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MODELLING OF THE DISTRIBUTION OF EUROPEAN MISTLETOE (*VISCUM ALBUM*) WITH DEPENDENCE ON LOCAL FACTORS IN THE CASTLE PARK IN LEDNICE

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Abstract

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The European mistletoe *(Viscum album)* infection intensity and frequency of their host taxa individuals was monitored within the sections of the Castle Park in Lednice during the last four years. The data analysis was carried out only with these infected host taxa which occur in the park the most frequently: *Acer campestre, A. platanoides, A. pseudoplatanus, Crataegus monogyna, C. pedicellata, Juglans nigra, Robinia pseudoacacia, Tilia cordata* and *T. platyphyllos*. For the statistical modelling it was used total 3039 individuals, among them 1424 are already infected by mistletoe (47%). Nine local factors (tree age, development stage, location of individuals, physiological and biomechanical aspect of vitality, tree height, diameter at breast height, crown projection area and crown volume) were examined with dependence on mistletoe infection. Due to our results, all of examined factors have strong impact to the infection in the majority of host taxa; except of vitality, this relationship is directly proportional. No statistical significant impact was observed in case of *Crataegus pedicellata*. There is a big difference among the hosts, the largest mistletoe amount was observed in case of *Juglans nigra*. It was also proved that neither host nor mistletoe distribution are spread uniformly.

Keywords: *Viscum album*, distribution of mistletoe, infection intensity, host woody species, statistical modelling

INTRODUCTION

European or white berry mistletoe (*Viscum album* L.) from the family *Viscaceae* (Nickrent *et al.*, 2010) is an evergreen, perennial, epiphytic, hemiparasitic angiosperm shrub that lives on the wide range of woody species in main parts of Europe (Zuber, 2004). As a semi-parasite, the mistletoe bushes takes aqueous solutions of mineral substances and provides the host with part of its own assimilates that protect it from animal pests and fungal diseases (Kuijt, 1969; Watson 2001; Zuber, 2004). The total number of host woody species is 452 taxa (species, subspecies, varieties and hybrids) belonging to 96 genera of 44 families (Barney *et al.*, 1998).

Three widely distributed subspecies that differ in host specificity and fourth subspecies only known from Crete have been recognised in Europe (Stopp, 1961; Ball, 1993; Böhling *et al.*, 2002): *V. album* subsp. *album* L. on dicotyledonous trees, the most frequently on *Salix, Populus, Acer, Malus, Crataegus, Prunus* and *Sorbus*; *V. album* subsp. *abietis* (Wiesb.) Abromeit on *Abies* sp. div., *V. album* subsp. *austriacum* (Wiesb.) Vollmann on *Pinus* sp. div., rarely *Larix* sp. div. and *Picea* sp. div., *V. album* subsp. *creticum* N. Böhling, Greuter, Raus, B. Snogerup, Snogerup and Zuber on *Pinus brutia* Ten. subsp. *brutia* exclusive from Crete.

The effects of habitat degradation and disturbance on parasitic plant populations are poorly understood. Parasitic plants are often involved in complex community-level interactions with host plants, pollinators and seeds dispersers, and therefore are considered keystone species in a variety of ecosystems (Watson, 2001; Press and Phoenix, 2005; Mathiesen *et al*., 2008). Despite increasing recognition of the role of parasitic plants in community ecology, little is known about how they will respond to local or regional changes to habitat or climate (Stanton *et al*., 2010; Türe *et al*., 2010).

According to Downey (2004), mistletoe expansions may occur either accidentally through the introduction of the hosts that are not indigenous to the particular area or as a result of evolutionary changes being a consequence of environmental pressures, such as habitat modifications and climate change. In this context the research on the relationships between the mistletoe occurrence and local habitat conditions seem to be crucial.

The vertical and horizontal extension of *V. album* depends on primarily temperature which needs for optimal growth (Dobbertin *et al*., 2005; Zuber, 2004). According to Iversen (1944) both summer and winter temperatures restrict the geographic distribution of the mistletoe. The mean monthly temperatures of the coldest and warmest months of the year correlate with the limits of the occurrence of *V. album* (Skre, 1972, 1979). Consequently, mistletoes benefit from the warming climate and its range will be expanded. This has already been shown to be the case for the mistletoes growing on pines with their range shifted 200 m to higher altitudes during the last century (Dobbertin *et al*., 2005).

The distribution of *V. album* within this area depends on primarily on the hosts, birds and man (Wangerin, 1937; Zuber, 2004). However, its current distribution is not the same as the distribution of host trees. Hosts clearly have a wider extension (Wangerin, 1937). According to Kartoolinejad *et al.* (2007), local distribution primarily depends on less important factors. Individual differences among host trees (especially diameter at breast height) play an important role in explaining local abundance and distribution of mistletoe plants. Previous researches have also shown that sex of host may influence the mistletoe distribution and abundance as well (Mathiesen *et al*., 2008; Zuber, 2004).

A lot of scientific publications deal with the role of local factors. It was showed that mistletoe abundance and infection intensity in case of *Parrotia persica* (DC.) C. A. Mey. were more linked than in the other host species. Further, positive significant relations were with diameter at breast height (DBH), distance to conspecific location in the stand edge, but no significant relation was observed between tree height and infection intensity (Kartoolinejad *et al*., 2007). In other cases (Kołodziejek *et al*., 2013) it was also proved that the mistletoe infection in the *Acer saccharinum* L. was affected by the individual tree characteristics, such as the height of the tree. The higher mistletoe infection prevalence in taller trees results from differential dispersal of mistletoe seeds to tall trees as well as differential survival of established mistletoes on tall trees. The factor age is also important, because older trees are more likely infected by mistletoe (Mathiesen *et al*., 2008; Kołodziejek *et al*., 2013).

Our previous research confirmed (Baltazár *et al*., 2013a) that the likelihood of infection increases with the age of trees or lowering vitality of tree. It was also proved (Baltazár, 2011; Baltazár *et al*., 2013b, 2014) that the infected trees are bigger, have larger diameter at breast height (DBH), have larger crown projection area and have greater crown volume than uninfected trees. There is also a big difference between the infection intensity and hosts, in case of *Tilia cordata* Mill. and *Juglans nigra* L. the infected individuals were averagely 6 m taller than uninfected specimens; in case of *Tilia cordata* Mill. and *Tilia platyphyllos* Scop. the infected trees have 20 cm larger diameter at breast height than uninfected individuals (Baltazár *et al*., 2013b, 2014).

