Dynamics of the health status of forest stands and its prediction on research plots in the Šumava Mts.

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ABSTRACT: The paper summarises the evaluation of the health status dynamics of allochthonous spruce stands in the Modrava Forest District and of natural stands in the Plešný Forest District. Analysis is based on dendroecological reactions of particular tree individuals in the stand texture. The tree damage was evaluated annually (in the period 1997–2005), based especially on defoliation. The most tolerant were the natural and semi-natural, especially mixed forest stands with dominant beech in the Plešný Forest District territory, the least tolerant were the allochthonous secondary spruce stands in the Modrava Forest District area. The damage dynamics was limited by the insect (bark beetle – Ips typographus) pest activity. Ozone damage appeared much more often in 2002, compared to the year 1999. The most damaged species were sycamore and rowan tree.

Keywords: health status; defoliation; air-pollution and ecological stress; bark beetle; ozone; transition matrix modelling

In the past two decades forests in the Šumava Mts. (Bohemian Forest Mts.) were afflicted by a marked air-pollution and ecological load that caused a substantial eco-physiological weakening of stands mainly in the highest mountain locations, manifested by specific symptoms of damage (defoliation, yellowing symptoms, necroses, etc.). Forest ecosystems in these locations are considerably influenced by acid deposition which exceeded the critical limit by 0.35–0.51 kmol/ha per year in total acidity at many sites (Moravčík 1994). Such a situation has negative impacts not only on production but also on ecological functions of forests, particularly as a consequence of the subsequent attack of harmful biotic factors (insect pests, fungal pathogens, etc.). Their expansion leads to stand structure destruction and marked disturbance of ecological stability and biodiversity of the entire ecosystems. Therefore regeneration and stabilisation of these stands become very important tasks of forest management and nature protection in these localities. To implement difficult regeneration and stabilisation practices it is necessary to acquire sufficient knowledge of the structure and development of natural forests and also of the dynamics of damage to restored stands. For this purpose the modelling of dynamics of forest stand defoliation by means of transition matrices is undoubtedly useful that takes into account probabilities of a change in the classification of a random tree from the given stand from one defoliation class in the first year to another defoliation class in the subsequent year. Transition matrices are frequently used for modelling in ecology and forestry (e.g. Dale, Hulshman 1988; Dragoi, Albeanu 1998; Huenneke, Marks 1987; Lippe et al. 1985; Lepš 1988; Mendoza, Setyarso 1986; Scott et al. 1990, and many others). This model approach was used to evaluate the dynamics of damage to forest stands in the Krkonoš Mts. (Vacek 1987; Vacek, Lepš 1995; Matějka et al. 1998; Vacek, Matějka 1999) and

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The objective of this paper is to evaluate the dynamics of the health status of secondary spruce stands in Modrava Forest District (FD) compared to natural mixed and spruce stands in Plešný FD. This paper is a follow-up of the papers of Vacek et al. (2000) and Vacek and Mayová (2000), Vacek et al. (2003), where the causes of damage to selected stands by air-pollution and ecological stresses were analysed.

MATERIAL AND METHODS

Table 1 shows the basic data on permanent research plots; the plots were described in greater detail in the paper of Ulbrichová and Podrážský (2000). Structural parameters such as height, breast height diameter and coenotic position of individual trees were measured or classified during the establishment of plots in 1997 and 2005 on nine permanent research plots (PRP 12–20) in natural mixed and spruce stands in Plešný FD and on nine PRP (1–4 and 7–11) in spruce monocultures in Modrava FD (Fig. 1). Standard dendroecological methods were used for this purpose. Coenotic positions of trees were classified according to Zlatník (1976). The results of these structural surveys were published in Vacek et al. (2000). The status and dynamics of (de)foliation of Norway spruce, European beech, other broadleaves (rowan, sycamore and Norway maple, wych elm, European ash and durmast oak) and silver fir were evaluated in all trees on the particular plots in 1997-2005. The classification based on the paper of Tesař and Temmllová (1971) was used for the evaluation of spruce foliation. Beech foliation was estimated according to the scale of Vacek and Jurásek (1985). The foliation (i.e. the proportion of the actual quantity of assimilatory tissues out of the highest potential quantity the living part of the crown would have in optimum local growth conditions) in the other above-mentioned tree species was evaluated on the basis of a similar principle like in spruce and beech. Foliation was estimated to the nearest 5%. These methods are compatible with so called International Cooperative Programme for the evaluation and monitoring of air-pollution and ecological stresses.

