49.8	46.3	41.2	47.5	46.5	45.3	44.9	50.2	48.1	47.8	50.1	50.2	49.5	43.2	48.1	47.7	43.1	43.1	41.5	36.9	35.4	30.4	18.7	16.4
11	78.4	78.4	78.4	77.4	74.8	56.2	52.2	50.0	48.5	45.0	40.4	37.3	32.6	37.0	34.0	31.8	31.5	31.8	31.0	30.6	35.8	31.7	30.6	27.7	32.2	33.3	29.8	28.0	29.4	30.4	31.2	28.8	30.5	33.5
12	80.4	80.4	80.4	79.6	78.3	65.5	62.0	62.7	58.5	55.0	45.5	42.3	36.9	39.7	35.1	32.2	31.7	33.2	29.1	29.9	26.8	25.0	23.7	21.9	24.2	24.5	22.1	21.2	19.9	22.5	22.5	22.0	21.9	23.5
20					75.4	74.6	72.0	67.8	61.7	60.3	54.2	51.8	47.3	49.0	47.9	46.9	50.7	45.0	49.8	49.0	48.7	40.6	39.8	37.7	37.8	36.3	33.7	34.1	32.2	34.7	33.7	30.3	29.9	29.9
13	82.6	83.0	83.2	82.6	82.1	76.1	70.9	71.1	68.3	65.4	59.3	57.6	55.5	62.0	57.4	51.5	54.0	57.7	61.0	62.4	61.4	60.9	33.5	19.2	18.2	17.2	14.0	13.5	13.3	12.1	12.1	12.3	11.4	11.7
14	82.9	83.4	83.7	83.6	83.6	78.0	78.2	76.4	69.7	66.8	61.5	61.4	56.0	63.0	57.7	53.7	50.5	52.1	56.8	50.6	42.6	40.6	15.1	7.8	0.3	0.3	0.3	0.3	0.3	0.3	0.3			
3					70.4	69.5	65.4																											
15	83.2	83.2	83.4	81.8	81.4	73.6	72.5	60.8	56.5	54.6	45.7	43.9	34.5	31.5	28.4	26.2	27.2	9.8	3.1	0.3	0.7													
18					74.2	73.0	66.9	59.9	50.0	45.4	42.7	40.4	36.5	42.9	37.9	33.8	32.1	31.3	31.2	30.0	4.5	3.0												
25					79.1	78.1	76.0	72.3	68.1	65.5	58.8	53.6	51.4	56.2	62.2	55.8	53.5	54.1	55.1	57.8	19.6	3.1												
16*					77.5	76.5	73.0	66.7	59.7	51.8	49.4	52.0	48.5	54.4	51.6	50.3	44.9	42.7	37.5	24.0	15.4													
17*					82.2	80.9	72.7	65.9	55.7	48.2	44.5	42.5	41.6																					
19*					75.5	74.6	72.0	67.4	62.2	59.8	53.0	48.7	48.0	53.9	50.3	47.7	50.0	46.9	53.4	53.3	53.8	53.4	52.9	8.1										
26*					82.6	75.8	67.6																											
AVG	81.5	81.7	81.8	81.0	77.2	73.5	70.3	66.5	61.1	57.8	51.6	48.9	45.7	50.7	48.6	46.0	46.0	45.2	46.1	44.8	40.0	42.3	43.8	36.4	39.4	39.6	36.5	37.5	36.3	36.3	35.8	37.1	36.4	35.9