The main aim of our work was to:

1) determine which hosts are distributed the most frequently in the park;
2) determine the average mistletoe bush number in the crown of these hosts with dependence on local factors (tree age, development stage, location of individuals, physiological and biomechanical aspect of vitality, tree height, diameter at breast height, crown projection area and crown volume);
3) determine the frequency of all individuals of host taxa and infected individuals within the sections of the park.

MATERIAL AND METHODS

This research was carried out in the dendrologically valuable castle park in Lednice (48°48’5” N, 16°48’20” E) in South Moravia which is the most important centre of occurrence of the European Mistletoe in the Czech Republic (Procházka, 2004). It is located in the area thermophyticum, in the 18a phytogeographic sub-district – Dyjsko-svratecký úval (Skalický, 1988). According to Quitt’s climate classification, the whole territory belongs to the warmest area of the Czech Republic labelled as T4 (Culek, 1996). Average annual temperature (1961–1990) is 9.3 °C and average annual precipitation for the same period is 481 mm. The warmest month is July with 19.2 °C and the coldest month is January with an average temperature of –1.7 °C. Vegetation period usually begins in middle-late March and ends in mid-November. The potential natural vegetation in the given locality is formed in particular by bottomland hardwood forests of the suballiance *Ulmenion* represented in particular with associations *Ficario-Ulmetum campestris* and *Fraxino pannonicae-Ulmetum*, which change into the associations of types *Primulo veris-Carpinetum* in the highest places of the alluvium and on anthropogenic soils (Culek, 1996).

The area of this park is approximately 170 ha large (without pond) and includes more than 10,000 trees. Among these woody plants we can also find several rarities. Total number of taxa (only trees without shrubs) is more than 360 (including intraspecific taxa). The territory of the park was divided to 13 sections (Pejchal and Šimek, 1996). Our field investigation was carried out in winter periods (usually from mid-December to mid-March) from 2011 to 2013. The basis for them was the inventory of woody species in 1996 (Pejchal and Šimek, 1996) and its update in 2009 (Šimek *et al*., 2009). First, tree inventory was drawn up and all trees were individually evaluated. The following data was recorded:

a) Identification, which included: section number, serial number of individual in the section, taxon (for this purpose we used the nomenclature according to Kubát (2010) and Erhardt *et al.* (2008).
b) Basic dendrometric quantities: tree height, crown width, diameter at breast height (DBH). Measured in practice by common methods (Machovec, 1982).
c) Additional dendrometric quantities:
   - Height to crown base (m).
   - Crown projection area (m^2): based on a regular ellipse, it was calculated as $A = \pi \times a \times b$, the 2a, 2b – the width of the crown, where 2a = 2b, or $2a \neq 2b$.
   - Ideal crown volume (m^3): was calculated as the volume of a regular ellipsoid, as:
     $V = 4/3\ (\pi \times a \times b \times c)$, the 2a – crown height, 2b, 2c – the width of the crown, where 2b = 2c, or $2b \neq 2c$.
   - Reduction of ideal crown volume (%): percentage estimation of the missing part of the ideal crown volume.
   - Real crown volume (m^3), hereinafter only crown volume: based on an ideal crown volume, the possible reduction/damage of ideal crown was deducted (Pejchal and Šimek, 1996, 2012).
d) Age category: 7-point scale (I. older than 205 years, II. 205–155 years, III. 155–95 years, IV. 95–75 years, V. 75–50 years, VI. 50–30 years, VII. younger than 30 years – corrected by Pejchal and Šimek, 1996, 2012).
e) Development stage (DS): 5-point scale (newly planted/germinating individual, rooted individual, stabilized maturating individual, mature individual and superannuated individual – Pejchal and Šimek, 1996, 2012).
f) Physiological aspect of vitality: Used a following scale: 0 – vitality optimum, 1 – mildly decreased, 2 – middle decreased, 3 – strongly decreased, 4 – very strongly decreased to none (Ehsen, 1988; Pejchal, 1995; Pejchal and Šimek, 1996, 2012; Roloff, 2001). This feature was evaluated pre-eminently with help of phase models of apical shoot architecture proposed by Roloff (2001).
g) Biomechanical aspect of vitality: Used a following scale: 1 – optimal condition, 2 – little abnormality, 3 – moderate abnormality, 4 – strong abnormality, 5 – huge abnormality, the existence of individuals are threatened. For evaluation of these quantities were used the following indicators: crown damage, trunk damage, occurrence of dry branches, occurrence of decay or cavity, occurrence of tree fungi, wrong-branching, unfavourable center of gravity and other damages (Ehsen, 1988; Pejchal, 1995; Pejchal and Šimek, 1996, 2012).
h) Location of individuals: 10-point grading (S – solitary plant, OCG – open canopy group, CCG – closed canopy group, MOCG – margin of open canopy group, MCCG – margin of closed canopy group, OCS – open canopy stand, CCS – closed canopy stand, MOCS – margin of open canopy stand, MCCS – margin of closed canopy stand, A – alley; Pejchal and Šimek, 1996, 2012).
i) Incidence of mistletoe: two categories – uninfected individuals (0) and infected individuals (1).
j) Exact mistletoe bush number.

