

Urban greenery in the context of the spread of *Viscum album* L. subsp. *album*. A case study of the Nicolaus Copernicus University campus and its surroundings in Toruń, Poland

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Abstract. The species composition, spatial distribution and infestation rate by common mistletoe in its typical form, *Viscum album* subsp. *album*, were investigated in the Bielany district in the north-western part of the city of Toruń. The study area covered the campus of Nicolaus Copernicus University (NCU campus) and its immediate surroundings. Observations of mistletoe hosts were conducted in a network of 143 squares, each measuring 100x100 m, delineated according to the principles used in monitoring for the Distribution Atlas of Vascular Plants in Poland (ATPOL). The number of trees infected with mistletoe was recorded in each ATPOL square. Based on data collected during field studies, a list of 1,140 hosts, representing 31 tree taxa, was compiled. It was found that of the 10 landscape structure parameters and biological and ecological traits of hosts considered, the proportion of green space developed around educational facilities and the DBH have a statistically significant effect on the distribution of mistletoe in the study area.

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1. Introduction

The distribution of common mistletoe can be analysed and interpreted on various spatial scales. It is often analysed within the range of a taxon or across an entire geographical region, a country or significant parts thereof, providing information on the main, overriding factors determining its distribution pattern. In recent years, there has been an increase in research on the occurrence of mistletoe on a local scale, especially in urban areas. (Rybalka, 2016; Gołabek & Sławiński, 2017; Rybalka & Vergeles, 2017; Bilonozhko et al., 2019, 2021, 2022, 2025; Chojnacki, 2019; Issakainen et al., 2019; Matusiak, 2019; Yurel, 2019; Chojnacki, 2020; Klymenko, 2020; Krasnylenko et al., 2020; Pischalenko et al., 2020; Skrypnik et al., 2020; Boltenko et al., 2021; Kavun et al., 2021; Nienartowicz et al., 2022; Skrypnik et al., 2022; Luguza et al., 2023; Rutkowski et al., 2023; Glogov & Bogdanov, 2024; Rybalka & Vergeles, 2024; Zhytova et al., 2024; Panasenko & Anishchenko, 2025; Skrylnyk et al., 2025; Zemskova et al., 2025; Sobolewski et al., 2026). The cited literature indicates that in the last decade, the study sites have often been cities located in Ukraine, Russia, and Belarus, i.e., close to the eastern and northeastern limits of the European mistletoe's continuous range, or even beyond, where the increase in the hemiparasite's population is likely more noticeable and intriguing to ecologists. Undertaking more detailed studies of the typical distribution of common mistletoe on a local scale seems highly justified, given the observed strong expansion of this subspecies, especially in urbanized environments, its high viability, and its resistance to harmful factors attacking contemporary biocenoses (Ciaciura et al., 2008). Because common mistletoe adapts well to the most altered and polluted habitats of large cities, it was concluded that it can be treated as a synanthropic species (Zachwatowicz et al., 2008).

It seems that, beyond the medicinal use of mistletoe, there are three main reasons for the growing interest in this hemiparasite. The first stems from its participation in complex interactions at the community level with host plants, animal pollinators, fruit consumers and seed dispersers, as well as with microorganisms that limit its growth, which is why it is considered a keystone species in various ecosystems (Watson & Herring, 2012; Watson et al., 2022). The role of the hemiparasite as a keystone species also includes changing the surface layer of the soil and thus the structure of the forest ecosystems and woodlands, accelerating the cycling of nutrients in the leaf litter and shifting the nutrient hotspots under

infected trees (Mellado et al., 2016; Hóðar et al., 2018; Těšitel et al., 2021).

The second reason stems from incomplete understanding of the mechanisms behind its increasing expansion, which poses threats to native ecosystems and their vegetation. According to Downey (2004) and Baltazar et al. (2015), mistletoe expansions can occur accidentally through the introduction of hosts that are not native to a given area or as a result of evolutionary changes resulting from environmental pressures such as habitat modification and climate change. The third reason is of an economic nature, as it results from the constantly increasing costs of maintaining green areas and the damage to forest plantations by the excessive spread of mistletoe (Rybalka, 2017; Ertuğrul & Komut, 2020; Winiarska, 2023; Mandziuk et al., 2024).

In this context, research on the relationships between the occurrence of mistletoe and the local pool of potential hosts, as well as local habitat conditions, appears crucial, as it may shed light on the causes and effects of its expansion (Kołodziejek et al., 2013). According to Walas et al. (2022), the future of *Viscum album* L. in Europe will be shaped by temperature and the availability of host plants. Modelling the potential range of these subspecies using MAXENT software showed that temperature is a key factor affecting the potential range of all common mistletoe subspecies occurring in Poland. According to the three future scenarios developed by the authors, *V. album* subsp. *abietis* will retreat from its current range. In the case of *V. album* subsp. *austriacum*, a slight shift in the range is observed. Only *V. album* subsp. *album* will spread without a specific direction. This is most likely due to the very large number of host species and greater genetic variability compared to the subspecies found on conifers (Walas et al., 2022).

Recognising the importance of this latter conclusion, as well as the findings of Bilonozhko et al. (2025) that determining the pattern of mistletoe distribution and the factors that determine its nature is of paramount importance for urban green space management, particularly in the context of climate change, we conducted an analysis of mistletoe occurrence in the Bielany district of Toruń, covering the University Campus and the surrounding area. This study was also inspired by the findings of Skrypnik et al. (2020), who noted that there is a lack of studies examining the complex influence of various environmental factors on the distribution of mistletoe in urban areas.

The objective of our research was to compile a list of mistletoe hosts in the study area, to determine the proportion of new and rare host species in Poland,

and to determine the proportion of native and alien tree and shrub species within this group. A further objective was to identify the main biotic, abiotic, and landscape factors whose combined influence determines the distribution of host-parasite systems and the abundance of mistletoe in the study area.

2. Study area

The study area is a part of the Bielany district in the NW part of Toruń, bounded by Szosa Okrężna Street to the west, św. Józefa Street to the east, Gagarina Street to the south, and Grunwaldzka Street to the north. In the hierarchical ATPOL grid of squares, according to which observations of floristic sites in Poland are usually conducted, the study area is located in 10 x 10 km square DC30 and in six 1 x 1 km squares (Fig. 1). However, the observations were carried out in a network of squares of even smaller dimensions, 100 x 100 m, plotted into squares of a higher level. The analysis took into account all squares that were located within the area covered by the four streets mentioned above, including all outer squares that contained at least a small part of these streets. The study area consisted of 143 squares. According to the ownership and user structure in 1973, i.e. at the time of the campus opening, approximately 82 ha, i.e. 57.34% of the total study area of 143 ha, was occupied by the Nicolaus Copernicus University campus (Staszewski, 1973).

The campus grounds are located mainly in the southern and western parts of the study area. The campus area, adjacent to the buildings – research institute buildings, teaching facilities, and student dormitories – is dominated by greenery, lawns, single trees and shrubberies.

In the eastern part of the study area, the 'Universitatis' University Housing Estate is located, with sparse, medium-high buildings. It was built on the site of a former military training ground. The estate consists of nine four-storey buildings surrounded by lush, well-maintained vegetation. A similar type of housing and spatial development is found in the outer squares in the south-eastern part of the study area, i.e. the squares covering the beginning of św. Józefa Street. The 'Reja' housing estate, with tall 11-storey and lower 5-storey residential buildings, comprises the outer squares in the southern part of the study area, located along the western section of Gagarina Street and the tram line running alongside it. In addition to tall residential buildings, these squares feature low-rise service buildings with shops and small businesses. The buildings are surrounded by green areas, but these are

not as rich in species and biomass as those of the 'Universitatis' housing estate. A different type of residential development is found at the northern end of the study area. The central section of Grunwaldzka Street is bordered on the south by the 'św. Klemens' housing estate, a villa-style residential area with single-family houses surrounded by small gardens dominated by ornamental and fruit trees and shrubs. The Brzezina housing estate with terraced single-family houses is located on the north-western side. The buildings of the first housing estate were built in the 1950s, while those of the second in the 1980s and 1990s.

The 'św. Klemens' housing estate is adjacent to the east by a complex of Redemptorist monastery buildings, erected between 1926 and 1929, and St. Joseph's Church, built between 1958 and 1963, surrounded by gardens. Part of the monastery buildings located amidst old trees houses the Rector's Office of the Higher School of Social and Media Culture. A similar character of development and functions can be found in the squares encompassing the intersection of H. Sienkiewicza and Gagarina streets, where a building used until the 1990s by the Teacher Training College now houses the Higher Seminary of the Diocese of Toruń. In the vicinity of the Redemptorist church and monastery, on the eastern side of św. Józefa Street, secondary schools are located – the Complex of Mechanical, Electrical and Electronic Schools and the Economic School Complex. The educational buildings were erected in the 1950s and 1960s. The green areas and sports facilities are planted with trees that are older than those on the NCU campus.

To the north of St. Joseph's Church, behind Grunwaldzka Street, lies the premises of the 'Wodociągi Toruńskie' (Toruń waterworks) company, which continues the operations of the 'Stare Bielany' waterworks station, established here in 1893–1894. A park was established next to the station, in the centre of which, since 1811, there has been a small (0.02 ha) Protestant cemetery of the Elsner family, former tenants of the 'Bielany' manor (Skonieczny, 2009). The sparse forest stand, with almost no shrub layer, is dominated by old Norway maples and black locusts, accompanied by a few pedunculate oak trees. Numerous birds were observed in the tree crowns and sparse undergrowth, including mistle thrushes (*Turdus viscivorus*) and song thrushes (*Turdus philomelos*).

