

THE RELATIONSHIP BETWEEN SOME FOREST STAND PROPERTIES AND THE OCCURRENCE OF ORCHIDS IN THE CENTRAL PART OF THE MORAVIAN KARST PROTECTED LANDSCAPE AREA

Alois Procházka¹, Tomáš Mikita², Petr Jelínek³

¹Department of Applied and Landscape Ecology, Faculty of AgriSciences, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic

²Department of Forest Management and Applied Geoinformatics, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic

³Department of Forest Botany, Dendrology and Geobiocenology, Mendel University in Brno, Zemědělská 1, 613 00 Brno, Czech Republic

Abstract

PROCHÁZKA ALOIS, MIKITA TOMÁŠ, JELÍNEK PETR. 2017. The Relationship between some Forest Stand Properties and the Occurrence of Orchids in the Central Part of the Moravian Karst Protected Landscape Area. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, 65(3): 919–931.

The aim of this study is to determine the relationship between some forest stand properties and the occurrence of orchids in the territory of the Křtiny Training Forest Enterprise. The research took place between the villages of Babice nad Svitavou, Kanice and Křtiny and largely spans the Moravian Karst Protected Landscape Area, partly in the core zone as well as the second zone of the Moravian Karst, where ordinary logging practices are used. Only a small part falls into the core area (first zone) – the two small-scale nature reserves with a total area of 61 hectares and a non-intervention regime. The selected area is situated mainly in forest ecosystems with beech and oak (*Fagi-Querceta* and *Querci-Fageta*) covering an area of 853 ha. The occurrence of orchids was examined in relation to natural conditions, forest type and forestry land use. In particular the occurrence of orchids to the height of the tree vegetation, to the Lidar Penetration Index and to the distance from roads and cleared boundary lines were investigated.

Keywords: Moravian Karst Protected Landscape Area, Křtiny Training Forest Enterprise, forest ecosystems, orchids, forest management, conifers

INTRODUCTION

Most species of *Orchidaceae* grow in tropical Africa, America and Asia, where about 30,000 species of plants of this family occur, but there are also species that grow in temperate zone ecosystems in both the northern and the southern hemisphere (Ježek, 2003). In Europe 489 species of orchids grow, and 57 species occur in the Czech Republic, while another two species are considered extinct (Procházka and Velíšek, 1983).

In the last century, especially from the 1950s to the 1990s, there was great damage and destruction

of many orchid sites. It resulted in great decline in the habitats of these delicate plants. Loss of appropriate environment, fragmentation and anthropogenic disturbance was behind a loss of biodiversity worldwide (Fahring, 2003). Although the main reason for the loss of diversity was a decrease in suitable habitats (Hannah, Carr and Lankerani, 1995; Foley *et al.*, 2005), the importance of the influence of degradation of habitat should also be mentioned (Rimbach *et al.*, 2013). The loss of orchids in Moravia and Silesia was described by Jatiová and Šmiták (1996), in the protected area of the Moravian

Karst by Vaněčková *et al.* (1997), and near the village of Křtiny in the central part of the Křtiny Training Forest Enterprise (TFE) by Jelínek (2009). Despite the fact that most orchids in the Czech Republic are included in the list of endangered species in accordance with Decree 395/1992 Coll. in order to protect these plants effectively, a comprehensive approach to orchid protection is needed. We have to protect not only the plant itself but the entire ecosystem. Ways of caring for orchid locations were analysed by Jersáková and Kindlmann (2004).

A comprehensive survey of the site near Babice, Kanice and Křtiny has not yet been made but some information on the occurrence of the most endangered plant species in the central part of the Moravian Karst exists (Štefka and Müller, 1995; Vaněčková and Vašátko, 1992; Vaněčková *et al.*, 1997). We received further information about the occurrence of orchids in the area from the publication of Jatiová and Šmiták (1996). In the Moravian Karst the occurrence of orchids is higher in comparison with other regions of the Czech Republic. The higher incidence of *Orchidaceae* in the surveyed area is due to several major aspects of the site, particularly because of the autochthonous tree species composition with a rich herb layer, favourable soil conditions and the low degree of anthropic influence with a favourable state of preservation of the ecosystem (Dykyjová, 2003).

