Surface Structures of *Pinus sylvestris* Needles under the Influence of Low-Level Industrial Emissions

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The aim of the study was to compare the surface wax structure of *Pinus sylvestris* needles in the neighborhood of a nitrogen fertilizer factory (Jonava district, Lithuania), and "relatively clean" sites. Nine morphological types of the wax were distinguished: initial tubes (IT), tubes slightly fused to each other (TSF), tubes fused together (TF), net lying on the surface (NET), alone tubes lying on the surface (AMT), even amorphous wax (AME), uneven amorphous wax (AMU), small granules (GRA), short tubes that arise from amorphous wax and seem recrystallized (REC). In all cases the abundance of each type of the wax was estimated as its proportion of the total coverage of the epicuticular wax. In accordance with the examination in 1990 and 1993 occlusion with eroded wax types was significantly higher on one-year-old needles of pines from site located near the nitrogen fertilizer factory. The detailed classification of morphological types of wax in some cases may be a helpful tool for identifying differences, which may be undetected when needle surface is classified just into two different appearance parts.

Key words: conifers, Scots pine, needle surface, epicuticular wax morphology, SEM, nitrogen pollution

Introduction

Acid deposition and photo oxidants are factors responsible for the economic loss of forest growth and crop yield in North America and Europe. Well-established national surveys in various countries of Europe rely on visual tree observations made from the ground (Innes, 1993; Kairiūkštis et al., 1992; 1994; UN/ECE and EC, 1997). A change in color and loss of needles have been used as bioindicators of damage caused by air pollution. They are to some extent subjective, and there is a clear need to devise objective methods of quantifying the extent of forest tree damage (Innes, 1993; Skuodiene, 1996; Skuodienė & Kairiūkštis, 1996).

Hitherto, studies of diagnostic tests for conifers identified leaf surface characteristics as good indicators of tree vitality (Cape et al., 1988; Tuomisto, 1988; Mehlhorn et al. 1988; Percy et al., 1990; Turunen & Huttunen, 1990; Turunen et al., 1991).

The waxy coverage of the plants is continuously exposed to a variety of natural and man-made factors (Riederer, 1989; Turunen & Huttunen, 1990). As leaves are in direct contact with air-borne pollutants, we may expect that the first symptoms of damage should appear on the needle surface.

Air pollutants may alter synthesis of the wax, resulting in a reduced concentration or changed composition of the waxes, both of which lead to a changed physical structure of the waxes (Günthardt-Goerg & Keller, 1987; Riederer, M. 1989; Percy et al., 1990; Günthardt-Goerg et al., 1994; Gordon et al., 1998).

Air pollutants may affect not only the production but also subsequent 'weathering' of epicuticular wax (Cape et al., 1988; Percy, 1990; Cape, 1993; Garrec, 1994; Huttunen, 1994). As wax degradation proceeds, a variety of different symptoms appear in stomatal areas, including amorphous, flattened, or melted areas and stomatal occlusions. Cracks and ruptures of wax were observed as well. Air pollution induced wax erosion resembles accelerated natural weathering of the needle surfaces, which differs from mechanical, fungal or insect damage (Turunen & Huttunen, 1990). A chemical study of alkanes has permitted a distinction between aging response and pollution symptoms (Kerfourn, 1992).

The overall erosion rate is usually related to the level of air pollution and based on the comparison of areas with different emission loads (Huttunen & Laine 1983; Sauter & Voß, 1986; Tuomisto, 1988; Turunen et al., 1991). Acid rain or polluted air can destroy the crystalloid epicuticular waxes in a few weeks after needle flushing, the rate being 2 to 5 times faster than in clean areas, where it usually starts during the second year of the needles existence (Huttunen, 1994).

Erosion of surface waxes was observed as a consequence of the effect of gaseous pollutants (Riding & Percy, 1985), simulated acid rain (Schmitt et al. 1987), acid mist or acid fog (Mengel et al., 1987) and aggressive basic dust (Bermadinger et al., 1987). Ozone and acid fog (pH 3,0; 4,2) applied at near ambient doses, can alter epicuticular wax morphology on elongating red spruce needles. New structures consisting of upright irregular wax plates were also observed (Percy et al., 1990).

Conifer needles in some European areas where trees are in decline have been reported to manifest accelerated weathering of epicuticular waxes (Cape, 1993; Huttunen, 1994). There are several processes that can be connected with epicuticular wax degradation in forest decline: leaching of nutrients after increased needle wettability; dry-out as a result of increased cuticular and stomatal transpiration; fungal infection (Turunen & Huttunen, 1990).

Majority of investigators focus their attention on the general state of the wax. Since early 1980's, in most studies carried out with *Pinus sylvestris* needles only two main wax forms have been distinquished: structural and amorphous (Cape & Fowler, 1981; Huttunen & Laine, 1983; Crossley & Fowler, 1986; Turunen et al., 1991). In addition to general state of the wax, a more detailed classification of the wax form has been proposed (Tuomisto, 1988). Precise observation may reveal features that go unnoticed if the specimen are examined more superficially.

To achieve an early diagnosis of forest decline, research mainly was concentrated in controlled condition experiments (Günthardt-Goerg & Keller, 1987; Mengel et al., 1989; Turunen & Huttunen, 1990), but processes undergoing in field conditions are still poorly understood (Turunen & Huttunen, 1996).

Investigation of the state of pollution in Lithuania revealed the nitrogen fertilizer plant to be one of the most important point source polluters in Lithuania (Armolaitis, 1991; 1998; Armolaitis et al., 1993; Augliene & Bilkis, 1994). Since opening of the factory in 1965 emissions of the nitrogen fertilizer plant were negatively affecting conifer forest stands within 20-25 km distance from the polluter. The first damages in terms of defoliation and discoloration of pines were detected in 1972-1975, and the state of the stands was getting worse until 1990 (Šepetienė & Mastauskis, 1996). Various approaches and tests were used to evaluate forest health near the main local pollution sources of Lithuania (Armolaitis, 1991; Armolaitis et al., 1993; Kairiūkštis et al., 1994; Nemaniūtė et al., 1997; Skuodiene, 1996; Skuodiene & Kairiukštis, 1996; Raguotis, 1997). The aim of this study was to test applicability of surface structures of *Pinus sylvestris* needles in order to reveal the effects of low-level local pollution in Lithuania.

