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Extent of infection by *Viscum album* L. and changes in its occurrence on ornamental woody species in the locality of Lednice (Czech Republic)

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ABSTRACT

The main goal of the research conducted in the Lednice chateau park was to map the current spectrum of host trees and shrubs. The aim of the investigation was also to record changes in the host species, namely between the years 1985 and 2016, and to get an overview of the extent and degree of mistletoe infection on the most significant tree species present in the park. Furthermore, the occurrence of mistletoe across the developmental stages of woody species was monitored. Apart from taxonomic changes also the quantitative extent and the degree of infection reported in the last 31 years, and the impact on the development stages of woody plants in the past 20 years were analysed. Among the most frequently infected taxa are currently: *Acer campestre, Acer platanoides, Acer pseudoplatanus, Crataegus monogyna*, *Robinia pseudoacacia*, *Tilia cordata* and *Tilia platyphyllos.* The average share of infected specimens of the above host species amounts to 34.28%. A distinctive change in frequency and infection degree was recorded in the aggregate spectrum of hosts. The presence of mistletoe was recorded in a total of 1,362 specimens (almost 12% of the trees growing in the area). Compared to 1985, the occurrence of mistletoe was newly recorded in a total of 13 families (+3), 19 genera (+5) and 42 species (+18). In *Aesculus ×marylandica, Fraxinus biltmoreana, Magnolia hypoleuca ×tripetala* or *Malus ×moerlandsii,* it was probably described for the first time ever. At the moment, the most existentially endangered taxon is *Tilia cordata*.

Key words: European mistletoe, host structure change, host woody species, infection intensity

INTRODUCTION

Today, the extensive genus *Viscum* is systematically classified in the *Santalales* order and in the Santalaceae family (Der and Nickrent 2008, Nickrent et al. 2010). The European mistletoe (*Viscum album* L.) is a native hemiparasitic shrub, spread widely yet locally in many places of Europe and Asia (Hegi 1981, Luther and Becker 1987, Slavík 1997, Zuber 2004, Rist et al. 2011, Kołodziejek et al. 2013, Varga et. al 2014). In the Czech Republic, its occurrence is largely uneven (Procházka 2004). Within this species, a total of four subspecies have been described (Ball 1993, Böhling et al. 2002, Barbu 2010), three of which can be found in the Czech Republic (Koblížek 2000, Kubát et al. 2002). By far the most widespread native subspecies, occurring at the same time on the largest number of host trees and shrubs, and having the largest impact on their quality, is *Viscum album* L. subsp. *album* P.W. BALL. In numerous localities

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with high density of its natural occurrence, this mistletoe is a preeminent pathogenic factor, and hence also a subject of research (Hawksworth et al. 1991, Butin 1995, Mathiasen et al. 2008). With its parasitic activities, it causes much damage to the host trees and shrubs, not only economic damage, e.g. in forestry (Tsopelas et al. 2004), but also socio-cultural, aesthetical and cultivation damage, e.g. in landscape architecture (Spálavský 2001, Zachwatowicz et al. 2008, Eliáš 2010, Huber 2011). The frequency or extent of occurrence of this mistletoe, as well as the study of the spectrum of its host woody species have been the subject of many scientific papers and comprehensive studies (Wangerin 1937, Stopp 1961, Barney et al. 1998). Much of this research has been carried out mainly in urban environments and in gardens and parks (Unar 1985, Procházka 2004, Święs 2008, Zachwatowicz et al. 2008, Kołodziejek et al. 2013), which contained both autochthonous and allochthonous woody plants. Long-term and often expansive and aggressive infection of a host plant by mistletoe leads to damage of its above-ground architecture. It causes a gradual physiological weakening of the infected trees and shrubs, leads to signs of premature senescence, but above all it leads to an increased sensitivity of the infected trees and shrubs to other pathological agents (Mathiasen et al. 2008). The lifespan of infected trees is significantly shortened. Also the usable potential, based on the biological and aesthetical condition of the tree or shrub concerned, and on its spatial and age structure, tends to be low in the case of infected specimens. The spectrum of host trees and shrubs is different in individual localities. Similarly, the examined habitats differ, as probably do the consequences of long-term impact of mistletoe on the qualitative parameters of their hosts. In this respect, there is still lack of sound information on the actual spectrum, extent and degree of infection of individual host trees and shrubs in the context of a longer chronological development. Therefore, the aim of our investigation was to analyse these fundamental facts. At the same time, the impact on the development stages (DS) of woody plants was monitored and evaluated. The knowledge acquired can be a valuable source of information which can help improve landscape management not only on this world heritage site but also in many other historical parks with mistletoe occurrence. It can lead to more effective methods of tree growing and maintenance, or help modify the way in which trees are pruned. During ongoing restoration of historical garden monuments in places with high mistletoe occurrence, this information can also serve as a basis for choosing the right tree species for new plantings.

