Ecological monitoring of Scots pine (*Pinus sylvestris* L.) growing in forest ecosystems at roadsides

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ABSTRACT: The results of monitoring of Scots pine (*Pinus sylvestris* L.) conducted in 1998–2000 according to international forest monitoring methodology (UN/ECE 1994) are presented. The indicatorial parameters (crown defoliation, foliage discolouration, state of tree tops, amount of dry branches etc.) of 684 sample trees at the distances of 10–20, 50–100,150–200, 250–300, 350–400 and 450–500 m from a highway were evaluated and discussed. The results have indicated that pines at the farthest distance (450–500 m) from the roadbed have the best health condition (mean defoliation 23.6 ± 2.2%) in comparison with trees growing close to the highway (43.3 ± 1.5%). Amount of dry branches depends on a distance from the highway as follows: at the permanent observation plots closest to the highway – 30.2 ± 1.2%, furthest – 12.8 ± 1.8%. State of pine tops is good – at all permanent observation plots more than 70% of the healthy tree tops were estimated.

Keywords: monitoring; Scots pine; roadsides; indicatorial parameters

Under increasing environmental pollution and its impact on nature, biological tests for the assessment of environmental state are applied at a larger scale. Trees are considered to be sensitive indicators of climatic changes and anthropogenic activity, resembling environmental variations in their growth and state. Crowns of trees have a contact area with the atmosphere several times bigger than other plants. The crown's filter transfers pollutants five or six times more effectively than other vegetation (KAIRIUKŠTIS et al. 1992). Conifers, especially Scots pine (*Pinus sylvestris* L.), are very sensitive to the environment pollution and can serve as biological tests for the assessment of pollution impact (SPOREK 1981; STRAVINSKIENE 1997, etc.).

Transport is the largest source of pollution in Lithuania. More than 70% of car traffic falls to the main highways and suburban roads. Traffic emissions are gradually increasing. Burning fuels emits into the environment carbon monoxide (80%), hydrocarbons (15%), nitrogen oxides (5%), small amounts of lead, benzapyrene and other harmful substances. The largest share of traffic emissions in Lithuania include the following pollutants: carbon monoxide – 258 thousand tons, hydrocarbons – 60 thousand tons, nitrogen oxides – 36 thousand tons and sulphur dioxide – 5.5 thousand tons (BALTRENAS et al. 1996).

In winter, seeking to avoid ice formation on the road surface, sodium and calcium chlorides are spread on Lithuanian highways. The amount of spread salts depends on meteorological conditions in winter. Approximately 30–40 thousand kg of chlorides fall per one km of highways each winter. It was found (ARMOLAITIS, BARTKEVIČIUS 1996) that the residues of these substances (small amount of chlorides) may accumulate even at 50–100 m from the highway. Aerosol droplets of the substances damage trees, growing up to 10–15 m from the roadbed. Therefore, in spring the needles on lower branches of pine trees become brownish.

Studies have shown (ARMOLAITIS, BARTKEVIČIUS 1996) that in forests nearly the main highway in Lithuania "Vilnius-Klaipeda" the most polluted by nitrogen oxides, benzapyrenes and heavy metals (Pb, Cr, Ni, Ti, V, Fe, etc.) is up to 50–60 m wide roadside belt, whereas in open areas even 100–200 m wide roadside belt is contaminated. Especially effective against pollutants is a dense forest with undergrowth and underbrush.

Forest plantations at roadsides accumulate pollutants near the roadbed and prevent their further distribution. Trees that grow as forest shelterbelts absorb carbon monoxide, sulphur dioxide and other harmful substances. They also accumulate heavy metals that are found in traffic emissions. Even 3–5 m of protective road plantings collect and accumulate about 40–60% of lead and heavy metals from traffic emissions. Trees reduce the contamination near the roadbed and at the same time indicate the influence of pollution on trees. Forest ecosystems serve as a cleaning equipment and are gathering pollutants, which are disseminated in open fields in the environs.