Table 1. Characteristics of permanent research plots (PRP) established in the period 1997–1998. Forest management plan valid since 1994 (Modrava) and 2002 (Plešný)

<table>
<thead>
<tr>
<th>Plot</th>
<th>Forest district</th>
<th>Stand</th>
<th>Altitude (m a.s.l.)</th>
<th>Forest site type</th>
<th>Stand age in 2002 (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Modrava</td>
<td>68B4</td>
<td>1,140</td>
<td>8N3</td>
<td>137</td>
</tr>
<tr>
<td>3</td>
<td>Modrava</td>
<td>67A7</td>
<td>1,120</td>
<td>8R1</td>
<td>141</td>
</tr>
<tr>
<td>7</td>
<td>Modrava</td>
<td>76C5/8</td>
<td>1,230</td>
<td>8S1</td>
<td>119/157*</td>
</tr>
<tr>
<td>12</td>
<td>Plešný</td>
<td>2C3/2/1</td>
<td>1,020</td>
<td>7S2</td>
<td>10, 25, 221</td>
</tr>
<tr>
<td>13</td>
<td>Plešný</td>
<td>2C3/2/1</td>
<td>1,030</td>
<td>7S2</td>
<td>10, 25, 221</td>
</tr>
<tr>
<td>14</td>
<td>Plešný</td>
<td>3C4/3/1</td>
<td>1,030</td>
<td>7S2</td>
<td>15, 25, 206</td>
</tr>
<tr>
<td>15</td>
<td>Plešný</td>
<td>3A3/2/1</td>
<td>1,060</td>
<td>7S2</td>
<td>15, 25, 206</td>
</tr>
<tr>
<td>16</td>
<td>Plešný</td>
<td>4A6/2/1</td>
<td>1,120</td>
<td>7S1, 7N3</td>
<td>12, 25, 196</td>
</tr>
<tr>
<td>17</td>
<td>Plešný</td>
<td>4A6/2/1</td>
<td>1,150</td>
<td>7N3</td>
<td>12, 25, 196</td>
</tr>
<tr>
<td>18</td>
<td>Plešný</td>
<td>4A6/2/1</td>
<td>1,250</td>
<td>7N3</td>
<td>12, 25, 196</td>
</tr>
<tr>
<td>19</td>
<td>Plešný</td>
<td>5A3/1</td>
<td>1,300</td>
<td>8Y2</td>
<td>15/156</td>
</tr>
<tr>
<td>20</td>
<td>Plešný</td>
<td>5A3/1</td>
<td>1,370</td>
<td>8K2, 8N3</td>
<td>15/156</td>
</tr>
</tbody>
</table>

*The stand did not reach this age because it declined totally by 2000.
ecological impacts on forests (ICP – Forests). From the aspect of potential management the values of foliation and yellowing symptoms were evaluated in relation to coenotic position and diameter structure. The foliation values were subsequently divided into six empirical degrees of defoliation, corresponding to the degrees of tree damage caused by air-pollution and ecological factors:

<table>
<thead>
<tr>
<th>Defoliation degree</th>
<th>Foliation (%)</th>
<th>Tree description</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>91–100</td>
<td>healthy</td>
</tr>
<tr>
<td>1</td>
<td>71–90</td>
<td>slightly damaged</td>
</tr>
<tr>
<td>2</td>
<td>51–70</td>
<td>medium damaged</td>
</tr>
<tr>
<td>3</td>
<td>31–50</td>
<td>heavily damaged</td>
</tr>
<tr>
<td>4</td>
<td>1–30</td>
<td>dying back</td>
</tr>
<tr>
<td>5</td>
<td>0</td>
<td>dead</td>
</tr>
</tbody>
</table>

The complements of foliation values up to 100% were designated as defoliation values. The particular values of defoliation for each tree can be placed into one defoliation class \( C_i \) to \( C_n \). The instantaneous status of the stand is described by the vector \( X = (x_1, \ldots, x_n) \) where \( x_i \) is the number of values placed into class \( C_i \) (and/or the number of trees in which defoliation was evaluated in class \( C_i \)).