Materials and methods

In the experiment of 1990 the needles of *Pinus sylvestris* were obtained from 2 Lithuanian districts: in Jonava district as a polluted site (further called site 1) located at a 0.5 km distance from the nitrogen fertilizer plant and in Kačerginės district as a "control" site (further called site 2) - a pine forest situated far away from marked local pollution sources. In 1993, two sites in Jonava district were examined: the previous site 1 near the nitrogen fertilizer plant and an other site (further called site 3) located at 18 km distance according to prevailing north-east wind. Selection of comparable in our study sites was based at different level of pollution in those places: total atmospheric deposition of nitrogen ranged between 21.6-121.0 kg ha^{-1} $year^{-1}$ in 1988 and 16.8-26.8 kg ha^{-1} $year^{-1}$ in 1996 (Armolaitis 1998). In addition, concentrations of aerial NO_2 on site 1 have been found higher as compared to site 3 (Kupčinskienė et al., 1996). Trees on all three sites belonged to young pine stands of *Vaccinium-myrtillosa* type. The forest soils were classified as Haplic Podzols and Dystric Podzoluvisols (Armolaitis, 1998). The sampling dates were middle of September in 1990 and November in 1993. At each site 4 dominant trees (5-8 m height) were studied. Sampling was performed from the east-west side of the trees. Needles were taken from the first order lateral branches on the 3rd or 4th whorls from the top of the trees. In the study with *Picea abies*, it was revealed variation among the needles taken from the same tree, but this showed no consistent pattern with respect to the sampling height or compass direction (Tuomisto & Neuvonen, 1993). The samples were excised from the middle part of the current-year and one-year-old shoots with forceps. Only green undamaged needles were taken from the trees. The surface moisture was allowed to evaporate for some time as many researchers use air-dried samples in order to preserve and dehydrate needles for wax morphology studies (Bermadinger et al., 1987; Tuomisto & Neuvonen, 1993). The center of 10 mm of needles were secured with abaxial surface exposed uppermost. The samples were coated with silver using sputting device (VUP-4K) and examined with JEOL-JXA 50A scanning electron microscope (15 kV accelerating voltage). Representative areas of each needle were photographed at magnifications in the interval of 100^x -

10000^x. Areas investigated were: the stomatal area - slopes of the epistomatal chamber and the interstomatal area - a surface between 2 rows of stomata. The surface of the epistomatal chambers was not investigated. In accordance with a precise classification of the structural forms of *Picea abies* needles (Tuomisto, 1988) the following morphological types of wax on pine needles were distinguished (Fig. 1): initial tubes (IT); tubes slightly fused to each other (TSF); tubes fused together (TF); net lying on the surface (NET); alone tubes lying on the eroded surface (AMT); uneven amorphous wax (AMU); even amorphous wax (AME); granules (GRA); short tubes that arise from amorphous wax and seem recrystallized (REC).

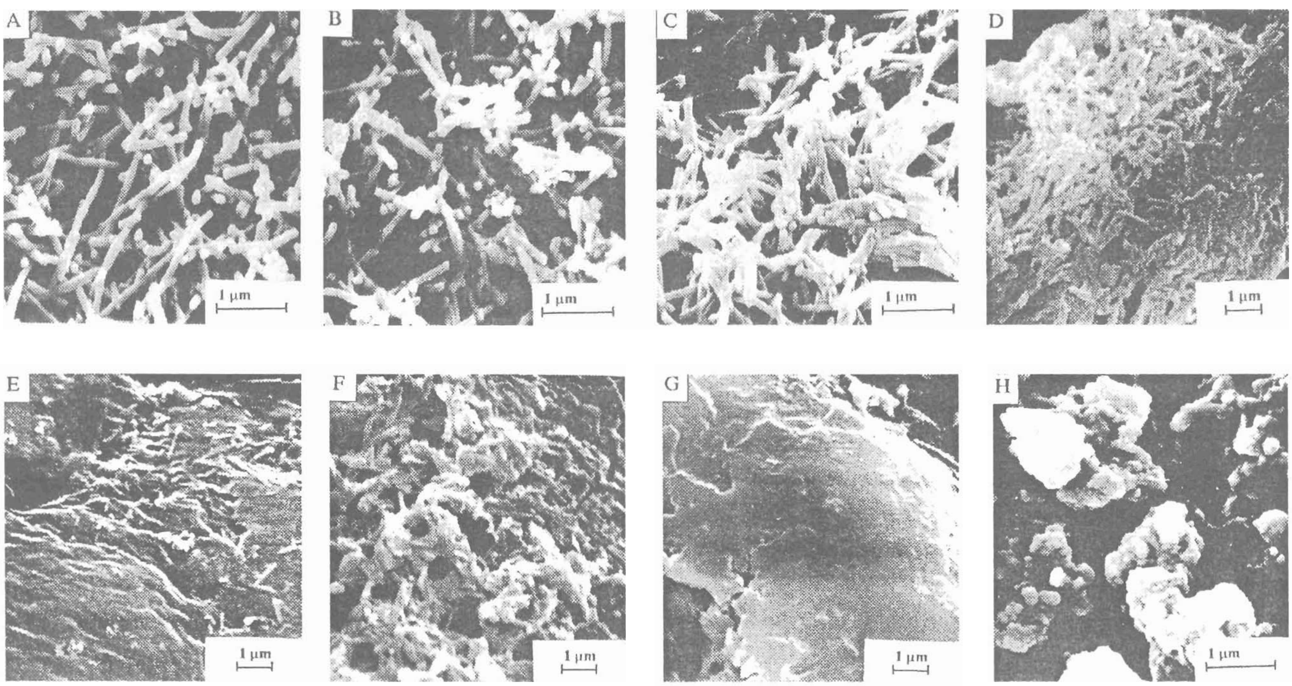
In 1990 experiment, amorphous wax (AM) was not classifieded into two separate classes (AME and AMU) and recrystallized tubes were not detected (REC). Needle surface covered with tubular wax was calculated summing areas with initial tubes, tubes slightly fused to each other, tubes fused together, net lying on the surface. Eroded wax surface was calculated adding up areas with alone tubes lying on the surface, granules, even and uneven amorphous wax. In all the cases the abundance of each of the wax types was estimated as its proportion of the total coverage of the epicuticular wax projecting from the surface. In addition, the frequency of areas (% of areas containing each morphological type of wax compared to total amount of areas examined) was calculated.