MATERIAL AND METHODS

The research locality of Lednice (Fig. 1) is situated in South Moravia, in the area of thermophyticum,

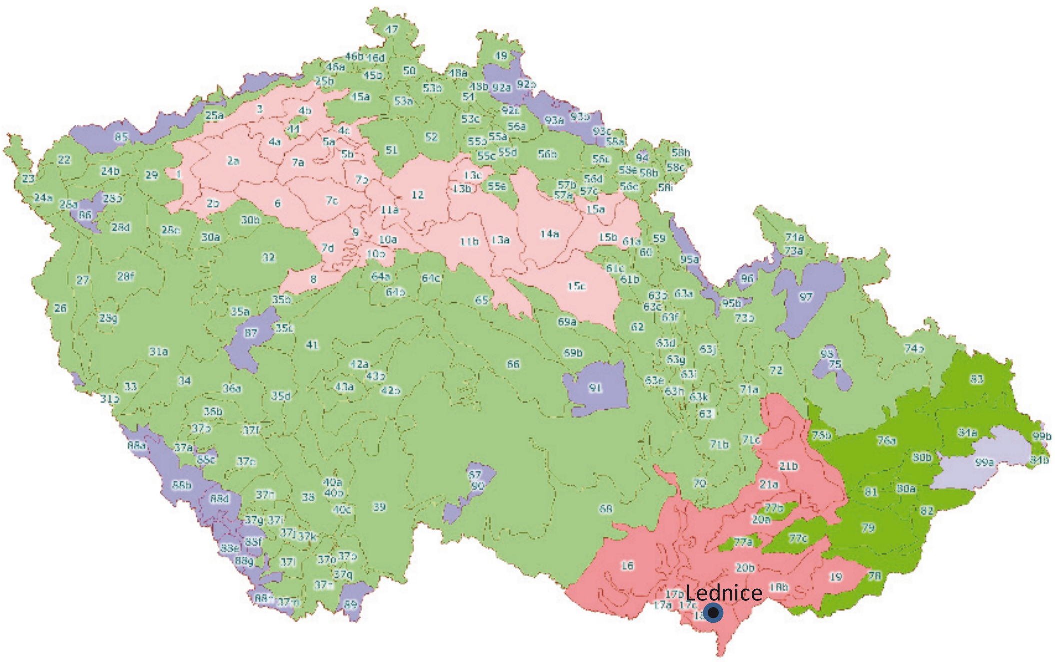


Figure 1. The research locality of Lednice is situated in South Moravia, in the area of Pannonian thermophyticum (Slavík 1988)

in the 18a phytogeographic sub-district – Dyjsko-svratecký úval (Skalický 1988, Slavík 1988).

With respect to the targets of our investigation, the locality in question was narrowed to a field research area of 170 ha covering the chateau parkland and its closest surroundings. The whole administrative cadastral area of Lednice (31.2 km^2) was considered only for comparing the development of the spectrum of host trees and shrubs over time. The selected locality 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 (Procházka 2004). The locality is situated at an altitude of 165-176 m above sea level. According to Quitt's climate classification (Culek 1996), the whole territory belongs to the warmest area of the Czech Republic labelled as T4. The mean annual temperature is 9°C and the mean precipitation amount ranges between 300-350 mm during the vegetation period and 200-300 mm in winter. The potential natural vegetation in this locality is formed mainly by bottomland hardwood forests of the suballiance *Ulmenion* represented in particular by the associations *Ficario-Ulmetum campestris* and *Fraxino pannonicae-Ulmetum*, which change into associations of the type *Primuloveris-Carpinetum* in the highest places of the alluvium and on anthropogenic soils (Culek 1996). The field research was carried out on the whole present spectrum of tree species in the 2012-2016 period, mainly in winter time. Two attributes were simultaneously recorded: mistletoe occurrence and tree development stage. For the subsequent detailed evaluation, only seven important tree species were selected. These are currently the most frequent host species and at the same time the trees that form the main vegetation structure of the park. In order to evaluate mistletoe occurrence, on a selected sample of trees and shrubs in the given locality, we assessed the percentage of the overall active assimilation volume of the crown of the host tree or shrub against the proportion of the volume of parasitizing mistletoe. For mistletoe occurrence evaluation, we used a four-degree rating system: *0 degree: no occurrence* – no signs of mistletoe infection were found on the evaluated tree or shrub; *1st degree: insignificant occurrence* – assimilation mass of the host plant clearly prevails on the evaluated tree or shrub. The specimen is usually infected unevenly or in clusters with mistletoe shrubs forming up to 30% of the total volume of the crown of the host tree or shrub; *2nd degree: significant occurrence* – the evaluated tree or shrub is infected to a significant extent, either evenly or in clusters. Its physiological vitality is visibly decreased. Mistletoe shrubs form 30-60% of the active assimilation volume of the crown of the host tree or shrub; *3rd degree: critical occurrence* – assimilation mass of mistletoe exceeds the mass of the assimilation apparatus of the host tree or shrub. Mistletoe shrubs form more than 60% of the total volume of the crown of the host tree or shrub. The infected plant is visibly wilting. For development stage (DS) evaluation, we used the following codes: DS 1 – newly planted/germinating specimen, DS 2 – rooted specimen, DS 3 – stabilized maturing specimen, DS 4 – mature specimen, DS 5 – superannuated specimen. The recorded development stage data (DS) for the most important host trees and shrubs were then compared with available values (Pejchal and Šimek 1996). The occurrence of mistletoe or its extent was evaluated in relation to the records published by Unar (1985) and Spálavský (2001). The nomenclature used is in accordance with the publication by Roloff and Bärtels (2006). The value for the frequency of occurrence, expressed as an absolute or equivalent percentage value, was selected for processing and evaluating the data. The data were ordered and analysed according to the key quantitative and qualitative features using contingency tables processed in MS Excel for the seven most important host taxa. For the purposes of this evaluation, the constant feature was mistletoe occurrence (degrees 0-3). The variable attributes analysed individual development stages (DS) in 1996 and in 2016. In the following steps, the level of infection probability of a plant of a particular taxon was analysed. The probability was expressed in %. The sum of specimens of a given taxon was thus compared with the relevant number of infected taxa. These values were then adjusted by the qualitative attributes of the development stages; for these values, the structure of infection probability was also established.