AVG – average, *alochthonous stands present

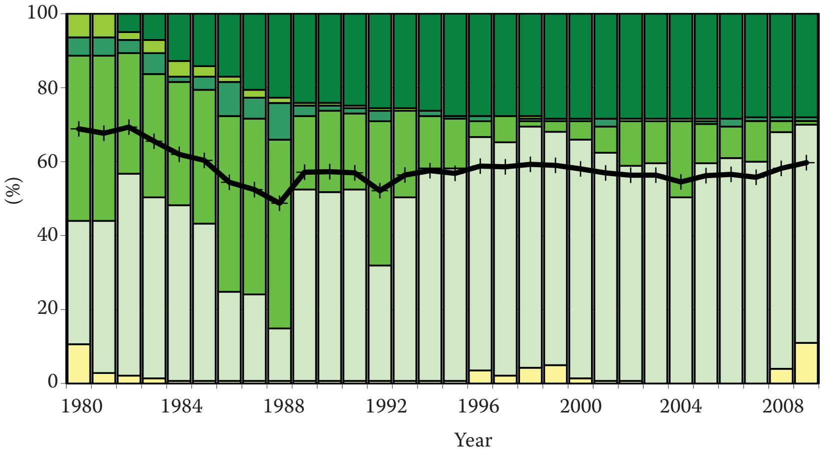
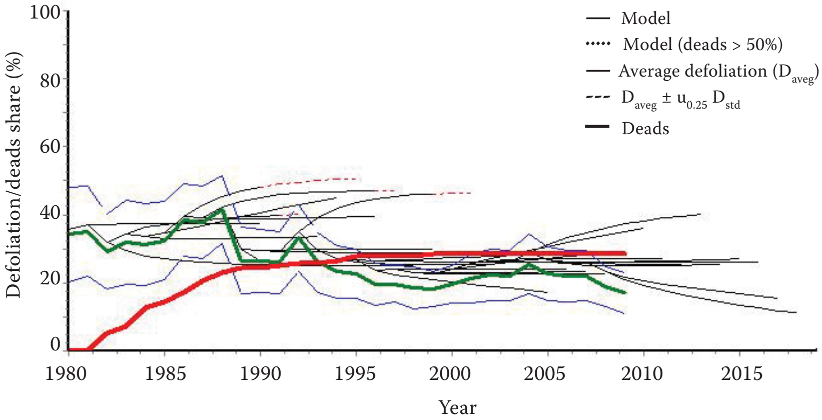


Fig. 6. Dynamics of average foliage and the proportion of defoliation degrees in an autochthonous spruce stand on PRP 21 – Modrý důl



Spruce stands

Dynamics of mean foliation of spruce in the spruce stands on PRP 3–5, 10–26 in the years 1976–2009 is demonstrated in the Table 2. Plots are grouped according to defoliation.

In an autochthonous spruce stand on PRP 4 – Pod Voseckou boudou severe defoliation of Norway spruce obviously occurred in 1981–1987. After 1988 the trend of foliage relatively stabilized but mainly in the years 1992, 2000, and 2001 smaller oscillations were observed. A moderate increase in Norway spruce defoliation was also recorded in 2007.

In an autochthonous spruce stand on PRP 5 – Pod Lysou horou pronounced defoliation was observed in 1981–1987. The trend of foliage stabilized with great oscillations in 1989–1994 and this trend was more or less steady after 1996. Rather severe defoliation occurred only in 2002.

The development of average foliage and of the proportion of defoliation degrees in an autochthonous spruce stand on PRP 21 – Modrý důl shows severe defoliation of Norway spruce (Fig. 6) in 1983–1988. After 1988 the trend of foliage relatively stabilized and a greater oscillation was recorded only in 1992 as a result of winter desiccation.

In an autochthonous spruce stand on PRP 22 – Obří důl severe defoliation of Norway spruce was recorded in 1981–1988. After 1988 the trend of foliage with moderate oscillations stabilized and this trend has been more or less steady until now.

In an autochthonous peaty spruce stand on PRP 23 – Václavák severe defoliation occurred in Norway spruce in 1981–1988. After 1988 the trend of foliage relatively stabilized, but greater oscillations were observed mainly in 1999 and 2009. A marked increase in foliage in 2009 was surprising.

In an autochthonous spruce stand on PRP 24 – Střední hora the defoliation of Norway spruce was severe in 1981–1988. After 1988 the trend of foliage relatively stabilized but oscillations were recorded mainly in 1996 and 2002. A pronounced increase in Norway spruce defoliation was observed since 2007 due to the feeding of the eight-toothed spruce bark beetle that was enormous in 2009.

