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Effects of road traffic on bark pH and epiphytic lichens in Tallinn

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Abstract: The relationships between traffic-related air pollution, bark pH and epiphytic lichen mycota on *Pinus sylvestris* and *Tilia cordata* were studied. Traffic is considered the main source of air pollution in Tallinn and, therefore, greatly influences lichen composition and species richness, their diversity increasing on *Pinus sylvestris* near roadways but decreasing on *Tilia cordata*. Traffic also affected bark pH of *Pinus sylvestris*, but not of *Tilia cordata*: the bark of *Pinus sylvestris* is normally acid (mean pH in control plot 3.0) and is modified to subneutral (up to 5.7) near roadways. The influence of alkaline dust pollution, connected with traffic, is clearly observed on epiphytic lichen composition of *P. sylvestris* in Tallinn. Besides dust, nitrogen oxides are important pollutants too, but the effects of acidic air pollution are less evident now compared to the previous studies.

Kokkuvõte: Autoliikluse mõju puukoore pH-tasemele ja epifüütsetele samblikele Tallinnas.

Töös uuriti autoliiklusega kaasneva saaste mõjusid puukoore pH tasemele, epifüütsete samblike liigilisele koosseisule ja liigirikkusele Tallinnas, kuna transport on seal praegu kõige olulisem õhusaaste allikas. Uuritavate samblike substraadiks valiti harilik mänd (*Pinus sylvestris*) ja harilik pärn (*Tilia cordata*). Töö tulemusena selgus, et liiklussaaste mõjutab männi koore pH taset (see tõuseb autoteede läheduses), kuid mitte pärna oma. Epifüütsete samblikuliikide arv männi tüvel suureneb autoteede läheduses, kuid väheneb pärnal. Liiklusega seotud aluselise tolmusaaste mõju männi epifüütsetele samblikele on Tallinnas selgesti täheldatav. Ka lämmastikoksiidide sisaldus õhus on kõrge, kuid, erinevalt varasematest uuringutest, happelise õhusaaste mõju samblikele ei ilmnenud.

INTRODUCTION

Most epiphytic lichen species prefer substrata with specific chemical and physical qualities and, therefore, choose to grow on certain tree species. One of the main factors, affecting their occurrence is the acidity of bark (Hawksworth & Hill, 1984), which varies according to tree species; for example, *Betula pendula* Roth, *Picea abies* (L.) H. Karst. and *Pinus sylvestris* L. have normally acid (pH 3.4–4.0) and *Acer platanoides* L., *Fraxinus excelsior* L. and *Tilia cordata* Mill. subneutral (pH 4.9–7.5) bark in clean-air areas (Wirth, 1995).

Acidic pollutants reduce bark pH and alkaline pollutants increase it, which in turn causes significant changes in the composition of epiphytic lichen species; for example, in areas subjected to SO_2 pollution, acidophytic lichens grow on tree species which normally have subneutral bark (Türk & Wirth, 1975) and in areas subjected to alkaline dust pollution epilithic lichens inhabit trees (Gilbert, 1976) and neutrophytic lichens grow on phorophyte species which normally have acid bark (Martin & Martin, 2000). Nitrophytic species are usually associated with eutrophication or hypertrophication (Seaward & Coppins, 2004), but other factors such as dust may also be important (van Haluwyn & van Herk, 2002). Gilbert (1976) found that concurrent acid and alkaline pollutants neutralise each other's effects leading to higher species richness when compared to areas with only acidic pollution.

Pollutants have, besides the indirect influence causing a change in substrate pH, also direct effect on lichens; for example, the toxic nature of SO_2 is probably the primary factor affecting lichen physiology rather than acidified bark (Hawksworth & Hill, 1984). There is a clearly defined negative relationship between species diversity and sulphur dioxide concentration in conditions of stable high air pollution (Seaward, 1992). NO_2, predominantly released by road traffic, is considered another important pollutant influencing epiphytic lichen vegetation in urban environments and close to motorways (Gombert et al., 2002); a phytotoxic effect on lichens has been recorded when NO_x exceeds 70 µg/m³ and NO_2 exceeds 40 µg/m³ (Davies et al., 2007). Still, some lichen species respond positively to NO_2 pollution (van Dobben & ter Braak, 1999; Larsen et al., 2007). NH_3 air pollution, caused by intensive livestock farming, is a significant factor in some countries, such as Netherlands and Denmark, and results in a considerable increase of nitrophytic lichens and the disappearance of acidophytic species (van Herk, 2001; Sparrius, 2007). It is also recognised that air pollution often comprises different pollutants and their effect on lichens is complex; for example, attempts to find correlations between NO_x concentrations and lichen distribution may be confounded by strong positive correlations between SO_2 and NO_x concentrations (van Dobben & ter Braak, 1999; van Herk, 2001).

Motor traffic, which emits NO_x, CO_2, CO, SO_2, fine dust particles, volatile organic compounds etc., is the main source of air pollution in Tallinn today. The aim of the present study was to investigate how traffic-related pollutants influence the acidity of tree bark and the occurrence of epiphytic lichens in Tallinn. As the impact of air pollution on lichen composition may depend on tree species, two phorophyte species with radically different bark qualities were studied: *Pinus sylvestris* with acid bark and *Tilia cordata* with subneutral bark.

MATERIALS AND METHODS

Study area

Tallinn, the capital of Estonia with a territory of 159 km^2 and registered population ca 400,000, is located on the eastern coast of the Baltic Sea (Fig. 1). Closeness of the sea influences the climate; southern and western winds prevail, the latter bringing about maritime air masses. The mean annual air temperature is 5°C; the mean temperature from December to March is below 0°C; the mean annual precipitation is 668 mm (EMHI, http://www.emhi.ee).

Fig. 1. Location of Tallinn (study area).

Field methods

Fieldwork was carried out between June and August 2006. The sample plots were situated in city parks and nature reserves of Tallinn. Green areas (excluding private gardens) cover ca 27% of the city territory. There are three nature reserves within Tallinn, to protect the landscapes of Aegna Island (301 ha), Pirita River basin (527 ha) and recreational pine forests in Nõmme-Mustamäe district (200 ha), and numerous parks. Parks with an area of less than 1 ha or lacking the selected phorophyte species were excluded from the study.

Sample plots each contained five trees of the same species. Tree girths ranged from 27 to 302 cm with an average of 116 cm. A total of 57 sample plots (Fig. 2) and 285 trees were examined in Tallinn; 39 sample plots comprised *Pinus sylvestris* and 18 *Tilia cordata*. The sample plots with the different phorophytes were situated separately and heterogeneously in the city as the two tree species did not grow in the same area.