Data Analysis

The data analysis was carried out only with these infected host taxa which occurred in the park the most frequently: *Acer campestre* L. (total: 1266, infected: 533), *Acer platanoides* L. (total: 159, infected: 93), *Acer pseudoplatanus* L. (total: 205, infected: 80), *Crataegus monogyna* Jacq. (total: 106, infected: 61), *C. pedicellata* Sarg. (total: 82, infected: 34), *Juglans nigra* L. (total: 117, infected: 83), *Robinia pseudoacacia* L. (total: 142, infected: 78), *Tilia cordata* Mill. (total: 515, infected: 292) and *Tilia platyphyllos* Scop. (total: 447, infected: 170). The total number of the most frequent host trees is 3039 individuals (infected: 1424). The following data was added for further analyses: exact mistletoe bush number as continuous response variable; age, development stage, location of individuals, physiological and biomechanical aspect of vitality as a categorical explanatory variable. Besides, it was newly created categorical explanatory variable from the dendrometric quantities using the following scale:

- **Tree height:** I. 1–5 m, II. 5–10 m, III. 11–15 m, IV. 16–20 m, V. 21–25 m, VI. 26–30 m, VII. 31–35 m, VIII. 36–40 m.
- **Diameter at breast height:** I. 1–10 cm, II. 11–20 cm, III. 21–30 cm, IV. 31–40 cm, V. 41–50 cm, VI. 51–60 cm, VII. 61–70 cm, VIII. 71–80 cm, IX. 81–90 cm, X. 91–100 cm, XI. 101–110 cm, XII. 111–120 cm, XIII. more than 120 cm.
- **Crown projection area:** I. 1–15 m^2, II. 15–30 m^2, III. 31–60 m^2, IV. 61–100 m^2, V. 101–140 m^2,

VI. 141–200 m^2, VII. 201–300 m^2, VIII. more than 300 m^2.

- **Crown volume:** I. 1–20 m^3, II. 21–40 m^3, III. 41–60 m^3, IV. 61–100 m^3, V. 101–150 m^3, VI. 151–200 m^3, VII. 201–250 m^3, VIII. 250–300 m^3, IX. 301–400 m^3, X. 401–550 m^3, XI. 551–750 m^3, XII. 751–950 m^3, XIII. 951–1400 m^3, XIV. 1401–2500 m^3, XV. more than 2500 m^3.

For characterization of this relationship the *one-way analysis of variance* (*ANOVA*) type I (sequential) sum of squares was used at 0.05 significance level. Because the data was not normally distributed and variance was not constant, logarithmic transformation was applied to the data prior analysis, but the measured values were used to produce the tables. After the analysis, the assumptions of the Anova were checked pre-eminently with the help of different tests and diagnostics plots.

For displaying the frequency distribution of the most frequently host trees in the park, two contingency tables were created (the first for all specimens of host taxa and the second only for infected individuals) where column variable was host taxa and row variable was section numbers in park. To test the dependence between these variables it was used *Pearson's Chi-square test of independence* at 0.05 significance level. Because in more cases table cells contained values less than 5, the analysis was repeated with help of *Monte Carlo simulation*. To determine the association of row and column variable it were used *Cramer's V coefficient, the Phi-Coefficient* and *the contingency coefficient*.

The data processing and evaluating was carried out in Microsoft Office Excel 2010 and all statistical analyses were performed using the statistical program R version 3.0.2. (R Core Team, 2013) with additional packages *"BaylorEdPsych"* (Beaujean, 2012), *"vcd"* (Meyer *et al.*, 2012) and *"gmodels"* (Warnes, 2013). It was used Tinn-R code editor for editing R scripts (Faria, 2013).

RESULTS

Due to the results of the one-way Anova, we can conclude that in case of the most host taxa the impact of all examined local factors are statistically significant:

