

## Effects of climatic factors and air pollution on damage of London plane (*Platanus hispanica* Mill.)

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### Abstract

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London plane (*Platanus hispanica* Mill.) is considered as very tolerant to pollution and other stresses and in the Czech Republic it has been unaffected by important pathogens until now. However, in recent years the health status of London plane has been significantly deteriorating. During an 11-year survey it was found out that development of London plane damage was characterized by important fluctuations. Minimum value of population damage was 3.6% and maximum 97.5%. The health status of London plane was negatively influenced by long-term precipitation totals, higher total precipitation in May, low average air temperatures in January and May and higher NO<sub>x</sub> concentrations in the vegetation season. Using the multiple regression analysis a highly significant regression model was obtained, wherein the average air temperatures in January and May explain together 84% variability of London plane population damage. During the period of the highest damage, planes were moreover affected by the pathogen *Apiognomonia veneta* (Sacc. et Spegg.) Höhn.

**Keywords:** *Platanus hispanica*; health status; air pollutants; air temperature; precipitation; anthracnose

The population of London plane, a very popular urban and periurban tree in Europe, exhibits almost the northern border of its cultivation in Central Europe in the Czech Republic (KRÜSSMANN 1979). The London plane (*Platanus hispanica* Mill., synonym *P. orientalis* L. var. *acerifolia* Ait., *P. acerifolia* (Ait.) Willd., *P. hybrida* Brot., *P. acerifolia* var. *hispanica* (Mill.) Bean) is a hybrid of the Oriental plane (*P. orientalis* L.) with the American plane (*P. occidentalis* L.) (SLAVÍK, HEJNÝ 1997). London plane trees are extensively cultivated pre-eminently in the most temperate latitudes, as ornamental trees in parks or gardens and often used in linear plantings along streets in cities throughout the temperate regions of the world. In the Czech Republic the London plane has been grown since 1835 (SVOBODA 1981).

London plane trees, considered tolerant to climatic factors, atmospheric pollution, soil compaction and other stresses, have not shown important health problems in the Czech Republic. Until recently, they have been affected neither by the important dangerous pathogen *Ceratocystis fimbriata* Ell. et Halst. nor by critical spread of the insect *Corythucha ciliata* Say common in warmer regions of Europe (VIGOUROUX 1986; PANCONESI 1981; PANCONESI 1999; SINCLAIR, LYON 2005; STEHLÍK 1997; ŠEFROVÁ, LAŠTŮVKA 2005). The most widely distributed disease of plane trees – anthracnose caused by *A. veneta* has affected London plane trees in the Prague area only occasionally and to different degree.

Yet, in recent years the health status of London plane has been significantly deteriorating in the

Table 1. Development of climatic factors (temperature, precipitation) in Prague during 1990–2002 period ( $P_s$  – ratio between vegetation season and annual precipitation, in %)

Year	Average air temperature and precipitation				
	Temperature (°C)		Precipitation (mm)		$P_s$
	April to September	annual	April to September	annual	
1990	15.3	10.1	212	378	56.1
1991	14.8	8.7	263	389	67.6
1992	16.8	10.2	274	446	61.4
1993	15.6	9.1	362	541	66.9
1994	16.4	10.5	318	469	67.8
1995	15.5	9.5	409	541	75.6
1996	14.4	7.7	426	527	80.8
1997	15.3	9.2	313	478	65.5
1998	16.0	10.0	289	447	64.6
1999	16.5	10.1	259	405	63.9
2000	16.6	10.7	223	447	49.9
2001	15.2	9.3	418	599	69.8
2002	16.3	10.2	497	739	67.2

Czech Republic. Discussions around possible influence of frequent unfavourable climatic fluctuations and other stressors on the health status of trees during the past years prompted our long-term monitoring of health status and damage of various tree species including also London plane (GREGOROVÁ et al. 2006). The major goal of this monitoring (1992–2002) was to identify the crucial factors responsible for this deterioration.