Presence or absence of 60 earlier selected lichen species was recorded on all examined trees (Table 1). All these lichens are rather common in Estonia (Trass & Randlane, 1994; Randlane & Saag, 2004) and most of them have been reported in the previous studies in Tallinn (Martin, 1984; Sander & Lensment, 1996; Lensment, 2001). Among selected lichens, both acidophytes and nitrophytes (van Herk, 2002), as well as NO_x tolerant species (Davies et al., 2007) are represented. Other species were not included in the study.

To compare the results with clean-air areas, two control plots were chosen in the countryside. The control plot for *Pinus sylvestris* was situated in Kõrvemaa Nature Reserve in Harju County, ca 53 km from the centre of Tallinn, and the control plot for *Tilia cordata* was in the park of Jäneda estate in Järva County, ca 57 km from Tallinn.

The following data were recorded for every tree:

tree species;
geographical coordinates;
presence or absence of selected lichen species (Table 1) on tree trunk at a height of 0.5–2.0 m;

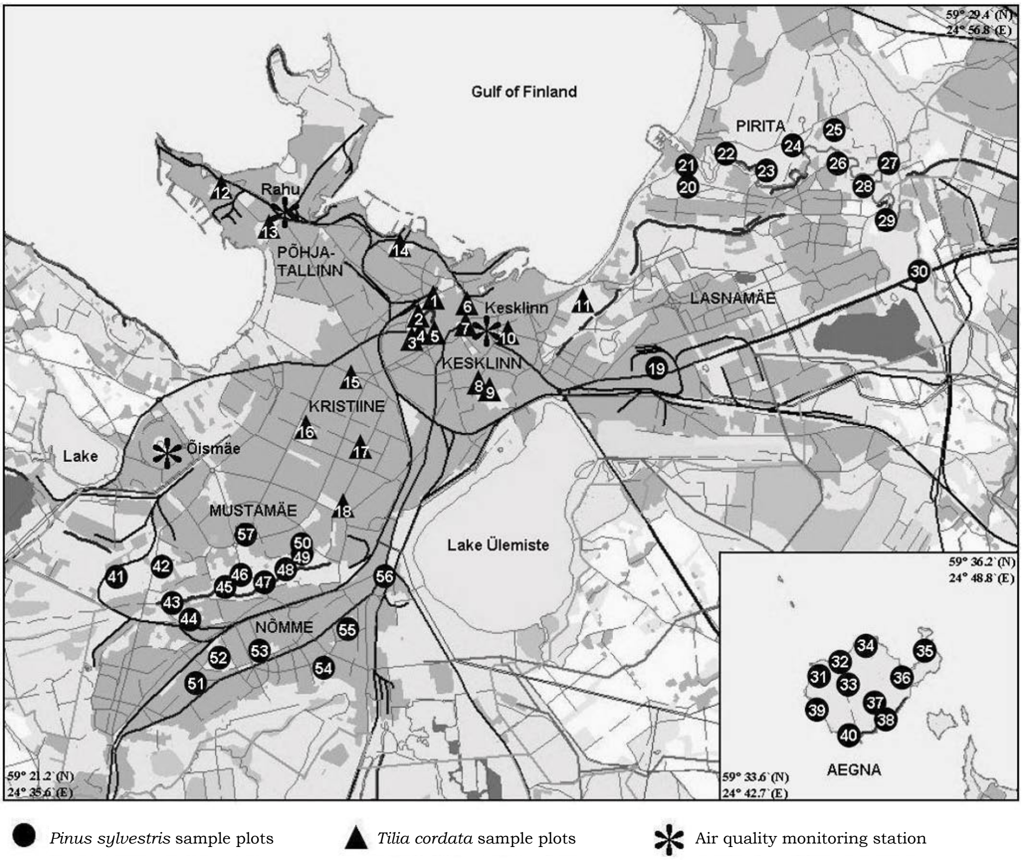

Fig. 2. Location of sample plots and air quality monitoring stations in Tallinn (the city map originates from Estonian Land Board).

circumference of tree trunk (cm);
bark pH;
distance from the nearest roadway (m).

Geographical coordinates were recorded with GPS receiver Garmin GPSmap 60C. Distance from the nearest road was found on the web map server of Estonian Land Board (Maa-amet, http://www.maaamet.ee).

For bark pH measurements two bark pieces were collected from every tree trunk at a height of 1.5 m (from opposite sides of the trunk in randomly selected places) and determined in the laboratory using the pH meter Consort C532; 0.5 ml of 0.1 M KCl water solution was dripped on the bark one minute before measurements as previously employed in lichenological studies (Farmer et al., 1990; Schmidt et al., 2001; Kricke, 2002).

Statistical analysis

Bark pH was expressed as the arithmetic mean of the two measured bark pieces. The mean bark pH, distance from the nearest road and geographical coordinates of a sample plot were found as arithmetic mean of five trees. The calculations of mean bark pH were based on mean H^+-ion concentrations.

Software applications R and STATISTICA 7 were used for the statistical analysis. As the barks of *Pinus sylvestris* and *Tilia cordata* have different qualities, sample plots were analysed separately according to the tree species. The control plots were ignored in the statistical analysis. Spearman's rank correlation coefficient was used for describing the relationships between variables. Logistic regression was used

Table 1. Frequency of recorded species on *Pinus sylvestris* and *Tilia cordata* in 57 sample plots in Tallinn (the species marked with * were recorded in control plots only)