The landscape and height of roadbed influence the distribution of pollutants at the roadside. When the height of the roadbed is 0.5–1.2 m, the largest portion of pollutants fall out at the distance of 10–25 m from roadsides, when the height of the roadbed is 1.2–1.5 m the largest flow of emissions falls out at the distance of 20–30 m. Therefore, the concentration of pollutants at the distance of 10–20 m from the roadbed is also high. If the road surface is close to the level of surroundings, then, farther from the roadside the concentration of traffic pollutants evenly diminishes (MAGONE 1989).

The monitoring of forest ecosystems at the roadsides has not been conducted and the state of trees at the roadsides has not been widely studied until now; therefore the morphological indicatorial parameters of Scots pines (*Pinus sylvestris* L.) growing at the roadsides were chosen as the object of present study.

MATERIAL AND METHODS

The aim of the investigation was to conduct an ecological monitoring and to estimate the health condition of Scots pine trees at different distances from the highway "Vilnius-Klaipeda" according to the main indicatorial parameters (crown defoliation, foliage discolouration, the state of tree tops, the amount of dead branches, etc.) of forest monitoring.

The following studies were carried out: choice of the study object; gathering of experimental information; estimation of the health condition of pines according to their crown defoliation and foliage discolouration (dechromation), state of the tree tops and amount of dead branches; estimation of pine needle retention at different distances from the highway.

Monitoring of Scots pine was performed and the experimental material was collected in the summer seasons 1998, 1999 and 2000 according to international forest monitoring methodology (UN/ECE 1994). The end of July and the beginning of August present the most suitable time for forest monitoring (HANISH, KILZ 1990).

The sample trees were selected at permanent observation plots (POP). At different distances from the roadbed (10–20; 50–100; 150–200; 250–300; 350–400 and 450–500 m) 36 sample trees were selected for the assessment in each POP and distributed within 6 assessment subplots (AS) with 6 sample trees in each, located at the distance of 25 m to the north, east, south and west of the POP centre. Distribution of sample trees into 6 assessment subplots (6 sample trees in each) differs from the international forest monitoring methodology (UN/ECE 1994). The sample trees from the upper layer belonging to 1–3 Kraft class were chosen. The total number of AS is 114, the total number of examined trees – 684.

Crown defoliation and foliage discolouration are the most important biological diagnostic tests for tree health condition assessment.

Crown defoliation is not only the loss of existing foliage, but also that part of the foliage which is able to form in normal conditions, but did not form in the existing ones. The natural fall of leaves during autumn is not considered. In other words, defoliation means the loss compared to the reference tree whose crown defoliation does not exceed 10% (OZOLINČIUS 1996). The reference tree is usually a tree of the same growth, social class as the sample tree, belongs to the same type of branching, grows in the vicinity of the sample tree. The photo of the reference tree corresponding to a sample tree according to special atlases can be used. We used special atlases with the photos of reference trees (MULLER, STIERLIN 1990).

Defoliation degree of the whole crown and of the upper third of the crown was estimated in 5% gradation.

According to crown defoliation degree the sample trees were divided into 5 defoliation classes: 0 – conditionally healthy trees (crown defoliation up to 10%); 1 – slightly defoliated trees (11–25%); 2 – moderately defoliated trees (26–60%); 3 – severely defoliated trees (61–99%); 4 – dead trees (crown defoliation equals 100%).

Foliage discolouration (dechromation) – one of the main forest monitoring parameters – shows the part of needles or leaves (%) which have changed their colour due to the negative impact of external environmental factors. Sample trees were divided into 4 discolouration classes: 0 – without foliage changes in colour (discolouration up to 10%); 1 – slight discolouration (11–25% of foliage has a changed colour); 2 – moderate discolouration (26–60%); 3 – severe discolouration, when over 60% of the foliage does not have the natural colour.

Changes of tree foliage colour due to the lack or excess of some elements (nitrogen, potassium, magnesium, etc.), impact of heavy atmospheric pollution or effects of fungal diseases (TAYLOR et al. 1991), droughts (INNES, BOSWELL 1989) and other reasons are widely known and spread in some countries of Western Europe. The foliage discolouration of Scots pine is not a common phenomenon in Lithuanian forest ecosystems (Monitoring... 1999).

Severe crown defoliation and foliage discolouration show the negative influence of environmental impact on a tree and indicate its damage (UN/ECE 1994).