Jersáková and Kindlmann (2004) give the main factors influencing the occurrence of orchids, which include the ecological requirements of the species, suitable habitat, the species composition of forests, the incidence of non-indigenous species and also various kinds of demands on the light, especially the canopy density of the forest. While the description of the habitat and the age, species, and partly also the spatial composition of forests can be obtained on the basis of the available databases of Regional Plans of Forest Development (RPF) and Forest Management Plans (FMP) in the Czech Republic, information about canopy density is not available or, more precisely, its spatial variability is not known. Likewise, from FMPs we can get an idea about the species composition of vegetation, but not for the mixing ratio and spatial distribution. The technologies enabling the classification of an area or canopy species composition are mainly remote sensing (RS) methods, namely Light Detection and Ranging and multispectral imaging.

Light Detection and Ranging (LiDAR) is a modern, progressive method of RS. This method allows the mass collection of highly accurate elevation and topographical data on the Earth's surface and about objects on it (vegetation and buildings) (Mikita *et al.*, 2013). A laser pulse emitted from a plane touches an object and is reflected from each facet of the object, thereby creating a sequence of reflections from closest to farthest. When scanning a stand of forest reflections may behave differently. Either it is reflected from the first canopy layer, or only part

strikes it and the remaining part may then proceed down to the lower layers. When reflected from the first layer, preferably from the tips and surfaces of the treetops, this is called the first echo (first return). Through gaps in the canopy the laser pulse travels to the earth's surface thus creating additional reflections. The final reflection (last return) we understand to be the reflection from the surface of the earth itself; so we can get an idea of the earth's surface under the canopy and of the lower storey stand. This creates a distinctive cluster of data points (a point cloud) which is used in other analyses (Ackermann, 1999).

Based on the ratio of the pulse reflected from the first layer to the reflection from the Earth's surface it is possible to calculate the so-called Lidar Penetration Index (LPI), which indirectly expresses the forest canopy density per unit area. LPI values range from 0 to 1. Values close to 1 show the presence of dense vegetation and, conversely, a value close to 0 characterises open canopy or land surface (Musselman *et al.*, 2013).

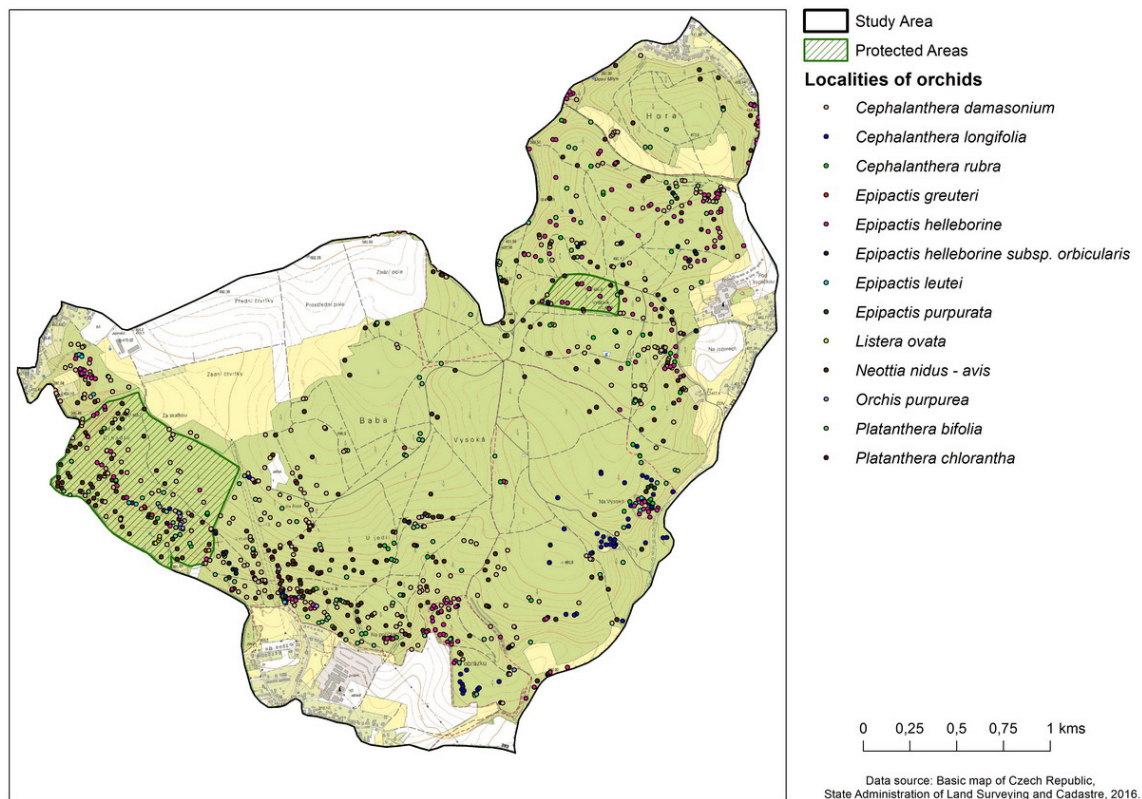
This paper seeks to find the relationship between orchid occurrence and forest stand properties: species composition, ecological grid, height of tree vegetation, light in the forest, the distance from roads and cleared boundary lines.