RESULTS AND DISCUSSION

The spectrum of host trees and shrubs, and the distribution of mistletoe in the locality of Lednice were recorded by many authors in the past (Houfek 1973, Unar et al. 1985, Spálavský 2001, Bulíř 2010). Indirectly, possibly among other damage, its occurrence was also partly monitored in connection with the evaluation of the dendrological potential of the local chateau park (Pejchal and Šimek 1996). However, from among the sources mentioned, only Unar et al. (1985) and Spálavský (2001) provide quantitatively, qualitatively and, in particular, territorially comparable data. Based on the experiment conducted and on its results, a summary table was compiled (Tab. 1), providing an overview of the present-day spectrum of host trees and shrubs as well as the extent of their infection over time, namely between 1985 and 2016. The results clearly show a sharp increase in the number of host taxa. Thirty-one years ago, Unar et al. (1985) reported within the chateau park a total of 24 infected woody species belonging to 14 genera and 10 families. In the whole cadastral area of Lednice (31.2 km^2), there were 36 host woody species belonging to 15 genera and 11 families. The results of this investigation, carried out between 2012 and 2016, described 42 host woody species belonging to 19 genera and 13 families within the chateau park alone. Data published in 2001 (Spálavský 2001) suggest an even broader spectrum of host woody species, since they were collected before some hazardous individuals were felled in the last five years. The number of host taxa varies over time and is thus subject to change. In the selected time period (between 1985 and 2016), the occurrence of mistletoe was observed in a total of 17 families, 30 genera and 87 species. In the context of the data available so far for the whole Czech Republic (Houfek 1973, Procházka 2004) this positively confirms the quantitative primacy of the locality. Among the reported host trees and shrubs there are also *Aesculus ×marylandica, Fraxinus biltmoreana, Magnolia hypoleuca ×tripetala* and *Malus ×moerlandsii*, which are species not included in the comprehensive list of 452 hosts of mistletoe recorded primarily in Europe and Asia by Barney et al. (1998). This also confirms the fact that mistletoe responds even to partial changes in the environmental conditions. These changes and long-term landscape management (particularly the technology of tree maintenance) probably also influence its preferences for a certain group of host plants in time and space. Striking is also the apparent change in the frequency of infection of individual host taxa as well as other observed changes of predominantly quantitative nature. According to the records published by Unar et al. (1985), 31 years ago there was no mistletoe occurrence in the chateau park on *Acer campestre* (and only sporadically outside the park), on *Crataegus monogyna* and *Tilia platyphyllos* (frequently outside the park). However, according to the results of our investigation, all of the above taxa belong today to much infected species. The probability of colonisation of every specimen growing in the chateau park presently amounts to 29.87% for *Acer campestre*, 38.78% for *Crataegus monogyna* and 38.48% for *Tilia platyphyllos* (Tab. 2). Moreover, the above species are presently among the seven most significant host woody species (the remaining in this locality are *Acer platanoides, Acer pseudoplatanus, Robinia pseudoacacia* and *Tilia cordata*). Similarly, the intensity and extent of infection increased also in other species described in all the compared researches (Tab. 1), e.g. *Tilia cordata* or *Carpinus betulus*. An opposite trend can be observed in the representatives of the *Malus, Salix* and *Populus* genera, where the extent of infection has decreased compared to 31 years ago. In particular, this might be caused by several jointly acting factors. In the first place, these taxa generally have shorter lives and their lifespan has been further reduced by the pathogenic activities of mistletoe. The existing populations of these trees have been significantly reduced also by the activities of the European beaver (*Castor fiber*). Finally, irrecoverably damaged trees were removed without adequate taxonomic replacement in the context of the renewal measures that are continuously performed in the park. In other host trees and shrubs, where the occurrence of mistletoe was detected in 1985 (Unar et al. 1985), such as *Acer negundo, Aesculus hippocastanum, Fraxinus americana, Fraxinus angustifolia* and *Loranthus europaeus*, later researches did not find mistletoe at all or only rarely (Spálavský 2001), although in the course of time the overall number of specimens of these taxa has changed rather insignificantly. This phenomenon might be explained by the fact that mistletoe continuously specialises in a certain group of preferred host trees and shrubs, a process that is also influenced by changing environmental conditions. According to the overview mentioned, basically a constant change in the extent and degree of infection over time has been recorded in, among others, *Acer platanoides, Acer pseudoplatanus, Celtis occidentalis* and *Juglans nigra* – taxa which are infected relatively frequently, even extensively.