The dynamics of stand damage is described as a change in the status – vector \( X \). Let the status in year \( y \) be described by vector \( X_y \), and the status in the subsequent year by vector \( X_{y+1} \), we can construct the model

\[
X_{y+1} = A \times X_y
\]

Square matrix \( A \) is composed of probabilities \( a_{ij} \) that the tree with defoliation evaluated by class \( C_i \) in year \( y \) will have defoliation evaluated by class \( C_j \) in year \( y+1 \). These probabilities are estimated from the number of trees evaluated in the particular classes of defoliation in two subsequent years. In unchanged conditions it is to assume that these probabilities will not change in the subsequent period. The sequences \( Y_1, Y_2, Y_3, \ldots \) represent so called Markov chain (see e.g. Mandl 1985).

A model of transition matrices is the basic element of TDM [Tree Defoliation Modelling] programme for the evaluation of data on forest stand development that was used in this study.

A series of models was computed for each plot, based on the classification of defoliation of all trees of one tree species always in two consecutive years – the respective transition matrices were computed in this way. The following defoliation classes were used: \( C_1 = (0\%, 10\%) \), \( C_2 = (10\%, 30\%) \), \( C_3 = (30\%, 50\%) \), \( C_4 = (50\%, 70\%) \), \( C_5 = (70\%, 90\%) \), \( C_6 = (90\%, 100\%) \).

The computation of eigenvalues and eigenvectors of these matrices is crucial for the analysis of transition matrices. The eigenvector corresponding to each eigenvalue \( \lambda_i = 1 \) describes the stable status of the system. Oscillations of the system are to be expected in case that one or several eigenvalues assume the complex values (cf. Legendre, Legendre 1983).

The presented graphical output of TDM programme documents average defoliation of trees of a given species, average defoliation of the least and/or most damaged trees (the values correspond to the lower and/or upper quartile under normal distribution of defoliation values with the given computed mean and standard deviation). Dynamics of the proportions of dead trees in the stand and predictions of further development computed on the basis of data are also represented. A special modal
was computed for each pair of consecutive years in which the stand on the given area was evaluated. The length of modelling period was always 10 years. In the models of development there is a period with less than 50% of dead trees and more than 50% of dead trees (dead trees are trees placed into class $C_6$). The comparison of actual dynamics of stand defoliation with the model in the period immediately after those two years on the basis of which the model was constructed shows whether the conditions of stand development remained stable (actual state corresponds to predicted one) or changed (predicted and actual state are markedly different). Considered conditions may be external ones (e.g. climatic fluctuations) or internal ones (e.g. depletion of a certain “buffering” capacity of the ecosystem).

We also examined the relations of defoliation to the spatial structure of stands. Based on the surveying of the position of each tree on the study plot we computed a distance to the nearest adjacent trees ($r_1$ is a distance to the first nearest tree, $r_2$ is a distance to the second nearest tree, etc.). The parameter LIVINGAREA – an estimation of the area used by a tree for its growth was computed from these values:

$$LIVINGAREA = (r_1 \times r_2 \times r_3)^{2/3}$$

We sought a relationship between damage to a tree (its defoliation) and this area on the basis of linear regression for trees with defoliation lower than or equal 50%.