In an autochthonous spruce stand on PRP 10 – Pod Vysokým pronounced defoliation of Norway spruce occurred in 1981–1988. The trend of foliage stabilized in 1988–2001 but a marked oscillation was recorded especially in 1999. Moderate defoliation was observed in 2002–2006, which was followed by severe defoliation since 2007 as a result of the bark beetle disturbance.

On PRP 11 – Strmá stráň A the trend of foliage in Norway spruce was stabilized in 1976–1980 while very high defoliation was recorded in 1981, in the year with extreme air pollution. The pronounced trend of defoliation continued until 1988, then the foliage relatively stabilized, but smaller oscillations occurred particularly in 1996, 1999, and 2007.

On PRP 12 – Strmá stráň B the trend of foliage in Norway spruce was stabilized in 1976–1980 while very high defoliation was recorded in 1981, in the year with extreme air pollution. The pronounced trend of defoliation continued as a result of air pollution stress and feeding of the eight-toothed spruce bark beetle until 1999, then the foliage relatively stabilized.

On PRP 20 – Pod Liščí horou a severe defoliation occurred in Norway spruce in 1982–1988. The trend of foliage relatively stabilized in 1989–1996. As a result of the eight-toothed spruce bark beetle feeding there was a marked decrease in foliage in 1997 and the situation was more or less stabilized since 1998 even though inconsiderable defoliation was observed there also in that period due to the infestation with the eight-toothed spruce bark beetle.

On PRP 13 – Strmá Stráň C the trend of foliage in Norway spruce was obviously stabilized in 1976–1980 and very high defoliation occurred in 1981, in the year with extreme air pollution. The pronounced trend of defoliation continued until 1988 while in 1998–1997 the foliage relatively stabilized, with smaller or larger oscillations, mainly in 1989 and 1991. Massive defoliation was recorded in 1998 and 1999 due to severe disturbance caused by bark beetles and since 2000 the trend of foliage almost stabilized.

The development of average foliage and of the proportion of defoliation degrees in the autochthonous spruce stand on PRP 14 – Strmá stráň D documents that the trend of foliage in Norway spruce was stabilized in 1976–1980 while very high defoliation occurred in 1981, in the year with extreme air pollution. The pronounced trend of defoliation continued until 1988; in 1988–1995 the foliage relatively stabilized, but there occurred smaller or larger oscillations, particularly in 1989, 1992, and 1995. After 1996 massive defoliation occurred due to severe disturbance caused by bark beetles that resulted in the dieback of the tree layer of spruce (Fig. 7).

In a spruce stand on PRP 3 – U Lubošské bystřiny the trend of foliage in Norway spruce was stabilized in 1980–1981 and rather severe defoliation occurred after the attack of the eight-toothed