- **Age:** significant effects in case of *Acer campestre* ($F_{5,527} = 15.46$, $p < 0.001$, $\eta_p^2 = 0.13$), *Acer platanoides* ($F_{4,88} = 3.86$, $p = 0.006$, $\eta_p^2 = 0.15$), *Crataegus monogyna* ($F_{4,56} = 3.47$, $p = 0.01$, $\eta_p^2 = 0.20$), *Juglans nigra* ($F_{5,77} = 4.64$, $p < 0.001$, $\eta_p^2 = 0.23$), *Robinia pseudoacacia* ($F_{4,73} = 5.64$, $p < 0.001$, $\eta_p^2 = 0.24$), *Tilia cordata* ($F_{6,285} = 23.13$, $p < 0.001$, $\eta_p^2 = 0.33$) and *Tilia platyhllos* ($F_{5,164} = 18.68$, $p < 0.001$, $\eta_p^2 = 0.36$). Non-significant effects in case of *Acer pseudoplatanus* ($F_{5,74} = 1.00$, $p = 0.43$, $\eta_p^2 = 0.06$) and *Crataegus pedicellata* ($F_{2,31} = 1.40$, $p = 0.26$, $\eta_p^2 = 0.08$).
- **Development stage:** significant effects in case of *Acer campestre* ($F_{3,529} = 22.07$, $p < 0.001$, $\eta_p^2 = 0.11$), *Acer platanoides* ($F_{3,89} = 3.32$, $p = 0.02$, $\eta_p^2 = 0.10$), *Juglans nigra* ($F_{3,79} = 11.84$, $p < 0.001$, $\eta_p^2 = 0.31$), *Robinia pseudoacacia* ($F_{3,74} = 10.73$, $p < 0.001$, $\eta_p^2 = 0.30$), *Tilia cordata* ($F_{2,289} = 37.42$, $p < 0.001$, $\eta_p^2 = 0.21$) and *Tilia platyphyllos* ($F_{3,166} = 8.01$, $p < 0.001$, $\eta_p^2 = 0.13$). Non-significant effects in case of *Acer pseudoplatanus* ($F_{3,76} = 2.76$, $p = 0.05$, $\eta_p^2 = 0.10$), *Crataegus monogyna* ($F_{3,57} = 1.18$, $p = 0.32$, $\eta_p^2 = 0.06$) and *Crataegus pedicellata* ($F_{2,31} = 1.71$, $p = 0.20$, $\eta_p^2 = 0.10$).
- **Physiological aspect of vitality:** significant effects in case of *Acer campestre* ($F_{4,528} = 8.14$, $p < 0.001$, $\eta_p^2 = 0.06$), *Acer platanoides* ($F_{3,89} = 4.06$, $p = 0.009$, $\eta_p^2 = 0.12$), *Acer pseudoplatanus* ($F_{2,77} = 7.55$, $p = 0.001$, $\eta_p^2 = 0.16$), *Juglans nigra* ($F_{4,78} = 11.03$, $p < 0.001$, $\eta_p^2 = 0.36$), *Robinia pseudoacacia* ($F_{3,74} = 5.69$, $p = 0.001$, $\eta_p^2 = 0.19$), *Tilia cordata* ($F_{3,288} = 29.19$, $p < 0.001$, $\eta_p^2 = 0.23$) and *Tilia platyphyllos* ($F_{3,166} = 25.27$, $p < 0.001$, $\eta_p^2 = 0.31$). Non-significant effects in case of *Crataegus monogyna* ($F_{3,57} = 0.91$, $p = 0.44$, $\eta_p^2 = 0.05$) and *Crataegus pedicellata* ($F_{1,32} = 1.36$, $p = 0.25$, $\eta_p^2 = 0.04$).
- **Biomechanical aspect of vitality:** significant effects in case of *Acer campestre* ($F_{3,529} = 6.34$, $p < 0.001$, $\eta_p^2 = 0.03$), *Acer pseudoplatanus* ($F_{3,76} = 8.15$, $p < 0.001$, $\eta_p^2 = 0.24$), *Juglans nigra* ($F_{3,79} = 13.13$, $p < 0.001$, $\eta_p^2 = 0.33$), *Robinia pseudoacacia* ($F_{4,73} = 4.00$, $p = 0.005$, $\eta_p^2 = 0.18$), *Tilia cordata* ($F_{4,287} = 8.49$, $p < 0.001$, $\eta_p^2 = 0.11$) and *Tilia platyphyllos* ($F_{3,166} = 13.39$, $p < 0.001$, $\eta_p^2 = 0.19$). Non-significant effects in case of *Acer platanoides* ($F_{3,89} = 1.87$, $p = 0.14$, $\eta_p^2 = 0.06$), *Crataegus monogyna* ($F_{2,58} = 2.35$, $p = 0.10$, $\eta_p^2 = 0.07$) and *Crataegus pedicellata* ($F_{2,31} = 2.70$, $p = 0.08$, $\eta_p^2 = 0.15$).
- **Location of individuals:** significant effects in case of *Acer campestre* ($F_{5,527} = 4.21$, $p < 0.001$, $\eta_p^2 = 0.04$), *Crataegus monogyna* ($F_{3,57} = 5.42$, $p = 0.002$, $\eta_p^2 = 0.22$), *Tilia cordata* ($F_{4,287} = 8.62$, $p < 0.001$, $\eta_p^2 = 011$) and *Tilia platyphyllos* ($F_{4,165} = 5.69$, $p < 0.001$, $\eta_p^2 = 0.12$). Non-significant effects in case of *Acer platanoides* ($F_{5,87} = 1.10$, $p = 0.37$, $\eta_p^2 = 0.06$), *Acer pseudoplatanus* ($F_{4,75} = 0.57$, $p = 0.69$, $\eta_p^2 = 0.03$), *Crataegus pedicellata* ($F_{4,29} = 0.79$, $p = 0.54$, $\eta_p^2 = 0.10$), *Juglans nigra* ($F_{4,78} = 0.84$, $p = 0.50$, $\eta_p^2 = 0.04$) and *Robinia pseudoacacia* ($F_{4,73} = 0.41$, $p = 0.80$, $\eta_p^2 = 0.02$).
- **Tree height:** significant effects in case of *Acer campestre* ($F_{5,527} = 8.41$, $p < 0.001$, $\eta_p^2 = 0.07$), *Acer platanoides* ($F_{4,88} = 4.50$, $p = 0.002$, $\eta_p^2 = 0.17$), *Juglans nigra* ($F_{5,77} = 17.91$, $p < 0.001$, $\eta_p^2 = 0.54$), *Robinia pseudoacacia* ($F_{5,72} = 4.87$, $p < 0.001$, $\eta_p^2 = 0.25$), *Tilia cordata* ($F_{6,285} = 12.53$, $p < 0.001$, $\eta_p^2 = 0.21$) and *Tilia platyphyllos* ($F_{7,162} = 3.02$, $p = 0.005$, $\eta_p^2 = 0.12$. Non-significant effects in case of *Acer pseudoplatanus* ($F_{3,76} = 1.59$, $p = 0.20$, $\eta_p^2 = 0.06$), *Crataegus monogyna* ($F_{2,58} = 2.35$, $p = 0.10$, $\eta_p^2 = 0.08$) and *Crataegus pedicellata* ($F_{1,32} = 0.25$, $p = 0.62$, $\eta_p^2 = 0.01$).
- **Diameter at breast height:** significant effects in case of *Acer campestre* ($F_{12,520} = 7.89$, $p < 0.001$, $\eta_p^2 = 0.15$), *Acer platanoides* ($F_{9,83} = 2.83$, $p = 0.006$, $\eta_p^2 = 0.23$), *Juglans nigra* ($F_{11,71} = 15.45$, $p < 0.001$, $\eta_p^2 = 0.71$), *Robinia pseudoacacia* ($F_{11,66} = 3.79$, $p < 0.001$, $\eta_p^2 = 0.39$), *Tilia cordata* ($F_{12,279} = 11.00$, $p < 0.001$, $\eta_p^2 = 0.32$) and *Tilia platyphyllos* ($F_{11,158} = 9.83$, $p < 0.001$, $\eta_p^2 = 0.41$). Non-significant effects in

case of *Acer pseudoplatanus* ($F_{10,69}$ = 1.67, p = 0.10, η_p^2 = 0.20), *Crataegus monogyna* ($F_{4,56}$ = 2.22, p = 0.08, η_p^2 = 0.14) and *Crataegus pedicellata* ($F_{2,31}$ = 1.49, p = 0.24, η_p^2 = 0.09).