Traits describing the health status of the crown were also evaluated (damage caused by snow, icing, wood-decaying fungi, insects, ozone, etc.). The average value of foliation and degree of defoliation was computed for all tree species on each plot, also in relation to the coenotic position.
Table 2. Species composition (living individuals of the tree layer) on PRP in the Modrava and Plešný Forest District (1997)

<table>
<thead>
<tr>
<th>Plot</th>
<th>Number of individuals</th>
<th>Proportion (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>beech</td>
<td>spruce</td>
</tr>
<tr>
<td>1</td>
<td>0</td>
<td>86</td>
</tr>
<tr>
<td>3</td>
<td>0</td>
<td>156</td>
</tr>
<tr>
<td>7</td>
<td>0</td>
<td>11*</td>
</tr>
<tr>
<td>12</td>
<td>570</td>
<td>7</td>
</tr>
<tr>
<td>13</td>
<td>167</td>
<td>61</td>
</tr>
<tr>
<td>14</td>
<td>239</td>
<td>185</td>
</tr>
<tr>
<td>15</td>
<td>380</td>
<td>74</td>
</tr>
<tr>
<td>16</td>
<td>169</td>
<td>52</td>
</tr>
<tr>
<td>17</td>
<td>45</td>
<td>25</td>
</tr>
<tr>
<td>18</td>
<td>48</td>
<td>25</td>
</tr>
<tr>
<td>19</td>
<td>136</td>
<td>2</td>
</tr>
<tr>
<td>20</td>
<td>64</td>
<td>64</td>
</tr>
<tr>
<td>Total</td>
<td>1,570</td>
<td>652</td>
</tr>
</tbody>
</table>

*124 bark-beetle trees were identified on the plot in the period 1994–1996

![Graph](image_url)

Fig. 3. Average defoliation and mortality of beech (species bk) and sycamore (species kl) trees in natural mixed stands on PRP No. 12
RESULTS

Foliation was chosen as a typical trait and as a criterion of the relatively objective decision on tree damage and health status of stands while defoliation class was used for the prediction of health status dynamics.

Secondary spruce monocultures

These stands in Modrava FD were afflicted by many air-pollution and ecological stresses in the past decade. The stand destruction culminated by an extensive bark-beetle mass outbreak, and therefore foliation has been evaluated on three (PRP 1, 3, 7) out of 11 plots (PRP 1–11) since 1997. Table 2 shows the representation of the main tree species on these plots.

Fig. 2 documents that after a marked increase in defoliation in 1997–1998 the health status on plots 1 and 3 was partly stabilised. But the health of these stands has deteriorated very much since 2003. The turn of the years 2004 and 2005 seems to be crucial; it might be a result of the preceding climatic period with significant precipitation deficit when this adverse trend was not reversed although the deficit was balanced in 2005. The proportion of dead trees increased on PRP 3 until the last year of observation. Marked dieback of spruce trees caused by bark beetles occurred in the course of 2005 (Fig. 2a). Nevertheless, the prediction of development of these stands in variants according to defoliation trends in the particular years is quite positive (prediction of average defoliation is done only for the set of living trees, so this variable does not involve the rate of die-back). If the bark beetle is controlled successfully in
Fig. 5. Average defoliation and mortality of spruce (species sm), beech (species bk) and rowan (species jr) trees in natural mixed stands on PRP No. 14.
these localities, these stands are expected to prosper thanks to their vitality.

Natural forests

Autochthonous or near-natural forest ecosystems were studied in a vertical transect in the Plechý Mt. massif (PRP 12–20) in Plešný FD. Table 2 shows the representation of tree species in these localities.

The prediction of a further trend of defoliation in the mixed stand on PRP 12 shows that after the critical winter 1998/1999 the defoliation situation was apparently stabilised in beech (Fig. 3a) but considering the results of the analysis of transition matrix for the period 1999–2005 some oscillations are to be expected in future (see the presence of complex values among the eigenvalues of transition matrix). On the contrary, the prediction of the trend in sycamore maple (Fig. 3b) is far from being positive due to a great increase in defoliation in 2001–2002. If such a trend were maintained, more than 50% of sycamore maple trees would die in 2008. The analysis of the transition matrix for the last three years shows that there may exist several potentially stable situations that are however characterised by the majority of rather defoliated trees or dead trees. The trend of defoliation has partly stabilised since 2003, even though there have been oscillations as a result of climatic fluctuations.