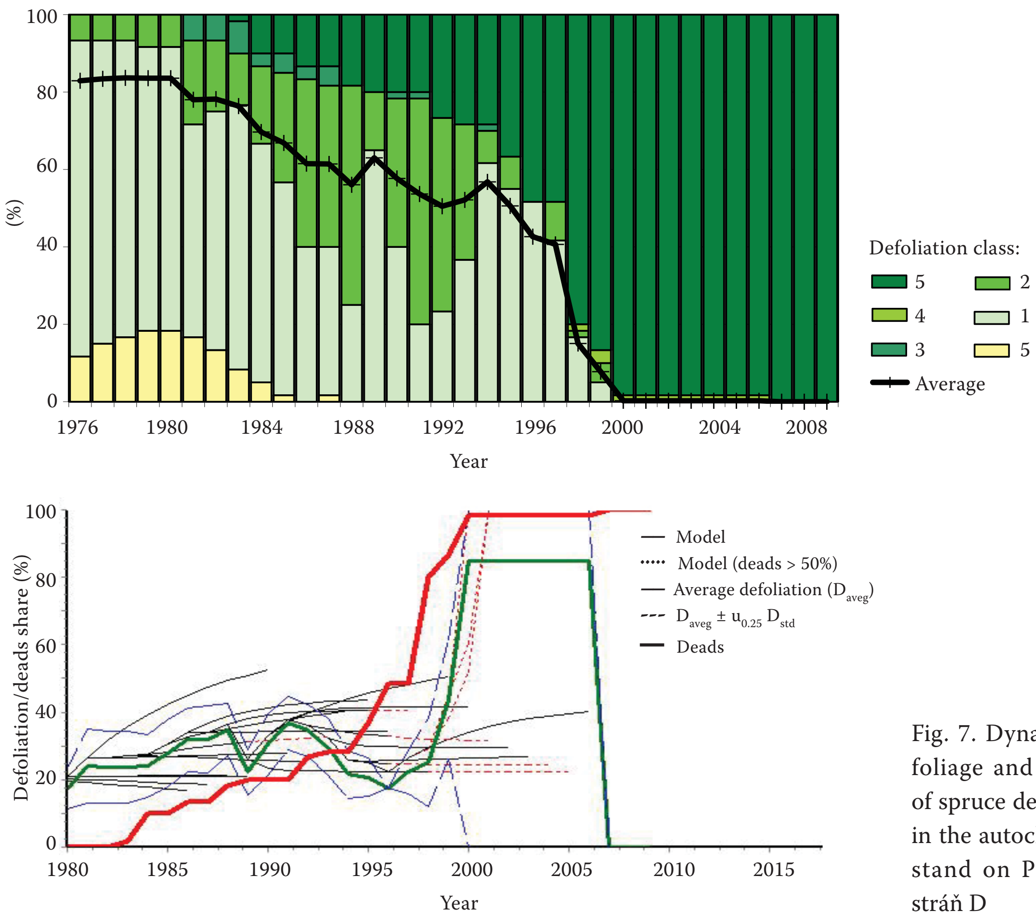


Fig. 7. Dynamics of average foliage and the proportion of spruce defoliation degrees in the autochthonous spruce stand on PRP 14 – Strmá stráň D

spruce bark beetle in 1982. The stand was heavily infested with bark beetles in 1983 and therefore it was sanitized.

The development of average foliage and of the proportion of defoliation degrees in an autochthonous spruce stand on PRP 15 – Strmá stráň D shows that the trend of foliage in Norway spruce was stabilized in 1976–1980 while very high defoliation occurred in 1981, in the year with extreme air pollution. The pronounced trend of defoliation as a result of disturbance caused by air pollution and by heavy bark beetle infestation continued until 1995. The tree layer completely died in 1997.

In a spruce stand on PRP 18 – U Čertovy strouhy the trend of foliage in Norway spruce was stabilized in 1980–1981 and more pronounced defoliation occurred on this plot in 1982–1988. The trend of defoliation was moderate or stabilized in 1989 to 1995. In 1996 this stand was heavily infested with bark beetles and in spite of sanitation measures the tree layer completely died in 1997.

In a spruce stand on PRP 25 – Pod Koulí the trend of defoliation in Norway spruce was obviously quite moderate in 1980–1985. In 1986–1995 the trend of foliage stabilized. In 1996 this stand was heavily infested with the eight-toothed spruce bark beetle and the tree layer completely died in 1998.

In an allochthonous spruce stand on PRP 16 – Pod Martinovkou the trend of defoliation in Norway spruce was pronounced in 1982–1985. Partial stabilisation of the foliage trend was recorded in 1986–1993. Due to wind disturbance in 1994 and subsequently to the bark beetle infestation the disintegration of this stand occurred while its tree layer completely died in 1997.

In a spruce stand on PRP 17 – U Bílého Labe severe defoliation of Norway spruce occurred since 1982 as a result of heavy air pollution stress, which culminated in 1989 by complete disturbance (dieback) of the tree layer caused by bark beetles.