The tree top state and the amount of dead branches in the tree crown was estimated as follows. The scale of the state of tree tops: 0 – top is healthy; 1 – completely broken; 2 – dead; 3 – damaged. The scale for the amount of dead branches in the crown: 0 – up to 15% of dead branches, 1 – 16–30% of dead branches, 2 – 31–50% of dead branches, 3 – over 50% of dead branches. Dead branches under a live crown are not included.

Average needle retention of pine is indicated visually within 0.1 year accuracy. For the evaluation of needle retention, 3–4 model branches in the upper third of the crown were selected. Age of terminal shoots containing all needles and the share of the length of the last (oldest) shoot with remaining needles are evaluated with the help of binoculars.

When the crown defoliation exceeds 10%, defoliation type is defined for each sample tree. The following crown defoliation types were defined: 1 – top defoliation; 2 – defoliation under the top; 3 – base; 4 – peripheral 5 – inner; 6 – uniform and 7 – window.

Top (1) defoliation type is defined for the cases when defoliation of the upper part of the crown exceeds defoliation in the rest of the crown by not less than 20%. Under-top (2) defoliation type should be applied when defoliation of the under-top part of the crown is at least by 20% higher than that of the other crown part. Base (3) defoliation type is applicable in the case when defoliation at the bottom part of the crown is by 20% higher than in the other parts. The peripheral (4) type of defoliation is used for the cases when over 25% of all tree branches have dead terminal shoots due to late or early frosts and insect damage. The inner (5) defoliation type is common for trees, the older needles of which are damaged by fungi and diseases and the crown is more sparse in the interior. The uniform (6) crown defoliation type is applicable when defoliation in various crown parts does not differ by more than 20%. This defoliation type can be caused by changes in environmental conditions and is characteristic of tree responses to air pollution. Window (7) crown defoliation type is used when defoliation in the window (the most sparse part of the crown) is at least 20% higher than in the other parts of the crown (Monitoring... 1999).

RESULTS AND DISCUSSION

The results of investigation have indicated that the crowns of Scots pine (*Pinus sylvestris* L.) trees growing at the closest distance to the highway are mostly defoliated. Even 48% of sample trees growing at the closest distance from the highway are severely damaged (class 3 of defoliation), 45% of sample trees were included in class 2 of defoliation. Only 7% of dead trees (defoliation 100%) have been identified here. No healthy trees showing the good environmental state were found here. The status of pines growing at the distance of 50–100 m from the highway is slightly better than that of the pines growing 10–20 m away. At such a distance the greatest part (52%) of the examined pines are moderately defoliated (crown defoliation is 26–60%), severely defoliated trees whose crown defoliation reaches 61–99% account for 44% and only 4% of the examined trees are mostly defoliated (4 classes of defoliation). No conditionally healthy and slightly defoliated trees were found at this distance. Health condition of trees at the distances of 150–200 and 250–300 m from the highway is gradually improving. At the latter distance conditionally healthy tree represent 3% and 8%; slightly defoliated ones – 14% and 19% of sample trees; even 61% and 56% are moderately defoliated and included in 2 defoliation class; 22% and 17% of the sample trees show severe defoliation, respectively. At the distance of 350–400 m, only 7% of sample pine trees are severely, 33% – moderately, 45% – slightly defoliated and 15% are conditionally healthy. Health condition of sample pine trees at the furthest distance (450–500 m) from the highway is the best according to crown defoliation parameters (Fig. 1).

At the closest distance of 10–20 m from the highway, mean defoliation of pine trees amounts to 43.3 ± 1.5%. With the increasing distance from the roadside, defoliation of Scots pine trees is decreasing as follows: at the distance of 50–100 m the mean defoliation of sample pine trees is 41.5 ± 2.3%, at 150–200 m – 38.7 ± 1.7%, at 250–300 m – 35.3 ± 2.2%, at 350–400 m – 28.4 ± 2.4% and at 450–500 m – only 23.6 ± 1.3% (Table 1). Crown defoliation of pine trees growing at the closest distances from the roadbed exceeds by 15–20% mean defoliation of pines in Lithuanian forests. This difference indicates the traffic pollution impact on pine forest plantations at the roadsides.