Statistical analysis. The ANOVA analysis was used to evaluate the significance of differences between data sets.

Results and discussion

1. General view of the needles

Study of samples at low magnifications has shown that the shape of the subsidiary cells of stomata on the



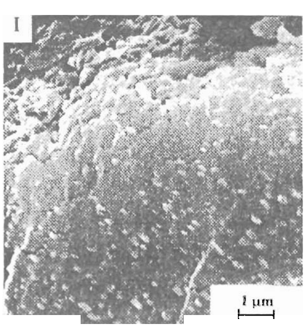


Figure 1. Morphological types of wax detected on ***Pinus sylvestris*** needle surface.
A. Initial tubes (IT). B. Tubes slightly fused to each other (TSF). C. Tubes fused together (TF). D. Net lying on the surface (NET). E. Alone tubes lying on the eroded surface (AMT). F. Uneven amorphous wax (AME). G. Even amorphous wax (AME). H. Granules (GRA). I. Short tubes that arise from amorphous wax and seem recrystallized (REC).

needles taken from both polluted and control sites in most cases had oval form and showed no signs of deformation. In addition to gaseous pollutants, hard particles may take part in the induction of wax erosion (Bermadinger et al., 1987). That is why doing examination of waxes special attention is to be paid to the amount of deposited air-borne substances on the needle surface (Crossley & Fowler, 1986; Bermadinger et al., 1987; Tuomisto, 1988; Turunen et al., 1991). Our SEM observations revealed the few hard air-borne particles on the surface between the stomata and within the epistomatal chamber of needles picked from both control and polluted sites. Innumerable particulate pollutants on the surface of needle samples might be caused by rainy weather within 2 weeks proceeding the sampling in 1990. There was possibility of removal of pollutants mechanically by rain. In addition, it was found that 40 - 90% of rain-washed down fractions were water-soluble (Simleit et al., 1989). Particles were scarce in period with rare rainfall in our 1993 observation also. The results obtained in the studies conducted in 1990 and 1993 have refuted major importance of dust as a sort of pollutant causing erosion of needle surfaces at site 1. The data obtained by us during examination of needle surfaces agree with small amount of dust among other types of emissions of nitrogen fertilizer plant.

According to our observation of the surface quality there were significant similarities among stomata of the same needle. Concerning reasonable amount of stomata needed for present investigation fully agrees with assumptions of the other authors: analysis of variance at different hierarchical levels (among trees, among needles and within needles) suggested that the sampling effort is better invested by sampling 1-4 replicate needles per tree and observing 1-2 stomata per needle (Tuomisto & Neuvonen, 1993).

In our study 7-9 morphological wax forms on the surface of pine needles were detected. According to literature precise examination of needle surface was performed only on Norway spruce where 11 morphological types of wax were distinguished (Tuomisto, 1988). Among them only 8 structural types were common for both stomatal and interstomatal areas. Higher amount of separate forms classified on spruce could be due to differences in species depended specificity of structural wax distribution: *Picea abies* needles have a protective tubular wax architecture all over the surface, whereas *Pinus sylvestris* only in the stomatal rows (Huttunen, 1994). The other reason could be a more precise classification undertaken in the spruce study (subdivision of granules into two different forms according to the size, etc.).

In the 1990 year study conducted in 1990, seven morphological wax types were distinguished, whereas in 1993 the needle surface was subdivided into nine forms. Differences between the types of the wax distinguished in the studies performed in 1990- and 1993 might have two reasons: the first reason was an attempt made in 1993 to assess separately indicatory values of two different amorphous wax forms: even and uneven; the second reason was identification of new forms of the wax (recrystallized tubes) undetected in 1990. Absence of the later morphological type in 1990 needle surface could be caused by different conditions in which needles where kept after excision from the trees till the time of observation under SEM. Collection of the needles into paper bags is the most frequent and approved pattern known for needle transportation and storage before SEM examination (Huttunen, personal communications; Bermadinger-Stabentheiner, 1995). Although air permeable paper bags are the best for preservation of the leaves there is still possibility left for some extent of physical injury. Our results obtained could be in support to it. No REC was found on the needle surface in case the needles were separated from the branch and sticked by base of small shoot to the bottom of drying box straight in the sampling place. On the contrary, REC was found on needle surfaces in 1993 when needles were separated from the branch, placed inside the bags in the sampling place, and subsequently transported and kept in paper packages till the SEM analysis. In addition, our results have shown, that recrystallized short tubes have appeared only on the needles taken from site 1. One among assumptions explaining it could be different ability for regeneration of more eroded needle surfaces exposed to polluted air in site 1 compared to the "control" site.

2. Comparison of wax structure on the slopes of epistomatal chamber and in the area between stomata.

Generally, the same seven wax types were detected during examination of both interstomatal and stomatal areas in 1990 as well as eight to nine wax types were distinguished in both surface areas on needles taken in 1993 (Fig.2).