In the vicinity of the waterworks, there are forest and park areas with the residence of Janitzen, the founder of the 'Bielany' manor from the late 18th century. In the interwar period, as the so-called 'Bielanski Dwór' manor, it served as the seat of the Mayor of Toruń. Currently, it houses the John Paul II 'Światło' Hospice Centre for Medical Care. From the north, the forest and park complex is adjoined by the grounds

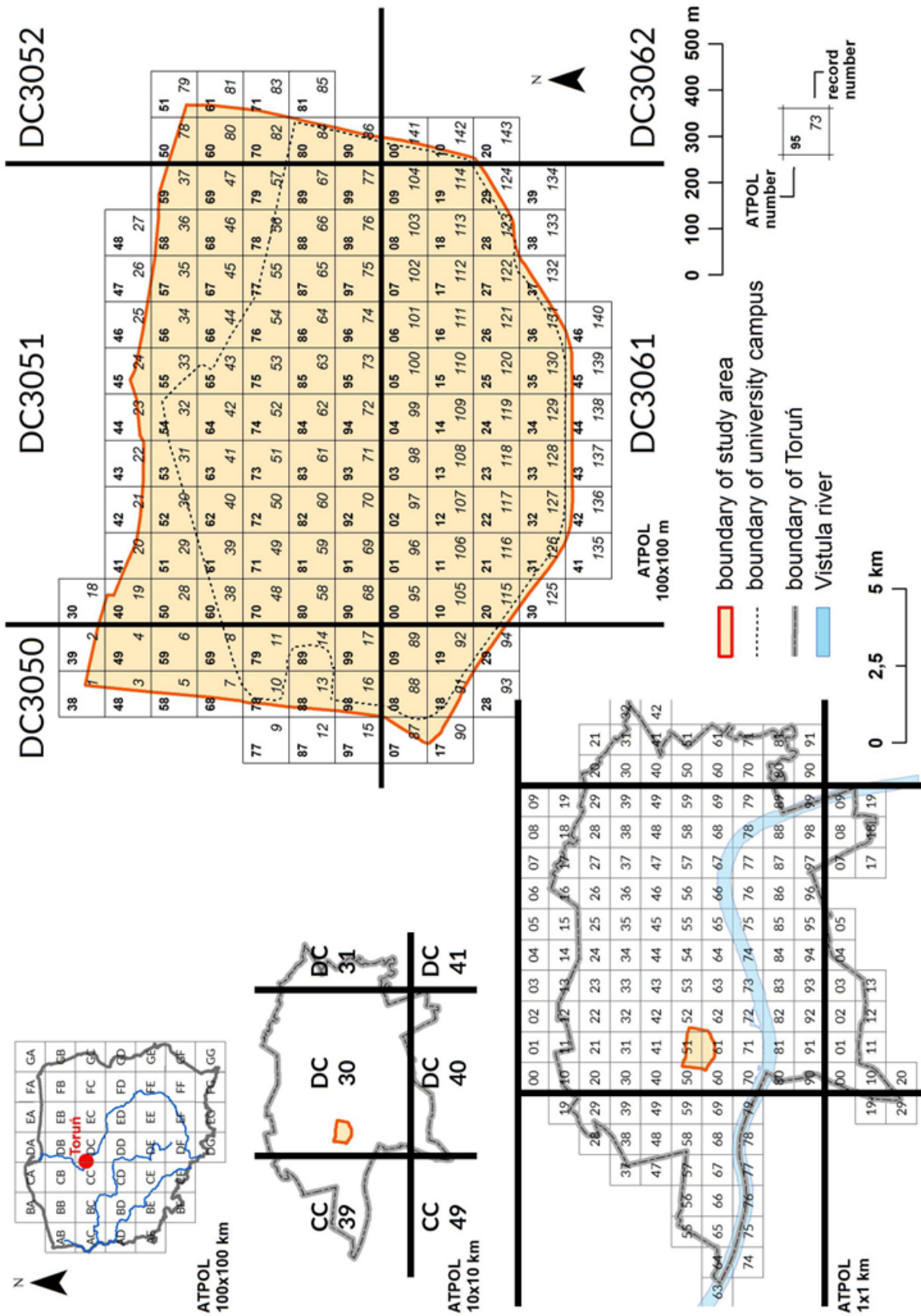


Fig. 1. Location of the study area on a map of Poland and the city of Toruń covered with ATPOL square
Source: author's own elaboration

of the Ludwik Rydygier Provincial Hospital built in the 1960s. Forests grow on the most fertile habitats throughout the study area. The old forest stand of the park is dominated by small-leaved lime trees, Norway maple trees, ash-leaved maples and sycamores. The circumference of some lime tree specimens exceeds 6 m. In the southern part of the complex, adjacent to Grunwaldzka Street, there are numerous specimens of black locust and field maple *Acer campestre*. Young specimens of *Salix x fragilis* grow in the strip of greenery covering the excavations of the sewage collector running along the street.

Along Okrężna Street, which follows the route of a former rocade road connecting the forts and shelters of the former Prussian fortress of Thorn, there are allotment gardens on the western side and a strip of pine trees several decades old surrounding the nearby airfield. Before World War II, this area was completely devoid of trees. Today, old maple trees grow along the fortification road leading from Okrężna Street to Fort VIII. Stately Norway maples and black locusts grow near the infantry bunker and artillery bunker located at the intersection of Gagarina Street and Okrężna Street, and on the earth mounds resting on bunkers' ceilings. On the eastern side of Okrężna Street, there is a 40 m wide strip of trees dominated by Norway maples, accompanied by sparse field maples and single specimens of *Populus x canadensis*.

The strip of roadside woodland is bordered by wasteland. Dry grasslands and shrubs of wild rose, blackthorn, hawthorn, and common lilac dominate there, with small clusters of tall trees. Debris from demolished buildings lie scattered in many places. This area has been used for many years by construction and hydrotechnical companies erecting university buildings and installing sewage collectors to drain treated sewage from industrial plants in the eastern part of the city. Wild fruit trees, mainly *Malus domestica* apple trees, grow among the piles of rubble from makeshift buildings. The area is designated for the construction of a cross-city route along the existing Grunwaldzka Street, only a small section of which is paved. However, the start date of the investment is constantly being postponed.

The central part of the study area is covered with pine forests with wild black cherry trees in the undergrowth. Other deciduous tree species, mainly Norway maples and pedunculate oaks, grow along roads that cut through the forest and in the western part of the forest complex. The area is used for recreational purposes by the residents of Toruń. The average annual air temperature in this part of the city between 1991 and 2012 was 8.6°C, and the total annual sunshine duration reached approximately 1,650 h. Average annual precipitation ranged from 520 mm to 540

mm, and the average annual air humidity was 78–79% (*Atlas województwa kujawsko-pomorskiego*, 2015).

3. Methods

Observations were conducted between 2022 and 2024. The distribution of mistletoe hosts in the study area was investigated during the winter months. During this period, evergreen clumps of mistletoe were easily observed on the leafless trees. The taxonomic affiliation and diameter at breast height of the hosts, as well as the abundance of the hemiparasite on infected trees were determined. If two or more generative or vegetative mistletoe shoots, usually of very different sizes, grew from the same thickening of the host trunk or branch, they were treated as adventitious shoots and recorded as a single organism (so-called cluster). A Garmin GPSMap 66s location device was used to determine tree coordinates. An up-to-date orthophotomap was also used to accurately determine the location of each trunk. The taxonomic identification of the hosts was verified during the flowering and full foliage stages of the trees. The nomenclature of taxa follows Seneta et al. (2021).

The collected data were processed and the results were visualised using ArcGIS – ArcMap ver. 10.4 software (Esri). After exploring the entire area, a first summary table of results was prepared, including a list of hosts, the number of records of each taxon in 143 squares, and the frequency of its occurrence in these squares expressed in %. The table also provides the total number of hosts of each species, as well as the total number of mistletoe specimens on each host taxon and the average number of mistletoes occurring on a single tree of each taxon. The order of taxa in the table is given according to the decreasing importance value, which was calculated for each host as the sum of its relative abundance, relative number of records in the 143 squares and relative number of mistletoe specimens occurring on trees classified as belonging to that host. The relative values of each of the three parameters were calculated as a percentage of the total value obtained for all host taxa. Histograms of mistletoe abundance in tree thickness classes were drawn up for the three host taxa with the highest importance value.

The second summary table provided a dataset for numerical classification and ordination. It contained information on the taxonomic composition of mistletoe hosts and the abundance of each taxon across 143 plots of 100 x 100 m. The squares were numbered in the order in which the records were loaded, in accordance with the rules applied in the ATPOL system (Zajac & Zajac, 2001). This is illustrated in Figure 1.

Maps showing the abundance and species diversity of mistletoe hosts in each square were prepared using GIS technology. Similarities between squares in terms of the occurrence of mistletoe hosts were determined using Ward's method and PAST 4.16c software (Hammer et al., 2001).

In order to determine the effect of various factors on the occurrence of mistletoe, a numerical ordination was carried out on 143 squares, characterised by the species composition of hosts and the abundance of their infestation by common mistletoe. Biological and environmental factors determining the species composition and abundance of mistletoe were expressed using the following 10 additional characteristics describing each square:

1. Educational buildings with sports and recreational areas with landscaped greenery and religious buildings with park greenery (*edu*);
2. High-rise multi-family residential buildings with commercial facilities and green areas (*hmb*);
3. Forests dominated by deciduous trees (*fdt*);
4. Wastelands with grasslands and scattered young trees (*gst*);
5. Main transport routes (streets and tram tracks running alongside them) with low greenery and rows of trees, length expressed in metres (*spl*);
6. Distance from the source of infection, i.e. from the centre of the square to the nearest old tree (usually Canadian poplars, Norway maples) heavily infested with mistletoe, expressed in metres (*dsi*);
7. Average tree trunk diameter at a height of 1.3 m, expressed in cm (*dbh*);
8. Number of trunk thickness classes (*ntc*);
9. Susceptibility of trees to mistletoe infection (*sti*);
10. Number of deciduous tree taxa per square (*div*).