For the most numerous host species as well as for the species forming the vegetation framework of the chateau park, a separate detailed overview has been drawn up (Tab. 2), presenting the level of probability and showing the extent and degree of their infection. The share of infected specimens in

Table 1. Overview of mistletoe occurrence in the locality of Lednice between 1985 and 2016

Research		Bulíř (2016) – this experiment [1]			Spálavský (2001) [2]			Unar et al. (1985) [2]	
Host woody species	Family	Recorded occurrence	Infected trees total (pcs)	Not infected trees total (pcs)	Recorded occurrence	Infected trees total (pcs)	Not infected trees total (pcs)	Recorded occurrence	Frequency of occurrence (verbal description)
Acer campestre	Aceraceae	/	362	850	/	377	976	/*	sporadic
Acer ginnala	Aceraceae				/	2	21		
Acer monspessulanum	Aceraceae				/	1	6		
Acer negundo	Aceraceae							/	fairly often
Acer nigrum	Aceraceae	/	1	0	/	1	0		
Acer platanoides	Aceraceae	/	65	94	/	72	116	/	often
Acer pseudoplatanus	Aceraceae	/	62	128	/	69	142	/	fairly often
Acer rubrum	Aceraceae	/	2	2	/	3	3		
Acer saccharinum	Aceraceae	/	4	3	/	4	4	/	not seldom
Acer saccharum	Aceraceae	/	11	5	/	14	3	/	strong
Acer tataricum	Aceraceae				/	1	3	/*	sporadic
Aesculus hippocastanum	Hippocastanaceae				/	1	207	/*	sporadic
Aesculus flava	Hippocastanaceae				/	1	1		
Aesculus ×marylandica	Hippocastanaceae	/	2	0	/	1	1		
Alnus glutinosa	Betulaceae	/	38	133	/	2	216	/	seldom
Amelanchier lamarckii	Rosaceae				/	1	1		
Betula pendula	Betulaceae	/	10	75	/	5	96	/	seldom
Betula pubescens	Betulaceae	/	1	2	/	1	4		
Caragana arborescens	Fabaceae				/	1	4		
Carpinus betulus	Betulaceae	/	53	255	/	18	39	/	very seldom
Celtis occidentalis	Ulmaceae	/	20	23	/	20	22	/	often
Crataegus chrysocarpa	Rosaceae				/	1	2	/	seldom
Crataegus laevigata	Rosaceae				/	3	36		
Crataegus ×lavallei	Rosaceae				/	2	2		
Crataegus macrocarpa	Rosaceae							/	often
Crataegus monogyna	Rosaceae	/	38	60	/	71	154		
Crataegus pedicellata	Rosaceae	/	34	52	/	44	107		
Crataegus persimilis	Rosaceae				/	3	4		
Corylus avellana	Betulaceae				/	8	157		
Corylus chinensis	Betulaceae				/	1	3		
Euodia daniellii	Rutaceae				/	2	1		
Fraxinus americana	Oleaceae				/	2	2	/	fairly strong
Fraxinus angustifolia	Oleaceae				/	1	188	/*	fairly often
Fraxinus biltmoreana	Oleaceae	/	1	1	/	1	1		
Fraxinus excelsior	Oleaceae	/	43	154	/	23	219		
Fraxinus pensylvanica	Oleaceae	/	9	11	/	10	17		
Fraxinus tomentosa	Oleaceae							/	fairly strong
Juglans ailantifolia	Juglandaceae	/	2	1	/	3	0		
Juglans cinerea	Juglandaceae	/	1	0	/	1	0		
Juglans mandshurica	Juglandaceae	/	1	0	/	1	0		

Table 1 continued.