In an allochthonous spruce stand on PRP 19 – U Klínové boudy the trend of Norway spruce defoliation was pronounced in 1982–1988. Partial stabilisation of the foliage trend was observed in 1989–1998. As a result of wind disturbance in 1999 and subsequently due to a disturbance caused by bark beetles the disintegration of this stand occurred and its tree layer completely died in 2000.

In an allochthonous spruce stand on PRP 26 – Lysečinský hřeben the air pollution stress in 1981 and 1982 accelerated the dynamics of the tree layer disintegration. In 1983 the stand infested with the eight-toothed spruce bark beetle was sanitized.

From the aspect of defoliation dynamics the health status is markedly better in European beech compared to Norway spruce or rowan, both in pure beech stands and in mixed spruce-beech stands. A considerable deceleration of the trend of average defoliation dynamics was observed after 1986. Similarly like in beech, markedly accelerated dynamics of defoliation was recorded since 1981 both in Norway spruce and in rowan and this trend largely decelerated since 1986–1987. The results explicitly document that the dynamics of spruce defoliation was influenced to a larger extent by the eight-toothed spruce bark beetle than by air pollutants,

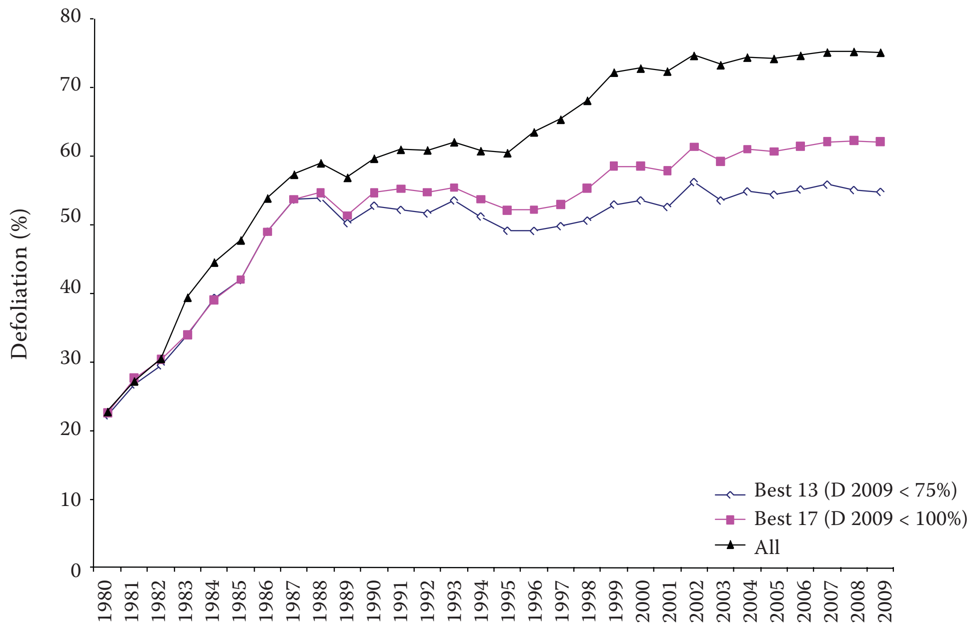


Fig. 8. Development of the Norway spruce defoliation since 1980. The plot groups are the same as in Table 3.

Table 3. Average yearly change of the Norway spruce defoliation in selected periods

Period	A	B	C
1980–1987	4.5	4.3	5.2
1987–1993	–0.1	0.3	0.8
1993–1995	–2.2	–1.6	–0.8
1995–2002	1.0	1.3	2.0
2002–2009	0.0	0.3	0.2

A – 13 plots with average defoliation at 2009 less than 75 %, B – all plots with living spruce trees at 2009 (17 plots), C – all 26 plots

particularly in the last period when more or less pronounced regeneration processes took place in stands without the influence of bark beetles or after its elimination. The trend of defoliation in rowan was substantially influenced by damage caused by game, mainly by peeling; similarly like the spruce infestation with bark beetles, heavy damage to rowan stems by peeling mostly led to the dieback of afflicted trees in this case.