MATERIALS AND METHODS

Botanical Research

Data on the occurrence of *Orchidaceae* are from the 2009 survey, which was recorded using the GPS Trimble Juno SC with program Arc Pad 8.0 sp2. Based on the analysis of documents from former botanical surveys an area of interest was defined using the road network between the villages Babice nad Svitavou, Křtiny, Brezina, Ochoz u Brna (crossroads), Kanice and Babice nad Svitavou. This boundary defined a research area of about 853 ha, mostly located on the territory of the Moravian Karst. Mendel University represented by TFE is one of the most important forest owners within the study area. The forest is managed normally; however it is a special-purpose forest to educate students of forestry at Mendel University, north of the Moravian capital of Brno.

In particular taxa of the orchid family the exact position was recorded. Given the accuracy of GPS devices, individuals of the same species within a circle with a diameter of 5 m were entered as the same point. The number of individuals at every point was recorded. Points on the Fig. 1 thus represent different locations of particular orchid species. These are in following text and figures regarded as localities of orchids. The mapping took place in detail in strips, one after another. The nomenclature of all recorded plants at the site is taken from Kubát (2002). *Epipactis* species were determined according to Batoušek (2005).



1: Study area with positions of localities of Orchidaceae species found.

The species were categorised by category of threat according to Grulich (2012).

The soil properties and altitudinal climatic zoning expressed by forest vegetation zones make up the so-called ecological grid which is commonly used in the Czech Republic in forestry (Viewegh *et al.*, 2003). The following ecological grids were recorded in the studied area: 1J *Carpineto-Aceretum saxatile*, 1X *Corneto-Quercetum (xerothermicum)*, 2A *Aceri-Fageto-Quercetum lapidosum*, 2B *Fageto-Quercetum mesotrophicum*, 2C *Fageto-Quercetum subxerothermicum*, 2D *Fageto-Quercetum acerosum diluvium*, 2H *Fageto-Quercetum illimerosum mesotrophicum*, 2K *Fageto-Quercetum acidophilum*, 2S *Fageto-Quercetum oligo-mesotrophicum*, 2X *Corneto-Fagi-Quercetum (xerothermicum)*, 2Z *Fageto-Quercetum humile*, 3A *Tilii-Querceto-Fagetum acerosum lapidosum*, 3B *Querceto-Fagetum mesotrophicum*, 3D *Querceto-Fagetum acerosum diluvium*, 3H *Querceto-Fagetum illimerosum mesotrophicum*, 3J *Tilieto-Aceretum saxatile*, 3K *Querceto-Fagetum acidophilum*, 3L *Fraxinetum-Alnetum alluviale*, 3N *Querceto-Fagetum lapidosum acidophilum*, 3S *Querceto-Fagetum oligo-mesotrophicum*, 3W *Querceto-Fagetum calcarium*, 3X *Corneto-Fagetum (xerothermicum)*, 4A *Tilieto-Fagetum acerosum lapidosum*, 4D *Fagetum acerosum diluvium*, 4G *Querceto-Abietum piceosum paludosum mesotrophicum*, 4S *Fagetum oligo-mesotrophicum*, 4V *Fagetum fraxinosum humidum*, 4W *Fagetum calcarium*, 4X *Fagetum dealpinum (xerothermicum)*.