The prediction of defoliation trend in the spruce-beech stand on PRP 13 after 2000 is relatively positive (Fig. 4). It is slightly better for spruce (Fig. 4a) than for beech (Fig. 4b); it is explained by great damage to the beech stand caused by icing at the turn of 1998 and 1999. The health status of both these species was gradually stabilised in the next years. From this aspect the situation is worse in PRP 14 (Fig. 5), where individual trees of rowan and spruce in the 3rd and 4th tree class were damaged by peeling
by red deer and beech trees were damaged by icing at the turn of 1998–1999. Heavy browsing on rowan stems led to quite a steep increase in defoliation with a high proportion of dead trees after 2004. The transition matrix computed for the last three-year period in rowan shows a different rate of model convergence compared to other considered models (see the low second highest eigenvalue of transition matrix). In subsequent years this trend was stabilised, also in rowan (Fig. 5c) where 24% of trees died in 1997–2005. The trends of health status dynamics in the mixed stand on PRP 15 after 2000 are quite positive, both in beech and in spruce (Fig. 6). In 2001 and 2004 a ca. 6–7% increase in spruce mortality was recorded on this plot (Fig. 6a) caused by the feeding of eight-toothed spruce bark beetle, but it stabilised later on. Considering the presence of complex values among the eigenvalues of transition matrix for the dynamics of spruce defoliation in 1999–2005 some oscillations in the model behaviour are to be expected. Subdominant beech trees were heavily damaged by icing at the turn of the years 1998–1999, which markedly influenced predictions of development of this stand after 2000 (Fig. 6b). The situation was similar in the mixed stand on PRP 16 (Fig. 7). The trend of the spruce-beech stand development on PRP 17 shows a considerably worse situation (Fig. 8). While beech development is basically stabilised given the prevailing developmental stage, the increase in mortality of spruce trees (Fig. 8a) is great due to the feeding of the eight-toothed spruce bark beetle even though it slowed down after 2000 and has been stabilised since 2002. The continuation of this trend suggests that as much as 50% of spruce trees would be dead in 2008. The influence of the eight-toothed spruce bark beetle reaches to the zone of climax spruce stands, which is proved by a marked increase in mortal-
ity on PRP 18 in 2002 and 2004 (Fig. 9). Mainly in spruce stands of the highest locations of the Šumava Mts. (on PRP 19 and 20 – Figs. 10 and 11) the prediction of defoliation dynamics for the nearest period was very positive in 2002. A sudden change occurred in 2005 as a result of the eight-toothed spruce bark beetle attack, when the proportion of dead trees increased by 7%. Such development can be explained by a climatic extreme of the preceding year characterised by drought. If this trend continued, the average defoliation would exceed 60% in these localities in 2014.

Research on the relationship between defoliation and living area of the represented tree species indicates that damage to spruce is greater at places where the stand density is highest (Fig. 12). On the contrary, damage to beech increases with the openness of the place where the tree grows (Fig. 13). There are also differences between localities. This relationship in spruce was observed on plots 16, 19 and 20 compared to plots 17 and 18 where it was not demonstrated. Earlier dieback of trees in relatively dense parts of the stand was observed on PRP 16 (and/or 12). The set of all surviving trees displays a positive correlation between defoliation and open canopy of trees. It applies to younger beech stands where self-thinning processes take place. The beech on PRP 17 is damaged to a small extent while the relationship between defoliation and open canopy is obvious (Fig. 13). The above-mentioned trends need not be perceivable in all stands, they may be only indicated at some places and they are often weakly statistically significant (Table 3).
Fig. 9. Average defoliation and mortality of Norway spruce trees in the autochthonous spruce stand on PRP No. 18

Fig. 10. Average defoliation and mortality of Norway spruce trees in the autochthonous spruce stand on PRP No. 19

Fig. 11. Average defoliation and mortality of Norway spruce trees in the autochthonous spruce stand on PRP No. 20
CONCLUSION

With regard to the need of long-term monitoring of the health status of forest stands the results obtained in 1997–2005 should be considered as preliminary. When damage to forest stands is evaluated, it is necessary to take into account the variability of climatic conditions in the particular years (mainly the occurrence of extreme situations, namely precipitation deficit) and the fact that an air-pollu-