Seasons since 1980 can be divided into periods with specific changes in the Norway spruce defoliation (Table 3, Fig. 8). The first period (1980–1987) is typical by severe defoliation increase, but stands of only two plots (3 and 26) totally died. Period of stabilization (1987–1993) comes after first one. The last three periods can be characterized by defoliation decrease (1993–1995), new moderate worsening (1995–2002) and stabilization (2002–2009). The period of new moderate worsening embraces the stand dieback in lot of plots. These distinguished periods can be described on the base of classification of the transition matrices as was illustrated in Vacek et al. (2007).

CONCLUSION

The results document that air pollutants, in synergism with negative influences of other biotic pests and abiotic factors, were the main cause of forest decline in the period of air-pollution disaster. In the period of observation (1976–2009) the accelerated dynamics of damage and consequently of development in spruce stands was caused by bark beetles.

Three characteristic periods were distinguished according to different trend of foliage dynamics. In the period of the first symptoms of damage (1976 to 1980) foliage in the studied stands decreased on average by 1% per year. In the period of severe damage (1981–1988) annual defoliation was on average around 3–16%. In the period of damage abatement (1989–2009) annual defoliation varied between 0% and 4% while the average foliage increased by 1–4%. Last period did not show one clear trend and can be subdivided into periods 1989–1995 (temporary stabilization), 1996–1999 (mild worsening of the healthy status, especially as the consequence of bark beetle attack), and 2000–2009 (stabilization again). In contrast to the Bohemian Forest Mts., there is not observed the worsening of status after climatically extreme year 2003 (Vacek et al. 2009). The specific trend for the spruce is indicated in the Table 3.

The resistance of autochthonous stands to air pollution culminating during the eighties of the last century was incomparably higher. Forest stands with a high proportion of European beech, sycamore maple and autochthonous spruce have always formed the natural ecological framework of forest ecosystems in the Krkonoše Mts.

Abiotic and biotic disturbances occurred in forest ecosystems of the Krkonoše Mts. also in the remote past but environmental disasters have never been so extensive as in coeval spruce monocultures in the 80s to 90s of the 20th century. Therefore these stands should be converted and ecologically stabilized by efficient close-to-nature management.

References

Lepš J., Vacek S. (1986): Use of transition matrices for prediction of the development of the spruce population in the Giant Mountains. In: Simulation of Systems in Biology and Medicine. Praha, Dům techniky ČSVTS: 1–5.

Lorenz M. (1995): International co-operative programme on assessment and monitoring of air pollution effects on forests – ICP forests. Water, Air and Soil Pollution, ***85***: 1221–1226.

Matějka K. (1993): Monitoring the forest state in the Czech republic. Methodological comments, list of research plots and some previous results. Praha, VÚLHM: 68. (in Czech)

Matějka K. (2009): PlotOA software help (Plotting of ordination diagrams and cartograms). Available at http://www.infodatasys.cz/software/hlp_PlotOA/PlotOA.htm (accessed on December 2, 2009) (in Czech)

Matějka K., Vacek S., Podrázský V. (2010): Development of forest soils in the Krkonoše Mts. in the period 1980–2009. Journal of Forest Science, ***56***: 485–504.

Matějka K., Vacek S., Schwarz O. (1998): Modelling the health status development of spruce stands in Krkonoše Mts. on the basis of satellite photographs. Lesnictví-Forestry, ***44***: 333–343. (in Czech)

Schwarz O. (1997): Reconstruction of forest ecosystems in the Krkonoše Mts. Instruction manual. Vrchlabí, KRNAP Administration: 174. (in Czech)

Schwarz O., Vacek S., Podrázský V., Kuś J. (2007): Development of hoofed game stocks and damage caused by the game in the bilateral biosphere reserve Krkonoše/ Karkonosze. Opera Corcontica, ***44***: 441–452. (in Czech)

Tesař V., Temmlová B. (1971): Tree foliation as criterion for health status evaluation of forest stands in air-pollution areas. Lesnictví, ***17***: 1017–1032. (in Czech)