Fig. 2 illustrates the mean pine crown defoliation dynamics in 1998–2000. Assessing changes in the state of pine trees growing near the highway according to crown defoliation parameters in 1998–2000, a statistically reliable (P = 0.95) improvement was observed in 1999–2000, as compared to 1998, expressed by a decreased defoliation of sample trees growing up to 300 m from the roadbed. At the further distance from the roadbed changes in the state of pine trees are insignificant, statistically unreliable – in separate years crown defoliation of the trees differs insignificantly from mean pine defoliation indices in Lithuanian forests.

Crown defoliation type of the examined Scots pines has also been investigated. The base (3) and uniform (6) crown defoliation types are dominating at all permanent observation plots (Table 1). The greatest part of examined pines growing at the distance up to 300 m from the roadbed has the base (3) crown defoliation type. The uni-

Table 1. Mean crown defoliation (%); distribution of sample Scots pine trees (%) according to crown defoliation type and classes of foliage discolouration

Distance from highway (m)	Number of sample trees	Mean crown defoliation (%)	Crown defoliation type							Foliage discolouration class			
			1*	2	3	4	5	6	7	0	1	2	3
10–20	162	43.3 ± 1.5	0	9	40	12	5	34	0	45	55	0	0
50–100	66	41.5 ± 2.3	0	3	42	24	5	26	0	57	43	0	0
150–200	162	38.7 ± 1.7	2	8	48	3	2	32	5	66	34	0	0
250–300	66	35.3 ± 2.2	0	2	46	8	2	28	14	83	17	0	0
350–400	66	28.4 ± 2.4	0	0	40	9	3	38	10	73	27	0	0
450–500	162	23.6 ± 1.3	0	2	34	11	6	45	0	82	18	0	0

Note: crown defoliation types: 1* – top defoliation; 2 – defoliation under the top; 3 – base; 4 – peripheral; 5 – inner; 6 – uniform; 7 – window