Characteristics defining the landscape structure, i.e. land use/land cover (LU/LC), lengths of transport routes and distances from old trees in squares were obtained from OpenStreetMap (OSM) resources for the city of Toruń.

The susceptibility of trees to mistletoe infection was defined as the percentage of infected trees of a given host taxon to the total number of trees of that taxon occurring in the study area. For *Acer platanoides*, *A. dasycarpum*, *Tilia cordata*, *Robinia pseudoacacia*, *Populus × canadensis*, *Sorbus aucuparia*, and *S. intermedia*, these values were calculated based on previous observations conducted in Toruń and the Kujawsko-Pomorskie Province. For the remaining taxa were obtained from the literature, mainly addressing the spread of mistletoe infection in the palace park in Lednice, Moravia (Buliř,

2017). The value of the *sti* characteristic for a square was defined as the sum of these percentage values for all infested trees of each taxon occurring in that square.

The numerical ordination of squares based on the composition and abundance of mistletoe hosts and environmental parameters was performed using the CCA (Canonical Correspondence Analysis) method with forward selection and Monte Carlo permutation test procedures. The calculations were performed using Canoco 5.0 (ter Braak & Šmilauer, 2012).

4. Results

4.1. Mistletoe hosts in the study area

A total of 1,140 trees infected with common mistletoe, belonging to 31 taxa, including four species, four hybrids and three cultivars, were recorded throughout the study area (Table 1). There were 13 native host taxa and 18 taxa of alien origin. The host taxa belonged to seven families. The most numerous families were Rosaceae (11 taxa), Sapindaceae (7) and Salicaceae (6). A total of 7,519 mistletoe individuals were recorded on infected trees.

Slightly more than half of the infected trees (584, i.e. 51.23%) were specimens of *Acer platanoides*. The importance value of this species was 133.43. *Robinia pseudoacacia* ranked second in terms of the number of infected trees, their percentage in the total number of hosts and the importance index, with values of 231, 20.26% and 52.21, respectively, followed by *Tilia cordata*, with 133, 11.67% and 42.09, respectively. The number of infected trees belonging to the next four taxa on the list (*Acer campestre*, *Crataegus monogyna*, *Populus × canadensis*, *Sorbus aucuparia*) ranged from 16 to 46, i.e. did not exceed 5% of the total number of infected trees (Fig. 2).

The number of trees infected with mistletoe in each of the remaining 24 taxa was less than 10 (Table 1). In the case of seven taxa, only one tree was infected. Among these seven taxa were rare host species of common mistletoe, such as *Laburnum anagyroides* and *Quercus robur*. The former, with a single mistletoe shrub, grows on the university campus within ATPOL square DC306019 (square No. 92 in the sequence of consecutive squares), while the pedunculate oak, infested with five mistletoe shrubs, is located on the opposite side of the study area, and outside the university campus, within ATPOL square DC305250 or No.78 in the sequence of consecutive squares (Fig. 1). This oak tree, with a DBH of 64.5 cm, grows in an old park on the grounds of the Toruń waterworks. The site is located on the slope of a historical bunker that protected the

former water intake system for the northwestern part of the city. Mistletoe shrubs grow in the upper part of the tree crown on thinner branch tips. In the vicinity of the bunker, there is a one dying specimen of horse chestnut *Aesculus hippocastanum* with three withering shrubs of mistletoe. A rare host species, represented in our study

area by a single infected tree, is *Pyrus communis*. This specimen was observed in the northeastern part of the study area, outside the university campus, on the edge of a former garden converted into a storage site.

Prunus serotina, *Acer negundo*, *Sorbus mougeotii* and *Crataegus nigra* are rare mistletoe hosts, with two,

Table 1. Hosts of the European mistletoe in the study area according to their importance values and other characteristics

No.	Name of host taxon	Importance value	Number of host squares by taxon	Attendance in 143 squares [%]	Number of mistletoes cluster	Number of trees	Average number of mistletoes per tree
1.	<i>Acer platanoides</i> L.	133.43	52	36.36	4264	584	7.30
2.	<i>Robinia pseudoacacia</i> L.	52.21	40	27.97	928	231	4.00
3.	<i>Tilia cordata</i> Mill.	42.10	31	21.68	1145	133	8.61
4.	<i>Populus ×canadensis</i> Moench	10.95	10	6.99	336	18	18.67
5.	<i>Acer campestre</i> L.	10.72	7	4.90	245	46	5.33
6.	<i>Crataegus monogyna</i> Jacq.	7.89	8	5.59	87	32	2.72
7.	<i>Sorbus aucuparia</i> L.	5.78	7	4.90	71	16	4.44
8.	<i>Populus simonii</i> Carrière 'Fastigiata'	4.01	5	3.50	58	9	6.44
9.	<i>Salix alba</i> L.	3.00	5	3.50	57	9	6.33
10.	<i>Sorbus intermedia</i> (Ehrh.) Pers. (= <i>Scandosorbus intermedia</i> (Ehrh.) Sennikov)	3.55	5	3.50	23	9	2.56
11.	<i>Acer saccharinum</i> L. 'Laciniatum Wieri'	2.78	2	1.40	96	6	16.00
12.	<i>Acer pseudoplatanus</i> L.	2.40	3	2.10	37	5	7.40
13.	<i>Betula pendula</i> Roth	2.12	3	2.10	22	4	5.50
14.	<i>Prunus cerasifera</i> Ehrh.	1.89	3	2.10	5	4	1.25
15.	<i>Crataegus laevigata</i> (Poir.) DC.	1.39	2	1.40	18	2	9.00
16.	<i>Acer negundo</i> L.	1.31	2	1.40	5	3	1.67
17.	<i>Malus domestica</i> (Suckow) Borkh.	1.31	2	1.40	5	3	1.67
18.	<i>Tilia platyphyllos</i> Scop.	1.30	1	0.70	48	2	24.00
19.	<i>Tilia ×europaea</i> L.	1.24	2	1.40	6	2	3.00
20.	<i>Salix ×pendulina</i> nothof. <i>xsalamonii</i> (Carrière) I.V.Belyaeva	1.20	2	1.40	3	2	1.50
21.	<i>Prunus serotina</i> Ehrh.	1.18	2	1.40	2	2	1.00
22.	<i>Crataegus nigra</i> Waldst. & Kit.	1.04	1	0.70	15	4	3.75
23.	<i>Sorbus mougeotii</i> Soy.-Will. & Godr. (= <i>Hedlundia mougeotii</i> (Soy.-Will. & Godr.) Sennikov & Kurtto)	0.95	1	0.70	15	3	5.00
24.	<i>Populus alba</i> L.	0.95	1	0.70	8	4	2.00
25.	<i>Pyrus communis</i> L.	0.64	1	0.70	5	1	5.00
26.	<i>Quercus robur</i> L.	0.64	1	0.70	5	1	5.00
27.	<i>Salix ×fragilis</i> L.	0.63	1	0.70	4	1	4.00
28.	<i>Aesculus hippocastanum</i> L.	0.62	1	0.70	3	1	3.00
29.	<i>Acer saccharinum</i> L.	0.59	1	0.70	1	1	1.00
30.	<i>Laburnum anagyroides</i> Medik.	0.59	1	0.70	1	1	1.00
31.	<i>Prunus cerasifera</i> Ehrh. 'Woodii'	0.59	1	0.70	1	1	1.00
Total			204		7519	1140	

Source: author's own elaboration

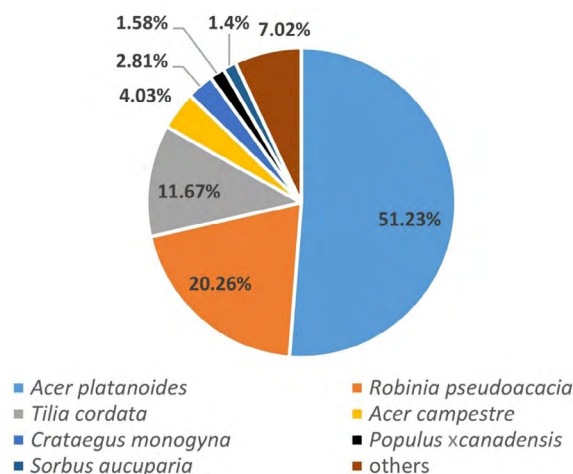


Fig. 2. The spectrum of host plant taxa of *Viscum album* subsp. *album* in the study area. Percentage ratio of plant taxa out of the total number of trees affected by mistletoe

Source: author's own calculations

three, three, and four mistletoe-infested trees in the study area, respectively (Table 1). Trees of the first two species grow in poor habitats, in areas previously disturbed by excavation and the storage of construction materials. Today, these sites are sparsely overgrown with xerothermic grasses and scattered trees.

The infected trees of the two other species grow in green areas near the university's educational buildings. The *Sorbus maugotii* specimens are estimated to be approximately 20 years old and 3–4.5 m tall. The infected *Crataegus nigra* trees, along with numerous uninfected ones, formed a hedge approximately 1.2 m high along the path. Near the section of the hedge containing the infected trees, a tall silver birch *Betula pendula* infested with mistletoe grew.

Of the three most infected taxa, *Tilia cordata* showed the greatest range of DBH variability. Only specimens of this species were recorded in 14 distinguished trunk thickness classes, including the highest range of 106.1–112 cm (Fig. 3). The largest number of mistletoe shrubs on trees of this species was recorded in the 52.1–58 cm DBH range. In the case of *Acer platanoides* and *Robinia pseudoacacia*, the largest number of mistletoe shrubs per tree was recorded in the 70.1–76 cm DBH class. Figure 3 shows that in almost all DBH classes, the number of mistletoe per *Robinia pseudoacacia* tree was usually lower than the corresponding values for *Acer platanoides* and *Tilia cordata*. The latter host reached higher values than the other two in the lowest DBH classes. In the higher DBH classes, the largest number of mistletoe shrubs per tree was found on *Acer platanoides*. The average number of mistletoes

for all infected trees of the compared hosts was 4.02 for *Robinia pseudoacacia*, 7.3 for *Acer pseudoplatanus* and 8.61 for *Tilia cordata* (Table 1).