Tesař V., Anděl P., Schwarz O., Vacek S. (1982): Knowledge of the air pollution impact on forest stands in the Krkonoše Mts. in the 1979 horizon. Opera Corcontica, ***19***: 79–94. (in Czech)

Vacek S. (1981): Health condition and reduced fructification of autochthonous Norway spruce stands as a consequence of air pollution load in the area of the anemo-orographic system of Mumlava Brook. Opera Corcontica. ***18***: 89–103. (in Czech)

Vacek S. (1983): Morphological variability of autochthonous Norway spruce populations in the Krkonoše Mts. Lesnictví, ***29***: 265–284. (in Czech)

Vacek S. (1984): Ecological consequences of forest stand damage in the timberline area in the Krkonoše Mts. Opera Corcontica, ***21***: 157–165. (in Czech)

Vacek S. (1986a): Dynamics of defoliation of protective forests exposed to air pollution in the Krkonoše Mts. Zprávy lesnického Výzkumu, ***31***: 4–7. (in Czech)

Vacek S. (1986b): Texture and tree damage in protective Norway spruce stands exposed to air pollution stress. Práce VÚLHM. ***69***: 167–188. (in Czech)

Vacek S. (1987): Structural changes of Norway spruce stands exposed to air pollution stress. Práce VÚLHM, ***71***: 155–192. (in Czech)

Vacek S. (1988): Dynamics of the defoliation of beech forest stands under the influence of air pollution. In: Proccedings 3. IUFRO Buchensymposium. Zvolen, 3.–6. June 1988. Zvolen, VŠLD: 377–388. (in Czech)

Vacek S. (1989): Dynamics of changes in spruce and beech stands under the influence of air pollution. Práce VÚLHM, ***74***: 239–276. (in Czech)

Vacek S. (1990): Fructification of beech stands influenced by air pollution in the Krkonoše Mts. In: Major tasks for seed production and tree breeding for forest management in air-pollution areas. In: Proceedings of the 8th National Conference held in Špindlerův Mlýn. Špindlerův Mlýn, ČSAZ 145–151. (in Czech)

Vacek S. (1992): Damage symptoms of Norway spruce (*Picea abies* [L.] Karst.). Opera Corcontica, ***29***: 183–189.

Vacek S. (1993): Health state of beech stands in different air pollution environmental conditions. Opera Corcontica, ***30***: 21–51. (in Czech)

Vacek S. (1995): Decline dynamics in mixed spruce – beech stands of the Krkonoše Mts. In: Matějka K. (ed.): Investigation of Forest Ecosystems and Forest Damage. Proceedings of a Workshop held in Opočno on April 25.–27. 1995. Praha, VULHM. 119–129. (in Czech)

Vacek S. (2000): Structure, development and management of forest ecosystems in Krkonoše Mts. [DrSc. Thesis.] Opočno, Prague, Forestry and Game Management Research Institute, Czech University of Life Sciences Prague: 684. (in Czech)

Vacek S. (2001): Healthy state development of forest stands on permanent research plots in the Giant Mountains. Opera Corcontica, ***37***: Proceedings of the International Conference Geoecological problems of the Giant Mountains, Krkonoše National Park. Svoboda nad Úpou, 19.–21. September 2000. Vrchlabí, KRNAP Administration: 536–541. (in Czech)

Vacek S., Jurásek A. (1985): Tree foliation as criterion for health status of beech stands in air-pollution areas. Lesnictví, ***31***: 579–600. (in Czech)

Vacek S., Lepš J. (1987): Changes in the horizontal structure in a spruce forest over a 9-year period of pollutant exposure in the Krkonoše Mountains, Czechoslovakia. Forest Ecology and Management, ***22***: 291–295.