- **Crown projection area:** significant effects in case of *Acer campestre* ($F_{7,525}$ = 11.47, p < 0.001, η_p^2 = 0.13), *Acer platanoides* ($F_{6,86}$ = 2.28, p = 0.04, η_p^2 = 0.14), *Crataegus monogyna* ($F_{3,57}$ = 4.78, p = 0.005, η_p^2 = 0.20), *Juglans nigra* ($F_{7,75}$ = 9.12, p < 0.001, η_p^2 = 0.46), *Robinia pseudoacacia* ($F_{5,72}$ = 3.62, p = 0.006, η_p^2 = 0.20), *Tilia cordata* ($F_{7,284}$ = 13.92, p < 0.001, η_p^2 = 0.26) and *Tilia platyphyllos* ($F_{7,162}$ = 8.53, p < 0.001, η_p^2 = 0.27). Non-significant effects in case of *Acer pseudoplatanus* ($F_{6,73}$ = 0.44, p = 0.85, η_p^2 = 0.03) and *Crataegus pedicellata* ($F_{2,31}$ = 0.26, p = 0.78, η_p^2 = 0.02).
- **Crown volume:** significant effects in case of *Acer campestre* ($F_{14,518}$ = 6.31, p < 0.001, η_p^2 = 0.15), *Juglans nigra* ($F_{13,69}$ = 5.40, p < 0.001, η_p^2 = 0.50), *Robinia pseudoacacia* ($F_{14,63}$ = 3.49, p < 0.001, η_p^2 = 0.44), *Tilia cordata* ($F_{13,278}$ = 9.84, p < 0.001, η_p^2 = 0.32) and *Tilia platyphyllos* ($F_{13,156}$ = 4.53, p < 0.001, η_p^2 = 0.27). Non-significant effects in case of *Acer platanoides* ($F_{13,79}$ = 1.45, p = 0.15, η_p^2 = 0.19), *Acer pseudoplatanus* ($F_{13,66}$ = 0.63, p = 0.82, η_p^2 = 0.11), *Crataegus monogyna* ($F_{9,51}$ = 1.04, p = 0.42, η_p^2 = 0.16) and *Crataegus pedicellata* ($F_{4,29}$ = 0.33, p = 0.85, η_p^2 = 0.04).

Tabs. I, II and III indicate the average mistletoe bush number per tree with dependence on the local factors. In more cases there are no information about the exact values, because such tree does not exist in the park. In these cases, instead of number there are two letters: NA (not available). From the Tab. I it is obvious that with increasing age or development stage, the number of mistletoe in the crown is also higher. The largest value was observed in case of *Juglans nigra* (Age category: III. – 145 individuals and Development stage: category 5. – 136.25 individuals).

I: *Average number of mistletoe bushes with dependence on several factors (age, development stage and location of individuals)*

Taxon	Age						
	I.	II.	III.	IV.	V.	VI.	VII.
Acer campestre	NA	33.65	31.63	20.79	13.05	8.43	14.49
Acer platanoides	NA	NA	25.75	40.32	28.18	8.59	19.38
Acer pseudoplatanus	NA	70.50	40.38	38.92	31.79	12.89	29.35
Crataegus monogyna	NA	NA	35.33	35.15	25.00	11.92	10.00
Crataegus pedicellata	NA	NA	NA	NA	9.00	7.39	1.50
Juglans nigra	NA	115.00	145.00	108.00	54.82	21.00	41.06
Robinia pseudoacacia	NA	NA	23.89	14.11	12.78	10.36	5.43
Tilia cordata	110.00	129.42	94.37	50.16	32.51	22.39	23.40
Tilia platyphyllos	NA	125.75	68.47	22.71	10.37	8.49	48.82
Taxon	**Development stage**						
		1.	**2.**	**3.**	**4.**	**5.**	
Acer campestre		NA	1.00	9.00	19.76	30.85	
Acer platanoides		NA	3.00	7.03	36.00	45.80	
Acer pseudoplatanus		NA	7.00	12.89	37.89	57.00	
Crataegus monogyna		NA	4.00	14.00	19.97	26.84	
Crataegus pedicellata		NA	NA	1.67	7.41	9.00	
Juglans nigra		NA	5.00	41.97	73.02	136.25	
Robinia pseudoacacia		NA	2.17	6.18	12.27	22.50	
Tilia cordata		NA	NA	20.15	52.27	85.43	
Tilia platyphyllos		NA	5.00	12.09	33.62	65.92	
Taxon	**Location of individuals**						
	MOCG	**MCCG**	**OCS**	**OCG**	**S**	**CCS**	**CCG**
Acer campestre	24.88	22.40	32.00	16.89	19.43	NA	14.63
Acer platanoides	39.82	25.62	18.00	24.64	NA	1.00	21.46
Acer pseudoplatanus	31.90	33.90	NA	46.08	34.00	NA	26.60
Crataegus monogyna	14.67	29.19	NA	4.00	NA	NA	19.45
Crataegus pedicellata	4.00	7.00	NA	8.63	23.00	NA	5.82
Juglans nigra	50.08	62.11	NA	80.10	49.00	NA	53.86
Robinia pseudoacacia	11.06	10.83	NA	9.17	3.00	NA	7.54
Tilia cordata	67.91	53.40	NA	67.77	133.80	NA	35.78
Tilia platyphyllos	57.58	41.02	NA	43.14	105.00	NA	16.97

II: *Average number of mistletoe bushes with dependence on several factors (physiological and biomechanical aspect of vitality)*

Taxon	Physiological aspect of vitality				
	0.	1.	2.	3.	4.
Acer campestre	12.00	8.34	18.26	26.54	53.20
Acer platanoides	NA	10.58	31.47	49.38	1.00
Acer pseudoplatanus	NA	8.94	29.10	59.13	NA
Crataegus monogyna	NA	14.50	19.28	25.19	23.25
Crataegus pedicellata	NA	NA	5.27	7.96	NA
Juglans nigra	1.00	15.38	66.52	73.33	147.00
Robinia pseudoacacia	NA	3.47	10.19	12.23	39.00
Tilia cordata	12.68	47.58	87.17	72.87	NA
Tilia platyphyllos	NA	5.58	44.29	60.15	124.00
Taxon	**Biomechanical aspect of vitality**				
	1.	**2.**	**3.**	**4.**	**5.**
Acer campestre	9.43	17.09	24.13	25.70	NA
Acer platanoides	11.08	28.28	31.16	76.00	NA
Acer pseudoplatanus	5.50	28.02	62.22	45.25	NA
Crataegus monogyna	NA	13.63	27.80	23.75	NA
Crataegus pedicellata	4.00	8.11	1.50	NA	NA
Juglans nigra	22.00	63.07	76.75	147.00	NA
Robinia pseudoacacia	2.72	10.21	14.41	13.67	11.50
Tilia cordata	23.32	47.31	65.12	86.59	61.50
Tilia platyphyllos	5.80	25.34	60.27	63.00	NA

There is also a big difference among the hosts in case of location of individuals, but these differences in more cases are non-significant.

Tab. II indicates the impact of the physiological and biomechanical aspect of vitality to the mistletoe infection. From this table is obvious that the influence of vitality to mistletoe infection is inversely proportional, because with decreasing physiological or biomechanical vitality of tree the number of mistletoe bushes will be higher. The largest mistletoe bush value was also observed in case of *Juglans nigra* (Physiological vitality: category 4. – 147 individuals and Biomechanical vitality: category 5. – 147 individuals). There is also a big difference among the hosts.