Forestry Analysis

For the analysis of dependencies between the occurrence of orchids and the forest environment databases of Regional Plans of Forest Development (RPF), data from the forest management plan (FMP), Light Detection and Ranging (LiDAR) and multispectral aerial photography were used. Data from the typology layer of RPF were used and the incidence of species within the forest type (FT) was evaluated. FMP data served mainly to analyse the species composition of forests.

Light Detection and Ranging was carried out within the entire TFE in September 2014 resulting in an average density of 12 points per m². After classification of the first return points from the vegetation and the last returns from bare ground and after subsequent interpolation, detailed digital terrain (DTM) and surface (DSM) models with a resolution of 1 m were created. These models were used to create a so-called Canopy Height Model (CHM), which directly indicates the height of vegetation. CHM classifications identified places without vegetation, such as forest paths, clearings and cleared boundary lines. On the basis of calculating the ratio of first return points from vegetation and last return points from bare earth surface the LPI was calculated (Musselman *et al.*, 2013). Detection of the occurrence of conifers was performed using a controlled Maximum Likelihood Classification based on classification of

multispectral images with areas of Red, Green, Blue and Near Infrared.

The data obtained on the occurrence of orchids were then compared in ArcGIS Desktop 10.3, and were evaluated for the relevant dependencies. The relationship between the occurrence of orchids and height of vegetation indicates the ratio of the **frequency of orchids (localities of orchids) to the average height of forest vegetation**. The height of forest stands on the site ranges from 0 to 35 metres, obtained from so-called CHM created by LiDAR data processing (Fig. 11).

The relationship between the occurrence of orchids and canopy density – LPI (Lidar Penetration Index) is the ratio of the **frequency of orchids to the density of the forest stand (LPI)**. The index is expressed as a ratio of LiDAR points of surface vegetation and bare earth, where numbers close to 1 identify full canopy cover, while numbers below 0,7 indicate an area without vegetation. The relationship between the occurrence of orchids and tree species indicates the ratio of the **frequency of orchids to the main tree species** from the forest management plan. There are more tree species in the locality, however only the major tree species based on the digital FMP were evaluated. Representation of beech: *Fagus sylvatica*, oak: *Quercus petraea*, Norway spruce: *Picea abies* and other deciduous tree species: *Acer campestre*, *A. platanoides*, *A. pseudoplatanus*, *Alnus glutinosa*, *Betula pendula*, *Carpinus betulus*, *Fraxinus excelsior*, *Populus tremula*, *Robinia pseudoacacia*, *Salix caprea*, *Sorbus aucuparia*, *S. torminalis*, *Tilia cordata*, *Ulmus laevis* were compared. Numbers of locations of orchids were divided by the particular tree species area to get comparable datas.

The relationship between **the occurrence of orchids and forest type** is the ratio of the frequency of the orchid to forest type. Forestry in the Czech Republic uses forest types to characterise forest habitats with similar soil, climate and ground water conditions (Zlatník, 1956, Pliva, 1976). Forest types are grouped into larger units which are used for forest management. To compare the orchids occurrence in forest types the number of localities is divided by the area of specific forest type.

The relationship between the occurrence of orchids and distance from roads and cleared boundary lines indicates the ratio of the **frequency of orchids to the distance from roads and cleared boundary lines** which are identified as areas with no vegetation on the basis of the Canopy Height Model (CHM). Distances from cleared boundary lines and forest roads were calculated based on the Euclidean Distance followed by assigning values to the sites of occurrence, and are indicated in metres from 0 to 300 m.

The relationship between the occurrence of orchids in deciduous and coniferous forests is given by the **frequency of occurrence of orchids in deciduous and coniferous forests**. The incidence is given in % in relative numbers (divided by the area

of coniferous/broadleaved forest). The relationship between the occurrence of orchids and distance from coniferous forests is the **frequency of orchids with the distance from coniferous stands** and individual coniferous tree groups based on the classification of aerial photographs. The distance from coniferous trees has been calculated on the basis of the Euclidean Distance followed by assigning values to the sites of occurrence, and is indicated in metres from 0 to 300 m.