Observation under lower magnifications did not show pronounced differences between the surface zones. Some extent peculiarities of surface areas examined could be detected under higher magnifications. Distribution of

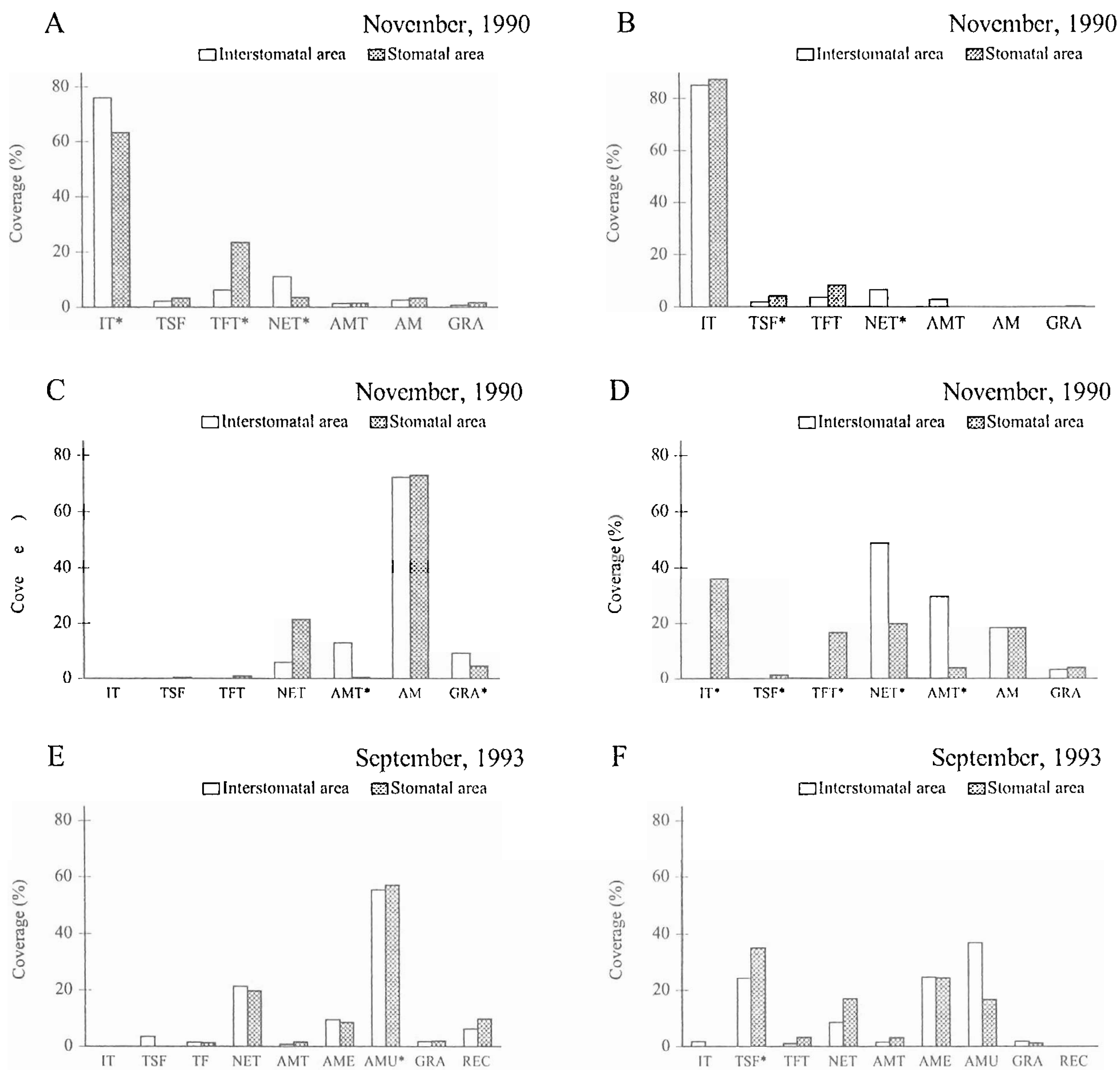


Figure 2. Comparison of various wax structures (coverage in %) of interstomatal and stomatal area on current-year (A, B) and one-year -old (C, D, E, F) needles of ***Pinus sylvestris*** growing at site 1 (A, C, E), site 2 (B, D) and site 3 (F). *Statistically significant difference ($p<0.05$) between areas.

wax tubes on the surface of subsidiary cells looked slightly thicker as compared to the adjacent zone.

Among current year needles statistically significant differences were found (Fig. 2, A & B) between interstomatal and stomatal areas according to various tubular forms of wax (IT, TFT, TSF, NET).

Evaluation of interstomatal and stomatal areas among one-year-old needles collected in 1990 revealed statistically significant differences according to some tubular (IT, TSF, TFT, NET for site 2) and eroded (GRA for site 2, AMT for both sites) wax types (Fig. 2, C & D). Coverage by amorphous wax coincides very well in comparable surfaces. Subdivision of amorphous wax into two forms revealed statistically significant differences of the uneven amorphous wax between the surface of subsidiary cells and adjacent zones on the needles taken from site 1 in 1993 (Fig. 2, E).

The most frequent distinct feature of one-year-old needles taken from control sites was significantly higher coverage by tubes slightly fused to each other (TSF) on stomatal areas compared to the interstomatal areas (Fig. 2, D &F).

3. Comparison of current-year and one-year-old needle wax structures.

In most cases statistically significant differences were found between current-year and one-year-old needle coverage in morphological forms of wax (Fig..3). Current-year needles contained mainly structural forms of wax, whereas one-year-old needles had eroded surfaces. These data correspond with the findings of other researchers that needles are mainly damaged in autumn-winter time compared to period between expansion of needles in June and sampling time in November (Huttunen and Laine, 1983).

matal and interstomatal areas of the same age needles (Fig. 2, 3).