Lichen species	Frequency on *Pinus sylvestris* (%)	Frequency on *Tilia cordata* (%)
Amandinea punctata (Hoffm.) Coppins & Scheid.	6	10
Anaptychia ciliaris (L.) Körb.	0	0*
Bryoria capillaris (Ach.) Brodo & D. Hawksw.	3	0
Bryoria fuscescens (Gyeln.) Brodo & D. Hawksw.	11	1
Calicium viride Pers.	0*	0*
Caloplaca holocarpa (Hoffm. ex Ach.) A. E. Wade	5	0
Candelariella vitellina(Hoffm.) Müll. Arg.	2	0
Candelariella xanthostigma (Ach.) Lettau	10	69
Chaenotheca chrysocephala (Turner ex Ach.) Th. Fr.	1	0
Chaenotheca ferruginea (Turner & Borrer) Mig.	7	0
Chrysothrix candelaris (L.) J. R. Laundon	0*	0
Evernia prunastri (L.) Ach.	3	24
Hypocenomyce scalaris (Ach.) M. Choisy	56	2
Hypogymnia physodes (L.) Nyl.	94	8
Imshaugia aleurites (Ach.) S. L. F. Meyer	2	0
Lecanora carpinea (L.) Vain.	1	11
Lecanora chlarotera Nyl.	0	3
Lecanora conizaeoides Nyl. ex Cromb.	3	4
Lecanora hagenii (Ach.) Ach.	6	6
Lecanora leptyrodes (Nyl.) Degel.	0	3
Lecanora pulicaris (Pers.) Ach.	29	10
Lecanora sambuci (Pers.) Nyl.	3	0
Lecanora symmicta (Ach.) Ach.	11	4
Lecanora varia (Hoffm.) Ach.	3	0
Lecidella elaeochroma (Ach.) M. Choisy	4	4
Lecidella euphorea (Flörke) Hertel	1	1
Lepraria spp.	73	57
Lobaria pulmonaria (L.) Hoffm.	0	0*
Melanelia exasperatula (Nyl.) Essl.	6	39
Melanelia subargentifera (Nyl.) Essl.	0	4
Melanelia subaurifera (Nyl.) Essl.	0	9
Parmelia sulcata Taylor	42	88
Parmeliopsis ambigua (Wulfen) Nyl.	31	1
Pertusaria amara (Ach.) Nyl.	0	0*
Phaeophyscia ciliata (Hoffm.) Moberg	0	0*

Table 1 (continued)

Lichen species	Frequency on *Pinus sylvestris* (%)	Frequency on *Tilia cordata* (%)
Phaeophyscia nigricans (Flörke) Moberg	1	3
Phaeophyscia orbicularis (Neck.) Moberg	6	56
Phlyctis argena (Spreng.) Flot.	0	2
Physcia adscendens (Fr.) H. Olivier	4	21
Physcia caesia (Hoffm.) Fürnr.	0	1
Physcia dubia (Hoffm.) Lettau	5	39
Physcia stellaris (L.) Nyl.	4	10
Physcia tenella (Scop.) DC.	13	82
Physconia distorta (With.) J. R. Laundon	1	3
Physconia enteroxantha (Nyl.) Poelt	1	12
Platismatia glauca (L.) W. L. Culb. & C. F. Culb.	14	1
Pseudevernia furfuracea (L.) Zopf	45	3
Ramalina farinacea (L.) Ach.	5	6
Ramalina fastigiata (Pers.) Ach.	0	0*
Ramalina fraxinea (L.) Ach.	0	8
Rinodina pyrina (Ach.) Arnold	10	4
Scoliciosporum chlorococcum (Stenh.) Vezda	54	68
Tuckermannopsis chlorophylla (Willd.) Hale	12	2
Usnea filipendula Stirt.	0*	0
Usnea hirta (L.) F. H . Wigg.	25	0
Usnea subfloridana Stirt.	1	0
Vulpicida pinastri (Scop.) J. -E. Mattsson & M. J. Lai	14	4
Xanthoria candelaria (L.) Th. Fr.	1	2
Xanthoria parietina (L.) Th. Fr.	13	38
Xanthoria polycarpa (Hoffm.) Th. Fr. ex Rieber	11	56

for describing the relationships between the presence of lichen species and bark pH; only those species which occurred in at least 5% of sample plots of the same tree species were considered for this.

RESULTS

Variation of bark pH and species richness of epiphytic lichens on *Pinus sylvestris*

Bark pH was measured on 195 specimens of *P. sylvestris* in Tallinn, its absolute value varying between 2.8 and 5.6 and the mean value of sample plots between 3.0 and 5.3 (Table 2). The five trees in the control plot varied between 2.8 and 3.2 (mean value 3.0).

The sample plots in which the bark pH was measured were situated at different distances from roadways. Bark pH of *P. sylvestris* was higher near roadways, the correlation being statistically significant (Fig. 3). There was also a significant correlation between bark pH and pH variance indicating that the dispersion of pH was bigger in sample plots with higher mean bark pH.

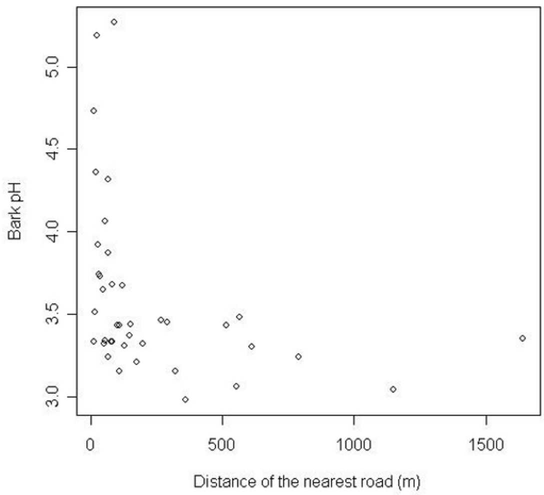

Fig. 3. Correlation between distance of the nearest road and bark pH in the sample plots with *Pinus sylvestris* (Rs = -0.59; N = 39; p = 0.000071).

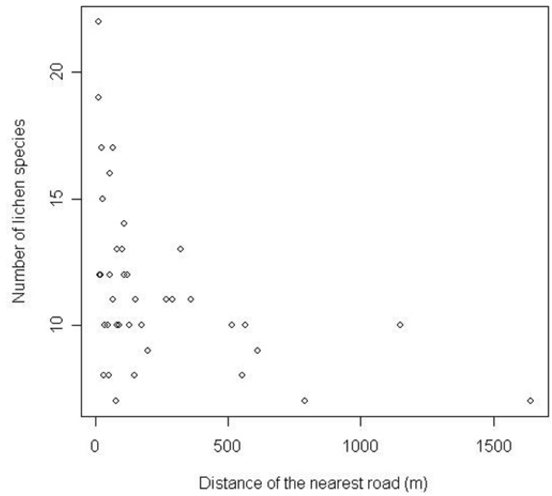

Fig. 4. Correlation between distance of the nearest road and number of lichen species in the sample plots with *Pinus sylvestris* (Rs = -0.50; N = 39; p = 0.0013).

Altogether 45 lichen species were recorded on the studied *P. sylvestris* in Tallinn, the most frequently recorded being *Hypogymnia physodes* (94%), *Lepraria* spp. (73%), *Hypocenomyce scalaris* (56%), *Scoliciosporum chlorococcum* (54%) and *Pseudevernia furfuracea* (45%) (Table 1). Seventeen lichen species were found in the control plot including some (*Calicium viride, Chrysothrix candelaris* and *Usnea filipendula*) not recorded in the sample plots in Tallinn.