## MATERIALS AND METHODS

Monitoring of the London plane trees health status was carried out within the Prague area (Central Bohemia) in the 1992–2002 period. Due to great variability of altitude (177 m a.s.l. to 399 m a.s.l.), microclimatic and habitat conditions within studied area, the localities were selected to represent all main habitat types. The Prague area represents a slightly moist zone with characteristic winter period, with certain characteristics of transition to slightly dry zone with hot summers and cold winters (QUITT 1971; TOLASZ et al. 2007). Table 1

Table 2. Development of air pollutions (nitrogen oxides, ozone) in Prague during 1992–2002 period (in  $\mu\text{g}/\text{m}^3$ )

Year	Average concentration of $\text{NO}_x$ and $\text{O}_3$ ( $\mu\text{g}/\text{m}^3$ )			
	$\text{NO}_x$		$\text{O}_3$	
	May to September	annual	May to September	annual
1992	45	53		
1993	44	64	54	42
1994	50	61	69	47
1995	57	62	52	37
1996	48	73	51	40
1997	61	69	57	36
1998	51	73	61	44
1999	54	68	60	45
2000	55	63	59	46
2001	49	70	48	35
2002	52	66	52	37

gives an overview of meteorological and Table 2 of air-polluting conditions during the studied period.

The research was focused on London plane trees growing in public gardens, parks or in linear plantings along streets. In total, 84 London plane trees were evaluated in the 5 representative localities in the Prague area within our 11-year survey. The age of studied trees ranged between 20 and 100 years, most of them were about 60 years old.

The health status of trees was assessed according to the percentage of crown defoliation (Table 3) and to percentage of damaged trees (trees with crown defoliation) in the London plane population (GREGOROVÁ et al. 2006). Defoliation is the most standard criterion for the health evaluation of

Table 3. Description of defoliation classes (class number, degree of defoliation, percentage of defoliation)

Defoliation class	Degree of defoliation	Percentage of defoliation
(0)	health tree	0
1	slight	> 0–25
2	moderate	> 25–50
3	severe	> 50–75
4	critical	> 75
(5)	dead tree	100

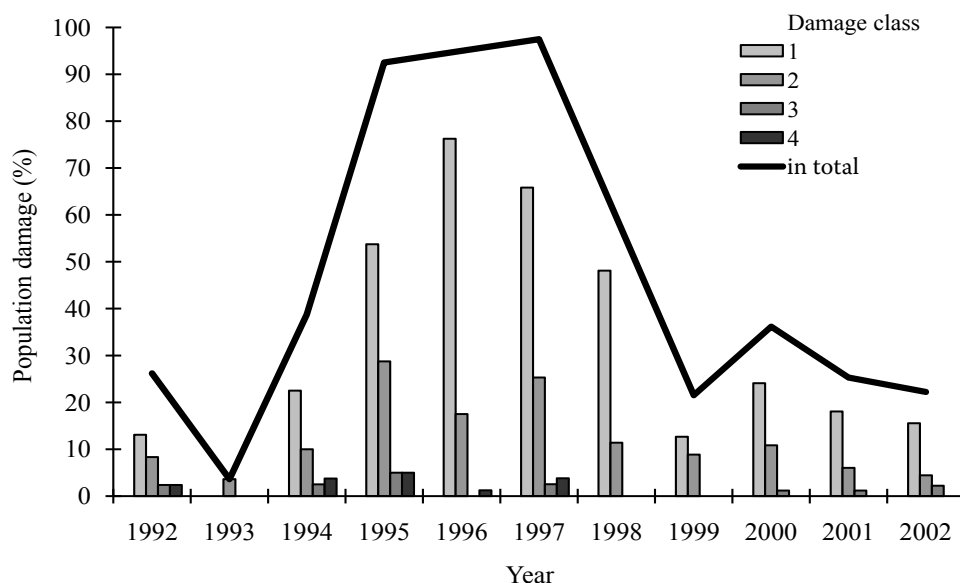


Fig. 1. Damage of *Platanus hispanica* population (rate of population in particular damage classes and total population damage) during 1992–2002

woods (LORENZ et al. 1998; UN/ECE 1998). Defoliation is defined as the relative loss of assimilative apparatus in crown in comparison with a healthy tree. Crown defoliation is an unspecific symptom of tree damage.