4. Comparison of epicuticular wax morphology between the needles from neighboring factory and further located sites.

Distribution of various wax morphological types on the current-year needles sampled from "relatively clean" site (site 2) and "polluted" site (site 1) is shown in Fig. 4. In addition to the prevailing structural forms (IT, TSF, TFT, NET) of interstomatal zone on site 1 current-year needles (Fig. 4, A), there were small areas (4.8%) of

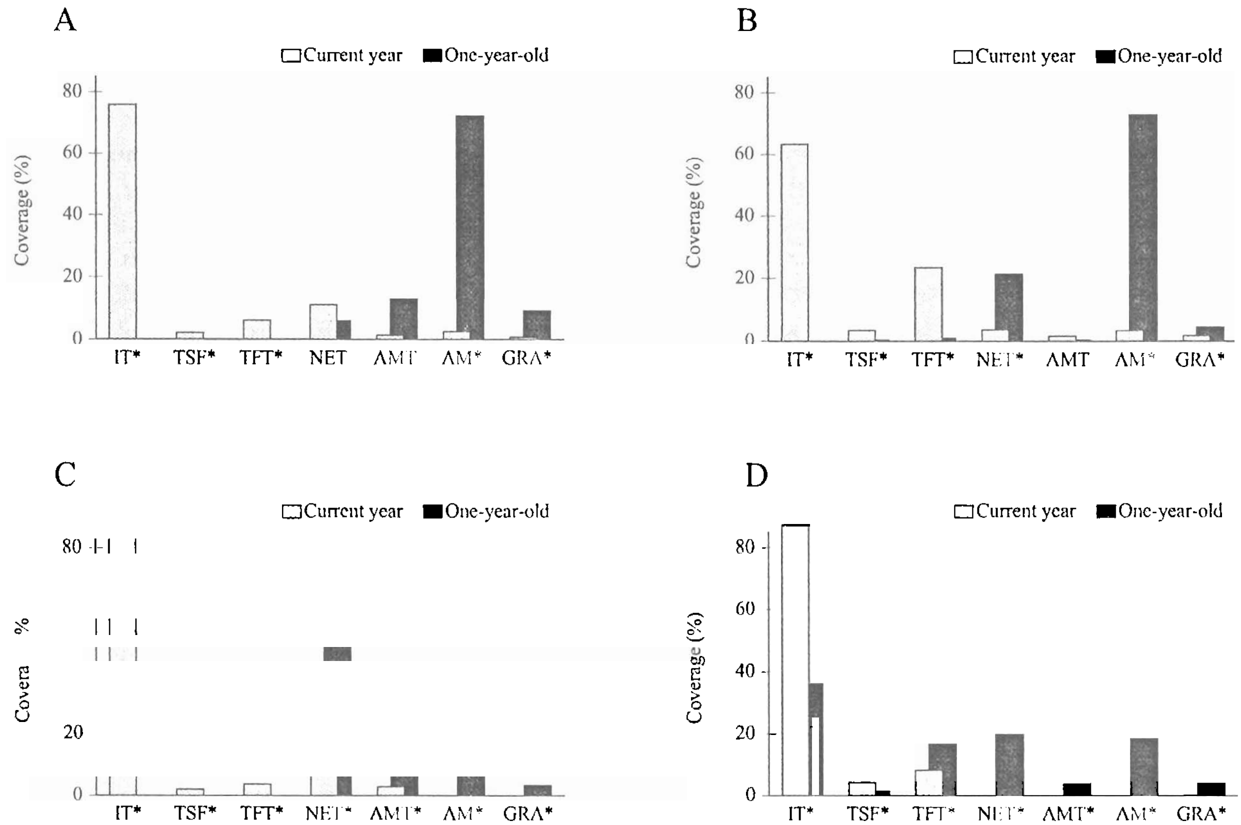


Figure 3. Comparison of various wax structures (coverage in %) of interstomatal (A, B) and stomatal (C, D) areas on current-year and one-year-old needles of ***Pinus sylvestris*** growing at site 1 (A, C) and site 2 (B, D) *Statistically significant difference ($p<0.05$) between needle age classes (1990).

Analysis of different age needles revealed initial tubes to be the most contrasting morphological type. A similar comment could be applied to amorphous wax, especially concerning the age differences in interstomatal area (Fig. 3, A&B). The least contrary situation of the stomatal area was found on needles taken from site 2. In general, age differences in surface erosion were higher at site 1 (Fig. 3, A&C) as compared with site 2 (Fig. 3 B&D).

Acid rain or polluted air can destroy crystalloid epicuticular waxes in a few weeks. In *Pinus sylvestris*, the first sign of pollution effect is the fusion of wax tubes (Huttunen, 1994). The accelerated erosion of needle surfaces can be detected in all needle age classes (Huttunen & Laine, 1983).

According to surface quality, needle age differences were more pronounced than differences between stoeroded wax (AMT, AM, GRA). Similar comments could be applied to interstomatal areas of current-year needles taken from site 2. Exception is a smaller extent of the area covered by eroded wax (2.8 %). However, the differences between the needles of control and polluted sites in distribution of various wax morphological types were not significant. In site 1 we may only notice a tendency of increased extent of area of wax forms which indicate the beginning of erosion.

Stomatal areas of current-year needles taken from site 1 and site 2 significantly differed (Fig. 4, B) in coverage by structural forms of wax (99.8 % and 93.6 %, respectively, p=0.014) as well as by eroded surfaces (6.4 % and 0.2 %, respectively, p=0.014). Statistically significant differences were found in coverage by separate morphological forms of wax: IT, TFT, NET, GRA. All differences detected showed higher extent of erosion in stomatal area of site 1 compared to site 2. Our data correspond with results obtained by other researchers (Huttunen and Laine, 1983). After these authors erosion of the surface wax in polluted areas begins almost immediately after the flushing and elongation period of needles. The accelerated erosion induced by air pollution was observed to develop in a few months. Any modification of the epicuticular wax layer during the first season may have cumulative, harmful consequences (Percy et al. 1990).