Tab. III shows the influence of the basic and the additional dendrometric quantities (tree height, diameter at breast height, crown projection area and crown volume) on the mistletoe infection. In all cases, this relationship is directly proportional, with larger dendrometric quantities we can expect higher mistletoe number per tree. The highest value was observed in case of *Juglans nigra* (tree height: 31–35 m – 168 individuals, diameter at breast height: larger than 120 cm – 191 individuals) and in case of *Tilia cordata* (crown projection area: 201–300 m^2 – 135.13 individuals, crown volume: larger than 2500 m^3 – 133.5 individuals). There are huge differences among the hosts, mostly statistically significant, in case of tree height in all hosts.

In the Tabs. III, IV and V the following abbreviations were used for the host taxa: I. – *Acer campestre*, II. – *A. platanoides*, III. – *A. pseudoplatanus*, IV. – *Crataegus monogyna*, V. – *Crataegus pedicellata*, VI. – *Juglans nigra*, VII. – *Robinia pseudoacacia*, VIII. – *Tilia cordata* and IX. – *Tilia platyphyllos*.

Due to the results of *Pearson's Chi-square test of independence* we can conclude that the frequency of all individuals of host taxa among the sections of the park are not equal ($\chi^2_{(96,\ N=3039)}$ = 1380.94, $p < 0.001$). Using *Monte Carlo simulation* (bases on 2000 replicates) the result is also statistically significant ($\chi^2_{(NA,\ N=3039)}$ = 1380.94, $p < 0.001$). The degree of these association are weak-middle strong (*Cramer's V coefficient: 0.24, the Phi-Coefficient: 0.67* and *Contingency coefficient*: 0.56). If we are testing only the infected individuals of host taxa, the results of analysis are also statistically significant (*Pearson's Chi-square test of independence:* $\chi^2_{(96,\ N=1424)}$ = 847.34, $p < 0.001$; *Monte Carlo simulation* (bases on 2000 replicates): $\chi^2_{(NA,\ N=1424)}$ = 847.34, $p < 0.001$). The degree of these association are weak-middle strong (*Cramer's V coefficient: 0.28, the Phi-Coefficient: 0.77* and *Contingency coefficient*: 0.61).

Tab. IV shows the frequency of all individuals of host taxa and table V shows the frequency of only infected individuals of host taxa in each section of the park which are also expressed by percentage values. Section number 4 contains the less individuals of host taxa – 24 (1%), among them are 11 (46%) already infected by mistletoe. Section number 9 contains the most individuals of host taxa – 685 (23%), among them are 195 (28%) already infected by mistletoe. The less infected specimens of host taxa – 11 (1%) are situated in section number 4 and the most infected individuals of host taxa – 224 (16%) can be found in section number 7. The most frequently infected host taxa is *Acer campestre* with 533 individuals (37%).

DISCUSSION

Based on our results we can conclude that impacts of all local factors are statistically significant for the most host species. Although, it was found huge difference among hosts, the influence of local factors have the same characters, because it was found directly or inversely proportional between selected factors and infection intensity.

Our results of a strong relationship between the intensity of mistletoe infection of hosts and their condition, expressed mainly by two aspects of vitality, are consistent with our previous results (Baltazár *et al.*, 2012) and with the results of Barbu (2012) who also confirmed that in case of European silver fir (*Abies alba* Mill.) the mistletoe infection (*Viscum album* subsp. *abietis*) conveyed by a reduction of needle length and a premature needle shedding had a negative impact on the crown of the host tree. The needles size and needle loss were significantly influenced by the infection class and the branch position in the crown showing that white mistletoe

III: *Average number of mistletoe bushes with dependence on several factors (tree height, diameter at breast height, crown projection area and crown volume)*

