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ASSESSMENT OF THE EFFECT OF ENVIRONMENTAL VARIABLES ON HEALTH STATUS OF *Tilia cordata* Mill. IN PARKS

OCENA WPŁYWU ZMIENNYCH ŚRODOWISKOWYCH NA STAN ZDROWOTNY LIPY DROBNOLISTNEJ W PARKACH

Abstract: Analyses concerned the effect of different environmental variables on the health status of little-leaf linden (*Tilia cordata* Mill.). The study comprised analyses and statistical models based on discriminatory analysis. These analyses indicated which variables may influence the health status of tress of the investigated species in the parks of Poznan. The model was based on the canonical variate analysis (CVA), *ie* Fisher's canonical variant of linear discriminatory analysis (LDA). The greatest negative effect on the health status of trees of *Tilia cordata* Mill. in Poznan parks was found for the small distance of the parks from the city centre and the immediate vicinity of two arterial roads. It was also found that the vicinity of buildings heated with fossil fuels, primarily coal, may have had a negative effect on the health status of *Tilia cordata* Mill. trees in the Poznan parks. Moreover, it was shown that specimens of the investigated species aged 81–120 years were characterised by the worst health status, while the best health condition was found in trees of *Tilia cordata* Mill. in the Millennium Park.

Keywords: urbanized areas, environmental changes, Poznan, statistical models

Introduction

The air quality in cities is a problem in view of the expansion of urbanised zones [1], [2]. Soil moisture, the content of nutrients as well as pathogens and pests have been found to influence the processes related with defoliation of tree crowns [2]. The trees in public open spaces have been proved to have influence on accumulation and retention of water and groundwater [3–8]. Studies have proved that trees growing in cities may reduce the pollution with O_3, SO_2, CO, NO_x and suspended particulate matter [9–14].

Under natural conditions of Poland *Tilia cordata* Mill. is a component of fertile, multi-species deciduous forests shedding leaves for winter. Under optimal conditions and

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in a compact stand it may reach a height of 38–42 m at stem diameter exceeding 200 cm. It is also of importance that trees from the genus *Tilia* do not form permanent, pure stands, although they may dominate in a multi-species stand. Trees of *Tilia cordata* Mill. prefer moist, permeable and fertile soils and tolerate the presence of calcium in soil. It was stated experimentally that the length of vegetation phases in the described species is influenced, among other things, by precipitation, insolation and winds. It was also found that the length of vegetation phases of *Tilia cordata* Mill. is more strongly affected by the number of cloudless days and the number of days with rainfall than annual precipitation total. It was also confirmed that weather with heavy rains and rapidly passing cloud cover is more advantageous for growth of this tree species that the weather with a lasting cloud cover and an extensive period of rainy weather [15]. It was also observed that the most advantageous living conditions for *Tilia cordata* Mill. are found in localities with predominant south-western and western winds. Trees from the genus *Tilia* are also relatively drought-resistant, being more resistant than trees from genera *Betula*, *Alnus* or *Carpinus*, but less resistant than trees from the genera *Fraxinus*, *Quercus* or *Sorbus* [16, 17].

Trees from the genus *Tilia* should be used in high greenery in residential districts and parks, while these trees were not recommended in planting of streets and squares due to the difficult environmental conditions. A more extensive application could be found for trees from the genus *Tilia* in countryside plantings, particularly as roadside trees [18, 19].

Threats to *Tilia cordata* Mill. trees in urbanised areas

Air pollution under urban conditions has an adverse effect on the activity of the shoot apex, which leads to a reduced leaf area or the appearance of double buds. In the experiments performed on trees of the investigated species it was found that trees of *Tilia cordata* Mill. are sensitive to the action of SO_2 and acid rain. The considerable reduction of photosynthetic activity was also observed in the environment polluted with fluorine. Elevated Na, Cl, Ca, Mg, Zn and Cu rates as well as elevated soil pH have a negative effect on the health status of trees of that species growing in the vicinity of traffic routes. Increased salinity or EC, caused by the elevated Na and Cl levels, also have a detrimental effect on trees of *Tilia cordata* Mill. and other species, resulting – particularly in spring – in the so-called physiological drought [20–22]. Trees of this species are also relatively resistant to air pollution in urbanised areas, as a greater seasonal accumulation of Cr, Fe, Ni and Pb ions in leaves than that in *Tilia cordata* Mill. is observed in trees of *Aesculus hippocastanum* L. *Tilia cordata* Mill. was not observed to accumulate Cu ions in its leaves. In contrast, trees of *Tilia cordata* Mill. are less resistant to air pollution in urbanised areas than trees from the genera *Carpinus* and *Robinia* [23]. It was also found that trees of *Tilia cordata* Mill. are markedly less sensitive to ozone air pollution than trees of *Salix alba* L., *Tilia platyphyllos* Scop. or *Fraxinus excelsior* L. [24].