Research		Bulíř (2016) – this experiment [1]			Spálavský (2001) [2]			Unar et al. (1985) [2]	
Host woody species	Family	Recorded occurrence	Infected trees total (pcs)	Not infected trees total (pcs)	Recorded occurrence	Infected trees total (pcs)	Not infected trees total (pcs)	Recorded occurrence	Frequency of occurrence (verbal description)
Juglans nigra	Juglandaceae	/	34	61	/	40	60	/	ample
Laburnum alpinum	Fabaceae				/	1	1		
Laburnum anagyroides	Fabaceae				/	1	12		
Lonicera maackii	Caprifoliaceae				/	3	40		
Maclura pomifera	Moraceae	/	4	12					
Loranthus europaeus	Loranthaceae							/	seldom
Magnolia hypoleuca ×tripetala	Magnoliaceae	/	1	4	/	1	4		
Malus dasyphylla	Rosaceae							/	strong
Malus ×atrosanguinea	Rosaceae				/	3	0		
Malus domestica	Rosaceae				/	4	0	/*	sporadic
Malus ×moerlandsii	Rosaceae	/	1	22					
Malus niedzwetzkyana	Rosaceae	/	1	0	/	1	0		
Malus sp.	Rosaceae				/	29	28	/*	scattered
Photinia villosa	Rosaceae				/	2	6		
Populus alba	Salicaceae	/	3	19	/	2	33	/*	seldom
Populus balsamifera	Salicaceae							/*	sporadic
Populus ×canadensis	Salicaceae							/*	scattered
Populus ×canescens	Salicaceae				/	4	11	/	fairly often
Populus nigra	Salicaceae							/	ample
Populus simonii	Salicaceae				/	3	2		
Populus tremula	Salicaceae				/	4	25		
Prunus padus	Rosaceae	/	13	94	/	11	198		
Prunus spinosa	Rosaceae				/	5	65		
Prunus virginiana	Rosaceae	/	6	13	/	3	46		
Prunus sp.	Rosaceae				/	2	4		
Quercus palustris	Fagaceae	/	18	0	/	6	17		
Quercus robur	Fagaceae				/	32	945		
Robinia pseudoacacia	Fabaceae	/	38	64	/	49	102	/	scattered
Salix ×sepulcralis	Salicaceae	/	8	4	/	8	7		
Salix alba	Salicaceae	/	1	30	/	10	39	/	fairly often
Salix fragilis	Salicaceae				/	1	1	/*	fairly often
Salix pentadra	Salicaceae				/	1	0		
Salix ×rubens	Salicaceae							/	often
Sorbus aucuparia	Rosaceae				/	1	2		
Syringa ×chinensis	Oleaceae				/	1	8		
Syringa reticulata	Oleaceae				/	3	20		
Syringa villosa	Oleaceae				/	1	1		
Swida sanguinea	Cornaceae				/	1	244		
Tilia americana	Tiliaceae	/	1	4	/	2	1	/	fairly strong

Table 1 continued.

Research		Bulíř (2016) – this experiment [1]			Spálavský (2001) [2]			Unar et al. (1985) [2]	
Host woody species	Family	Recorded occurrence	Infected trees total (pcs)	Not infected trees total (pcs)	Recorded occurrence	Infected trees total (pcs)	Not infected trees total (pcs)	Recorded occurrence	Frequency of occurrence (verbal description)
Tilia cordata	Tiliaceae	/	189	301	/	286	249	/	ample
Tilia ×vulgaris	Tiliaceae	/	19	13	/	12	21		
Tilia euchlora	Tiliaceae	/	2	4	/	1	3	/*	scattered
Tilia platyphyllos	Tiliaceae	/	162	259	/	102	367	/*	often
Tilia tomentosa	Tiliaceae	/	11	17	/	10	11	/	ample
Tilia petiolaris	Tiliaceae	/	8	14	/	12	23		
Ulmus laevis	Ulmaceae	/	56	145					
Ulmus minor	Ulmaceae	/	26	156					
Sum total (pcs)			1,362	3,085		1,430	5,354		

[1]chateau park, [2]Lednice cadastral area, / infection recorded within the chateau park, /* infection recorded only outside the borders of the chateau park

the mentioned taxa varies between 29.87% (*Acer campestre*) and 40.88% (*Acer platanoides*), with the average of 34.28% of their total number – in a sample of 2,672 specimens potentially prone to infection (Šimek et al. 2009) this corresponds to 916 infected trees and shrubs. From Table 2, it is evident that the 1st infection degree is the most frequent (24.02% on average). By contrast, critical occurrence of mistletoe (3rd degree) in the group of the seven compared species is the lowest (3.71% on average). This fact is essential for appropriate tree maintenance (mainly the extent of pruning) and also for the related economy of care in the historical garden. The highest share of 3rd degree infection is currently held by *Tilia cordata*, which is the most challenged species as regards both life expectancy and the ability to fulfil its functions in the park composition. Of particular interest in this respect is a comparison with related *Tilia platyphyllos* – under similar conditions and within a numerically comparable sample of specimens. This taxon is colonised by mistletoe with a similar probability, but according to the prevailing degree of infection, the occurrence of mistletoe over time can be characterized as insignificant. At the same time, the values presented in Table 2 are compared with known numbers of specimens in a given taxon (Pejchal and Šimek 1996), and this clearly shows