Tree height	Taxon								
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.
1–5 m	1.00	NA	NA	8.57	5.22	NA	1.00	23.00	NA
5–10 m	9.53	4.47	NA	18.05	7.76	NA	3.50	28.35	NA
11–15 m	16.84	19.58	44.85	41.91	NA	51.65	9.54	31.18	34.72
16–20 m	25.86	34.50	36.96	NA	NA	50.04	14.54	48.77	25.17
21–25 m	25.98	43.85	36.60	NA	NA	100.86	16.93	84.33	21.24
26–30 m	35.17	102.00	NA	NA	NA	93.69	12.50	104.75	51.84
31–35 m	NA	NA	NA	NA	NA	168.00	NA	65.50	124.60
36–40 m	NA	NA	NA	NA	NA	NA	NA	NA	101.00
Diameter at breast height	**Taxon**								
	I.	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**	**VIII.**	**IX.**
1–10 cm	5.50	2.00	9.00	9.00	4.56	1.00	2.00	19.50	NA
11–20 cm	8.31	5.57	8.94	12.14	10.00	10.50	7.95	19.48	3.15
21–30 cm	8.67	15.32	10.25	25.80	9.00	19.06	4.88	20.92	8.62
31–40 cm	15.14	20.93	34.83	38.60	NA	53.71	14.00	33.63	13.14
41–50 cm	24.93	37.85	31.94	52.25	NA	81.73	17.17	48.57	19.85
51–60 cm	20.77	16.50	63.56	NA	NA	87.83	11.80	66.44	29.08
61–70 cm	36.96	63.57	28.25	NA	NA	133.00	11.50	72.42	29.17
71–80 cm	33.54	11.75	49.00	NA	NA	63.67	20.67	90.35	68.62
81–90 cm	36.10	151.00	55.67	NA	NA	47.00	22.00	152.45	40.20
91–100 cm	47.90	59.50	9.00	NA	NA	39.00	49.00	94.83	97.56
101–110 cm	36.00	NA	89.00	NA	NA	NA	11.00	124.17	82.33
111–120 cm	22.33	NA	NA	NA	NA	168.00	NA	117.00	88.40
120 cm <	36.00	NA	NA	NA	NA	191.00	12.00	98.00	113.83
Crown projection area	**Taxon**								
	I.	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**	**VIII.**	**IX.**
1–15 m^2	10.86	5.00	14.18	11.95	6.90	5.25	4.91	21.65	11.80
15–30 m^2	7.82	21.25	27.29	10.68	4.50	40.57	9.64	21.09	11.00
31–60 m^2	14.84	13.32	31.81	37.11	12.50	33.95	12.67	32.67	15.75
61–100 m^2	19.59	28.88	34.68	39.80	NA	60.62	14.58	53.89	23.94
101–140 m^2	35.19	20.00	47.36	NA	NA	72.56	27.50	82.64	46.23
141–200 m^2	30.83	57.13	37.33	NA	NA	106.63	NA	83.43	71.73
201–300 m^2	49.33	63.17	70.50	NA	NA	128.43	12.00	135.13	116.89
300 m^2 <	47.33	NA	NA	NA	NA	122.00	NA	112.33	78.50
Crown volume	**Taxon**								
	I.	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**	**VIII.**	**IX.**
1–20 m^3	6.33	NA	NA	14.33	7.50	6.00	3.27	NA	NA
21–40 m^3	4.27	2.75	3.00	13.88	5.07	4.50	8.00	7.00	7.50
41–60 m^3	4.29	6.60	10.33	11.57	8.44	6.00	1.50	14.50	12.00
61–100 m^3	12.00	3.40	14.86	10.33	10.00	NA	7.71	18.42	10.43
101–150 m^3	8.17	6.00	13.60	24.92	8.50	27.33	5.50	24.47	10.09
151–200 m^3	10.93	9.17	11.00	24.13	NA	31.00	7.33	18.00	19.89
201–250 m^3	13.32	24.17	13.00	41.67	NA	44.00	22.17	17.79	34.00
250–300 m^3	10.55	12.67	35.00	25.00	NA	27.71	5.00	27.79	28.29
301–400 m^3	12.90	23.00	49.78	51.67	NA	62.00	6.60	27.20	12.20
401–550 m^3	22.83	18.80	32.82	45.50	NA	46.60	8.29	39.36	10.59
551–750 m^3	20.49	31.60	48.88	NA	NA	50.75	22.00	47.40	18.53
751–950 m^3	26.45	34.56	43.67	NA	NA	34.71	22.00	39.42	16.38
951–1400 m^3	31.85	36.22	39.75	NA	NA	71.67	32.67	84.31	34.27
1401–2500 m^3	33.22	51.80	29.71	NA	NA	95.56	44.00	89.41	56.35
2500 m^3 <	42.00	54.50	70.50	NA	NA	124.83	12.00	133.05	102.18

IV: *The frequency of all specimens of host taxa in the park with dependence on park sections*

Section number		Taxon								
	I.	II.	III.	IV.	V.	VI.	VII.	VIII.	IX.	Total
1	186	32	7	18	0	4	19	29	14	309
	6%	1%	0%	1%	0%	0%	1%	1%	0%	10%
2	5	0	3	0	0	7	4	7	6	32
	0%	0%	0%	0%	0%	0.5%	0%	0.5%	0%	1%
3	22	21	1	2	0	0	2	8	9	65
	1%	1%	0%	0%	0%	0%	0%	0%	0%	2%
4	3	4	12	0	1	1	0	3	0	24
	0%	0%	1%	0%	0%	0%	0%	0%	0%	1%
5	63	7	19	6	4	1	3	67	25	195
	2%	0%	1%	0%	0%	0%	0%	2%	1%	6%
6	98	21	7	8	0	0	0	19	9	162
	3%	1%	0%	0%	0%	0%	0%	1%	0%	5%
7	172	3	10	15	1	70	23	105	13	412
	6%	0%	0%	0%	0%	2%	1%	3%	0%	14%
8	99	12	13	4	9	26	2	61	29	255
	3%	0%	0%	0%	0%	1%	0%	2%	1%	8%
9	236	7	17	29	60	0	21	82	233	685
	8%	0%	1%	1%	2%	0%	1%	3%	8%	23%
10	120	10	23	5	2	4	2	45	42	253
	4%	0%	1%	0%	0%	0%	0%	1%	1%	8%
11	103	1	12	5	1	0	21	43	13	199
	3%	0%	0%	0%	0%	1%	1%	1%	0%	8%
12	72	18	47	6	1	2	29	28	36	239
	2%	1%	2%	0%	0%	1%	1%	1%	1%	8%
13	87	23	34	8	3	2	16	18	18	209
	3%	1%	1%	0%	0%	1%	1%	1%	1%	7%
Total	1266	159	205	106	82	117	142	515	447	3039
	42%	5%	7%	3%	3%	4%	5%	17%	15%	100%

negative influence on the crown of its host is increasing along with the infection degree.

Similar results were recorded in case of development stage and tree age. It was predictable, because the development stage is such variable which is related to vitality; in many cases, they are substitutive conversely. Similarly, the age is closely linked with these both variables. Our results of the relationship between the tree age and mistletoe infection are consistent with the findings of our previous results (Baltazár *et al.*, 2012, 2013a) and other authors (Kołodziejek *et al.*, 2013) who showed that infection was more severe in case of old trees; many of these were older than 80 years.

Although, in our cases the impact of location of individuals were significant only in case of 4 host taxa, the previous studies (Baltazár *et al.*, 2012, 2013a) confirmed the importance of this factor. In general, the most infected host individuals are located at the edge of stand, roads and open area places (Kartoolinejad *et al.*, 2007) which was also observed in our studies, because the largest mistletoe bushes were found in case of solitary plants (*Juglans nigra*, averagely 134 mistletoe bushes). Moreover, higher mistletoe number per tree was found in case open canopy group and margin of open canopy group. *Viscum album* is a light-demanding species, especially for germination, this may the reason why highlighted trees are stronger infected (Zuber, 2004; Kartoolinejad *et al.*, 2007).

The role of the dendrometric quantities of tree are also important, mainly the tree height. In general, larger or older trees showed greater predisposition to being infected than smaller ones. Very small trees were never seen with parasites; nor were any dead small trees with parasites observed (Kartoolinejad *et al.*, 2007; Kołodziejek *et al.*, 2013). In our previous results (Baltazár, 2011; Baltazár *et al.*, 2013b) also showed the infected individuals of *Tilia platyphyllos* were averagely 7 m higher than uninfected individuals. The largest difference (averagely 6 m) was observed in case of *Juglans nigra* and *Tilia cordata*.