Methods

Analyses covered public parks of historic value in the city of Poznan, in which the share of *Tilia cordata* Mill. trees was considerable. These parks include (the numbers follow those in Fig. 1):

1. The Polish State Millennium Park – the share of *Tilia cordata* Mill. trees in the park stand is 0.7 %,
2. The Park between Czecha and Rusa Housing Estates – the share of trees of the analysed species in the park stand is 1.3 %,
3. The John Paul II Park – the share of trees of the described species in the park stand is 5.1 %,
4. The Gorczynski Park – the share of *Tilia cordata* Mill. trees in the park stand is 38.8 %,
5. The Rev. Joseph Jasinski Park – the share of trees of the analysed species in the park stand is 2.4 %,
6. The Gustaw Manitius Park – the share of trees of the described species in the park stand is 12.9 %.

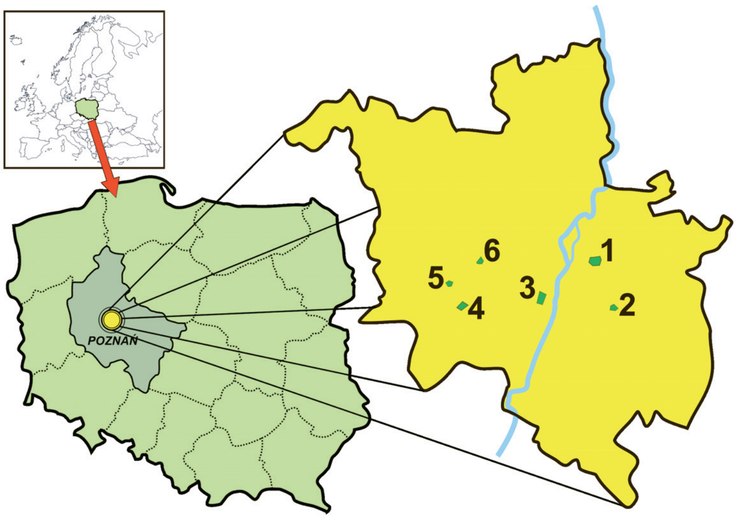

Fig. 1. Maps indicating the location of Poland in Europe, location of Poznan in Poland and a map of the city of Poznan with marked locations of parks analysed in this study (author of the maps: M. T. Walerzak)

Two of the above mentioned objects are parks established in the area of former forts of the outer ring of Prussian fortifications from the second half of the 19th century (the parks between the Czecha and Rusa Housing Estates, and the Rev. Joseph Jasinski Park), while two other parks were formed from the transformation of former Evangelical cemeteries (the Gorczynski Park and the Gustaw Manitius Park).

Field studies connected with the survey of *Tilia cordata* Mill. trees growing in the selected parks were conducted in the years 2010–2012 in the summer period (June–August). In the course of survey studies the following characteristic elements were recorded:

1. stem circumference of each tree (measured at a height of 130 cm above ground), while in the case of multi-stem trees, forked below the height of 130 cm each stem was measured separately;

2. crown diameter of each tree (in the case of trees with irregular crowns two extreme diameters were measured and their mean was calculated);

3. height of each tree;

4. health status of examined trees – health status was evaluated based on criteria for tree condition evaluation [25], taking into consideration the condition of the crown, stem and roots of the tree.

Statistical analyses and models were developed based on discriminatory analysis. The conducted analyses verified which variables may influence the health status of *Tilia cordata* Mill. trees in the parks of Poznan. The model was constructed using canonical variate analysis (CVA), *ie* a canonical variant of Fisher's linear discriminatory analysis (LDA) [26].

The discriminatory analysis was used to compare the effect of different variables on the health status of specimens in the examined parks. Parameters included in the analyses comprised distance of the parks from the city centre, vicinity of industrial areas, traffic routes, watercourses and water bodies as well as incorporation of the parks into the municipal green system, emission of gases from combustion of fossil fuels by households neighbouring with the parks or original use of the areas in which the analysed parks were established.