ed wax (94.1 % and 51.2 %, respectively, p<0.001) as well. The most common wax form on the stomatal area of one-year-old needles for site 1 was AM surface and for site 2 - IT. There were statistically significant differences between site 1 and site 2 according to coverage of stomatal areas by some separate forms of wax (IT, TFT, AMT and AM) with the smaller areas covered by IT, TFT and larger areas covered by AM on the needles of site 1 (Fig. 5, B) compared to site 2. Statistically significant differences between stomatal areas of needles taken from site 1 and site 2 were documented according to total tubular (22.3 % and 73.7 %, respectively, p<0.001) and total eroded wax areas (77.7 % and 26.3 %, respectively, p<0.001) as well. A comparison of morphological types of the wax found on the surface of one-year-old needles sampled from site 1 and site 3 in 1993 is shown in Fig. 6. The prevailing wax form in the interstomatal area of one-year-old needles taken from both sampling sites was uneven amorphous surface (Fig. 6, A). There are statistically significant differences between site 1 and site 2 according to coverage of interstomatal areas by some forms of wax (TSF, NET) with the smaller areas covered by TSF and larger areas covered by NET on the needles of site 1 compared to site 2. Statistically significant differences between site 1 and site 2 interstomatal areas of needles were not found according to total tubular (26.4 % and

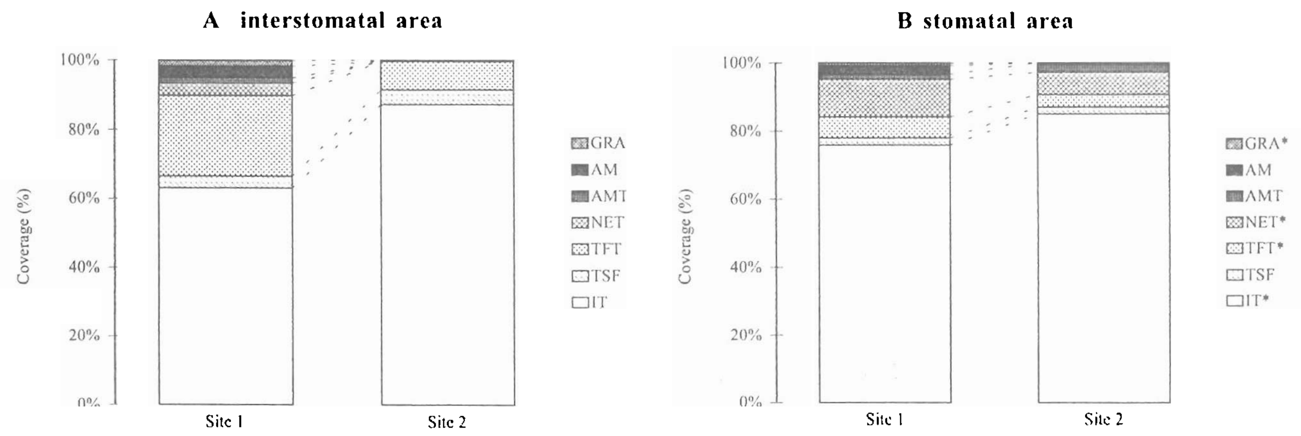


Figure 4. Comparison of various wax structures (coverage in %) of interstomatal (A) and stomatal (B) areas on current-year needles of ***Pinus sylvestris*** growing at sites situated at different distance from nitrogen fertilizer plant (September, 1990). *Statistically significant difference (p<0.05) between sites.

Analysis of morphological types of the wax on the surface of one-year-old needles sampled from site 1 and site 2 in 1990 is shown in Fig. 5. The prevailing wax form on the interstomatal area of one-year-old needles taken from site 1 was AM and from site 2 was NET. There were statistically significant differences between the samples taken from site 1 and site 2 according to coverage of interstomatal areas by some forms of wax (NET, AM and GRA) with the smaller areas covered by NET and larger areas covered by AM and GRA in site 1 needles (Fig. 5, A) compared to site 2. Statistically significant differences between interstomatal areas of needles taken from site 1 and site 2 were documented according to total tubular (5.9 % and 48.8 %, respectively, p<0.001) and total erod-

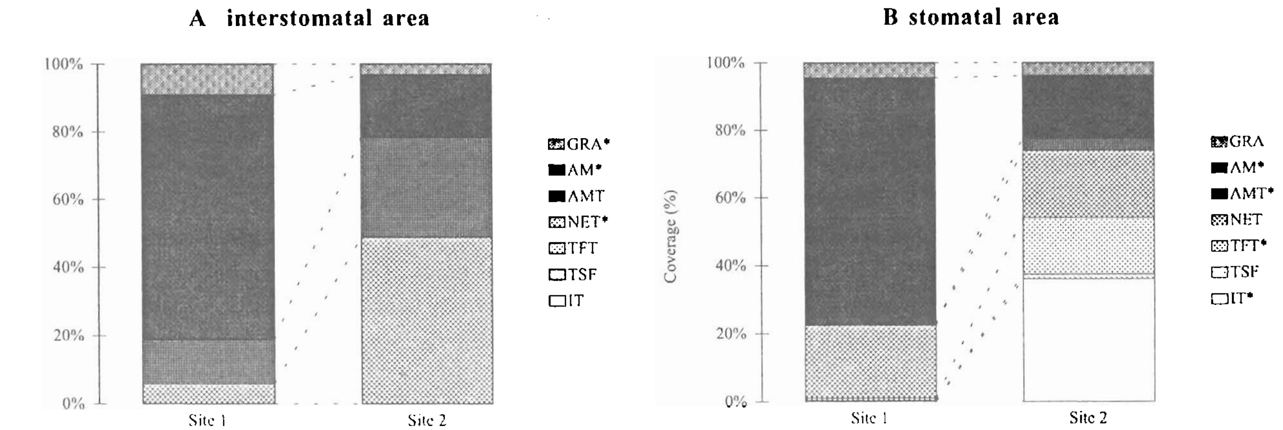


Figure 5. Comparison of various wax structures (coverage in %) of interstomatal (A) and stomatal (B) areas on one-year old needles of ***Pinus sylvestris*** growing in sites situated in different distance from nitrogen fertilizer plant (September, 1990). *Statistically significant difference ($p<0.05$) between sites.