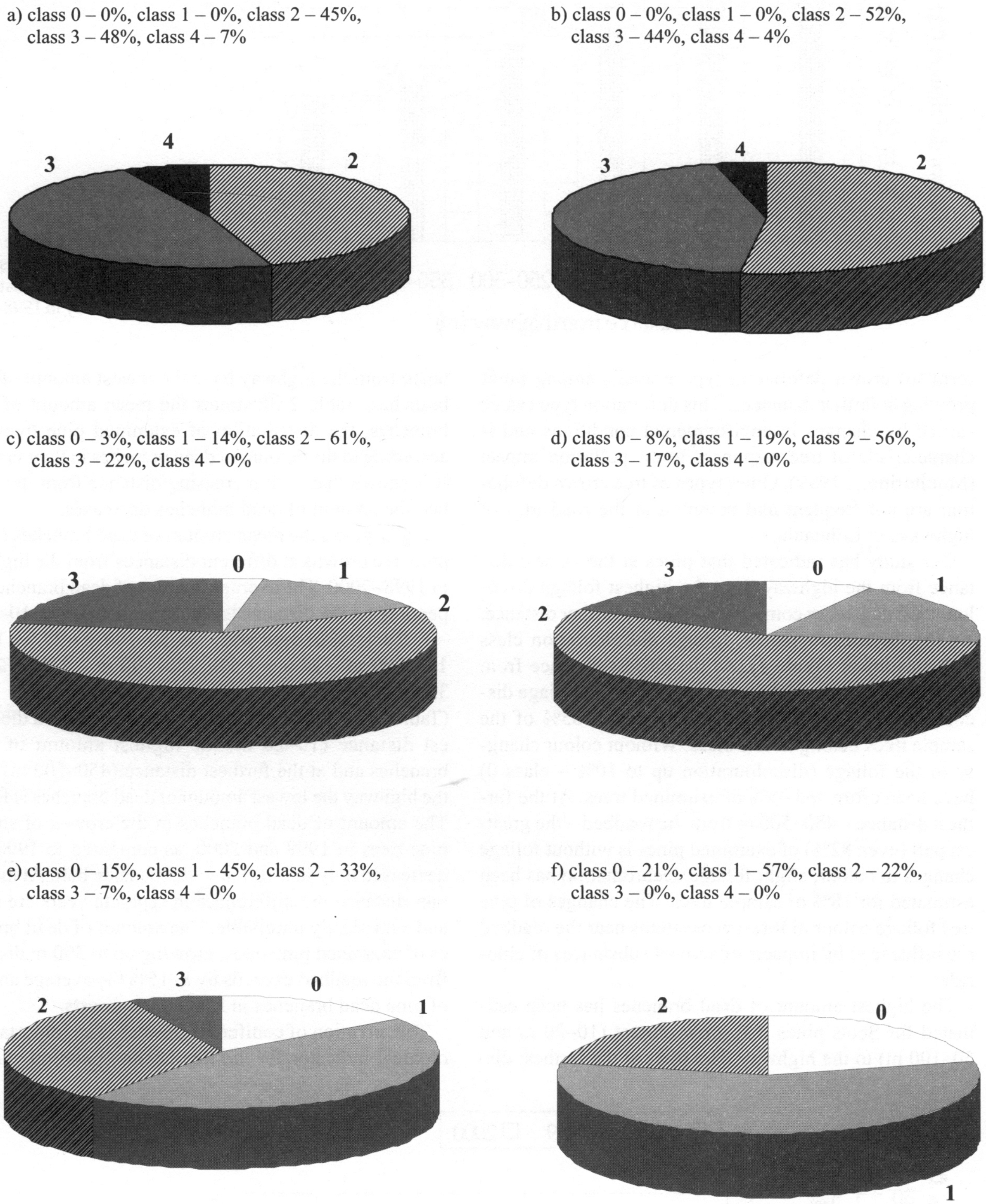

Fig. 1. Distribution of sample pine trees (%) growing at different distances – a) 10–20 m; b) 50–100 m; c) 150–200 m; d) 250–300 m; e) 350–400 m; f) 450–500 m – from the highway according to classes of crown defoliation

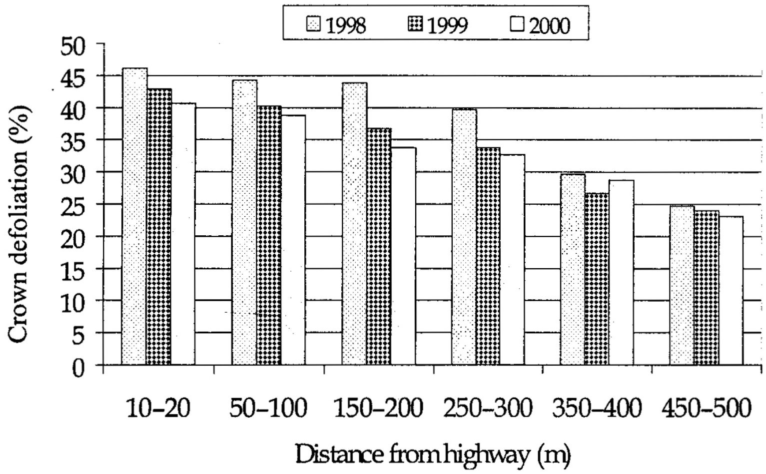

Fig. 2. Dynamics of the mean crown defoliation of Scots pines growing at different distances from the highway in 1998–2000

form (6) crown defoliation type prevails among pines growing at farther distances. This defoliation type can be caused by changes in environmental conditions and is characteristic of tree responses to air pollution impact (Monitoring... 1999). Other types of tree crown defoliation are not frequent and common at the roadsides of highways in Lithuania.

Our study has indicated that pines at the closest distance from the highway have the highest foliage discolouration degree, as compared to pines at further distance. As the distance increases, foliage discolouration class becomes lower (Table 1). At the closest distance from the highway, pines of discolouration class 1 (foliage discolouration 11–25%) predominate – even 55% of the sample trees belong to this class. Without colour changes of the foliage (discolouration up to 10% – class 0) have been estimated 45% of examined trees. At the furthest distance – 450–500 m from the roadbed – the greatest part (even 82%) of examined pines is without foliage changes in colour; slight foliage dechromation has been estimated for 18% of sample trees. The changes of pine tree foliage colour in forest ecosystems near the roadbed are influenced by impacts of aerosol substances of chlorides.