In order to verify which variables to the greatest degree determine the health status of *Tilia cordata* Mill. trees in the Poznan parks the progressive step-wise analysis was applied. All variables were assessed and next these variables were included into the model, which contributed most to the discrimination of groups based on values of p and F for the analysed variable. This process is repeated to the moment when value p dropped below 0.05 for the examined variable.

In order to determine the boundary level of significance the Monte Carlo permutation test (separately for each variable and next for the entire model). All lists, calculations and graphic elements were performed in the Canoco for Windows programme and the Microsoft Excel spreadsheet. The following tools of the Canoco for Windows package were used: Canoco for Windows 4.5, CanoDraw for Windows and WCanoIMP.

Results

Analysis of recorded results made it possible to identify differences concerning morphometric parameters and health condition of trees of *Tilia cordata* Mill. living in selected parks of the city of Poznan (Fig. 2). The most impressive specimens in terms of height and crown width were reported in 3 parks (the Gorczynski, the Rev. Joseph Jasinski and the Gustaw Manitius parks), they were the oldest specimens among the examined trees. Some specimens exceeded 25 m in height, while their crown width was over 17 m (Table 1). In terms of health condition the best specimens were those found in the Polish State Millennium Park, with the averaged health condition score Q of 1.14 and it was close to health class I. Trees of this species in the Gustaw Manitius Park had the lowest health condition class, with classes III and II predominating. Circumferences of the examined trees were correlated with their age and ranged from 12 cm to 233 cm.

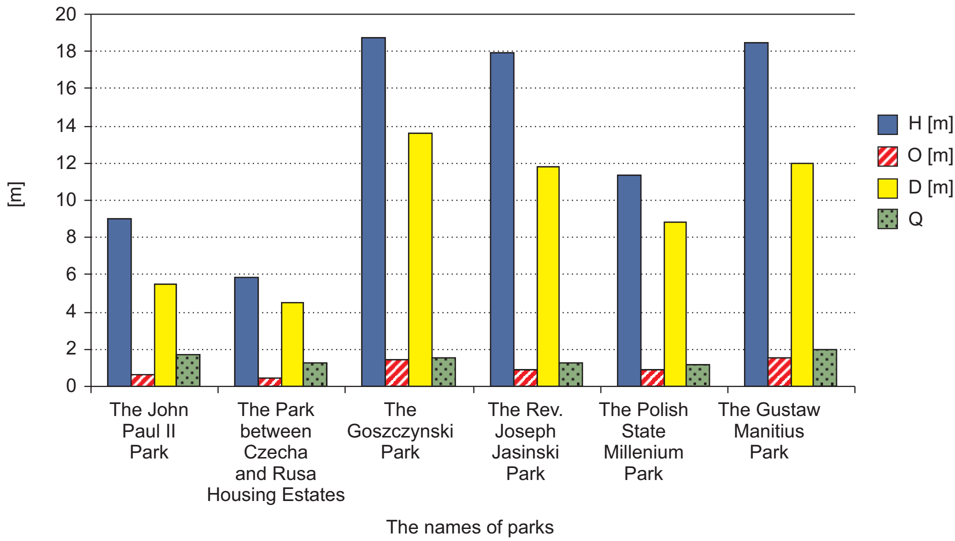

Fig. 2. Averaged values of analysed parameters for *Tilia cordata* Mill. in examined parks of the city of Poznan (H – tree height, O – stem circumference, D – crown diameter, Q – health condition)

Table 1

Minimum, maximum and mean values, and standard deviation for analysed parameters of *Tilia cordata* Mill. in Poznan parks

		H [m]	O [cm]	D [m]	Q			H [m]	O [cm]	D [m]	Q
The John Paul II Park	Min	3.5	23	2.5	1	The Rev. J. Jasinski Park	Min	7	35	4	1
	Max	16	159	10	5		Max	24	124	18	2
	$\bar{x}$	9.05	67.41	5.49	1.69		$\bar{x}$	17.90	92.80	11.80	1.30
	SD	2.90	25.99	1.53	0.81		SD	4.61	26.38	4.42	0.48
The Park between Czecha and Rusa Housing Estates	Min	2	13	1.8	1	The Polish State Millennium Park	Min	4	11.5	1.5	1
	Max	8	75	6.2	2		Max	20	168	13	2
	$\bar{x}$	5.83	45.90	4.47	1.25		$\bar{x}$	11.36	86.93	8.82	1.14
	SD	1.60	16.22	1.14	0.44		SD	3.80	30.24	2.28	0.35
The Gorczynski Park	Min	5	12	4	1	The Gustaw Manitius Park	Min	3.5	12	1.5	1
	Max	27	232	20	4		Max	22	233	17	3
	$\bar{x}$	18.78	142.69	13.63	1.57		$\bar{x}$	18.44	153.65	11.97	1.94
	SD	3.67	36.11	3.79	0.67		SD	3.35	40.92	3.25	0.77

H – tree height, O – stem circumference, D – crown diameter, Q – health condition.