4.2. Distribution of hosts in the ATPOL grid

Trees infected with mistletoe were found in 85 squares, which accounted for 59.44% of the total number of 143 squares. Squares with infected trees were located in the peripheral part of the study area. The central part, where the pine forest occurs, was completely devoid of them (Fig. 4). Between one and seven host taxa were found in the squares with mistletoe. The maximum number of seven hosts was recorded in three squares, and five host taxa occurred in six squares. Four taxa were recorded in nine squares, three in 14 squares, two in 21 squares, and one in 32 squares. The number of trees infected with mistletoe ranged from 1 to 80 per square. There were 42 squares with one to three trees, 21 squares with 4 to 15 trees, and 19 squares with 16 to 63 trees. Three squares with more than 63 infected trees were recorded.

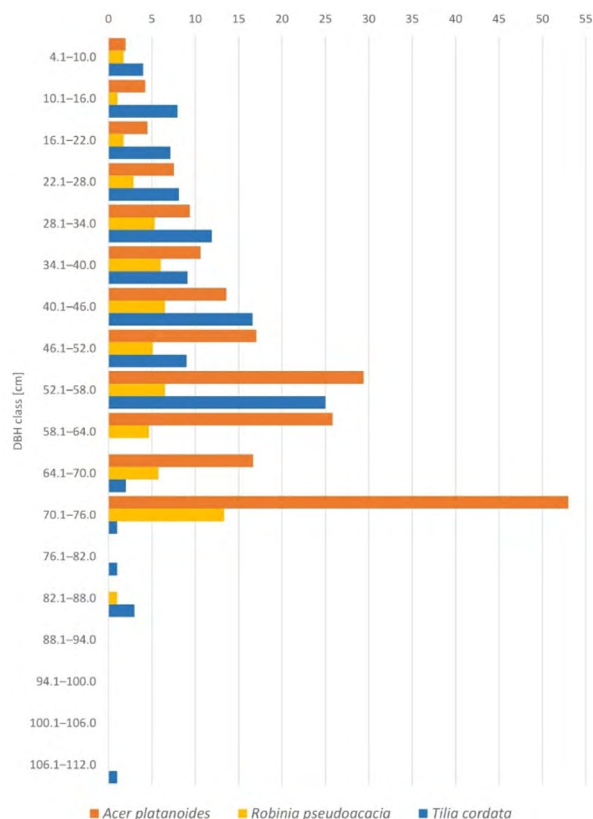


Fig. 3. Number of trees of the three dominant host taxa in DBH classes

Source: author's own elaboration

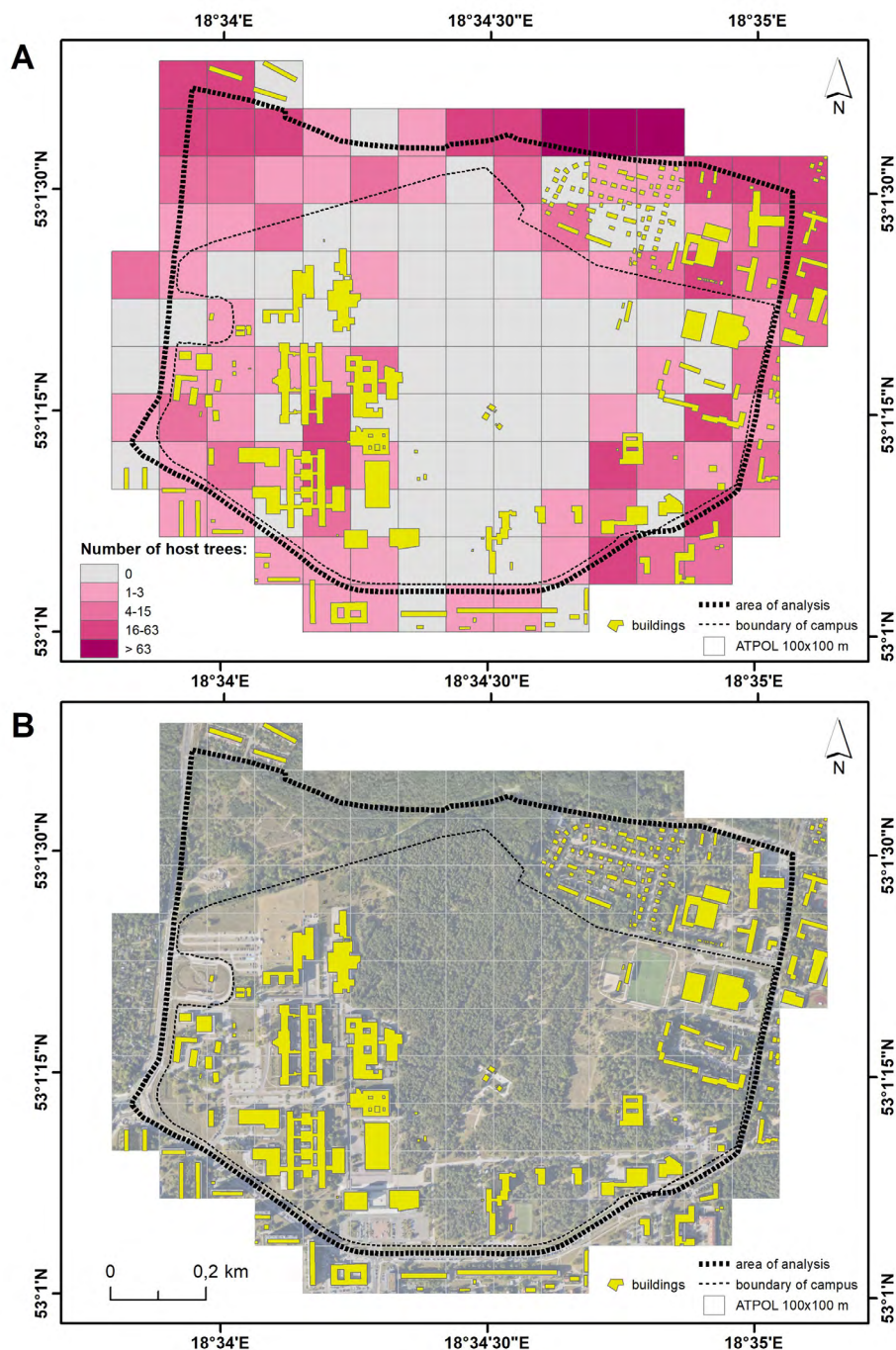


Fig. 4. **A.** Number of host trees in individual 100 x 100 m squares; **B.** spatial variation of land use/cover (LULC) presented on aerial orthophotomap
Source: author's own elaboration

Squares with the highest number of trees infected with mistletoe were found in the northern part of the study area (Fig. 4). In the peripheral zone, only two of them were free of infected trees. A fairly large number of trees infested with mistletoe were also recorded in several squares located on the NCU

campus. These were squares covering the green areas around the buildings of the Faculties of Biology and Environmental Protection, Earth Sciences and Chemistry in the SW part of the study area. In the SE part, these were squares covering green areas around the buildings of the Faculty of Psychology