The highest amount of dead branches has been estimated for Scots pines that grow closest (10–20 m and 50–100 m) to the highway. The trees at the farthest distance from the highway have the lowest amount of dead branches. Table 2 illustrates the mean amount of dead branches, the distribution of examined pine trees (%) according to the amount of dead branches in their crowns. It is shown that with increasing distance from the roadbed the amount of dead branches decreases.

Fig. 3 shows the mean amount of dead branches (%) in pine tree crowns at different distances from the highway in 1998–2000. The average amount of dead branches depending on the distance is changing as follows: 10–20 m – 32.2 ± 1.2% of dead branches, 50–100 m – 27.5 ± 1.9%, 150–200 m – 24.6 ± 1.5%, 250–300 m – 21.6 ± 2.0%, 350–400 m – 16.3 ± 2.1%, 450–500 m – 12.8 ± 1.8% (Table 2). As illustrated by the presented data, at the closest distance (10–20 m) the highest amount of dead branches and at the furthest distance (450–500 m) from the highway the lowest amount of dead branches is found. The amount of dead branches in the crowns of studied pine trees in 1999 and 2000, as compared to 1998, has decreased only in a 100 m wide roadside belt. At the further distance the differences in separate years are small and statistically unreliable. The amount of dead branches of examined pine trees, growing up to 300 m distance from the roadbed exceeds by 8–15% the average amount of pine dead branches in Lithuanian forests.

The retention of coniferous needles is an important biological indicator for the tree health condition and can

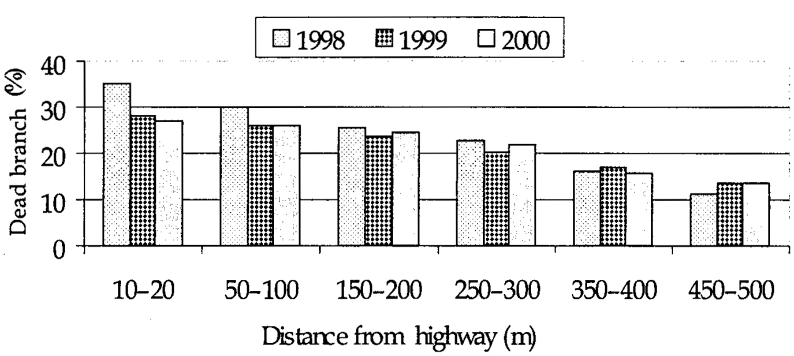

Fig. 3. Average amount of dead branches (%) in the crowns of Scots pine trees at different distances from the highway in 1998–2000

Table 2. Mean amount of dead branches and distribution of sample trees (%) according to the amount of dead branches in the crowns of pine trees

Distance from the highway (m)	Number of sample trees	Mean amount of dead branches (%)	Scale of dead branches (%)			
			up to 15	16–30	31–50	over 50
10–20	162	30.2 ± 1.2	6	43	51	0
50–100	66	27.5 ± 1.9	8	36	56	0
150–200	162	24.6 ± 1.5	11	46	38	0
250–300	66	21.6 ± 2.0	31	43	26	0
350–400	66	16.3 ± 2.1	36	53	11	0
450–500	162	12.8 ± 1.8	46	32	22	0

serve for environmental status assessment. Damaged trees usually lose their old needles sooner than healthy ones. Trees growing in optimal environmental conditions have longer retention of needles. The standard retention of Scots pine needles that indicates optimal tree growth conditions in Lithuanian forests is 4 years. It serves as a control. Short age of needles indicates unfavourable growth conditions.

It was established that needle retention depends on the meteorological conditions and geographic latitude (JUKOLA-SULONEN et al. 1990). The decrease of average needle retention of Scots pine during the last 30-year period is caused by growing atmospheric pollution (JALKANEN et al. 1995).

According to the results of our study mean retention of Scots pine needles at the closest distance (10–20 m) from the highway is the shortest (1.9 ± 0.04 years). At farther distances from the highway it has increased: at 50–100 m – 2.0 ± 0.07 years, at 150–200 m – 2.3 ± 0.04, at 250–300 m – 2.5 ± 0.07, at 350–400 m – 3.0 ± 0.05, at 450–500 m – 3.1 ± 0.03 years (Table 3). In comparison with control age (4 years) this diagnostic test shows the negative impact of traffic pollution on pine growth, state of environment at the closest distance and the negative influence of basic ecoclimatic factors at the farther distance from the highway.