Sample plots nos. 50, 24, 19 and 29 were the richest in epiphytic lichen species in Tallinn, having 22, 19, 17 and 17 species per plot, respectively (Fig. 2, Table 2). The number of species was higher near roadways (Fig. 4). The number of reported species in a sample plot was also positively correlated with bark pH values (Fig. 5).

The following species, according to the logistic regression analysis, preferred a lower bark pH on Scots Pine: *Bryoria fuscescens*, *Chaenotheca ferruginea*, *Hypocenomyce scalaris*, *Hypogymnia physodes*, *Lepraria* spp., *Parmeliopsis ambigua*, *Platismatia glauca*, *Pseudevernia furfuracea*, *Tuckermannopsis chlorophylla*, *Usnea hirta* and *Vulpicida pinastri* (Fig. 6). Different species had remarkable decline of occurrence probability at different values of bark pH, e.g. the occurrence probability of *Bryoria fuscescens, Chaenotheca ferruginea, Tuckermannopsis chlorophylla and*

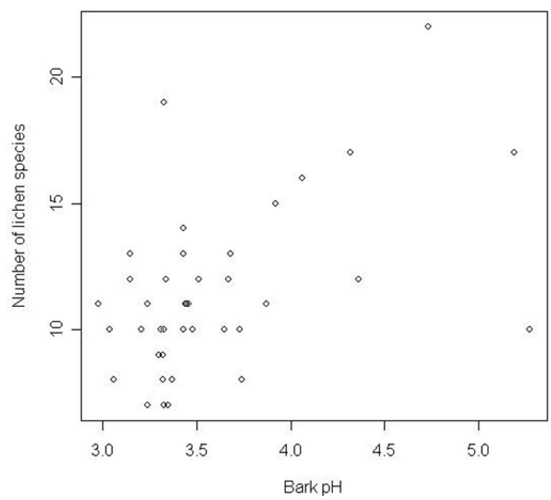

Fig. 5. Correlation between bark pH and number of lichen species in the sample plots with *Pinus sylvestris* (Rs = 0.42; N = 39; p = 0.0086).

Usnea hirta was less than 10% at bark pH over 4.0 while the occurrence probability of *Hypogymnia physodes* declined from almost 100% to 20% at a bark pH of 4.0–5.5.

The following species, according to the same analysis, preferred a higher bark pH on Scots Pines: *Caloplaca holocarpa*, *Candelariella* *xanthostigma*, *Lecanora hagenii*, *L. symmicta*, *Melanelia exasperatula*, *Phaeophyscia orbicularis*, *Physcia dubia*, *P. tenella*, *Rinodina pyrina*, *Xanthoria parietina* and *X. polycarpa* (Fig. 6). Most of these taxa had a steep rise in occurrence probability at a bark pH of 4.5–5.5.

Variation of bark pH and species richness of epiphytic lichens on *Tilia cordata*

Bark pH was measured on 90 specimens of *T. cordata* in Tallinn, its absolute value varying between 3.8 and 5.7, with a mean value for the sample plots between 4.1 and 5.5 (Table 2). The bark pH of the five trees in the control plot (the park of Jäneda estate) varied between 4.0 and 5.0 (mean value 4.4).

No effects of car traffic on bark pH of *T. cordata* were discovered, the statistical correlation between the distance from the nearest roadway and the acidity of the bark being non-significant (Fig. 7).

Altogether 42 lichen species were recorded on the studied trees of *T. cordata* in Tallinn, the most frequently recorded species on them being *Parmelia sulcata* (88%), *Physcia tenella* (82%), *Candelariella xanthostigma* (69%), *Scoliciosporum chlorococcum* (68%) and *Lepraria* spp. (57%) (Table 1). Twenty six lichen species were found in the control plot, including *Anaptychia ciliaris*, *Calicium viride, Lobaria pulmonaria, Pertusaria amara, Phaeophyscia ciliata* and *Ramalina fastigiata*, which were not recorded in the sample plots in Tallinn.

Sample plots nos. 11, 17 and 8 were the richest in epiphytic lichen species, having 23, 20 and 18 species per plot, respectively (Fig. 2, Table 2). The number of species was smaller near motorways (Fig. 8) and the number of reported species in a sample plot was not correlated with the bark pH values (Fig. 9).

The following species, according to the logistic regression analysis, preferred a higher bark pH on Small-leaved Lime: *Lecanora carpinea*, *Physcia stellaris*, *Ramalina fraxinea* and *Xanthoria parietina*, and only *Lepraria* spp. preferred a lower bark pH on this phorophyte (Fig. 10).

DISCUSSION

Several studies on lichens as indicators of air pollution have been carried out in Tallinn since the 1970s (Martin, 1984; Sander & Lensment, 1996; Lensment, 2001). According to these studies, the zones of strong and moderate acidic air pollution occurred in the northern and central parts of Tallinn while the distribution of eutrophication/strong dust pollution was disjunct having distinct polluted areas sparsely over the city.

Air pollution has decreased in Tallinn during the last decade due to a reduction in emissions from local sources, e.g. manufacturing plants and boilerhouses. However, emissions from traffic are increasing and are currently the cause of ca 90% of air pollution in Tallinn (Tallinna Sotsiaal- ja Tervishoiuamet, http://tallinn.andmevara.ee). To assess air pollution in Tallinn, three fully automatic monitoring stations permanently measure the following substances: CO, NO_2, O_3, SO_2 and PM_{10} (fine particles with <10 µm diam.). The monitoring station 'Kesklinn' is situated in the central part of Tallinn where the intensity of motor traffic is the highest; the monitoring station 'Rahu' is situated in the northern part of the city, on the peninsula of Kopli, which is the main industrial area; the station 'Õismäe' is located in the western part of the town, in a large residential district (Fig. 2).

Measurements from these monitoring stations show that (a) air quality is mainly influenced by the effects of motor traffic as the concentrations of CO, NO_2, SO_2 and PM_{10} are highest during working days, especially the rush hours; (b) the concentrations of SO_2 and CO have considerably decreased during the last decade (Figs 11 & 12); (c) concentration of NO_2 is continually rather high (e.g. 13–32 $\mu g/m^3$ in 2006), considering that according to the law the limit value for mean annual concentration is 40 $\mu g/m^3$ (Fig 13); (d) there is a very high dust pollution in the city (Fig. 14), e.g. in 2006, the 24h limit value of 50 $\mu g/m^3$ was exceeded in 42 occasions in the station 'Kesklinn' (Eesti Keskkonnauuringute Keskus, 2007).