Correlation between various environmental factors and trees damage was examined by means of correlation analysis and multiple regression analysis. From the results obtained only significant correlations between environmental factors and damage are presented. The following factors were

tested: total monthly precipitation, total June–September precipitation and total precipitation of the preceding 2 years, the number of days with snow cover each winter month during all winter period (December–February, or up to March), average monthly air temperature, average June–September and December–February air temperature as well as average air temperature of the preceding 2 years. Simultaneously, the number of frosty days (the number of days with temperature  $\leq 0^{\circ}\text{C}$ ) during each winter month and during the whole winter pe-

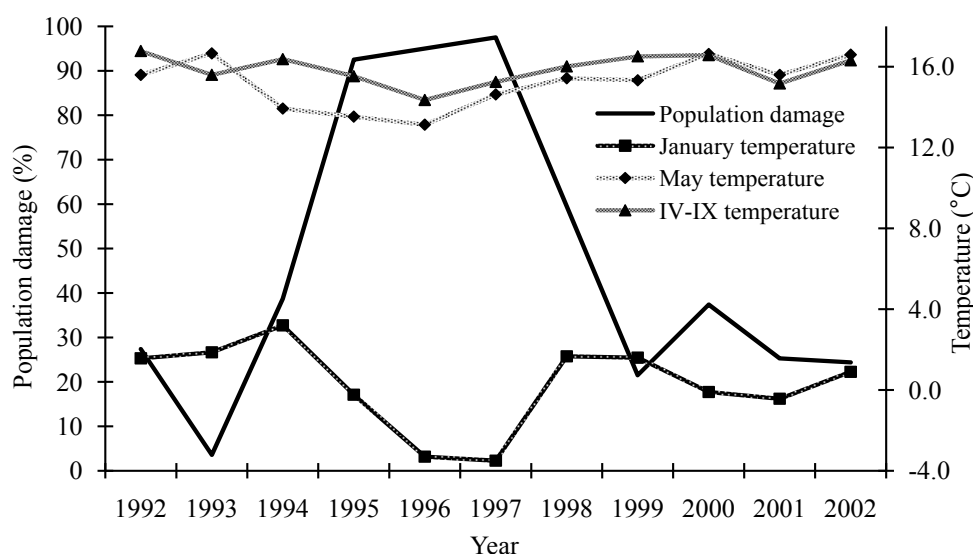


Fig. 2. Development of *Platanus hispanica* damage and average January, May and April–September temperatures during 1992–2002

riod (December–March) and likewise the number of days with temperature  $\leq -5^{\circ}\text{C}$  and increase of high temperature (the number days with temperature  $\geq +5^{\circ}\text{C}$ ) were tested. We tested also air pollutants: nitrogen oxides  $\text{NO}_x$  and ozone  $\text{O}_3$ . The nitrogen oxides are represented collectively as  $\text{NO}_x$  (ROWLAND et al. 1985; ANYANWU 1999).

The data of climatic factors and air pollutants (nitrogen oxides  $\text{NO}_x$ , ozone  $\text{O}_3$ ) in Prague were provided by the Czech Hydrometeorological Institute.

The statistical evaluation was performed in Statistica 8.0 (Statsoft Inc., Tulsa, USA).

## RESULTS

### Damage development

The 11-year survey (1992–2002) shows that the health status development of London plane trees was characterized by extreme fluctuations, in particular as to seasons (Fig. 1). Minimum value of population damage was 3.6% (in 1993) and maximum 97.5% (in 1997). The average value of damage reached 47.5% (SE = 10.1 %). The maximum of damaged trees was in the 1<sup>st</sup> damage class (up to 25% of defoliation). The highest damage of trees was observed during the period 1995–1997, when more than 90% of plane population was damaged.

The deterioration of the health status of London planes was characterized not only by an increasing percentage of damaged trees (trees with crown defoliation) in the plane population, but also by an increasing percentage of crown defoliation (Fig. 1, Table 3).