Table 2. Overview of the extent and degree of mistletoe infection in the most significant host woody species

Year	1996[1]	2016[2]								
Mistletoe occurrence	0-3	0		1		2		3		0-3
Host woody species	Σ	Σ	%	Σ	%	Σ	%	Σ	%	Σ
Acer campestre	1,315	850	70.13	267	22.03	69	5.69	26	2.15	1,212
Acer platanoides	168	94	59.12	44	27.67	16	10.06	5	3.14	159
Acer pseudoplatanus	201	128	67.37	49	25.79	9	4.74	4	2.11	190
Crataegus monogyna	107	60	61.22	21	21.43	13	13.27	4	4.08	98
Robinia pseudoacacia	130	64	62.75	29	28.43	7	6.86	2	1.96	102
Tilia cordata	552	301	61.43	92	18.78	40	8.16	57	11.63	490
Tilia platyphyllos	501	259	61.52	140	33.25	21	4.99	1	0.24	421
Total	2,974	1,756	65.72	642	24.02	175	6.56	99	3.71	2,672

[1]Pejchal and Šimek, [2]Bulíř; mistletoe occurrence: 0 – no occurrence, 1 – insignificant occurrence, 2 – significant occurrence, 3 – critical occurrence

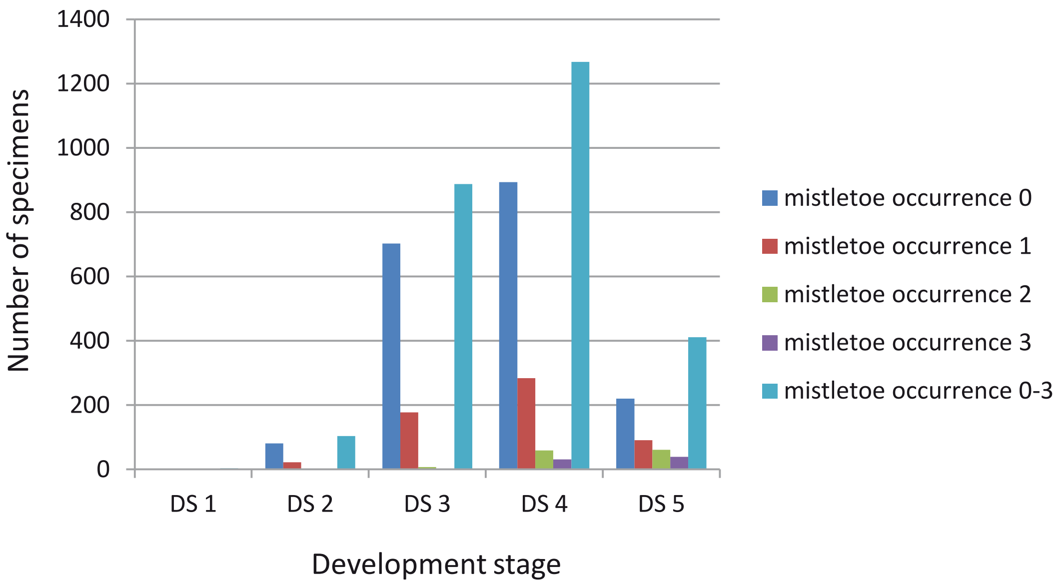
a decrease in host trees and shrubs, caused precisely by the significant pathogenic activity of mistletoe. The expansion of mistletoe in the locality of Lednice has been definitely supported by broadly suitable environmental conditions corresponding to the data further specified by, among others, Zuber (2004) and Mathiasen et al. (2008). It is in particular influenced by high average annual temperature and its favourable distribution during the year, by sufficient humidity available to host trees and shrubs throughout the year, and finally by the presence of numerous birds dispersing the seeds, such as the Mistle Thrush (*Turdus viscivorus*), the Fieldfare (*Turdus pilaris*), the Bohemian Waxwing (*Bombycilla garrulus*) and the Great Tit (*Parus major*). Moreover, an especially important factor influencing the local growth of mistletoe is undoubtedly the abundance of solitary trees, fully exposed to the sun, or of small groups or lines of trees. Favourable conditions for the growth of mistletoe are further enhanced by the presence of an unusual and taxonomically rich spectrum of 356 broad-leaved trees and shrubs potentially prone to infection (Pacáková-Hošťálková et al. 1999). The above facts correspond well to the results of our research, which aimed to find out, among others, the aggregate quantitative extent of infection of the trees and shrubs growing in the chateau park. Based on Table 1, out of the total number of 7,123 broad-leaved trees reported in 2009 (Šimek et al. 2009) and 2016 (62.65% of all trees), a total of 5,038 trees can be included among the potential host plants, i.e. 44.3% of all the trees and shrubs growing in the chateau park. The presence of mistletoe was demonstrably detected in 1,362 specimens, i.e. in almost 12% of the trees and shrubs present in the area, with 916 of the infected specimens (8%) belonging to the seven most significant host woody species (Tab. 2). The presence and impact of mistletoe on trees and shrubs have been observed in the composition of the park for many years. Several negative phenomena have been simultaneously observed in the qualitative (aesthetic and biological) parameters of the trees and shrubs, which are fundamental not only in relation to the care of such trees and shrubs, but also in relation to the conservation or renewal of the listed chateau park composition. Therefore, the research also analysed mistletoe occurrence and the degree of infection of the host tree or shrub in relation to individual development stages (DS) of woody plants (Pejchal 2008). A summary table (Tab. 3) documents the changes in the extent and degree of mistletoe infection between 1996 and 2016 in relation to the recorded development stages for the seven most significant host woody species. The parameter of development stage is probably the best one to reflect not only the distribution of mistletoe plants on individual host woody taxa, but also the overall biological and compositional potential of the trees and shrubs (Pejchal 2008). The comparison of new and previous available DS data (Pejchal and Šimek 1996) shows a progressive and striking decrease in the number of trees not yet infected by mistletoe (code 0), by a total of 10.3% over the past 20 years, which in absolute terms