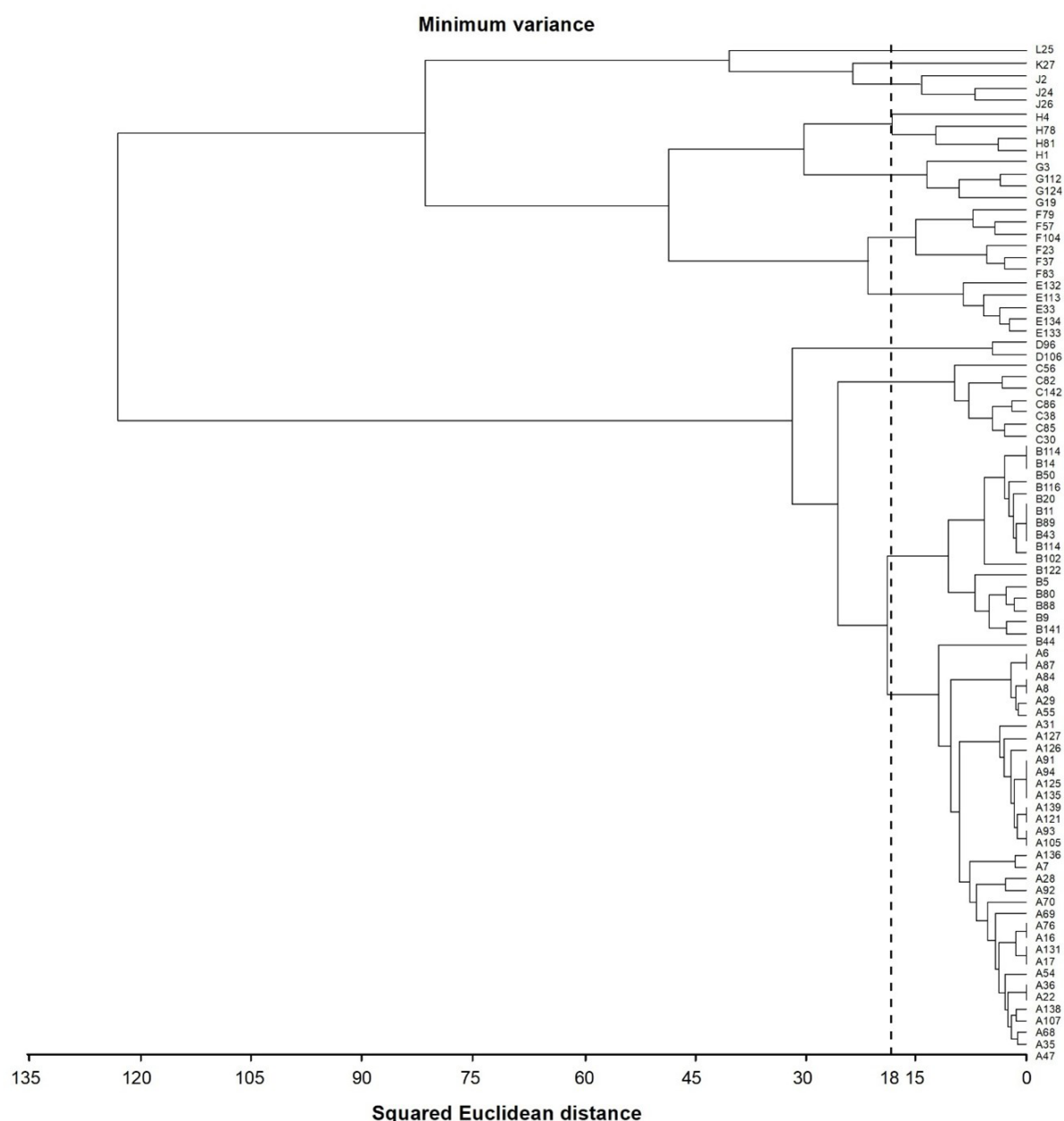


Fig. 5. Hierarchical classification of 143 squares according to taxonomic composition and the abundance of individual hosts. The dashed line indicates a distance level of 18, at which 11 groups of squares were distinguished. The letters in the labels of the squares indicate which group they belong to (A–L), whereas the numbers denote the order of the records as the data were loaded

Source: author's own elaboration

and deciduous forests dominated by *Acer platanoides* and *Robinia pseudoacacia* growing on the dunes surrounding the 'Universitas' housing estate from the south. In other squares located in this part of the campus, there were usually 1–3 infected trees. Among them, specimens of the most common host taxa prevailed, but there were also non-native taxa represented by a small number of individuals. Squares

without mistletoe were observed in the central part of the campus and other sites of the study area, where pine forests dominate.

The differentiation of our study area into two very distinct parts was confirmed by the results of the numerical classification of 85 squares with mistletoe hosts and the analysis of the spatial distribution of squares assigned to the distinguished groups. Ward's

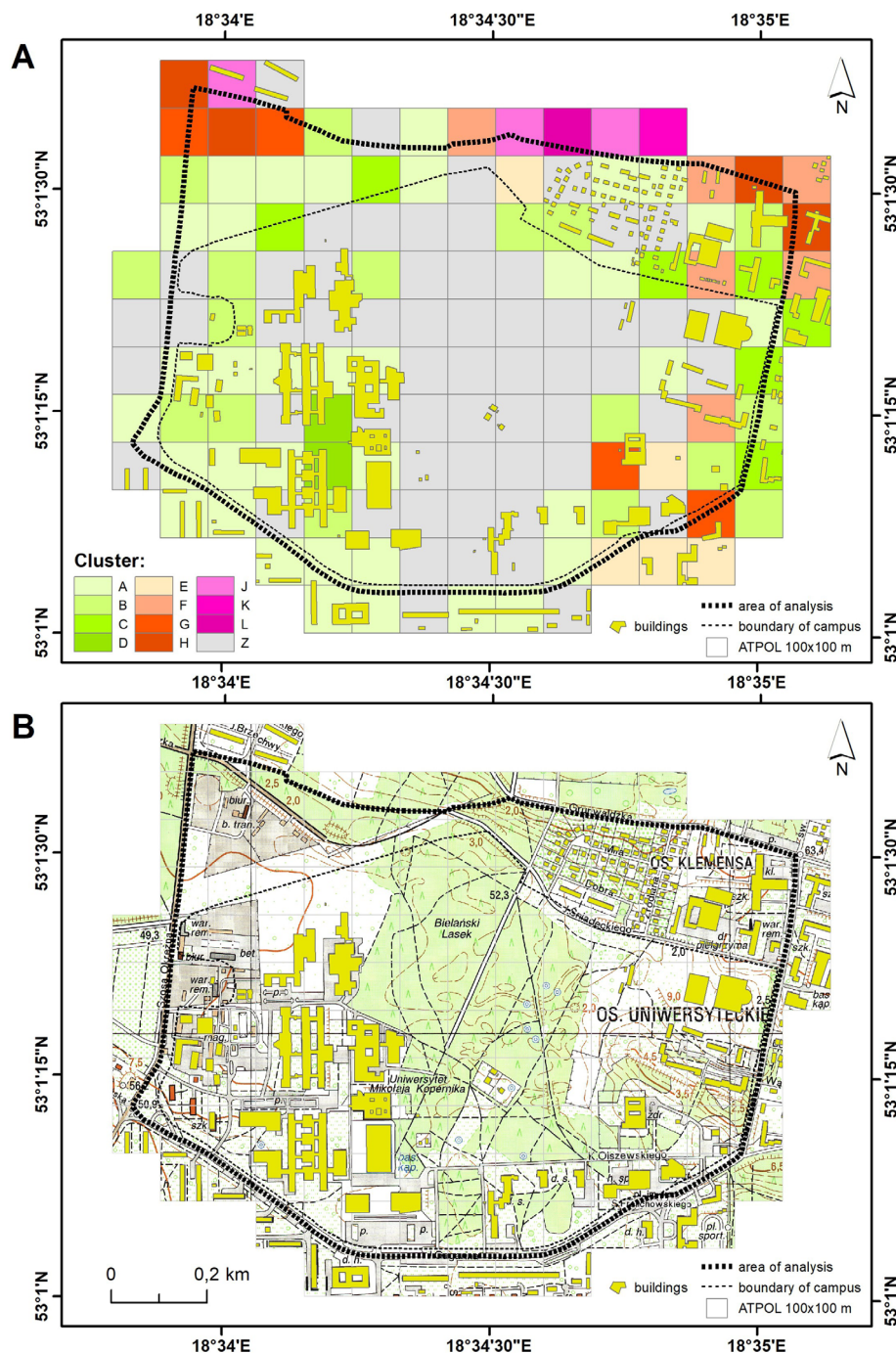


Fig. 6. A. Spatial distribution of squares belonging to the 11 groups distinguished in the numerical classification in the study area to group Z, which includes squares without the presence of mistletoe; B. of land use/cover (LULC) presented on the topographic map
Source: author's own elaboration

dendrogram presented in Figure 5 shows two subsets at the highest fusion level, differing in the number of hosts in the squares. In the larger subset, containing 61 elements, the number of infected trees in a square ranged from 1 to 21, with an average of 4.39. In the second subset, comprising only 24 elements, the

number of infected trees ranged from 12 to 80, with an average of 36.33.

Eleven groups were distinguished at a distance level of 18 in the dendrogram (Fig. 5). The first subset consisted of four groups labelled A, B, C, D. The average number of taxa per square was 1.46, 1.94,

2.57, and 4.0, respectively, and the average number of infected trees was 2.17, 5.0, 9.57 and 20.0, respectively. The smaller set was more diverse, comprising seven groups designated as follows: E, F, G, H, J, K, L, the last two of which were single-element sets. The average number of taxa per square ranged from 3.0 in group L to 5.75 in H, and the average number of infected trees ranged from 15 in E to 80 in group L.

Squares from groups A–D are located mainly in the southern and western parts of the study area. Squares belonging to groups E–L are located mainly on the northern and north-eastern edge of the study area and only a few in the south-eastern part (Fig. 6).

4.3. Factors determining the occurrence of mistletoe

Numerical ordination carried out using the CANOCO programme showed that, of the 10 landscape structure and biotic host characteristics considered, two were significant – i.e. the percentage of greenery around educational facilities located within a given square (*edu*) and the diameter at breast height (*dbh*). The vectors indicating the direction of influence of these two variables are marked in red in Figure 7. Both variables, which are significant for the variance of the analysed dataset (according to the Monte Carlo permutation test, $p < 0.05$), together account for 4.2% of the total variance of the analysed dataset. All variables used in the analysis account for only 14.5% of the total variation.