Due to the major effect of motor traffic on the air quality in Tallinn, the distance of sample plots from the nearest roadway was used as one of the variables, for which both bark pH and species richness of epiphytic lichens were analysed. These relationships varied according to the different phorophytes: the bark pH of Scots Pine was clearly higher near roads (correlation statistically significant) while there was no such correlation in the case of Small-leaved Lime. This

Table 2. Number of indicator species and mean bark pH in sample plots in Tallinn and control areas

Number of sample plot	Name of sample plot	Tree species	Number of lichen species	Mean bark pH
1	Park of Square of Towers (Tornide väljaku park)	*Tilia cordata*	16	4.9
2	Toompark	*Tilia cordata*	17	4.4
3	Falgi Park	*Tilia cordata*	11	4.5
4	Hirvepark	*Tilia cordata*	14	4.7
5	Harjumäe Park	*Tilia cordata*	13	4.9
6	Park of Garden of Kanut (Kanuti aia park)	*Tilia cordata*	14	4.8
7	Tammsaare Park	*Tilia cordata*	13	5.1
8	Tiigiveski Park	*Tilia cordata*	18	4.8
9	Poolamägi	*Tilia cordata*	16	4.8
10	Police Garden (Politseiaed)	*Tilia cordata*	15	4.9
11	Kadrioru Park	*Tilia cordata*	23	4.7
12	Süsta Park	*Tilia cordata*	10	4.5
13	Kopli Park	*Tilia cordata*	17	4.5
14	Kalamaja Park	*Tilia cordata*	16	4.1
15	Cederhilmi Park	*Tilia cordata*	17	4.9
16	Löwenruh Park	*Tilia cordata*	17	4.6
17	Räägu Park	*Tilia cordata*	20	5.2
18	Park of Road of Nõmme (Nõmme tee park)	*Tilia cordata*	16	5.5
19	Jüriöö Park	*Pinus sylvestris*	17	5.2
20	Lillepi Park	*Pinus sylvestris*	7	3.3
21	Pirita Nature Reserve No. 1	*Pinus sylvestris*	12	4.4
22	Pirita Nature Reserve No. 2	*Pinus sylvestris*	11	3.5
23	Pirita Nature Reserve No. 3	*Pinus sylvestris*	11	3.5
24	Pirita Nature Reserve No. 4	*Pinus sylvestris*	19	3.3
25	Pirita Nature Reserve No. 5	*Pinus sylvestris*	10	3.3
26	Pirita Nature Reserve No. 6	*Pinus sylvestris*	8	3.4
27	Pirita Nature Reserve No. 7	*Pinus sylvestris*	10	3.7
28	Pirita Nature Reserve No. 8	*Pinus sylvestris*	12	3.5
29	Pirita Nature Reserve No. 9	*Pinus sylvestris*	17	4.3
30	Pirita Nature Reserve No. 10	*Pinus sylvestris*	10	5.3
31	Aegna Nature Reserve No. 1	*Pinus sylvestris*	11	3.0
32	Aegna Nature Reserve No. 2	*Pinus sylvestris*	13	3.2
33	Aegna Nature Reserve No. 3	*Pinus sylvestris*	12	3.2
34	Aegna Nature Reserve No. 4	*Pinus sylvestris*	7	3.2
35	Aegna Nature Reserve No. 5	*Pinus sylvestris*	7	3.3
36	Aegna Nature Reserve No. 6	*Pinus sylvestris*	10	3.0
37	Aegna Nature Reserve No. 7	*Pinus sylvestris*	8	3.1

Table 2. (continued)

Number of sample plot	Name of sample plot	Tree species	Number of lichen species	Mean bark pH
38	Aegna Nature Reserve No. 8	*Pinus sylvestris*	9	3.3
39	Aegna Nature Reserve No. 9	*Pinus sylvestris*	13	3.4
40	Aegna Nature Reserve No. 10	*Pinus sylvestris*	10	3.5
41	Nõmme-Mustamäe Nature Reserve No. 1	*Pinus sylvestris*	10	3.4
42	Nõmme-Mustamäe Nature Reserve No. 2	*Pinus sylvestris*	11	3.9
43	Nõmme-Mustamäe Nature Reserve No. 3	*Pinus sylvestris*	10	3.2
44	Nõmme-Mustamäe Nature Reserve No. 4	*Pinus sylvestris*	8	3.7
45	Nõmme-Mustamäe Nature Reserve No. 5	*Pinus sylvestris*	9	3.3
46	Nõmme-Mustamäe Nature Reserve No. 6	*Pinus sylvestris*	11	3.2
47	Nõmme-Mustamäe Nature Reserve No. 7	*Pinus sylvestris*	15	3.9
48	Nõmme-Mustamäe Nature Reserve No. 8	*Pinus sylvestris*	11	3.4
49	Nõmme-Mustamäe Nature Reserve No. 9	*Pinus sylvestris*	10	3.7
50	Nõmme-Mustamäe Nature Reserve No. 10	*Pinus sylvestris*	22	4.7
51	Park-forest of Jannsen	*Pinus sylvestris*	12	3.3
52	Sanatooriumi Park	*Pinus sylvestris*	10	3.3
53	Park-forest of Vabaduse	*Pinus sylvestris*	8	3.3
54	Park-forest of Valdeku	*Pinus sylvestris*	14	3.4
55	Park-forest of Võidu	*Pinus sylvestris*	12	3.7
56	Oravamäe Park	*Pinus sylvestris*	16	4.1
57	Männi Park	*Pinus sylvestris*	13	3.7
58	Control plot (Kõrvemaa Nature Reserve)	*Pinus sylvestris*	17	3.0
59	Control plot (Jäneda Park)	*Tilia cordata*	26	4.4

can be explained by the naturally different bark qualities of these two phorophytes.

The bark of *Pinus sylvestris* is normally acid (mean pH in control plot 3.0) and is modified to subneutral (up to 5.7) near roadways, evidently due to the dust pollution which is a side effect of motor traffic, caused by burning of fuel, wearing out of tires and asphalt, and sanding of roads in winter (Eesti Keskkonnauuringute Keskus, 2007). The latter procedure is the reason why streets of Tallinn are extremely dusty in spring after melting of snow (Tallinna Sotsiaal- ja Tervishoiuamet, http://tallinn.andmevara.ee). Traffic also causes air turbulence that can re-entrain road and soil dust near roadways (WHO, 2006).

The bark pH of *Tilia cordata* is normally subneutral (mean pH in control plot 4.6) and, therefore, alkaline dust does not change its value significantly. According to the measurements of monitoring stations, concentrations of SO_2 have been highest in the northern part of Tallinn during recent years (Fig 11), and concentrations of NO_2 are continuously high in the centre of the city (Fig. 13). Atmospheric oxidation of NO_x and SO_2 leads to the formation of acids. Due to the concurrent impact of both acid and alkaline pollution, the effects of alkaline dust on the bark pH may be less evident in areas where plots with *T. cordata* were located (in the central and northern parts of the city).