The conducted statistical analysis showed a marked correlation (both positive and negative) for the distribution of environmental variables such as distance of the parks from the city centre, vicinity of traffic routes or industrial areas with the health status of the analysed species in the Poznan parks (Fig. 3). The greatest negative effect on the health condition of *Tilia cordata* Mill. trees in the Poznan parks was observed for such variables as distance of the parks from the city centre (with the worst health condition in specimens found in parks located within the radius of <2 km from the centre of Poznan). Moreover, a negative effect on the health condition for the examined species in the Poznan parks was recorded for the vicinity of traffic routes, running directly on both sides of the examined parks. The best health status was found for trees of *Tilia cordata* Mill. living in the parks, which were located farthest from the city centre (within the radius over 3 km), in the vicinity of which there were no industrial areas, while the parks were adjacent to one traffic route.

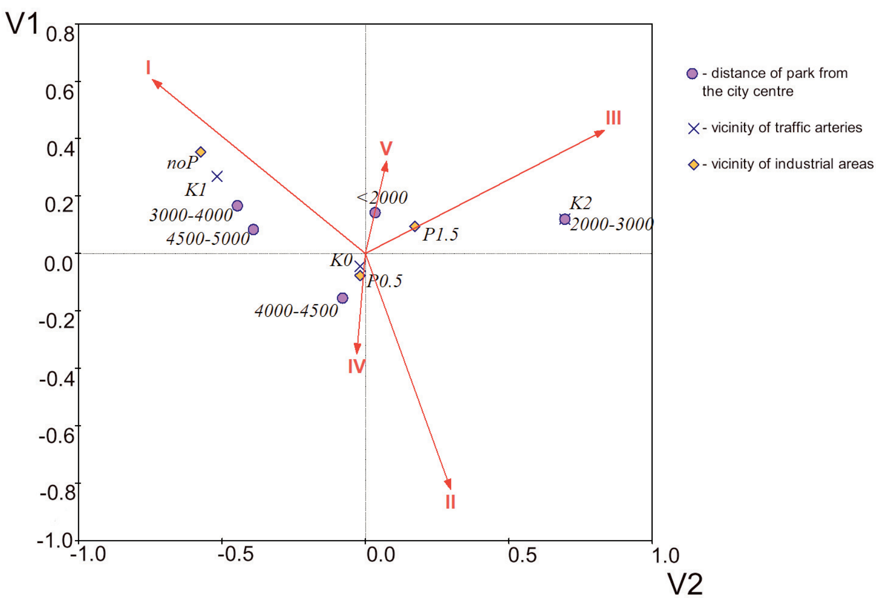

Fig. 3. The CVA model (n = 340) – dependencies between health condition of *Tilia cordata* Mill. in the Poznan parks and location of parks, vicinity of industrial areas, traffic arteries as well as watercourses and water reservoirs [2000–3000 – distance of park from the city centre; K0, K1, K2 – vicinity of one (two) traffic arteries; P0.5; P1.5 – vicinity of industrial areas at 0, <0.5 and <1.5 km; vicinity of watercourses and water reservoirs ($p < 0.05$)

The health condition of *Tilia cordata* Mill. trees living in the selected parks of Poznan was considerably affected by the heating method used in the residential buildings located in the adjacent areas. The vicinity of housing districts heated with fossil fuels, mainly carbon, could have had a negative effect on the health status of trees of the analysed species in the parks of Poznan. At the same time no potential negative effect was observed for the housing districts with the central heating system on the health status of the analysed species in the Poznan parks. In turn, no considerable correlation as a stimulant or destimulant was found between the health condition of *Tilia cordata* Mill. trees and the location in the wedge-ring system of the municipal green in Poznan. As it results from the above graph (Fig. 4), the health status of trees of the analysed species found in the area of former fortifications was class I, which could have been caused by the ring fortification system and the considerable distance from the city centre (no effect of urbanization factors).