RESULTS

Botanical and Natural Condition Analysis

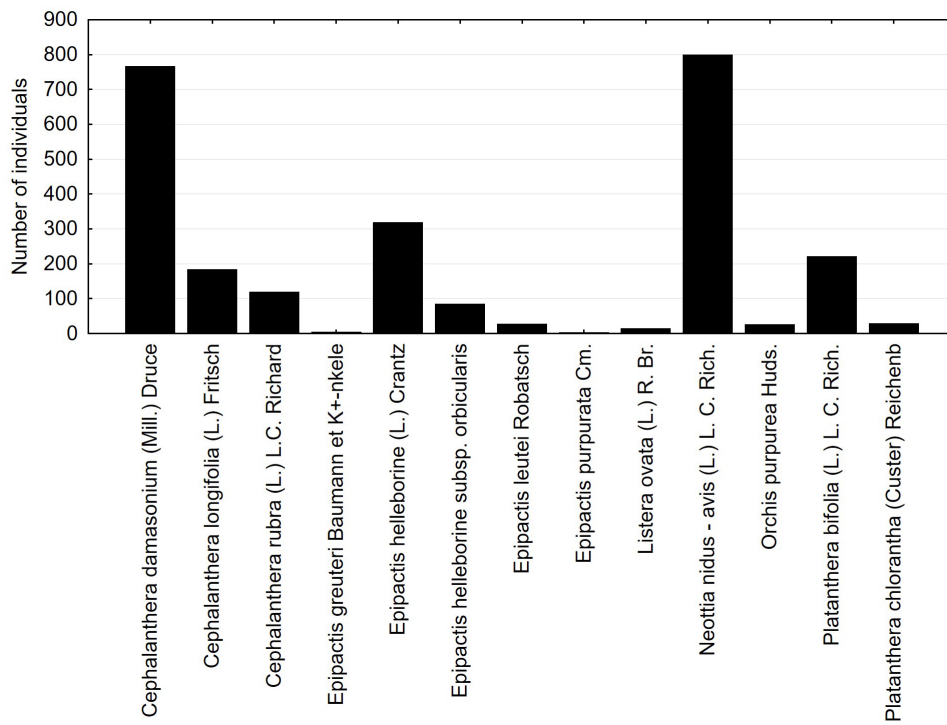
Ninety-three per cent of the research area is formed by deciduous forest with a predominance of oak (*Quercus petraea*) and beech (*Fagus sylvatica*). Seven per cent is composed of coniferous forest with spruce (*Picea abies*) dominated areas. Among the endangered woody species *Sorbus torminalis*, *Cornus mas* and *Staphylea pinnata* were found. Forty-three endangered plant species were found in the research area, the rarest were species from the *Orchidaceae* family.

Thirteen species of *Orchidaceae* were found with a total number of 2,599 individuals at 1,121 locations (Fig. 2). The most abundant orchids found at the site were *Neottia nidus-avis* with 800 plants and *Cephalanthera damasonium* with 767. The highly endangered species of orchid found were *Epipactis greuteri* with four plants, *Orchis purpurea* with 26, *Epipactis leutei* with 28 and *Cephalanthera rubra* with 119. All orchids are endangered species listed in the Red List of vascular plants of the Czech Republic (Grulich, 2012).