Species richness of lichens is one of widely used measures to estimate air pollution (van Haluwyn & van Herk, 2002). The number of epiphytic lichen species recorded on *Tilia cordata* decreased closer to the roadways in Tallinn,

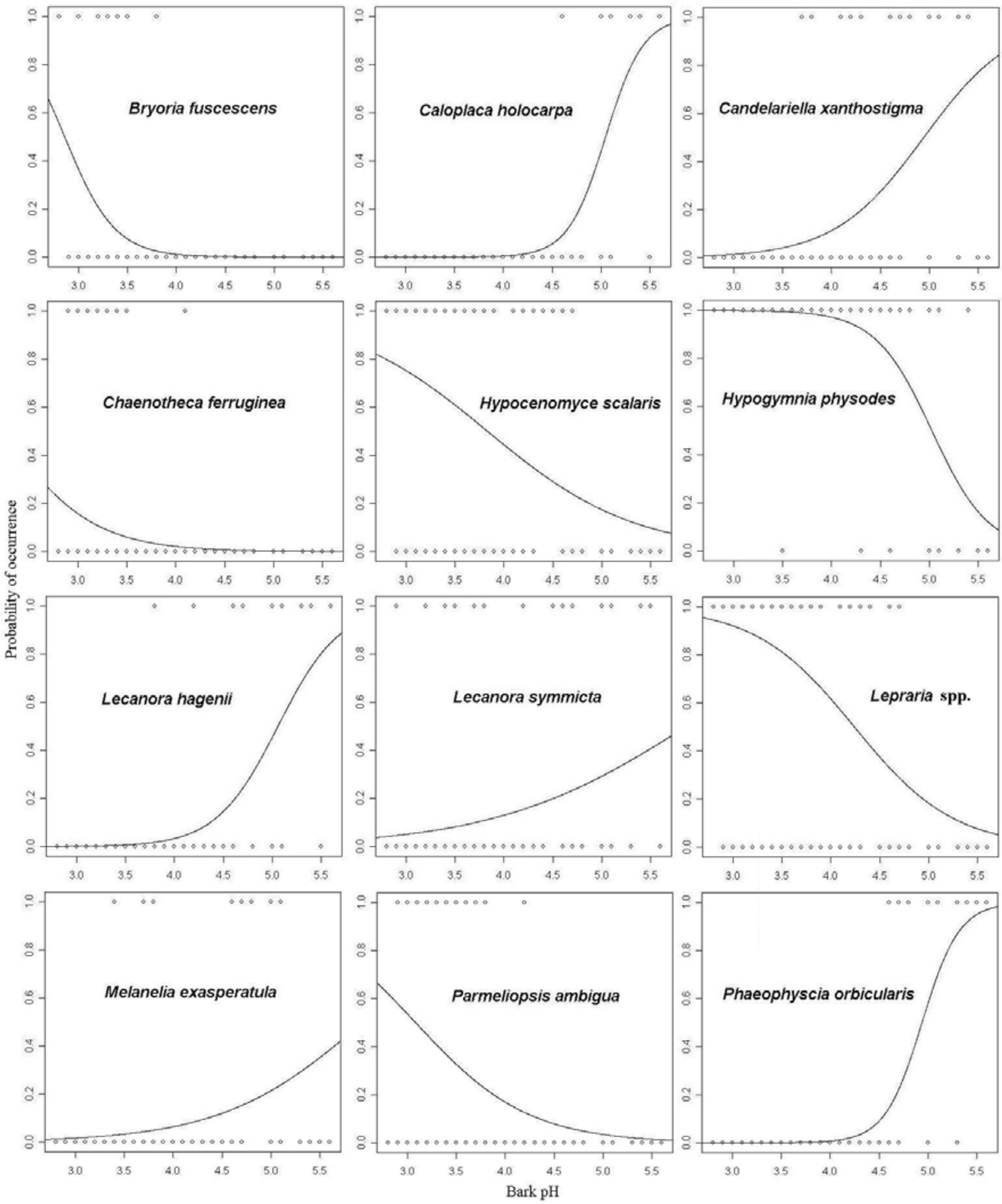

Fig. 6. Actual occurrence (marked with dots) and probability curves of lichen species by different values of bark pH on *Pinus sylvestris*.