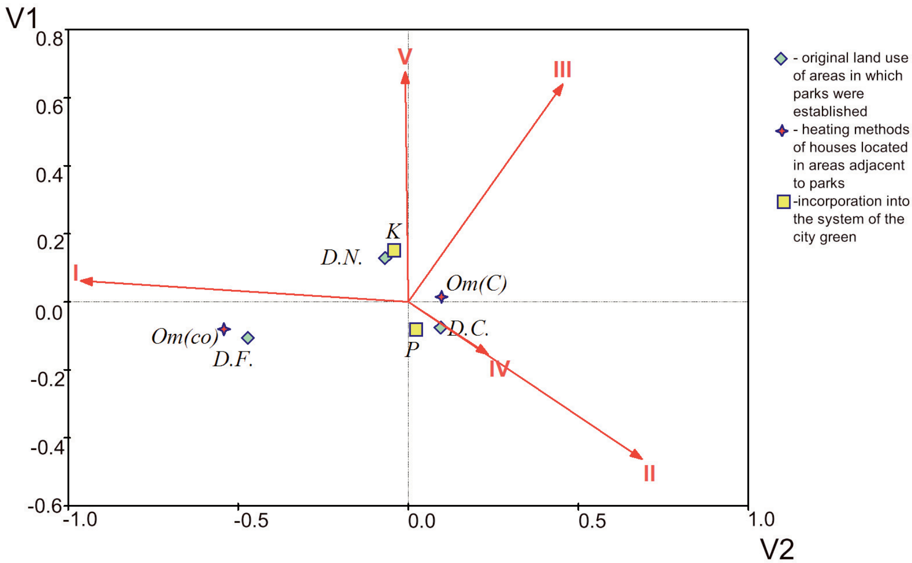

Fig. 4. The CVA model (n = 340) – dependencies between health condition of *Tilia cordata* Mill. in the Poznan parks and original land use of areas in which parks were established, heating methods of houses located in areas adjacent to parks and incorporation into the system of the city green [D.N. – former wasteland, D.C. – former cemeteries, D.F. – former forts; Om(co) – housing districts with central heating system, Om(C) – housing districts heated using fossil fuels; K – parks incorporated into green wedges, P – parks incorporated into green rings ($p < 0.05$)

The following model presents dependencies between the health status of *Tilia cordata* Mill. trees in the selected parks of the city of Poznan and the age ranges for individual specimens. As it results from the model given below (Fig. 5), the best health status was found for the youngest specimens belonging to the age ranges of 21–30 and 11–20 years. The worst health condition was found for lindens aged from 81 to 90 years. The greatest number of specimens belonging to health class IV was recorded for the age group from 111 to 120 years. Health class III was represented mainly by lindens aged from 91 to 100 years.

Health condition of *Tilia cordata* Mill. trees in the selected parks of the city of Poznan was influenced by many environmental conditions, as it was shown by the above models. Definitely the best health status was found for trees of the analysed species growing in The Polish State Millennium Park (Fig. 6). This park had optimal location

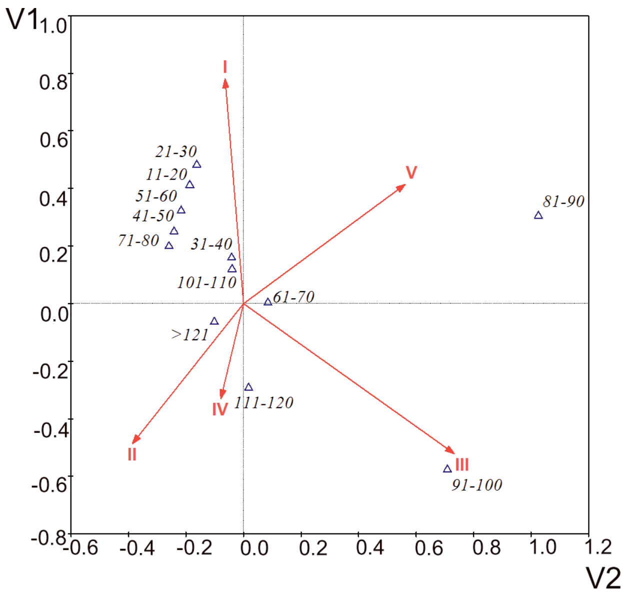

Fig. 5. The CVA model (n = 340) – dependencies between health condition of *Tilia cordata* Mill. in the Poznan parks and age of analysed trees ($p < 0.05$)