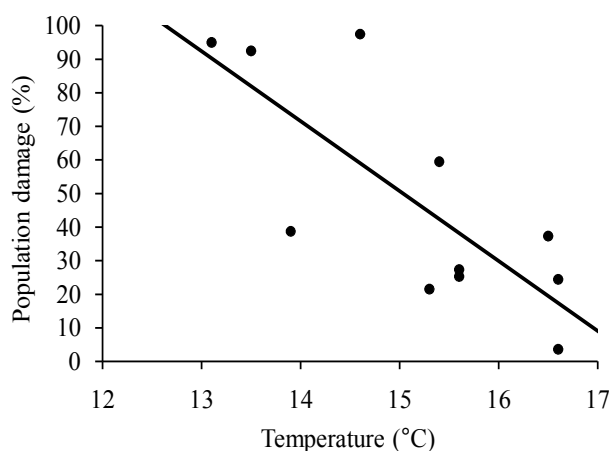


Fig. 3. Regression of *Platanus hispanica* damage to average May air temperature (1992–2002)

### Influence of the environment

Climatic factors were the most important environmental influences on the health status of London plane trees during the period studied (1992–2002), both in vegetation as well as in dormancy periods. These factors are also important for development and spreading of the most frequent plane pathogen – the fungus *A. veneta*.

Highly significant regression models ( $P < 0.01$ , Table 4) exist between damaging process of London plane trees and some of climatic factors. In a simplified way the average air temperatures in January and May explain together 84% (January 24.8%, May 59.2%) variability of population damage. Furthermore, it was found out that several environmental factors significantly correlated to plane damage.

The analyses show, that the health status of plane population was significantly correlated ( $P \leq 0.01$ ) to development of three climatic factors – average January air temperature, average May air temperature and total precipitation of the preceding 2 years (Table 4).

Damage of planes increased significantly with decreasing average January air temperature (Fig. 2). In the period of 1995–1997, when average January air temperature reached the lowest value ( $-3^{\circ}\text{C}$  up to  $-4^{\circ}\text{C}$ ) and when the highest number of frost days was observed, up to 97.5% of the plane population was damaged. With increasing average January air temperature ( $-0.5^{\circ}\text{C}$  up to  $+3^{\circ}\text{C}$ ) damage of planes decreased rapidly (Fig. 2).

The correlation of *Platanus hispanica* damage to average May air temperature is also significant (Table 4). The regression diagram (Fig. 3) shows that a higher average May air temperature is positively correlated with the health status of planes. If temperatures reached  $+15.0^{\circ}\text{C}$  up to  $+17.0^{\circ}\text{C}$ , plane damage was observed mostly in 20–25% of population, while lower May temperatures around  $+13^{\circ}\text{C}$  showed a positive correlation with a high population damage (up to more than 90%).

The amount of long-term precipitation is significantly related to the health status of planes (Table 4). The regression diagram (Fig. 4) shows that foregoing 2-year precipitation total is in a negative correlation with the health status of planes. In the case when foregoing 2-year precipitation total was over 500 mm, damage of plane trees could be seen in almost whole population (Fig. 5).

Total May and autumn (October, November) precipitation is significantly related to the health status of planes, too. Whereas a higher total May precipita-

Table 4. Correlation between damage of *Platanus hispanica* population and average May and January temperature, total 2-year precipitation and NO<sub>x</sub> concentration in May–September

Environmental factor	Correlation coefficient (significance level)
Average May air temperature	–0.77 (0.006)
Average January air temperature	–0.76 (0.018)
2-year precipitation totals	0.69 (0.018)
Average May–September NO <sub>x</sub> concentration	0.60 (0.050)

tion is significantly positively related to the damage of plane trees, higher total October and November precipitation is significantly negatively related to the damage of plane trees (Fig. 5, Table 4).

The relation between air pollution (nitrogen oxides concentration) during vegetation season and health status of plane was also found ( $P \leq 0.01$ ; Table 4, Fig. 6). A stronger positive correlation of average nitrogen oxides concentration to planes damage was found at the end of spring and at the beginning of summer (May–July). The correlation between damage of London plane trees and higher ozone concentration was not proved in the Prague area.