Table 3. Changes over time in the extent and degree of infection of trees and shrubs by mistletoe in relation to their development stage (DS)

Mistletoe occurrence	0			1			2			3		
Year	1996 [1], Σ (pcs)	2016 [2], Σ (pcs)	change in % 1996-2016	1996 [1], Σ (pcs)	2016 [2], Σ (pcs)	change in % 1996-2016	1996 [1], Σ (pcs)	2016 [2], Σ (pcs)	change in % 1996-2016	1996 [1], Σ (pcs)	2016 [2], Σ (pcs)	change in % 1996-2016
DS 1	16	2	-87.5	0	1	100	0	0	0	0	0	0
DS 2	94	81	-13.8	17	22	29.4	12	1	-91.7	0	0	0
DS 3	783	702	-10.4	138	177	28.3	31	7	-77.4	4	1	-75
DS 4	978	893	-8.7	203	284	39.9	97	59	-39.2	93	31	-66.7
DS 5	245	220	-10.2	74	91	23	103	61	-40.8	86	39	-54.7
Total	2,116	1,898	-10.3	432	575	33.1	243	128	-47.3	183	71	-61.2

For the most significant host woody species in Table 2.
[1]Pejchal and Šimek, [2]Bulíř; mistletoe occurrence: 0 – no occurrence, 1 – insignificant occurrence, 2 – significant occurrence, 3 – critical occurrence; development stage: DS 1 – newly planted/germinating specimen, DS 2 – rooted specimen, DS 3 – stabilized maturing specimen, DS 4 – mature specimen, DS 5 – superannuated specimen

represents a decline from 2,116 to 1,898 trees. The loss structure across the individual development stages is surprisingly balanced, with almost identical percentage values for DS 3 and DS 5 (10.4% and 10.2% decrease, respectively). The loss of trees in DS 4 reached 8.7%. On the other hand, in the same period, there was a 33.1% increase in the total number of trees insignificantly infected by mistletoe (1st degree), which was reported for all development stages. While in 1996 this degree of infection was observed in 432 specimens in absolute terms, in 2016 this number rose to as many as 575 specimens. The number of infected specimens increased most significantly in DS 4 (by 39.9%), from 203 to 284 specimens, followed by DS 3 (by 28.3%), from 138 to 177 specimens. The total number of significantly infected specimens (2nd degree) decreased especially in DS 4 (by 39.18%), from 97 to 59 specimens, and in DS 5 (by 40.78%). An analogous development process was also observed in critically infected trees (3rd degree), where the number of specimens in DS 4 and DS 5 decreased by as much as 66.7% and 54.7%, respectively. In this category, the highest change was in the total (61.2% decrease). The current distribution of development stages (DS) and infection intensity of all the trees and shrubs is shown in Figure 2. The minimum number of trees in DS 1 and DS 2 suggests that the probability of colonization of host woody trees by mistletoe grows with age. The number of non-infected stabilized maturing specimens (DS 3) accounts for 79.14% of their total number; in the case of mature specimens (DS 4) it is approximately 70.48%, while in the case of superannuated specimens (DS 5) their share is only 53.53%. The recorded infection intensity differs quantitatively across the individual development stages and host taxa. The situation is relatively balanced in the case of 1st infection degree, where different development stages of trees are colonised almost evenly (DS 3 – 19.95%, DS 4 – 22.42% and DS 5 – 22.14%). More advanced stages of colonisation of host plants, marked as 2nd infection degree and 3rd infection degree, are found mainly in development stages DS 4 and DS 5, where the sum of infected specimens reaches 14.84% and 9.49%, respectively. All in all, there is an evident downward trend in the number of colonised specimens accompanying a proportional increase in the intensity of their infection. However, in comparison with the standard natural development of trees and shrubs infected by mistletoe, in our locality this phenomenon is once again influenced and to a certain extent distorted, because distinctly damaged trees and shrubs have been removed in the context of ongoing cultivation measures. These often concerned significantly infected specimens (2nd infection degree), and even more often critically infected specimens (3rd infection degree). Between 1996 and 2016, within