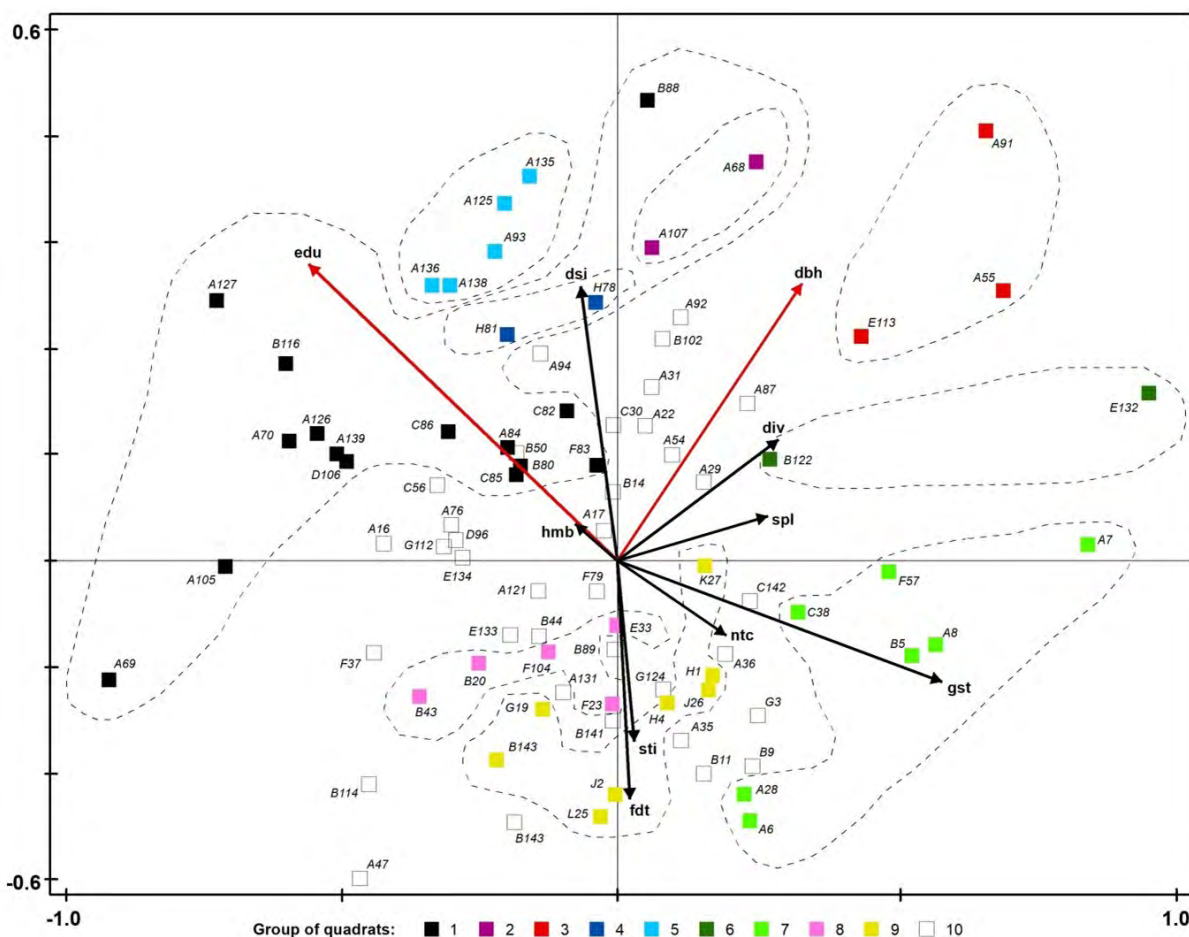


Fig. 7. Distribution of the squares relative to ordination axes I and II and the vectors representing the influence of landscape, environmental, and biological variables. The vectors indicating the direction of influence of the significant variables are marked in red. The letter symbols and the numbers of the squares are the same as in Figure 5. Colours 1–9 denote squares whose dominant feature corresponds to the symbol and direction of the corresponding vector; the number 10 is assigned to squares whose dominant feature does not correspond to the sign and direction of any vector. Detailed explanations are provided in the text

Source: author's own elaboration

The clouds of squares that were significantly characterised by the characteristic expressed by the vector directed towards them or located in their vicinity are encircled in the ordination diagram (Fig. 7) by dotted lines. The squares in the diagram have been assigned letter symbols corresponding to the groups/clusters distinguished in the numerical classification. The figure shows that squares marked with the same letter are located in different 'clouds' of squares, and conversely, squares marked with different letters are located in the same cloud. This means that squares with similar composition and abundance of taxa occur in different environmental conditions, and in similar combinations of ecological factors of squares,

the taxonomic structure may vary. Some clouds are very large, as indicated by the *edu* vector. This may be caused by the strong influence of another factor on a square with a predominance of green spaces in the land cover / land use structure. An example is the cloud covering squares A68 and A107 in the upper part of the diagram (Fig. 7), which, in addition to a high proportion of greenery in educational zones in the LU/LC structure, are characterised by large *dbh*. Squares H78 and H81, in addition to a high proportion of *edu*, are characterised by high taxonomic richness of potential hosts (each containing seven taxa) and a high *ntc* index (9 and 8 DBH classes, respectively).

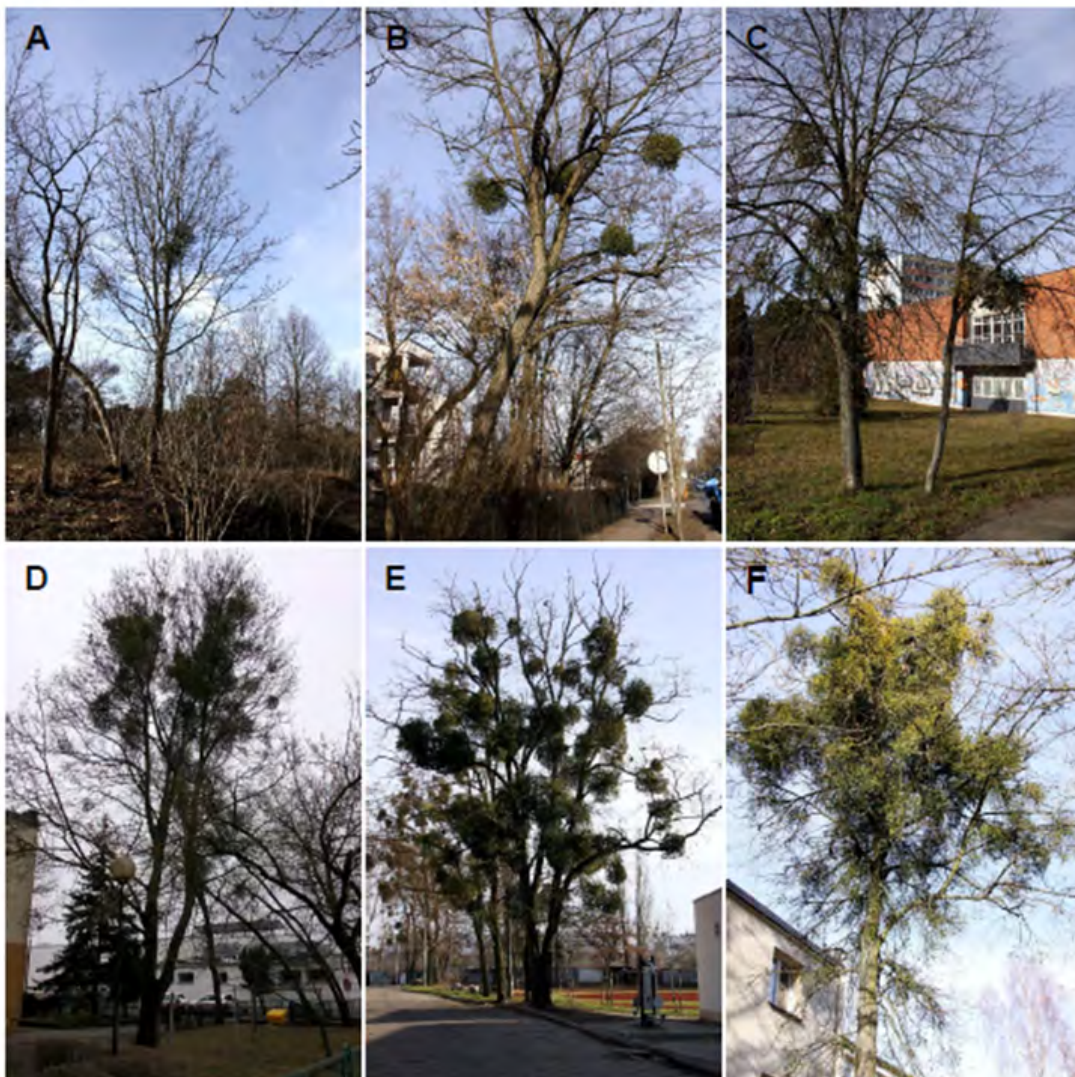


Fig. 8. Abundance of mistletoe typical form on trees of three dominant host species, *Acer platanoides*, *Robinia pseudoacacia* and *Tilia cordata*, growing in younger (A, B, C, respectively) and old (D, E, F) greenery in educational zones

Source: photo by Mieczysław Kunz

The distribution of squares within the extensive cloud indicated by the *edu* vector suggests that the period of their allocation to the 'educational areas' category has an indirect influence on their high degree of variation. In areas with recently constructed educational buildings and established greenery, there is a higher proportion of short trees with low DBH values and a low degree of mistletoe infestation than in older areas (Fig. 8). There are also fast-growing poplars with high values for both parameters, which increases the diversity of DBH classes. Plots located in the zones of older educational facilities have lower species diversity and high *edu* values. Younger green areas are characterised by greater diversity of observed and potential host taxa. Among these, non-native tree and shrub species account for a larger proportion.

The cloud to the right of the *edu* vector, covering squares A93, A125, A135, A136 and A138, is characterised by the highest proportions of residential areas in the entire set of squares, including buildings and the accompanying greenery zones (*hmb* factor), and the largest distances from old trees heavily infested with mistletoe (*dsi* factor). The *hmb* vector expressing the direction of the impact of this factor in the studied ordination space is the shortest among the ten vectors of the ecological factors considered (Fig. 7).

The deviation of the cloud of squares A55, A91 and E113, which are characterised by the highest mean *dbh* values in the entire set of 85 squares, to the right of the direction of the impact of this factor may be caused by a relatively large area of unused meadows and grasslands with single old trees or small clumps of young trees scattered throughout (*gst* factor).

Among the 35 squares for which it was impossible to determine the dominant factor, the squares classified in the numerical classification into groups A, B, C and D, characterised by a small number of taxa and trees infected with mistletoe, predominated – 27 squares in total. The remaining eight squares belonged to groups with a large number of hosts and their taxa: E, F, G. These 35 squares are located in the central part of the ordination diagram (Fig. 7).