The RDA diagram (Fig. 7) demonstrates the most important relations between individual years of field observation, London plane population damage and environmental factors which probably play the most decisive role in damage of trees. The diagram shows that damage of plane trees is positively correlated with total May precipitation and foregoing 2-year precipitation total (worsening the health status especially during 1995–1997). Average Janu-

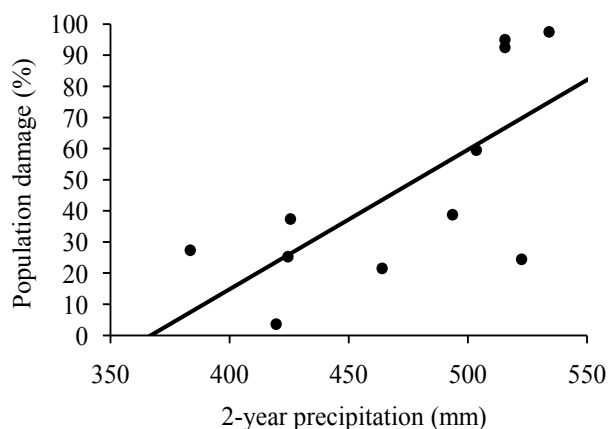


Fig. 4. Regression of *Platanus hispanica* damage to foregoing 2-year precipitation total (1992–2002)

ary and May air temperatures may influence the health status of the population in a positive way. Improved health status was noted in the years 1993, 1999, 2002, 1992, 2001, 2000, and 1994.

The interactions between damaging process and January and May temperatures together with total May precipitation (Fig. 7), are possibly important in *Apiognomonia veneta* (Sacc. et Spegg.) Höhn. epidemiology. The higher precipitation amount can be favourable to this pathogen spreading. Average January air temperature is negatively related to plane damage – its higher values can positively affect the health status of plane. The May average air temperature is in the same relation to the damage – its higher values can affect the health status positively. Total precipitation of the preceding 2 years and total May precipitation are positively related to the damage of plane trees, thus it can negatively affect their health status.

Differences in damage of plane trees growing in localities with different unfavourable conditions appeared especially in periods before and after the *A. veneta* impact – trees in localities with stronger abiotic impacts were damaged to a higher degree (up to 20%).

## DISCUSSION

The results show, that the London plane population in the Prague area could be affected by several stress factors. The most important stressors were winter and spring temperatures, long-term precipitation and nitrogen oxides (NO<sub>x</sub>) pollution.

In comparison with other *Platanus* species, *Platanus hispanica* is more hardy to frost in our conditions. Nevertheless, according to certain authors, even this species can be damaged during severe low temperatures, in inverse localities and in not too moist soils (KAVKA 1969; SLAVÍK, HEJNÝ 1997).

The results confirmed that specific winter conditions (especially low January temperature) could cause a damage of plane trees. Specific local conditions, such as low moisture of air and soil can contribute to a higher damage caused by low temperatures (KOZŁOWSKI et al. 1991; LARCHER 1995). Such conditions are typical for most of studied urban localities.

Many conclusions on reasons of the plane trees damage during winter have been published so far, some of them being even contradictory (NEELY, HIMELICK 1963; GIBBS, REFFOLD 1982; HIMELICK, NEELY 1988; TELLO et al. 2000; SINCLAIR, LYON 2005; WELLS,