It was determined that health condition of Scots pine trees depends on their social class: the examined pines of higher social Kraft class 1 have lower defoliation degree and lower amount of dead branches as compared with the sample trees of Kraft classes 2 and 3 (Table 4).

Table 3. Mean needle retention of sample Scots pine trees

Distance from the highway (m)	Mean needle retention (years)
10–20	1.9 ± 0.04
50–100	2.0 ± 0.07
150–200	2.3 ± 0.04
250–300	2.5 ± 0.07
350–400	3.0 ± 0.05
450–500	3.1 ± 0.03

Table 4. Mean crown defoliation and amount of dead branches of sample Scots pine trees (%) depending on Kraft classes and distance from the highway (according to average data of 1998–2000 year measurements)

Kraft class	Number of sample trees	Mean crown defoliation (%)	Mean amount of dead branches (%)
10–20 m from the highway			
1	27	37.3 ± 2.7	22.7 ± 2.2
2	84	41.0 ± 2.2	30.4 ± 2.2
3	51	51.2 ± 2.2	36.8 ± 1.4
50–100 m from the highway			
1	15	35.1 ± 3.9	21.5 ± 3.6
2	35	40.9 ± 2.0	27.4 ± 2.2
3	16	46.3 ± 1.3	35.0 ± 1.7
150–200 m from the highway			
1	33	33.9 ± 4.5	18.5 ± 5.7
2	87	37.4 ± 2.7	24.9 ± 3.3
3	42	43.0 ± 1.4	29.5 ± 2.1
250–300 m from the highway			
1	13	26.5 ± 2.5	16.5 ± 3.1
2	35	35.3 ± 1.8	21.5 ± 1.8
3	22	40.8 ± 1.6	26.7 ± 1.8
350–400 m from the highway			
1	18	22.5 ± 4.5	11.6 ± 3.2
2	29	29.9 ± 2.6	16.0 ± 2.7
3	19	35.2 ± 2.1	21.6 ± 2.5
450–500 m from the highway			
1	42	17.6 ± 3.6	8.2 ± 1.7
2	87	23.4 ± 1.6	11.6 ± 2.8
3	33	30.8 ± 1.5	20.6 ± 2.7

The mean crown defoliation of examined pines of Kraft class 1 growing at the distance of 10–20 m from the highway amounts to 37.3 ± 2.7%. Defoliation of pines of Kraft classes 2 and 3 is 41.0 ± 2.2% and 51.2 ± 2.2% respectively. At the farthest distances from the highway crown defoliation decreases: in pines of Kraft class 1 at the distance of 50–100 m it amounts to 35.1 ± 3.9%, of Kraft classes 2 and 3 – to 40.9 ± 2.0% and 46.3 ± 1.3% respectively. The pines of Kraft class 1 growing at the distance of 450–500 m have the lowest crown defoliation parameters, compared to close distances and sample trees of Kraft classes 2 and 3. The amount of dead branches depends on social classes in a very similar way (see Table 4).

Having checked variation reliability of pine crown morphological indices by the help of *F* criterion, it was found that in 1999–2000 the state of examined pines at the closest distance to the roadbed (up to 300 m) was reliably improving as compared to the state in 1998.

Visual assessment of tree crown parameters is comparatively fast and simple, but not completely objective. On the other hand it is noticed that a large part of deviations in the assessment data of these parameters is not systematic and depends on the number of sample trees: due to a higher number of sample trees the evaluation differences of monitoring parameters are decreasing (GERTNER, KÖHL 1995; DOBBERTIN et al. 1997). The monitoring parameters (crown defoliation, foliage discoloration, amount of dead branches in the crowns, needle retention, etc.) of Scots pine (*Pinus sylvestris* L.) serve as the natural monitors and indicators to objectively evaluate the influence of all changes taking place in forest ecosystems at roadsides, especially the impact of traffic pollution. Special studies on the impact of chlorides on the state of pine trees, carried out in 1994–1996 (ARMOLAITIS, BARTKEVIČIUS 1996), failed to prove that chlorides have a certain impact on the state of pine trees. Changes in the heath condition of roadside trees are related to the impact of transport pollutants, first of all, nitrogen oxides and benzapyrene.