5. Discussion

5.1. Abundance of mistletoe and its hosts

The density of typical common mistletoe hosts, at 797 trees/km², is very high within our 1.43 km² study area, which covers the NCU campus and its immediate surroundings. This figure exceeds the values previously reported in ecological literature for areas

in Poland with the highest abundance of hosts for this mistletoe subspecies. These areas include two sites in Gdańsk on the Baltic coast. The Gdańsk I site covers an area of 7.5 km², is home to 25,600 inhabitants, and is rich in parks, front gardens, residential green spaces and street-side greenery in the districts of Oliwa, VII Dwór and Strzyża. In these districts, characterised by a predominance of low-rise historic villa development, the density of mistletoe hosts was 467 trees/km² (Chojnacki, 2019). The density was therefore 330 trees/km² lower than in our study area. However, the taxonomic richness of mistletoe hosts was significantly higher at the Gdańsk I site, amounting to 46 taxa compared to the 31 recorded in the study area in Toruń. The mistletoe density at Gdańsk I was as high as 10,537 individuals per km² (Chojnacki, 2019). It was therefore twice as high as in our study area (5258 animals/km²). The high density of mistletoe was likely due to the abundance of old trees, native species and non-native species introduced particularly in the 19th century. According to Chojnacki (2019), Gdańsk's location on a bird migration route also contributed to the high abundance of mistletoe in this area. Another factor is the higher rainfall and air humidity in Gdańsk compared to Toruń.

At our study site in Toruń, the factor most strongly promoting mistletoe abundance – namely, the presence of old trees in historic parks – was found in several plots located in the northern part of the site. Amidst the lush greenery, however, there are only a few scattered buildings, whose presence would have displaced the tree vegetation. As a result, a dense undergrowth of Norway maple has developed, which is susceptible to severe mistletoe infestation. The seeds of this semi-parasite are spread via the droppings of birds perching on tall, old lime trees, black locusts and poplars scattered throughout the upper canopy of the established woods.

At the Gdańsk II site, which covers districts characterised by a predominance of high-rise, multi-unit housing blocks in the districts of Żabianka, Jelitkowo, Przymorze and Zaspą Młyniec, the host tree density was lower (421 trees/km²). The number of host taxa was the same as at the Gdańsk I site (46 taxa), but the mistletoe density per unit area was approximately 31% lower than at Gdańsk I, amounting to 6,561 individuals/km², which was 1,303 individuals/km² fewer than in the study area in Toruń.

Our results are among the highest values reported in the ecological literature for study sites of a similar size with abundant woody vegetation, such as parks, forest edges and cemeteries. The number of host trees per unit area determined in our study is closest to the figure of 801 host trees per km² reported by Bulř (2017) for the Lednice Chateau Park in South

Moravia, the Czech Republic, which covers an area of 1.7 km². However, the number of host taxa was significantly higher in the Lednice Chateau Park, amounting to 42 compared to 31 found in our study area. Such large differences in species richness are due to the park's location in South Moravia, i.e. in a different biogeographical region, which Bulíř (2017, after Slavík 1988) describes as the area of Pannonian thermophyticum. The park and its closest surroundings is part of Lednice-Valtice Cultural Landscape entered on the UNESCO World Heritage List. In this locality, there is probably the highest density of the European mistletoe occurrence and also the greatest number of potential host species in the Czech Republic (Prochazka, 2004; Bulíř, 2017). The second reason lies in the park's long-term management history, during which, over several centuries, efforts were made to introduce exotic species of trees and shrubs. As reported by Zachwatowicz et al. (2008), based on observations carried out in the central part of Warsaw and cited data from various European cities, non-native species are exceptionally susceptible to infection by European mistletoe and increase the taxonomic diversity of mistletoe hosts in urban areas.

The differences in taxonomic richness between the study site in Toruń and the park in Lednice may be even greater, as the data for the latter site relate to the situation in 2016. The time gap between the sites being compared was eight years, and the spread of European mistletoe in South Moravia is a very dynamic process. Bulíř (2017) reports that between 1985 and 2016, i.e. over a period of 31 years, as many as 18 new host species of mistletoe were recorded in the park. Sobolewski et al. (2026) also discuss the increase in recent years in the number of mistletoe host species in historic parks, based on observations made in Wrocław.

In the historic Olexandria Park in Bila Tserkva (approximately 85 km south of Kyiv), the density of mistletoe and its host trees is significantly lower than in the park in Lednice. The park covers an area of 2.97 km² and currently operates as a dendrological park of the National Academy of Sciences of Ukraine. Galkin et al. (2017) observed European mistletoe on 781 trees belonging to 28 taxa. The number of infected trees accounted for only 4.6% of all trees. In the chateau park in Lednice, the proportion of infected trees reached 30.6% (Bulíř, 2017).

Cemeteries are among the sites with an exceptionally high occurrence of mistletoe. Based on data published by Więclaw & Ciaciura (1997), we calculated that at the Central Cemetery in Szczecin, covering an area of 1.72 km², both the density of mistletoe (5,907 individuals/km²) and that of its hosts (1,185 trees/km²) were significantly higher than in the study area

in Toruń. The number of taxa represented by infected trees in the reference area in Szczecin was, however, lower than in our study area (31 taxa).

Boratyński and Piórkowska (2003) reported that, across almost half of the surveyed sites in the town of Grudziądz (total area 59.3 km², approximately 100,000 inhabitants), the most frequently infected sites included parks, forest edges and cemeteries. These land-use and land-cover types were predominant at 45.1% of the sites surveyed. Mistletoe was also frequently found in areas with low-rise buildings and numerous tree-lined avenues (37.9% of sites). Sites comprising open areas with isolated buildings and sparse tree cover accounted for 9.9%; new high-rise developments with few trees accounted for 5.9%, while sites in the city centre with old, dense high-rise development and trees only along wide streets accounted for just 1.2%. Similar correlations between mistletoe occurrence and land cover were observed in the small town of Praszka, with a total area of 9.45 km² and approximately 9,000 inhabitants (Gołabek & Sławiński, 2017).

5.2. Taxonomic structure of hosts and differences in mistletoe abundance on their trees

The four taxa that dominated among mistletoe hosts on the NCU campus and its surroundings, i.e. *Acer platanoides*, *Robinia pseudoacacia*, *Tilia cordata* and *Populus ×canadensis*, also frequently occupied the top positions on the lists of hosts compiled for the compared areas. *Acer platanoides* and *Tilia cordata* ranked first and second at the sites in Gdańsk. The other two taxa ranked slightly lower on this list – *P. ×canadensis* fifth and third, while *R. pseudoacacia* sixth and seventh, respectively. All four taxa, on the other hand, opened the list of hosts for the city of Grudziądz, located less than 54 km north-east of our study area in a straight line. The order of taxa on this list was almost identical to that for our study area. Only *Tilia cordata* preceded *Robinia pseudoacacia* in Grudziądz (Boratyński & Piórkowska, 2003).

These four host species accounted for 81.64% of all infected trees observed in Grudziądz, compared to 84.74% in Toruń. In the Krzyki district of Wrocław, based on data from Tomaszewska et al. (2004), the figure was estimated at 75.92%. At Gdańsk I and II, the proportion of these four species was already significantly lower (62.03% and 57.31% respectively). At the Central Cemetery in Szczecin, they accounted for only 6.23% (Więclaw & Ciaciura, 1997), but at cemeteries in Wrocław, 79.56% (Tomaszewska et al., 2004).

Four silver birch trees infested with mistletoe were found, which is a similar count to that recorded in

Gdańsk and Grudziądz – seven and four trees, respectively. This comparison shows that Toruń is located in an area with low occurrence of mistletoe on birch trees relative to other regions of Poland. This area covers the eastern part of Pomerania, the so-called Vistula Pomerania, as well as Kuyavia and the vicinity of Łódź in central Poland.

The abundance of mistletoe on small-leaved lime trees is also a characteristic that makes our study area similar to sites in other cities located on the Lower Vistula River, i.e. Grudziądz and Gdańsk.

In our study area, the tree species that is easily colonised by mistletoe is *Robinia pseudoacacia*. At our locality, as in Gdańsk, it is more difficult to find black locust trees without mistletoe than with mistletoe. As in Gdańsk, mistletoe shrubs on black locust trees were usually spherical and dense, and mainly located in the upper part of the crowns (Chojnacki, 2019). The relative abundance of black locust among all mistletoe hosts in our study area was 20.26%, compared to 10.50% in Grudziądz and 3.27% in Gdańsk.

Among the host taxa that occurred in only a few specimens in our study area, several belonged to species rarely found in Poland. *Laburnum anagyroides*, *Sorbus mougeotti* Soy.-Will. & Godr. and *Crataegus nigra* Waldst. et Kit., have not been recorded in other Polish cities or towns. *Quercus robur*, *Prunus cerasifera* ‘Woodii’ and *Prunus serotina* were recorded among the host plants of mistletoe in Szczecin by Zieliński (1997), but these were observations made almost thirty years earlier.

Outside our area, *Acer negundo* infected with mistletoe occurs in Toruń at one other location. One and two trees occur at both sites analysed by Chojnacki (2019) in Gdańsk. Two infected trees were recorded in Grudziądz. All infected specimens of ash-leaved maple in our study area grew outside the forest where this species was extremely abundant. Trees infected with mistletoe grew alone in open areas with neglected lawns and storage yards, on poor and heavily dried soil. This observation is consistent with the hypothesis of Petrović et al. (2007) and Kołodziejek et al. (2013) that urban environmental conditions favour mistletoe infection of non-native hosts. This is also consistent with the observations made by Chojnacki (2019) in Gdańsk, namely that degraded soil compromises a tree's health and reduces its resistance to mistletoe infestation.