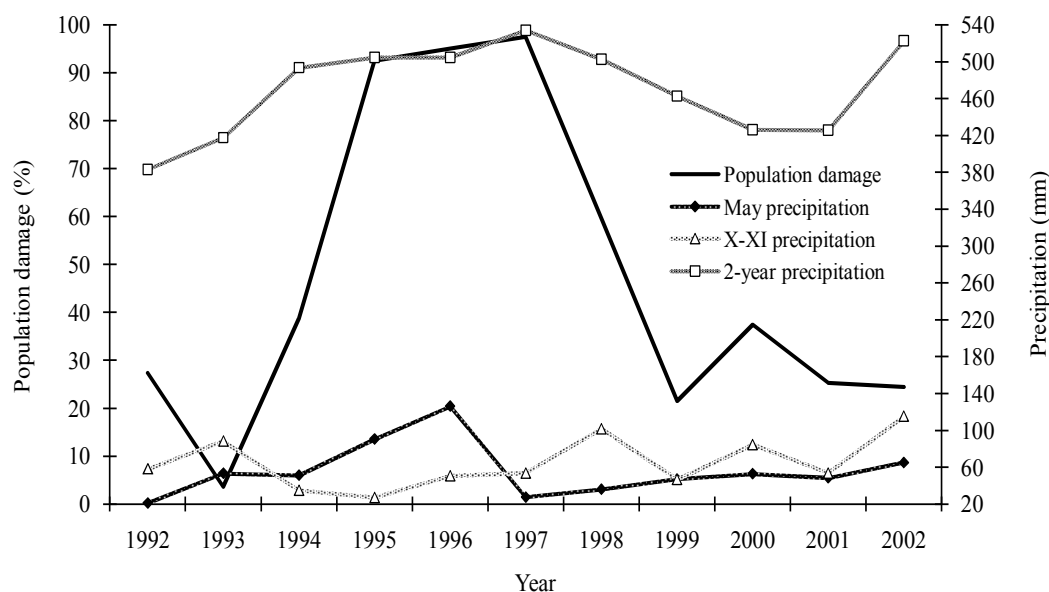


Fig. 5. Development of *Platanus hispanica* damage and average May, autumn (X–XI) and foregoing 2-year precipitation during 1992–2002

SCHMIDTLING 2008 etc.). However, these studies were carried out in diverse regions and the differences in outcomes could be well ascribed to diverse climatic conditions. The presented outcome is well supported by data (regression model, Table 4, Fig. 2, Fig. 7), so we suppose that the continental conditions (dry cold winter with temperatures deeply below zero) can importantly damage the plane trees. Damaging processes of trees during winter are more severe after preceding dry autumn, in repeating extreme conditions and younger trees are more damaged (TATTAR 1989; LARCHER 1995; ČERMÁK et al. 2004; SINCLAIR, LYON 2005). These outcomes are also in accordance with our results. In cases of winters and springs with only exceptional low temperatures, plane trees show a relatively rapid reconvalescence.

Low winter temperature may injure the cork cambium and cause sloughing off the outer bark. Late spring frosts may kill plane buds over wide crown space, and where this occurs, the damaged trees have characteristically long dead twigs with bushy masses of leaves around their bases by mid summer (WELLS, SCHMIDTLING 2008). Disease symptoms (canker of shoots and buds, twig blight) caused by the *A. veneta* in early spring can be easily confused with injury by late spring frost (TELLO et al. 2000; SINCLAIR, LYON 2005 etc.).

Spring temperature (May) seems to be one of the most important climatic factors affecting the health status of London plane. However, the May temperature influences the damage of planes indirectly.

In May, the opening buds could be invaded by the *A. veneta*. The temperature above 15–16°C favours the quick shoot growth and cessation of twig killing. The lower temperature (12–13°C) importantly extends the host susceptibility to the pathogen and leads to severe shoot blight (SINCLAIR, LYON 2005). Our outcomes (Table 4) and field observation of disease severity are in agreement with this statement. So, it is obvious, that temperature in the time of bud opening and frequency of the fungus infections could play an important role in the health status development of London plane in our area.

The amount of a long-term precipitation is significantly negatively related to the health status of planes (Table 4, Fig. 7) and the health status of planes is probably affected via *A. veneta* infection as well. Precipitation plays an important role in disease spreading – the conidia are produced especially in wet conditions and are distributed by splashing and spraying. The pathogen could grow and spread during nearly the whole year – with exception of hot dry summer days (when the host is resistant) and cold winter days when the temperature is below growth minimum of the fungus (SINCLAIR, LYON 2005). So, it seems that the higher long-term precipitation affects the spread of the disease in tree crowns and increases the disease severity nearly during the whole year.