Mistletoe occurrence: 0 – no occurrence, 1 – insignificant occurrence, 2 – significant occurrence, 3 – critical occurrence; development stage: DS 1 – newly planted/germinating specimen, DS 2 – rooted specimen, DS 3 – stabilized maturing specimen, DS 4 – mature specimen, DS 5 – superannuated specimen

Figure 2. Comparison of the actual structure of the development stages of all host woody species and the extent of their infection (year 2016)

the chateau park area a total of 302 specimens of mistletoe infected trees (only among the seven most frequent host woody species) died, or rather had to be removed for safety, health and aesthetical reasons. A more detailed structure of these data is to be found in Table 2.

The fact that the intensity of colonisation increases with the age of host woody species is most likely related to their decreasing vitality (Pejchal 2008) and is linked with the changes that take place in the architecture of their crowns, especially with crown thinning and degeneration. The intensity of colonisation is further modified by taxonomy-specific characteristics of the host species, by their location and by the environmental conditions of the habitat. All of the above findings thus clearly quantify the intensity and extent of mistletoe occurrence and suggest its development over time, including the qualitative consequences of its impact on the spectrum of significant host trees and shrubs. In the given locality, the consequences of mistletoe pathogenic activity are no doubt significant and they need to be given adequate attention. When looking for suitable solutions, in particular cultivation measures, they need to be considered together with the role of other pathogenic factors and environmental conditions, and also in relation to other environmental functions of these woody plants, as Watson (2001) and Mathiasen et al. (2008) note.

CONCLUSIONS

The research shows that during the selected time period, i.e. between 1985 and 2016, there were significant changes not only in the number of observed host trees and shrubs, but also in the extent of infection of individual hosts. More specifically, the following facts were observed:

1. The spectrum of host trees and shrubs described in the same area has changed noticeably over the last 31 years; as at 2016, it taxonomically includes 13 families (+3), 19 genera (+5) and a total of 42 species (+18), despite the fact that the number of taxa grown in the chateau park has not changed significantly since 1985. Parasitisation by mistletoe was recorded also in *Aesculus ×marylandica*, *Fraxinus biltmoreana*, *Magnolia hypoleuca ×tripetala* and *Malus ×moerlandsii* – species which are not included in the most extensive list of host species published (Barney 1998). The largest amount of species and specimens with mistletoe occurrence was recorded in 2001, before the extensive renewal measures (mainly felling of the hazardous individuals) performed in the park in the last five years;
2. A considerable change was observed in the frequency and degree of infection in the individual host species. The species in the chateau park which were not infected in the past, such as *Acer campestre*, *Crataegus monogyna* and *Tilia platyphyllos*, belong today to the group of the most frequently infected host trees and shrubs. On the other hand, the taxa that were often colonised by mistletoe in the past, such as representatives of the *Salix*, *Populus* or *Malus* genera, have become less significant for its occurrence. In *Acer negundo*, *Aesculus hippocastanum*, *Fraxinus americana*, and *Fraxinus angustifolia*, the occurrence of mistletoe was not detected any more. On the other hand, a stable occurrence of mistletoe over time was observed in the specimens of *Acer platanoides*, *Acer pseudoplatanus*, *Celtis occidentalis* and *Juglans nigra*, which are infected relatively often, even extensively;
3. Currently, the most heavily and most frequently infected woody species in the chateau park include, in particular, *Acer campestre*, *Acer platanoides*, *Acer pseudoplatanus*, *Crataegus monogyna*, *Robinia pseudoacacia*, *Tilia cordata* and *Tilia platyphyllos*. The share of infected specimens of these hosts amounts on average to 34.28% of their total number.

This information has key importance for choosing an appropriate and balanced management approach in the systems of care for heritage gardens, including solutions for complex renewal measures in the areas with naturally higher and high occurrence of mistletoe. It can, for instance, help with selecting appropriate substitute species less prone to mistletoe colonization. These data can also serve as a basis for a new approach to tree growing and maintenance. In particular, they can help modify the way trees are pruned. From the biological point of view the data provide us with, among other things, information for further studies of mistletoe occurrence and its pathogenic role on host woody species, not only in the Czech Republic.

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CONFLICT OF INTEREST

Authors declare no conflict of interest.

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