Table 3. The relationship between defoliation in 2005 (y) and living area (expressed as x = log LIVINGAREA) of spruce and beech in the altitudinal gradient of Plechý Mt. evaluated by linear regression. All trees with defoliation lower than or maximally equal 50% were considered. n – number of trees, r – correlation coefficient (statistically significant values on 1% and 5% level are designated by ** and *, respectively)

<table>
<thead>
<tr>
<th>Plot</th>
<th>Spruce</th>
<th>Beech</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$r^2$ (n)</td>
<td>regression</td>
</tr>
<tr>
<td>TVP20</td>
<td>0.046 * (56)</td>
<td>$y = 26.04 - 4.960x$</td>
</tr>
<tr>
<td>TVP19</td>
<td>0.076 ** (115)</td>
<td>$y = 28.69 - 5.847x$</td>
</tr>
<tr>
<td>TVP18</td>
<td>0.000 (35)</td>
<td></td>
</tr>
<tr>
<td>TVP17</td>
<td>0.001 (18)</td>
<td></td>
</tr>
<tr>
<td>TVP16</td>
<td>0.038 (46)</td>
<td>$y = 23.68 - 4.068x$</td>
</tr>
<tr>
<td>TVP12</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Fig. 12. The relationship between defoliation in 2005 and living area (LIVINGAREA) of Norway spruce on PRP 16–20
tion and ecological stress is usually accompanied by increased sensitivity to some biotic and abiotic factors, which is many times markedly reflected in the acceleration of dynamics of disintegration of these stands. A substantially higher tolerance to extreme air-pollution and ecological stresses was observed in autochthonous or natural stands in Plešný FD compared to secondary spruce monocultures in Modrava FD that are heavily damaged by the bark beetle feeding. As for the above-mentioned autochthonous and natural stands in the altitudinal gradient of the Plešý Mt. Massif, mixed stands showed the overall highest tolerance or ecological stability compared to spruce stands. These are increasingly attacked by the eight-toothed spruce bark beetle, especially on PRP 17, 18 and 20. A larger decrease in foliation in beech compared to spruce after the extreme winter 1998/1999 and as a result of ozone effects in the growing season 1999 was a deviation from this trend. Damage to assimilatory tissues caused by ozone in 2002, mainly in broadleaves, was greater than in 1999. Markedly larger defoliation than in beech was recorded in sycamore maple and rowan. Research on the relationship between defoliation and living area of the represented tree species documents that damage to spruce trees is greatest at places with the stand of the highest density while damage to beech increases with the openness of the place where the tree grows.

The definition of regeneration objectives should be based on long-term trends of tolerance of tree species, on their ecological valence, principles of zonation and possibilities of management whereas the present functional role of the site is respected.

References


Fig. 13. The relationship between defoliation in 2005 and living area of European beech on PRP 17, 16 and 12. Figures b2 and c2 show all trees, other ones contain trees of defoliation up to 50%.
Vývoj zdravotního stavu lesních porostů a jeho predikce na výzkumných plochách na Šumavě

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Lesy Šumavy jsou v uplynulých dvou deseti-
tích zasaženy markantním imisně ekologickým
zatížením, které zejména v nejvýše položených
horských partiích způsobuje značné ekofyziologi-
gické oslabení porostů, projevující se specifickými
symptomy poškození (odlistění, projevy žloutnutí,
nekrozy apod.). Lesní ekosystémy jsou zde značně
ovlivňovány především kyselou depozicí a ozonem.
Vzniklá situace negativně působí nejen na produkc
ní, ale především na ekologické funkce lesa, a to
zejména v důsledku následného ataku škodlivých
biodických činitelů (hmyzích škůdců, houbových
patogenů apod.). Jejich expanze vede až k destrukci
biotických činitelů (hmyzích škůdců, houbových
patogenů apod.). Jejich expanze vede až k destrukci
symptomy poškození (odlistění, projevy žloutnutí,
gické oslabení porostů, projevující se specifickými
záření porostů. Na základě zaměření polohy každého
hodnoty defoliace s daným vypočítaným průměrem
podílu odumřelých stromů v porostu a jednotlivé
české oslabení porostů. Na základě zaměření polohy každého
podílu odumřelých stromů v porostu a jednotlivé
české oslabení porostů. Na základě zaměření polohy každého
podílu odumřelých stromů v porostu a jednotlivé