Vacek S., Lepš J. (1991): The use of Leslie´s matrices for the prediction of development of spruce stands exposed to air pollution stress. Lesnictví, ***37***, 133–150. (in Czech)

Vacek S., Lepš J. (1995): Dynamics of decline and horizontal structure of the autochthonous mountain Norway spruce stands. In: Tesař V. (ed.): Management of Forests Damaged by Air Pollution. Proceedings of the Workshop IUFRO.Trutnov, 5.–9. June, 1994. Prague, Ministry of Agriculture: 9–14.

Vacek S., Lepš J. (1996): Spatial dynamics of forest decline: the role of neighbouring trees. Journal of Vegetation Science, ***7***: 789–798.

Vacek S., Matějka K. (1999): State of forest stands on permanent research plots in the Krkonoše Mts. in years 1976–1997. Journal of Forest Science, ***45***: 291–315.

Vacek S., Podrázský V. (1995): Development trends in forests of the Krkonoše Mts. under emission load. In: Flousek J., Roberts G.C.S. (eds): Mountain National Parks and Biosphere Reserves: Monitoring and Management. Proceedings of International Conference. Špindlerův Mlýn, Krkonoše National Park. Špindlerův Mlýn, 20.–23. September 1993. Vrchlabí, KRNAP Administration: 69–74.

Vacek S., Podrázský V. (1999): Soil chemistry changes in the Krkonoše Mts during the last decade. In: Vančura K., Šrámek V. (eds): Effect of Global Climate Change on Boreal and Temperate Forests. Prague, Forestry and Game Management Research Institute: 85–88.

Vacek S., Podrázský V. (2007): Healthy status development of forest stands on permanent research plots in the Giant Mts. Opera Corcontica, ***44***: 453–458. (in Czech)

Vacek S., Lokvenc T., Balcar V., Henžlík V. (1994): Forest regeneration and stabilization in the Sudeten Mountain

Region. In: Paschalis P., Zajaczkowski S. (eds): Protection of Forest Ecosystems. Selected problems of forestry in Sudety Mts. Warszawa, Biuro GEF: 93–119. (in Czech)

Vacek S., Lepš J., Štefančík I., Cicák A. (1996): Precision of visual estimates of tree defoliation. Lesnictví, ***43***: 49–53.

Vacek S., Bastl M., Lepš J. (1999): Vegetation changes in forests of the Krkonoše Mts. over a period of air pollution stress (1980–1995). Plant Ecology, ***143***: 1–11.

Vacek S., Podrázský V., Mikeska M., Simon J. (2006): Forests and ecosystems on the tree line in the National Parks of the Giant Mts. Kostelec nad Černými lesy, Lesnická práce: 112. (in Czech)

Vacek S., Matějka K., Simon J., Malík V., Podrázský V., Mikeska M. (2007): Health Status and Dynamics of Forest Ecosystems under Air Pollution Stress in the Giant Mts. Kostelec nad Černými lesy, Lesnická práce: 216. (in Czech)

Vacek S., Matějka K., Remeš J., Ulbrichová I., Simon J., Turčáni M., Viewegh J., Bednařík J., Malík K., Malík V., Bílek L., Štícha V., Semelová V., Ešnerová J., Baláš M. (2009): Forest Ecosystems of the Bohemian Forest National Park. Kostelec nad Černými lesy, Lesnická práce: 512. (in Czech)

Vacek S., Vacek Z., Schwarz O., Raj A,, Bílek L., Nosková I., Balcar Z., Zahradník D., Baláš M., Bednařík J., Mikeska M., Simon J., Minx T., Matějka K. (2010): Structure and Development of Forest Stands on Research Plots in the Krkonoše National Parks. Kostelec nad Černými lesy, Lesnická práce: 568. (in Czech)

Received for publication March 17,2010
Accepted after corrections June 20, 2010

Corresponding author:

Prof., RNDr. Stanislav Vacek, DrSc., Česká zemědělská univerzita, Fakulta lesnická a dřevařská,
Kamýcká 129, 165 21 Praha 6-Suchdol, Česká republika
tel.: + 420 224 382 870, fax: + 420 234 381 860, e-mail: vacekstanislav@fld.czu.cz