73.6 %, respectively) and total eroded wax areas (73.6 % and 64.5 %, respectively) as well. Common wax form in the stomatal area of one-year-old needles taken from site 1 was uneven amorphous surface and tubes slightly fused, taken from site 2 (Fig. 6, B). There were statistically significant differences between site 1 and site 2 according to coverage of stomatal areas by some forms of wax (TSF and AMU) with the smaller areas covered by TSF and larger areas covered by AMU on the needles of site 1 needles compared to site 2. Statistically significant differences between stomatal areas of needles taken from site 1 and site 2 were documented according to total tubular (21.0 % and 55.0 %, respectively, $p<0.001$) and total eroded wax areas (79.0 % and 45.0 %, respectively, $p<0.001$) as well.

Discriminant analysis was used to allocate each examined stomatal or interstomatal area to one of the two sampling sites according to the distribution of morphological types of the wax. When current-year needles were used 60% of the interstomatal areas and 87.5% of epistomatal chamber slope areas were correctly classified. All one-year-old needles (100%) were correctly distributed to the sites in the study conducted in 1990 (Kupcinskiene, 1992).

Our study has shown higher erosion of the stomatal areas (Fig. 6, A & B). It is in accordance with some other studies, where with age more considerable changes in stomatal areas compared to interstomatal were documented (Tuomisto, 1988; Turunen and Huttunen, 1990). Differences between the data obtained in 1990 and 1993 in one-year-old needle surface quality might be attributed to changes in the pressure of pollutants (emissions were more significant in 1990) on the environment and in climatic conditions (temperature and

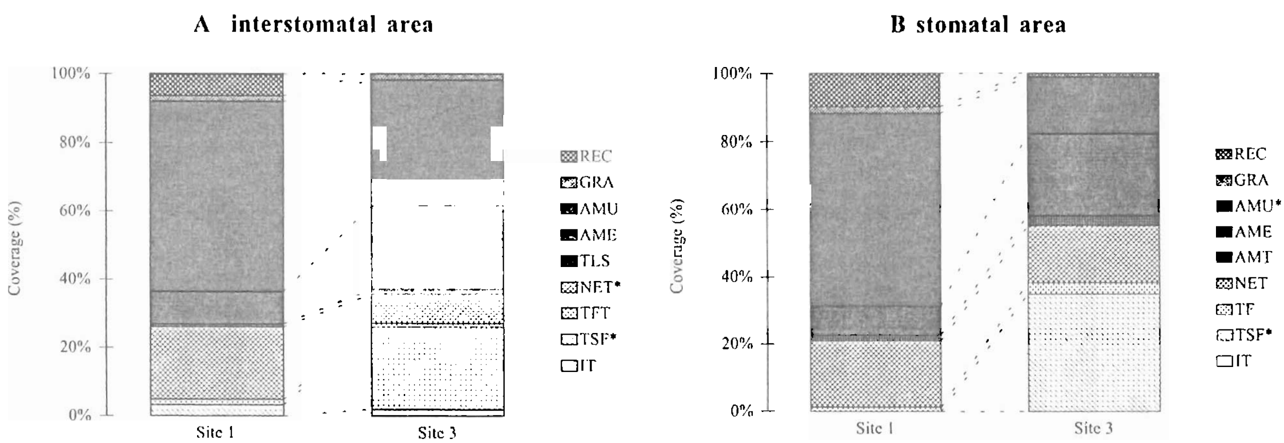


Figure 6. Comparison of various wax structures (coverage in %) of interstomatal (A) and stomatal (B) areas on one-year old needles of ***Pinus sylvestris*** growing at sites situated at different distance from nitrogen fertilizer plant (November, 1993). *Statistically significant difference ($p<0.05$) between sites.

rainfall) during vegetation season. Severe drought in the summer of 1993 could cause higher extent of surface damage including both polluted and control sites.

In five out six patterns examined (Fig. 4-6), more precise classification of needle surface morphology (7-9 types) showed the same results as more general subdivision of wax into two forms (structural and eroded). More detailed classification of morphological types of the wax on the surface of needles could be important in identifying differences which are undetectable when the surface is divided only into eroded and structural parts. Separation of REC or AMT has of no special importance, while NET, TSF, TFT AMU were useful in detecting smaller extent effects under the conditions of low level pollution.

The examined sites differed in abundance of stomata with various types of the wax in both interstomatal and stomatal areas of one-year-old *Pinus sylvestris* needles in Jonava district (Fig.7). Data concerning frequency of stomata covered with separate structural types