The amount of autumn precipitation (October, November) is significantly positively related to the health status of planes (Table 4, Figs 5 and 7). A higher precipitation total eliminates a negative impact of

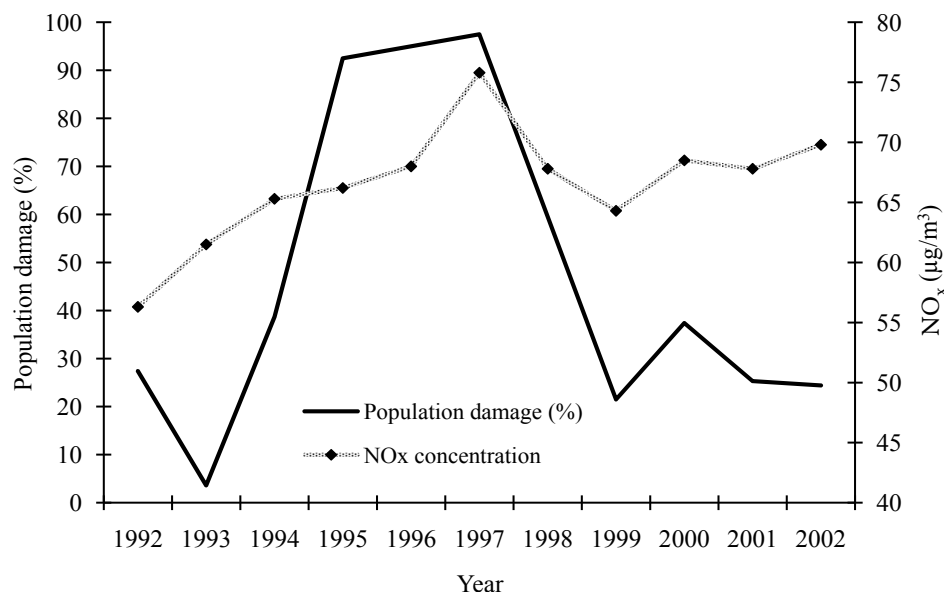


Fig. 6. Development of *Platanus hispanica* damage and average nitrogen oxides (NO<sub>x</sub>) concentration during 1992–2002

frost desiccation of sensitive tree tissues during the following winter and spring periods (KOZŁOWSKI et al. 1991; LARCHER 1995; SINCLAIR, LYON 2005). A positive influence of autumn precipitation can be observed especially in such years when the temperature sharply oscillates during winter and spring and when periods with a higher temperature are followed by periods with sharply decreased temperatures (TATTAR 1989; SINCLAIR, LYON 2005). These outcomes are also in accordance with our results. Lower precipitation total at the end of vegetation season causes greater vulnerability of trees to a higher damage due to frost as well as to pathogenic infection (THOMAS et al. 2002; SINCLAIR, LYON 2005; DESPREZ-LOUSTAU et al. 2006). In planes it caused a higher infection through fungus *A. veneta* (1995–1997).

High temperatures during vegetation season in the years 1992, 1994 and 1999–2000 together with a low precipitation total and a longer dry season (Table 1, Figs 2 and 5) reflected in a not too favourable health status of many trees, especially native woody species growing in the same localities as studied planes (GREGOROVÁ et al. 2006). Nevertheless, such damage was not observed in London plane trees, which is not surprising as this thermophile woody species was introduced to our country from the Mediterranean region (with warmer and drier summer season) (KRÜSSMANN 1979; MITCHELL 1979).

A significant relationship (Table 4) between air pollution (nitrogen oxides concentration) and health status of London plane was found during vegetation

season (Fig. 6), in particular at the end of spring and in summer (May–August). The nitrogen oxides are represented collectively as NO<sub>x</sub>. Each nitrogen oxide readily interconverts into another oxide in a very fast rate. The two major oxides of nitrogen (NO<sub>x</sub>) are nitric oxide (NO) and nitrogen dioxide (NO<sub>2</sub>). These are still rising in the atmosphere of the urban environment and in close proximity to automobile and airport traffic (ROWLAND et al. 1985; ANYANWU 1999). Majority of studied localities are situated near roads with a dense traffic.

Although oxides of nitrogen give rise to other phytotoxic pollutants, e.g. ozone they are also in their own right damaging to plant health (ROWLAND et al. 1985). The nitrogen oxides as one of the main air pollutant gases enter plants via stomata and are capable of suppressing the rate of photosynthesis, stimulating respiration and subsequently suppressing growth (KOZŁOWSKI et al. 1991; SINCLAIR, LYON 2005). In the period with a higher precipitation total, especially acid-forming pollutant nitrogen dioxide (NO<sub>2</sub>) can strongly damage buds, young leaves and growing sprouts (mainly during budding period) in the form of acid rain (SINCLAIR, LYON 2005). These outcomes are also in accordance with our results.