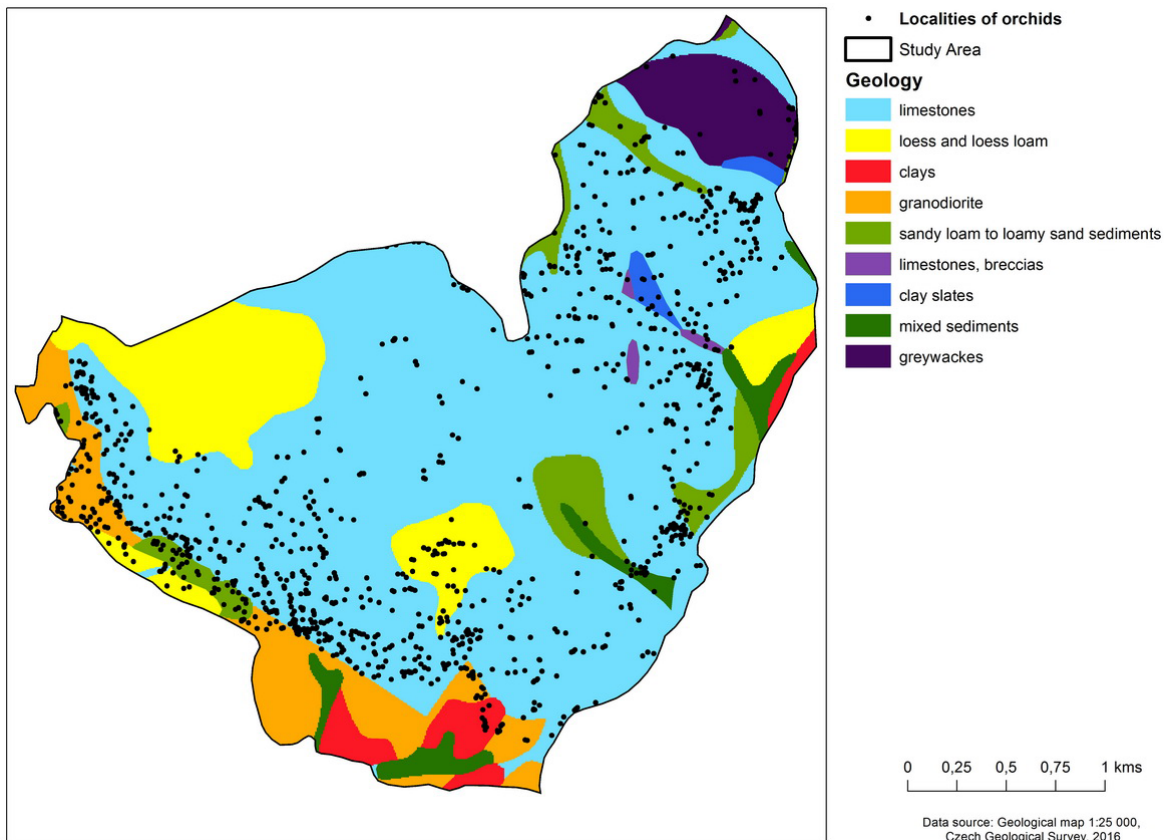
The historically documented species *Cypripedium calceolus*, *Epipogium aphyllum* and *Epipactis muelleri* that grew near the village of Babice nad Svitavou (Vaněčková and Vašátko, 1992, Stefka and Müller, 1995; Jatiová and Šmiták 1996; Vaněčková *et al.* 1997) were not found.

The map with the appearance of orchids also shows that orchids grow in both nature reserves with no logging (Čihadlo Nature Reserve and Březinka Nature Reserve), and outside those areas where shelterwood logging is being used (Fig. 1). Areas where clear-cutting was used and which are covered with coniferous monocultures are rare in the Moravian Karst and the rare plants of autochthonous broadleaved forest (*Orchidaceae* and *Liliaceae* for example) do not usually grow here (see Fig. 6 and analysis below).