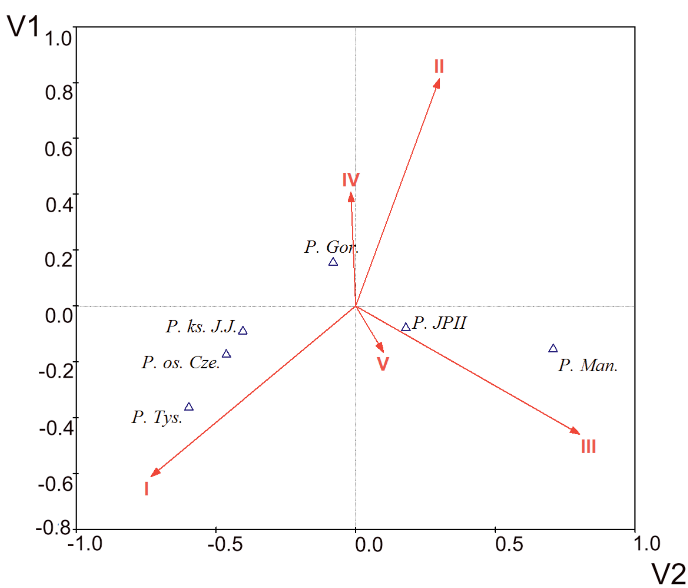

Fig. 6. The CVA model (n = 340) – dependencies between health condition of *Tilia cordata* Mill. in Poznan parks and analysed parks [P. Gor. – The Gorczynski Park, P. Tys. – The Polish State Millennium Park, P. Ks. J. J. – The Rev. J. Jasinski Park, P. Man. – The Gustaw Manitius Park, P. JPII – The John Paul II Park, P. os. Cze. – Park between Czecha and Rusa Housing Estate] ($p < 0.05$)

conditions, which resulted in a very good health status of the examined species. The Gustaw Manitius Park and the Jan Paweł II Park were those parks, in which *Tilia cordata* Mill. trees had the worst health status in comparison to the other analysed objects.

Conclusions

1. The greatest negative effect on the health condition of lindens in the parks of the city of Poznan was found for the distance of the parks from the city centre and the immediate vicinity of two traffic routes.

2. A statistically significant difference was found in the health status of lindens in relation to the heating method used in the housing buildings in the adjacent areas. Coal-heated housing districts could have had a negative effect on the health status of *Tilia cordata* Mill. trees in the Poznan parks.

3. Specimens aged 81–120 years old had the worst health status.

4. Trees of *Tilia cordata* Mill. found in The Polish State Millennium Park were characterised by the highest health status.

5. The most impressive specimens in terms of their height, stem circumference or crown width were reported in two parks: The Gorczynski Park and The Gustaw Manitius Park.

Acknowledgements

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OCENA WPŁYWU ZMIENNYCH ŚRODOWISKOWYCH NA STAN ZDROWOTNY LIPY DROBNOLISTNEJ W PARKACH

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Abstract: Badania dotyczyły wpływu różnych zmiennych środowiskowych na stan zdrowotny lipy drobnolistnej (*Tilia cordata* Mill.). W pracy wykorzystano analizy i modele statystyczne stworzone w oparciu o analizę dyskryminacyjną. Wynikiem przeprowadzonych analiz było wykazanie, które zmienne mogą wpływać na stan zdrowotny drzew badanego gatunku na terenie parków Poznania. Do skonstruowania modelu wykorzystano analizę CVA (canonical variate analysis) – kanoniczną odmianę liniowej analizy dyskryminacyjnej Fishera (LDA). Stwierdzono, że największy negatywny wpływ na stan zdrowotny drzew *Tilia cordata* Mill. w parkach Poznania miała niewielka odległość parków od centrum miasta oraz bezpośrednia bliskość dwóch arterii komunikacyjnych. Stwierdzono również, że bliskość zabudowań ogrzewanych paliwami kopalnymi, przede wszystkim węglem kamiennym, mogły wpływać negatywnie na stan zdrowotny drzew *Tilia cordata* Mill. na terenie parków Poznania. Wykazano również, że osobniki drzew badanego gatunku z przedziału wiekowego 81–120 lat charakteryzowały się najgorszym stanem zdrowotnym, a najlepszą zdrowotność drzew *Tilia cordata* Mill. stwierdzono w Parku Tysiąclecia Państwa Polskiego.

Słowa kluczowe: tereny zurbanizowane, Poznań, zmienne środowiskowe, modele statystyczne