1997–2005. Nejvyšší úroveň tolerance jevily přírodní porosty na území LS Plešný, zejména porosty smíšené s domi-
nancí buku, nejnižší naopak alochtóní smrkové porosty v oblasti LS Modrava. Porostní dynamika byla limitována
aktivitou hmyzích škůdců, v první řadě lýkožrouta smrkového (Ips typographus). Jako mnohem častější se ve srovnání
s rokem 1999 v roce 2002 jevily škody způsobené ozonem – nejvíce byl poškozen javor klen a jeřáb.

Klíčová slova: zdravotní stav; defoliace; imisní a ekologické stresy; kůrovec; ozon; přechodové matice
k prvnímu nejbližšímu stromu, \( r_j \) je vzdálenost ke druhému nejbližšímu stromu atd.). Na základě těchto hodnot byl vypočten parametr LIVINGAREA – odkaz plochy, kterou strom využívá ke svému růstu

\[
\text{LIVINGAREA} = (r_1 \times r_2 \times r_j)^{2/3}
\]

Byl hledán vztah mezi poškozením stromu (jeho defoliací) a touto plochou na základě lineární regrese pro stromy s defoliací menší nebo rovnou 50 %.

Z výsledků vyplývá, že alochtonní smrkové porosty na LS Modrava byly v uplynulém desetiletí ve značné míře postiženy četnými imisně ekologickými stresy. Destrukce porostů pak vyvrcholila rozsáhlou kůrovou kalamitou, proto z 11 ploch (TVP 1–11) bylo olistění od r. 1997 hodnoceno pouze na třech z nich (TVP 1, 3, 7). Zastoupení hlavních dřevin na těchto plochách je uvedeno v tab. 2.


Poměrně příznivé jsou i trendy vývoje zdravotního stavu smíšeného porostu na TVP 15 po r. 2000, a to jak u buku, tak i u smrku (obr. 6). V r. 2001 a 2004 byl na této ploše zaznamenán asi 6–7% nárůst mortality smrku (obr. 6a) v důsledku žíru lýkožrouta smrkového, který se posléze stabilizoval. Vzhlédem k výskytu komplexních hodnot mezi vlastními čísly přechodovevé matice pro vývoj defoliace smrku v období 1999 až 2005 lze očekávat určité oscilace v chování modelu.
na výrazným nárůstem mortality v roce 2002 a 2004 na TVP 18 (obr. 9). Především pak ve smrčinách nejvyšších poloh Šumavy (na TVP 19 a 20 – obr. 10 a 11) byla ještě v r. 2002 pro nejbližší období přediktice vývoje defoliace velice příznivá. K výraznému zvratu v důsledku ataku lýkožrouta smrkového došlo v r. 2005, kdy se podíl odumřelých stromů zvýšil o 7 %. Tento vývoj lze vysvětlit klimatickým extrémem předcházejícím roku s výrazným suchem. Pokud by tento trend pokračoval, tak by zde v r. 2014 průměrná defoliace přesahovala 60 %.


Získané výsledky v letech 1997–2005 je třeba vzhledem k nutnosti dlouhodobého monitorování zdravotního stavu porostů považovat za předběžné. Při posuzování poškození porostů je proto nutné brát v úvahu variabilitu klimatických podmínek jednotlivých let (především výskyt extrémních situací, jmenovitě nedostatek srážek) i to, že imisně ekologický stres je zpravidla provázen zvýšenou citlivostí vůči některým biotickým a abiotickým činitelům, což se mohou výrazně projevovat v říci rozvoj dynamičky rozpadu těchto porostů. Při volbě obnovních cílů je nutné vycházet především z dlouhodobých trendů tolerance dřevin, ale i z jejich ekologické valence, principů zonace a možností managementu při respektování současného funkčního významu stanoviště.

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