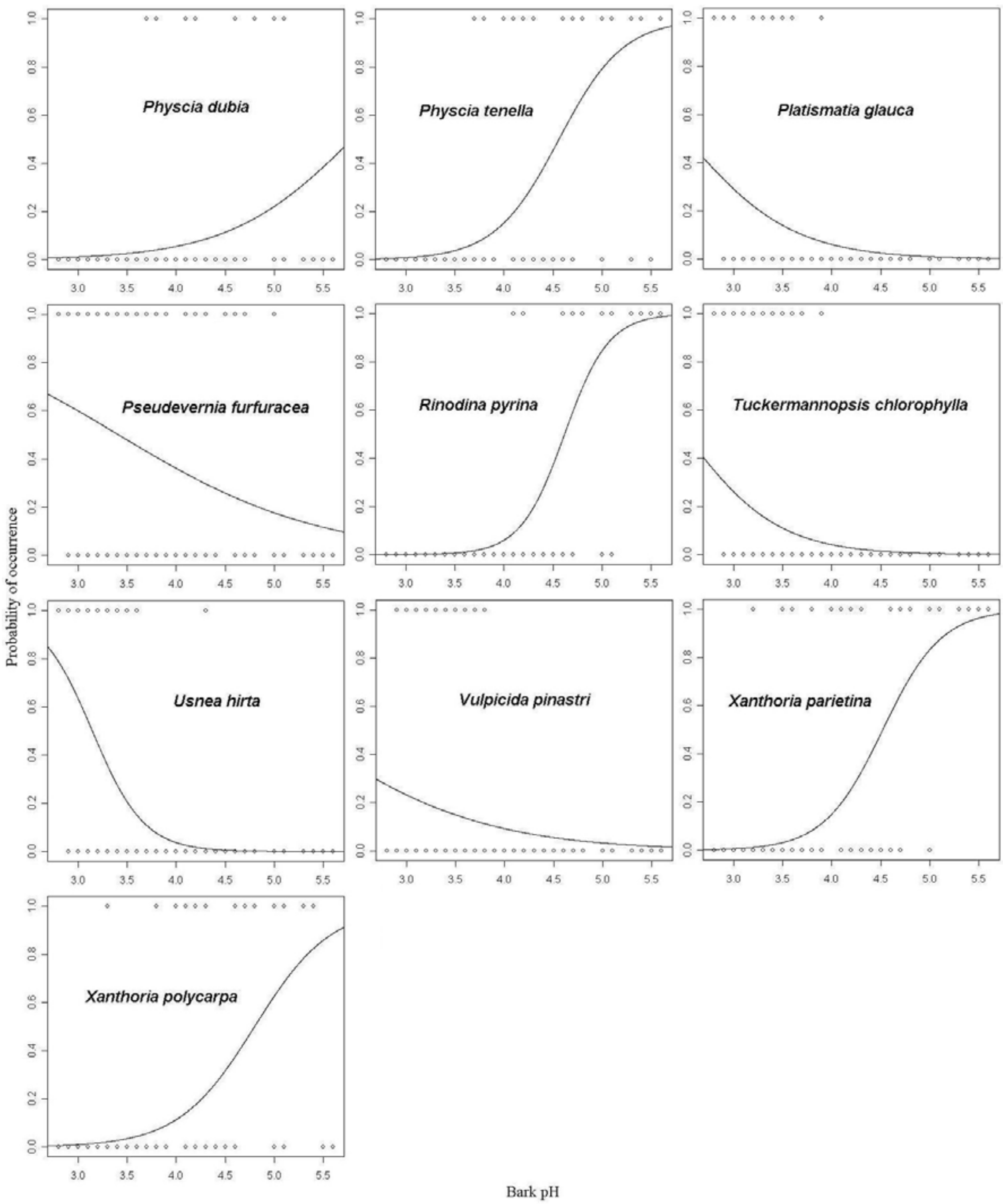

Fig. 6. (continued)

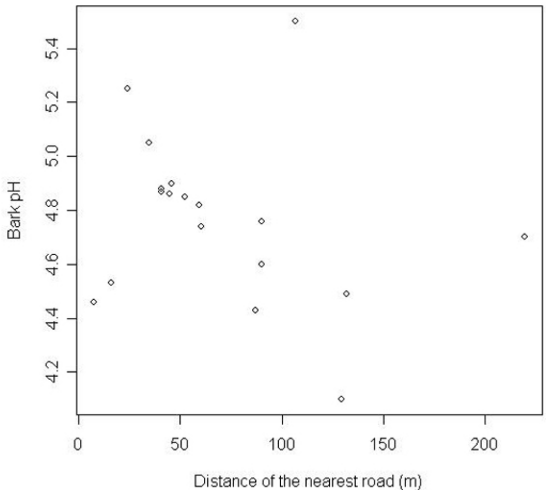

Fig. 7. Correlation between distance of the nearest road and bark pH in the sample plots with *Tilia cordata* (Rs = -0.31; N = 18; p = 0.21).

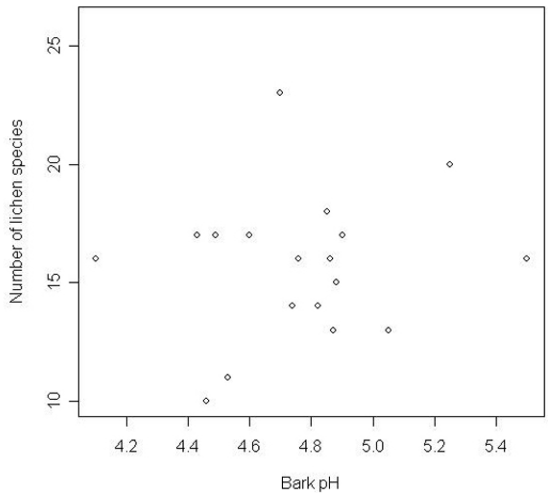

Fig. 9. Correlation between bark pH and number of lichen species in the sample plots with *Tilia cordata* (Rs = 0.05; N = 18; p = 0.85).

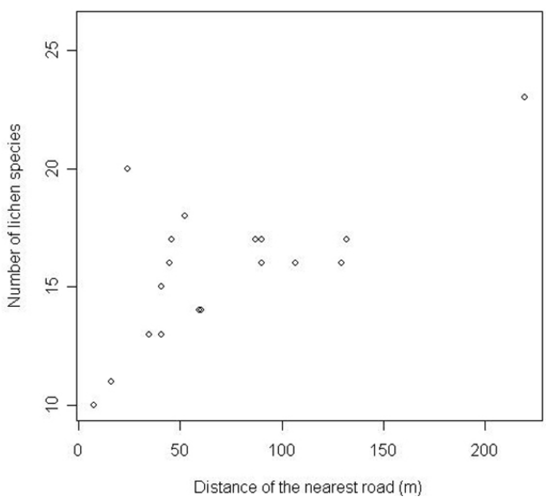

Fig. 8. Correlation between distance of the nearest road and number of lichen species in the sample plots with *Tilia cordata* (Rs = 0.54; N = 18; p = 0.021).

demonstrating the change usually described in areas with acidic pollution. Species which are tolerant to NO_x (Davies et al., 2007), e.g. *Lepraria* spp., *Parmelia sulcata, Phaeophyscia orbicularis, Physcia adscendens, P. tenella, Scoliciosporum chlorococcum, Xanthoria parietina* and *X. polycarpa*, dominate on *Tilia cordata*. Several of them are also considered nitrophytic (van Herk, 2002), e.g. *Candelariella xanthostigma, Phaeophyscia orbicularis, Physcia dubia, P. tenella, Xanthoria parietina, X. polycarpa.* The species richness and composition on *T. cordata* was not significantly influenced by the bark pH; according to our analysis, the presence of only a few species depended on bark pH (Fig. 10).

In the case of *Pinus sylvestris*, however, the number of recorded lichen species was larger near roadways. This is mainly due to the change of bark pH from acidic to subneutral which favours the addition of neutrophytic/nitrophytic species (e.g. *Caloplaca holocarpa, Candelariella xanthostigma, Lecanora hagenii, Physcia tenella*). At the same time, some species preferring a lower pH (e.g. *Hypocenomyce scalaris, Hypogymnia physodes, Pseudevernia furfuracea*) had also survived in sample plots with a relatively high mean bark pH. In these sample plots the pH variance was higher, indicating that the effects of alkaline dust pollution are not evenly distributed along the tree trunk. Therefore, some suitable microsites for acidophytic species might remain on such dust-polluted trees. The overlap of species with different air quality requirements in areas with changing air quality have also been observed on slightly acidic *Quercus* trees in London (Larsen, 2007). In general, the most frequent species recorded on *Pinus sylvestris* in Tallinn (Table 1) represent acidophytes, which dominate in suburbs and Aegna Island. Similar