Other studies confirmed that the impact of other dendrometric quantities also deserve attention.

V: *The frequency of infected individuals of host taxa in the park with dependence on park sections*

Section number	Taxon									
	I.	**II.**	**III.**	**IV.**	**V.**	**VI.**	**VII.**	**VIII.**	**IX.**	**Total**
1	119	25	2	17	0	4	13	20	7	207
	8%	2%	0%	1%	0%	0%	1%	1%	0%	15%
2	2	0	2	0	0	6	1	6	4	21
	0%	0%	0%	0%	0%	0.5%	0%	0.5%	0%	1%
3	12	13	1	1	0	0	0	1	4	32
	1%	1%	0%	0%	0%	0%	0%	0%	0%	2%
4	2	3	2	0	0	1	0	3	0	11
	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
5	28	4	9	2	1	1	2	44	10	101
	2%	0%	1%	0%	0%	0%	0%	3%	1%	7%
6	46	11	3	8	0	0	0	13	3	84
	3%	1%	0%	1%	0%	0%	0%	1%	0%	6%
7	62	2	4	8	0	52	14	70	12	224
	4%	0%	0%	1%	0%	4%	1%	5%	1%	16%
8	38	7	4	4	3	15	1	33	17	122
	3%	0%	0%	0%	0%	1%	0%	2%	1%	9%
9	52	3	7	12	29	0	6	26	60	195
	4%	0%	0%	1%	2%	0%	0%	2%	4%	14%
10	40	5	5	3	1	2	1	26	16	99
	3%	0%	0%	0%	0%	0%	0%	2%	1%	7%
11	54	0	6	0	0	0	5	27	19	101
	4%	0%	0%	0%	0%	0%	0%	2%	1%	7%
12	33	8	24	2	0	0	23	14	21	125
	2%	1%	2%	0%	0%	0%	2%	1%	1%	9%
13	45	12	11	4	0	2	12	9	7	102
	3%	1%	1%	0%	0%	0%	1%	1%	0%	7%
Total	533	93	80	61	34	83	78	292	170	1424
	37%	7%	6%	4%	2%	6%	5%	21%	12%	100%

In case of diameter at breast it was proved positive significance relation with mistletoe abundance (Kartoolinejad *et al.*, 2007). The author also states that especially this factor play an important role in explaining local abundance and distribution of mistletoe plants. Our previous studies (Baltazár *et al.*, 2014) also proved that in case of *Tilia cordata* and *T. platyphyllos* the infected individuals were averagely 22–24 cm thicker than uninfected specimens. The impact of tree height and diameter at breast height cannot be separate which was proved by our previous studies (Baltazár *et al.*, 2013b); strong relationship (75% or stronger) was found between the tree height and diameter at breast height in case of all host taxa.

The impact of crown projection area was also proved by our studies. The largest difference was found in case of *Tilia cordata* and *T. platyphyllos,* where the infected individuals averagely have 3 time larger crown projection area than uninfected specimens (Baltazár *et al.*, 2014). Similar result was found in case of crown volume. The infected individuals of *Juglans nigra* (averagely 3 times), *Tilia cordata* (averagely 4.5 times) and *Tilia platyphyllos* (averagely 5 times) have larger crown volume. Although, it was not analysed, but it is obvious, that there are strong relationship between the tree height and crown volume and between the crown projection area and crown volume.

The observation that taller, larger, and older trees have a higher frequency of parasitic attack and more intense infection than smaller trees is not uncommon. A common explanation is that larger and older trees could be more attractive to frugivorous birds for perching, which would therefore deposit more mistletoe seeds onto perches (Reid and Lange, 1988; Overton, 1994; Donohue, 1995; López de Buen *et al.,* 2002). However, Reid and Stafford-Smith (2000) suggest that a high number of mistletoes per tree results more from the attraction of dispersers to the presence of established mistletoes on trees than to host size by itself (Kołodziejek *et al.*, 2013).

The habitat is topographically and ecologically defined by the host tree (Wangerin, 1937). For example, when hosts are widely scattered, their mistletoe parasites may be less common and widely distributed as well (Zuber, 2004; Kołodziejek *et al.*, 2013). Birds that disseminate mistletoes often perch at the tops of the larger trees, thus depositing mistletoe seeds high in the canopy (Kołodziejek *et al.*, 2013) which was confirmed by our studies (Baltazár *et al.*, 2014), because in these sections of the park, where the most individuals of host taxa occur, the mistletoe infection is the highest. For dioecious tree species, bird visitation may be biased in favour of fruiting plants, thereby influencing overall mistletoe distribution (Kołodziejek *et al.*, 2013; Mathiesen *et al.*, 2008).

Although, we tried modelling the local distribution of *Viscum album* in the park, our results did not give answer which dendrometric quantities or other local factors have the most important role to mistletoe distribution in model area, therefore in the near future we are going to modelling of this distribution with help of advanced statistical methods.

CONCLUSION

There are 9 most significant mistletoe hosts in the castle park in Lednice: *Acer campestre, A. platanoides, A. pseudoplatanus, Crataegus monogya, C. pedicellata, Juglans nigra, Robinia pseudoacacia, Tilia cordata*, and *T. platyphyllos* which were used for the subsequent detailed analysis. In case of *Acer campestre*, *Tilia cordata*, and *T. platyphyllos* was proved statistically significant relation of all nine surveyed local factors (tree age, development stage, location of individuals, physiological and biomechanical aspect of vitality, tree height, diameter at breast height, crown projection area and crown volume) to their mistletoe infection. In case of *Juglans nigra* and *Robinia pseudoacacia* was found this statistically significant relation with the eight local factors; except for the location of individuals. No statistically significant relationship was proved in case of *Crataegus pedicellata*. The highest infestation with mistletoe was observed in the elderly individuals of *Juglans nigra* (trees of age category III. and older) whose individual crowns contained more than 100 mistletoe bushes. From our results it is also obvious that neither the host trees nor mistletoe are distributed evenly in the park. In section No. 4 in the park, there is only 1% of the total number of host trees, while the section No. 9 contains 23% of them. Of the total number of infected individuals of host trees, there are 1% of them in the section No. 4 and 16 % of them in the section No. 7.

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