On the basis of the correlation found between a higher NO<sub>x</sub> concentration, higher amount of May and long term precipitation (factors favourable to development of *A. veneta*, acid rain with NO<sub>x</sub>), lower average May temperature (factor favourable to development of *A. veneta*), and damage of planes, it can be

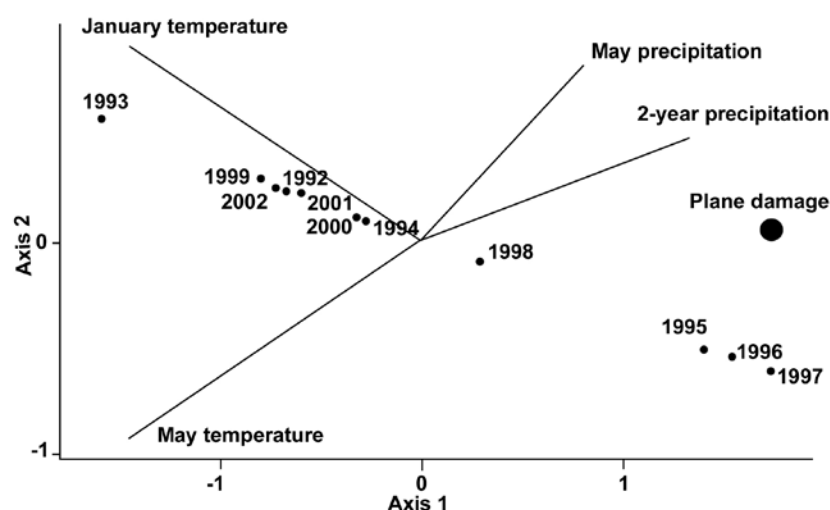


Fig. 7. Relation between *Platanus hispanica* damage and environmental factors (average January and May air temperature, total May precipitation and foregoing 2-year precipitation total) during 1992–2002

supposed that a joint influence of these abiotic factors during vegetation season plays the most important role in plane damage. In the case of the absence or suppressed development of the pathogen *A. veneta*, we can deduce that increased damage of plane population during the vegetation season is caused mainly by a higher concentration of nitrogen oxides. The deposit of nitrogen oxides in soil also contributes indirectly to a negative influence on nutrition and plane damage in addition to direct effect through acid rain. (MRKVA 1999; SINCLAIR, LYON 2005).

The results show that a considerable proportion of London plane population can be critically damaged in consequence of repeated climatically unfavourable years, probably with subsequent development of the *A. veneta* infection. The high impact of climatic factors and the pathogen on the health status of London plane in the Czech Republic can cause extreme fluctuation of percentage of damaged trees and thus contribute to delineation of ecological limits of this tree species in Central Europe.

## CONCLUSION

The results show that the health status of London plane during 1992–2002 was negatively and most significantly influenced by long-term precipitation amount, higher precipitation amount in May, higher number of freezing days in winter and marginal higher concentration of nitrogen oxides.

The damage development of London plane was characterized by important fluctuations. Minimum value of population damage was 3.6% (in 1993) and maximum 97.5% (in 1997). The highest damage was observed in 1995–1997 when over 90% of popula-

tion was damaged. The health status of trees was negatively correlated with low temperature in January and May, higher sum of long-term precipitation and higher concentration of nitrogen oxides ( $\text{NO}_x$ ) during vegetation season. Planes were importantly affected by *Apiognomonia veneta* during the period of the highest damage (1995–1997). It seems to be a reliable conclusion that the combination of low temperature in the time of bud opening and new shoot prolongation and high incidence of *A. veneta* infection may significantly affect the health status of trees. The results also show that a considerable proportion of London plane population can be damaged in consequence of repeated climatically unfavourable years with subsequent development of *A. veneta* infection. The high impact of climatic factors and the pathogen on the health status of London plane in the Czech Republic can cause extreme fluctuation of percentage of damaged trees as well as delineate the ecological limits of this tree in Central Europe.

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