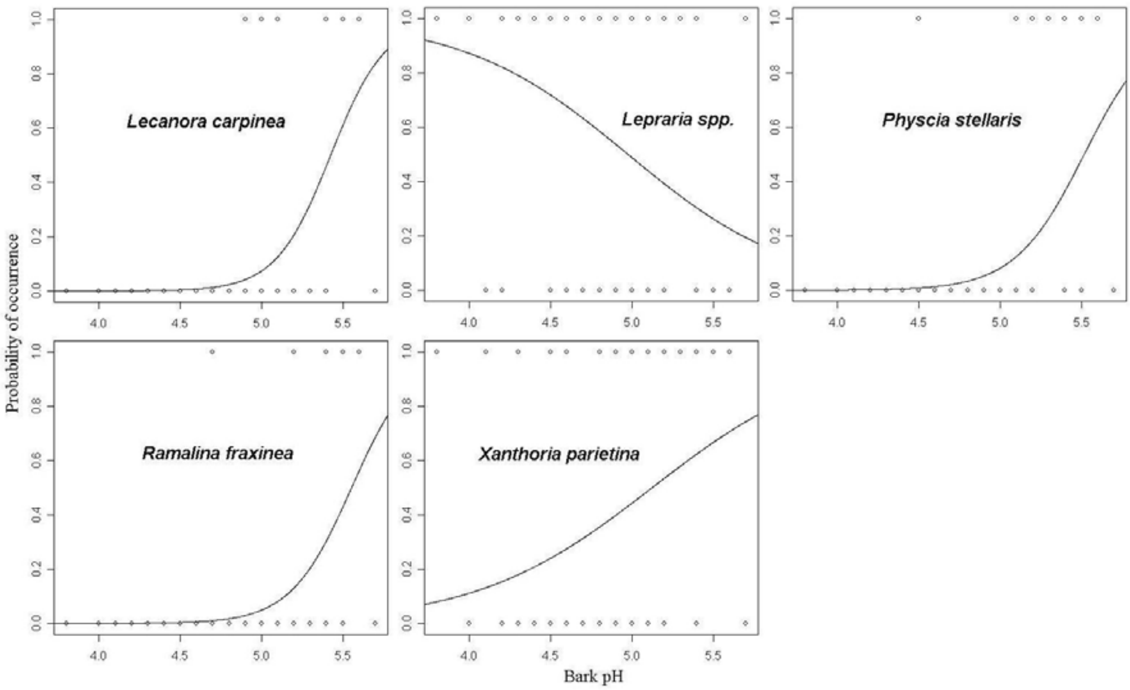

Fig. 10. Actual occurrence (marked with dots) and probability curves of lichen species by different values of bark pH on *Tilia cordata*.

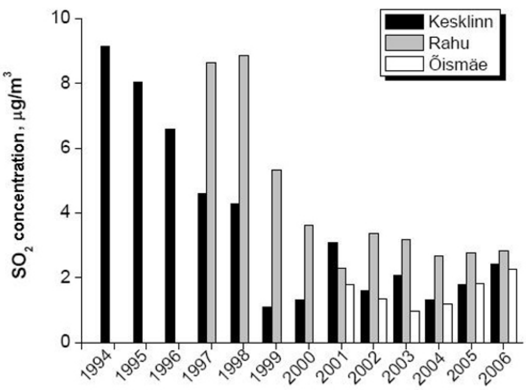

Fig. 11. Annual mean concentrations of SO_2 in Tallinn (according to Eesti Keskkonnauuringute Keskus, 2007).

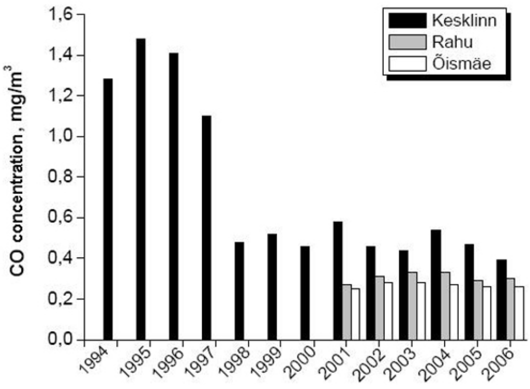

Fig. 12. Annual mean concentrations of CO in Tallinn (according to Eesti Keskkonnauuringute Keskus, 2007).

patterns where nitrophytic species prevail in the city and acidophytes in outer region have also been noticed in London (Larsen et al., 2007).

In conclusion, the influence of alkaline dust pollution on epiphytic lichen composition of *Pinus sylvestris* is clearly observed in Tallinn today. Besides dust, nitrogen oxides are important pollutants too, but the effects of acidic air pollution are less evident now compared to the previous studies. Factors determining lichen

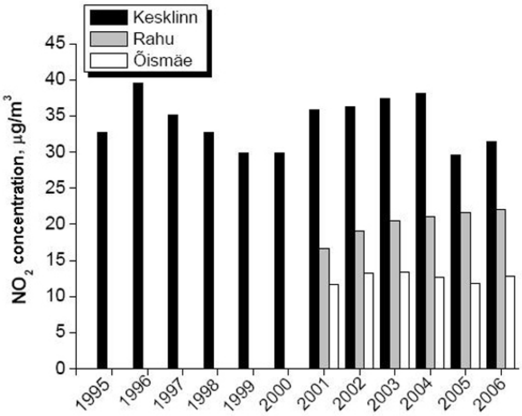

Fig. 13. Annual mean concentrations of NO_2 in Tallinn (according to Eesti Keskkonnauuringute Keskus, 2007).

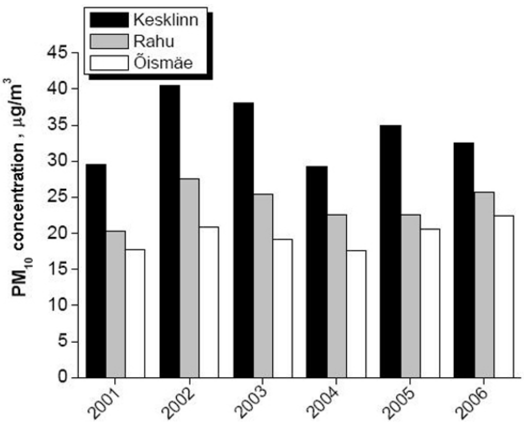

Fig. 14. Annual mean concentrations of PM_{10} in Tallinn (according to Eesti Keskkonnauuringute Keskus, 2007).

species composition on *Tilia cordata* remain unclear while the most frequent species on this phorophyte are considered nitrophytic and/or tolerant to NO_x.

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