In general, the average number of mistletoe individuals per tree in our study area was lower than the values reported for Gdańsk. This relationship applied to the majority of taxa. In the case of the four dominant taxa, the average number of shrubs in both areas in Gdańsk was approximately 2–3 times higher than in our study area. In Grudziądz, twenty years earlier,

a larger number of mistletoe specimens than in the research area in Toruń was recorded only on *Acer platanoides*

In the campus area, around schools and kindergartens, the reason may be greater attention to greenery and human safety, including a significant reduction in the crowns of trees infested with mistletoe. An additional reason may be differences in the accuracy of counting the individuals of the hemiparasite by observers. Not everyone would be able to spot as many as 322 mistletoe shrubs on a single Canadian poplar tree, or 259 shrubs on a single Norway maple tree. Such maximum numbers of mistletoe on individual trees of these species are reported by Chojnacki (2020) for the second study area in Gdańsk, including seaside parks and the seaside promenade. When observing from the ground, many small mistletoe shrubs in particular may be overlooked. The results of research by Piętka et al. (2023) indicate how many of them may be missed. These researchers found that the number of mistletoe shrubs recorded on standing *Pinus sylvestris* trees from the ground level was significantly lower than that found on trees after felling.

5.3. Environmental and biological factors

Our research has also confirmed the findings of other authors (Więclaw & Ciaciura, 1997; Skrypnik et al., 2020; Thomas et al., 2023) indicating the widespread occurrence of mistletoe in parks. The park area near the Toruń waterworks is the site with the highest abundance of mistletoe across our entire study site. The park is covered by a single-layered, old-growth stand, dominated by tall, old trees with heavily reduced crowns, on which numerous, large clumps of mistletoe are found; there is, however, no understory. Consequently, we were able to observe birds here frequently and easily – primarily Mistle Thrushes (*Turdus viscivorus*) and Song Thrushes (*Turdus philomelos*) pecking at fallen mistletoe berries amongst the blades of grass. According to Skórka and Wójcik (2005), the wintering of these species in areas rich in mistletoe berries is a factor that potentially promotes the local intensification of seed dispersal and subsequent changes in the spatial distribution and abundance of this hemiparasite.

We did not observe any other uses of mistletoe by birds other than food, such as for roosting or nesting – as reported by Antczak et al. (2004) in western Poland – in our study area. We do, however, confirm the observations made by Zachwatowicz et al. (2008) regarding the rare occurrence of this

hemiparasite in allotment and backyard gardens, where it is zealously removed.

Numerical analysis showed that the occurrence of mistletoe in the study area is associated with educational zones, and more specifically with the greenery of these zones. This greenery abounds in numerous trees growing scattered or in loose groups. A significant proportion of these belong to alien species, and those growing in urban areas are, according to Petrović et al. (2007), particularly susceptible to mistletoe infection. This indicates that it is more rational to inventory mistletoe taking into account not only taxa and specimens of trees infected with mistletoe, but also those that are not infected, including, in particular, specimens of alien origin.

Among the alien tree species growing on the Campus, which are rarely mentioned in the literature as mistletoe hosts, specimens of species such as *Sorbus mougeotti* and *Crataegus nigra* were infected several years after planting. The squares in which the land use and land cover structure was dominated by the greenery of educational zones were characterised by high heterogeneity, as evidenced by their large dispersion in the ordination diagram (Fig. 4). The heterogeneity resulted from the varied age of the trees growing there. In general, the trees on the campus of Nicolaus Copernicus University, which was built to commemorate the 500th anniversary of the birth of the university's patron, Nicolaus Copernicus, in 1973, were younger than those on the grounds of other educational institutions. The grounds of technical and economic schools were developed over twenty years earlier. The trees planted around the Redemptorist church, built between 1958 and 1963, are mostly about ten years older than the trees on the university campus. Older trees are usually more frequently and heavily infected with mistletoe, as confirmed by the comparison presented in Figure 8. Despite growth limitations caused by infection, they are also characterised by larger DBH compared to younger trees. Squares with high *edu* values but also high average dbh values are located closer to the vector indicating the direction of the latter factor on the ordination diagram.

Skrypnik et al. (2020) report that PCA analysis of data from Królewiec revealed a strong correlation between tree age and air humidity and the degree of mistletoe infection. Zachwatowicz et al. (2008) also report that the higher level of mistletoe infection in older residential areas in the centre of Warsaw was due to the predominance of older trees in these locations. A similar relationship was observed in Gdańsk, Praszka, and Lednice (Baltazar et al., 2013; Varga et al., 2014; Gołabek & Sławiński, 2017; Chojnacki, 2019, 2020). Kołodziejek et al. (2013) in their study

on the occurrence of mistletoe in the Łódź area found that thicker trees are usually more infected, but this correlation is not statistically significant. According to these authors, the statistically significant parameter affecting the abundance of mistletoe is the height of trees.

This latter assessment, concerning the positive correlation between the infection rate and the host tree's height, is in contradiction with the results of statistical analyses by Kartoolinejad et al. (2007), who found that the abundance of *Viscum album* and the intensity of *Parrotia persica* infestation showed significant positive correlations with the host tree's diameter at breast height, the distance of infected trees from conspecifics, and the location at the forest stand edge, but did not observe significant correlations between the infection intensity and the height of host trees. However, the results obtained by Kartoolinejad et al. (2007) suggest that individual differences among host trees (especially DBH) play an important role in explaining the local abundance and distribution of mistletoe. Their results suggest that individual differences between host trees (especially DBH) play an important role in explaining the local abundance and distribution of mistletoe plants.

Our observations have shown that tree height can contribute to increasing the level of mistletoe infection in forest stands by increasing the number of tree layers, i.e. its vertical diversity. This characteristic, combined with other important host characteristics, such as crown size and architecture, bark porosity and thickness, age and branch thickness, along with environmental factors such as humidity, may compensate for poorer light conditions inside the forest and promote mistletoe expansion. However, the different nature of these host traits may also enhance the trees' resistance to infection. The effects of various possible interactions were demonstrated, among others, in studies conducted by Kartoolinejad et al. (2007), Mellado & Zamora (2014), Ahmed & Dutt (2015) and Sayad et al. (2017).

The ordination diagram shows a significant length of the *gst* vector, which indicates the direction of the impact of the location of open grassland areas with single trees or small clumps of trees on the abundance of mistletoe. This would be consistent with the opinions of many authors (Stypiński, 1997; Zachwatowicz et al., 2008; Gołabek & Sławiński, 2017; Skrypnik et al., 2020) that an adequate amount of sunlight is an important condition for the distribution of mistletoe, as mistletoe occurs in sunny locations and needs a lot of light both in the early and later stages of development. When projected onto a two-dimensional plane, the length of the *gst* vector is even greater than the length of the dbh

vector, however, the effect of this factor proved to be statistically insignificant.

Despite the high abundance of mistletoe in forests dominated by deciduous tree species in fertile and moist habitats, the effect of this form of land cover also turned out to be statistically insignificant in the numerical analysis conducted. The characteristics of the squares in the analysed set, such as the distance of squares from source trees, the length of main communication routes and the susceptibility of trees to mistletoe infection, were not statistically significant. The importance of such characteristics in the distribution of mistletoe has often been emphasised in the literature used for comparison. Assessments indicating no significant effect may result from the heterogeneity of other parameters in the study areas that were not included in the correlation analyses (Skrypnik et al. 2020). This may be due to the inconsistency and heterogeneity of certain characteristics resulting from the use of squares with sides measuring 100 m. Given the size of the square and its location in the ATPOL network, a significant part of some squares was occupied by forest areas with high mistletoe infection, where sanitary pruning is not performed. However, part of the area of these squares was also occupied by allotment gardens or home gardens located in the vicinity of the forest, where mistletoe is removed. Another reason may be the simultaneous occurrence of high values of several characteristics in the same square. Such situations can be counteracted by carefully selecting a set of biotic, abiotic and landscape characteristics that describe the squares using forward selection and by using more appropriate locations and sizes of squares. When using GIS technology to analyse the spatial distribution of mistletoe and its determinants, the latter condition can be met by creating a precise map of land use and land cover and repeating the calculations for different grid sizes by combining small basic squares into larger fields using the block size change method. This would allow for the analysis of the distribution of hosts and hemiparasites at both local and landscape scales, in accordance with the principles recommended for studies of such ecological relationships by, among others, Roura-Pascual, et al. (2012).

6. Conclusions, study limitations and recommendations

Based on the field research and comparisons, it was determined that the area under study in the Bielany district of Toruń is one of the richest sites for hosts of

the European mistletoe in Poland and Central Europe. However, host species richness is not particularly high here, although some taxa of hosts that are new to Poland and rare were recorded among them. To analyse the spatial distribution of the European mistletoe in such a specific area, we used CANOCO 5.0 software. It had not previously been used for spatial analyses of this hemiparasite. The CCA method, performed using this software, allowed us to identify two statistically significant factors from a set of ten landscape, environmental and biological factors considered. These were the area of greenery surrounding educational facilities and the DBH of the hosts.

A limitation of our statistical analysis is that, in the 143 squares, we only took into account the number of trees within each host taxon, rather than the number of mistletoe individuals on the trees of each taxon. On the other hand, however, using the number of hosts allows us to avoid errors resulting from different methods of identifying individuals when comparing mistletoe occurrence in other cities or regions.

Another limitation is the inclusion of the number of potential taxa rather than the potential number of host trees for each taxon in these analyses. Including such parameters would allow for a more precise determination of the degree of mistletoe infection in individual taxa and, consequently, the use of more precise *sti* values in ordination analyses than the literature data used from other regions.

Another limitation is the use of squares that were too large, which may have resulted in increased heterogeneity of land cover / land use within them. The identification of the number of factors significantly affecting the distribution of mistletoe at local and landscape scales may also have been limited by the fact that the ordination analysis was performed using only one grid cell size across the grid covering our study area.

We therefore recommend that all the omitted parameters listed in the above conclusions be taken into account in future studies. Furthermore, we recommend:

- providing a precise description of how individual plants are identified within the analysed mistletoe populations and the method used to count their abundance, which will allow for more precise comparisons with other urban areas;
- making comparisons between sites within narrow time frames, which will ensure greater comparability of observations;
- conducting observations on permanent plots, which will increase the precision of determining temporal changes in the distribution of the typical subspecies of the European mistletoe.

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