CONCLUSIONS

According to the results of monitoring of Scots pine (*Pinus sylvestris* L.) growing in forest ecosystems at roadsides, performed in 1998–2000, the following conclusions were drawn. At the different distances from the roadbed the morphological parameters of pine tree crowns are different. The highest crown defoliation (43.3 ± 1.5%) is characteristic of trees growing near the highway. With increasing distance crown defoliation decreases: at the distance of 50–100 m defoliation amounts to 41.5 ± 2.3%, at 150–200 m – 38.7 ± 1.7%, at 250–300 m – 35.3 ± 2.2%, at 350–400 m – 28.4 ± 2.4%. The lowest (23.6 ± 1.3%) crown defoliation and the best health condition of pines were estimated at the farthest distance from the highway.

Discoloration of pine trees at the roadsides of highways of Lithuania is not a very widespread phenomenon in Lithuania. At the closest distance class 1 of discoloration (discoloration 11–25%) is dominating (55% of sample trees); class 0 (discoloration up to 10%) has been estimated for 35%. At the farthest distance even 82% of examined pines are without any symptoms of foliage dechromation, slight foliage discoloration has been estimated for 18% of sample trees.

It was found that the state of tree tops of pines at roadsides is generally good – more than 70% of healthy tree tops was observed on each permanent observation plot.

The amount of dead branches at a certain distance from the highway is changing as follows: 10–20 m – 30.2 ± 1.2% of dead branches, 50–100 m – 27.5 ± 1.9%, 150–200 m – 24.6 ± 1.5%, 250–300 m – 21.6 ± 2.0%, 350–400 m – 16.3 ± 2.1%, 450–500 m – 12.8 ± 1.8%. The lowest amount of dead branches has been estimated at the farthest distance from the highway, the highest – at the closest one. It has indicated the largest influence of traffic emissions on the pine state near the highway.

The shortest needle retention (1.9 ± 0.04 years) has been estimated at the closest roadsides. At larger distances from the highway it has increased: at 50–100 m – 2.0 ± 0.07 years, at 150–200 m – 2.3 ± 0.04, at 250–300 m – 2.5 ± 0.07, at 350–400 m – 3.0 ± 0.05, at 450–500 m – 3.1 ± 0.03 years. This diagnostic test indicates the unfavourable growth conditions caused by the negative impact of traffic pollution on pine growth at the closest distances.

The results of forest monitoring at roadsides have indicated that differences in morphological parameters of Scots pine (*Pinus sylvestris* L.) at different distances from the highway are statistically reliable ($P = 0.95$) and can reflect the environmental conditions at roadsides depending on the amount of traffic emissions and their distribution.

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Ekologický monitoring borovice lesní (*Pinus sylvestris* L.) v lesních ekosystémech podél silnic

ABSTRAKT: V práci jsou předloženy výsledky sledování borovice lesní (*Pinus sylvestris* L.), které se uskutečnilo v letech 1998–2000 podle mezinárodní metodiky lesnického monitoringu (UN/ECE 1994). Byly zhodnoceny a diskutovány indikativní parametry (defoliace koruny, ztráta barvy jehličí, stav vrcholků stromů, množství uschlých větví atd.) u 684 vzorníků rostoucích ve vzdálenosti 10–20, 50–100, 150–200, 250–300, 350–400 a 450–500 m od hlavní silnice. Výsledky naznačily, že borovice nacházející se v největší vzdálenosti (450–500 m) od vozovky vykazují nejlepší zdravotní stav (střední defoliace 23,6 ± 2,2 %) ve srovnání se stromy rostoucími v blízkosti vozovky (43,3 ± 1,5 %). Množství uschlých větví závisí na vzdálenosti od hlavní silnice takto: na trvalých pozorovacích plochách nejblíže k silnici – 30,2 ± 1,2 %, nejdále od silnice – 12,8 ± 1,8 %. Stav vrcholků borovic je dobrý; na všech trvalých pozorovacích plochách bylo zjištěno více než 70 % zdravých vrcholků.

Klíčová slova: monitoring; borovice lesní; okolí silnic; indikativní parametry

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