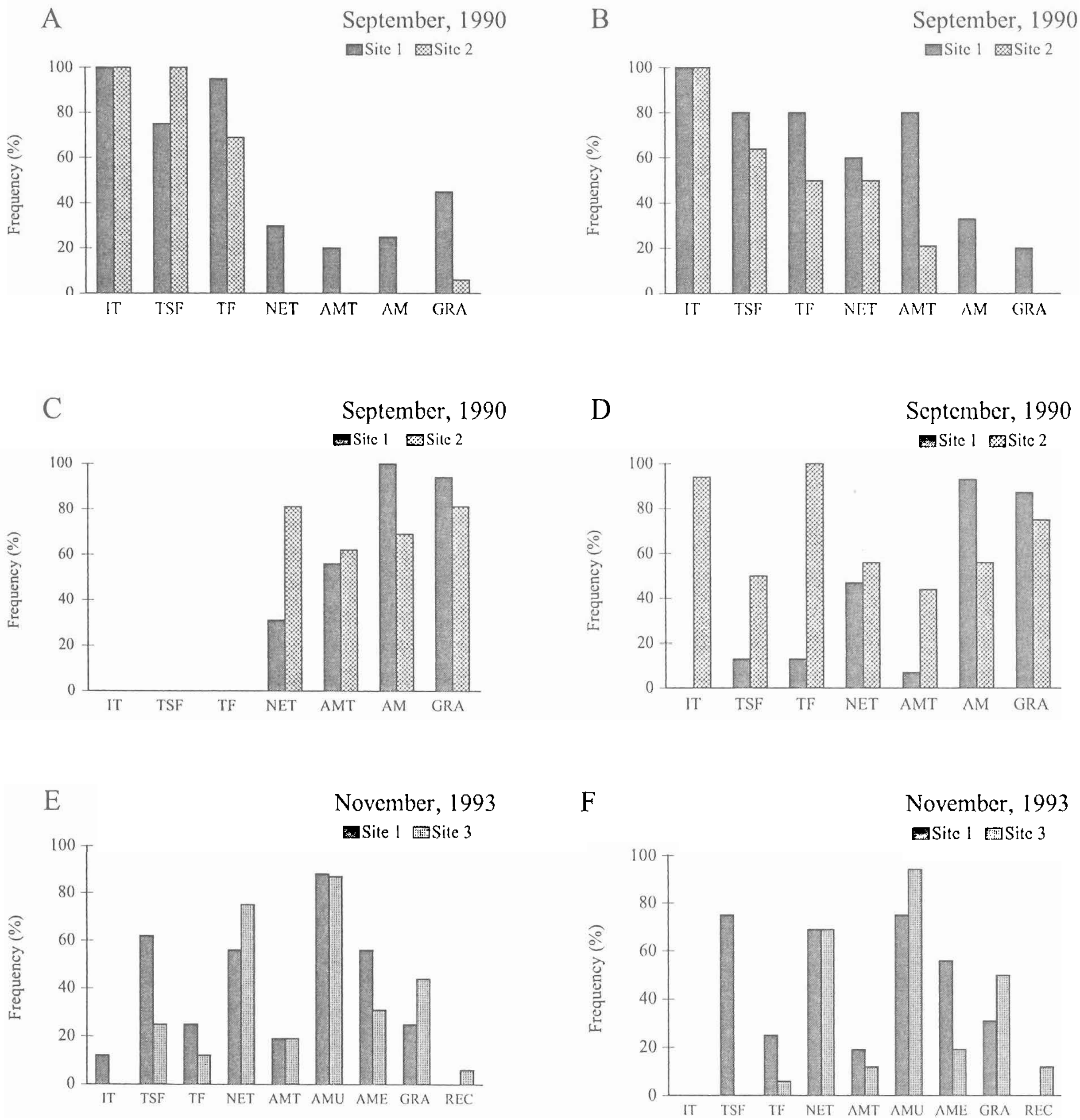


Figure 7. Frequency of various wax types in the interstomatal (A, C, E) and stomatal (B, D, F) areas on current-year (A, B) and one-year-old (C, D, E, F) needles of ***Pinus sylvestris*** growing at different sites (A, B, C, D - sites 1 and 2; E, F- sites 1 and 3).

revealed a great variety of wax structures on the surface of needles taken in the vicinity of the nitrogen fertilizer plant compared to those taken from the sites situated further from the polluter.

Wax tubes increase the ability to repel water. When the wax tubes erode, the contact angle between the surface of the needle and the water droplet decrease (Turunen, Huttunen, 1990). An increased wettability of needles at the polluted site 1 was documented in our study performed in 1993 (Kupcinskiene et al., 1996) as well as many other studies confirm the same fact concerning the lower angle of water droplets on needles at the polluted sites (Cape, 1983; Crossley & Fowler, 1986; Nemaniūtė et al., 1997).

The results obtained observing *Pinus sylvestris* needles under SEM once more demonstrate possibility to detect changes in the leaf surface under the conditions of low-level pollution.

Conclusions

The comparison of epicuticular wax structure of the needles from polluted and control sites has revealed:

1. Significant differences in wax structure between current-year and one-year-old needles both in control and polluted sites.

2. There were no marked differences in the needle wax structure between the epistomatal chamber slopes surface and interstomatal area.

3. In the polluted site the process of one-year-old needles wax degradation from tubular to amorphous form is by far more expressed as compared with control site.

4. In five out six patterns examined, more detailed classification of needle surface morphology (7-9 types) has shown the same results as more general subdivision of waxes into two forms (structural and eroded). Detailed classification of morphological types of wax found on the surface of needles, used in the present study could be important in some cases of identification of differences which are undetectable when the surface is divided only into eroded and structural parts. Separation of REC or AMT was of no special importance, whereas NET, TSF, TFT AMU were useful in detecting smaller extent effects under the conditions of low-level pollution.

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ВЛИЯНИЕ НЕВЫСОКОГО УРОВНЯ ПРОМЫШЛЕННОГО ЗАГРЯЗНЕНИЯ НА ПОВЕРХНОСТНЫЕ СТРУКТУРЫ ХВОИНОК СОСНЫ ОБЫКНОВЕННОЙ.

Э. Купчинскене

Резюме

Целью исследования было сравнение поверхностных структур хвоинок сосны обыкновенной, собраной вблизи завода азотных удобрений (район Ионава, Литва) и более отдаленных ‘относительно чистых’ районах. Было обнаружено девять морфологических типов воска: начальные трубочки (IT), слегка сплавленные трубочки (TSF), сплавленные трубочки (TSF), сеть, лежащая на поверхности (NET), одиночные трубочки лежащие на поверхности (AMT), ровный аморфный воск (AME), неровный аморфный воск (AMU), маленькие гранулы (GRA), короткие трубочки, выдвигающиеся над поверхностью воска и выглядящие как рекристализованные (REC). Во всех случаях частота каждого типа восковой поверхности была вычислена в виде ее доли по отношению ко всей исследованной поверхности. По данным исследования 1990 и 1993 г.г. покрытие однолетних хвоинок эродированным воском было статистически достоверно выше в точке исследования вблизи завода азотных удобрений. В данной работе осуществлен более детальный анализ восковых поверхностей может выявить изменения, которых нельзя обнаружить, используя часто применяемую более общую классификацию поверхности выделяя два морфологических типа.

Ключевые слова: сосна обыкновенная, поверхность хвои, эпикутикулярный воск, загрязнение азотом.