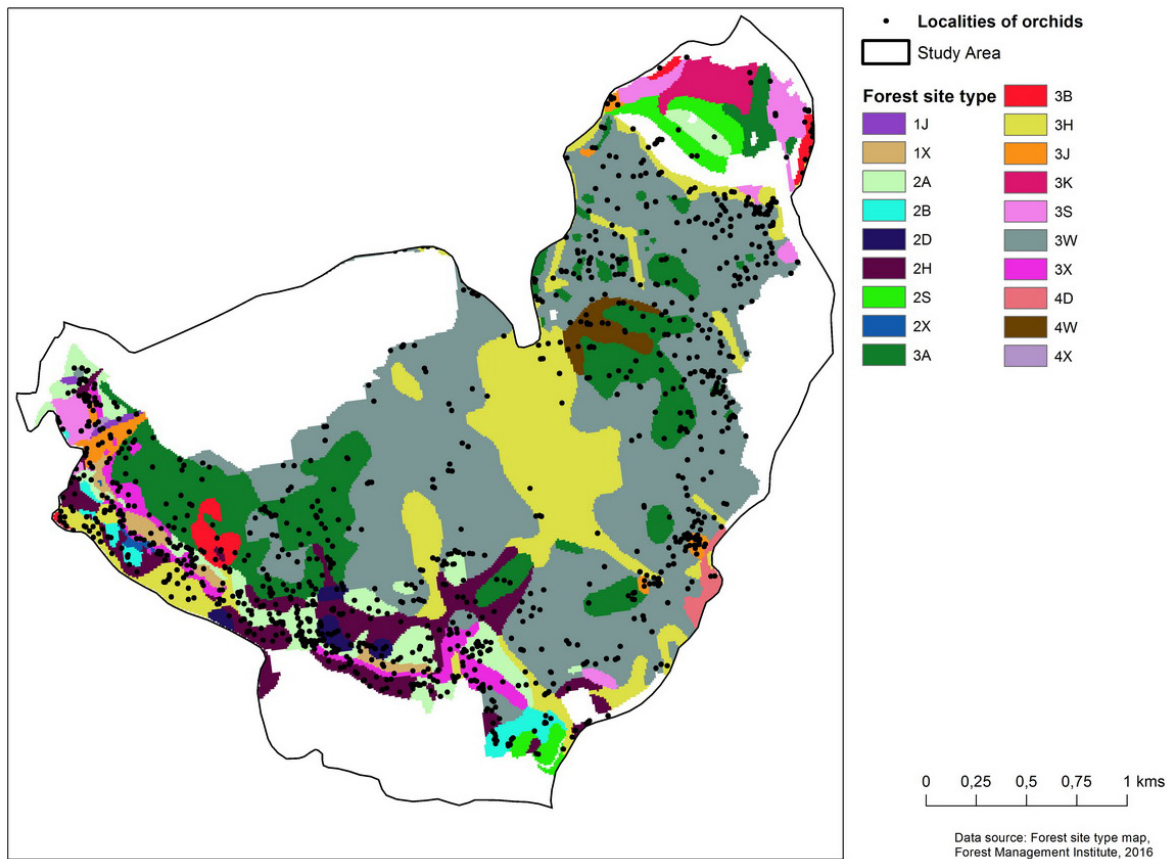
Figs. 3 and 4 show the different ecological conditions of the study area with orchids marked. The geological map (Fig. 3) clearly shows the presence of orchids preferentially on limestone. The forest type map (Fig. 4) reflects soil and climatic conditions. The 3W *Querceto-Fagetum calcarium* forest type accounted for the largest number of orchid localities ($n = 340$). In fact it is the most common forest type in the research area. More relevant is



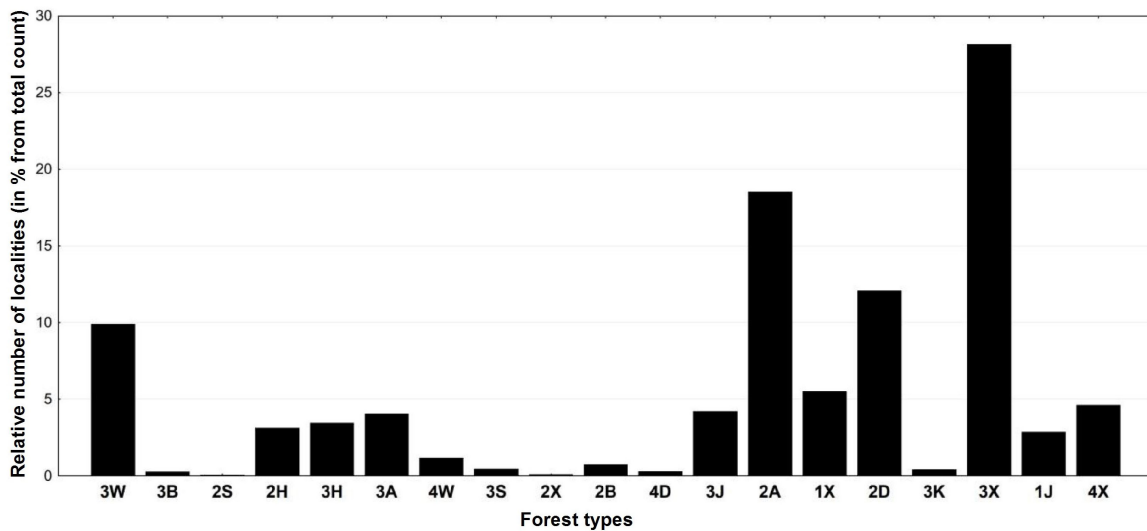
2: The occurrence of orchids in the surveyed area in 2009 (number of individuals).



3: Geological map of the study area.



4: Locations of orchids in forest site types. For details, see Materials and Methods.

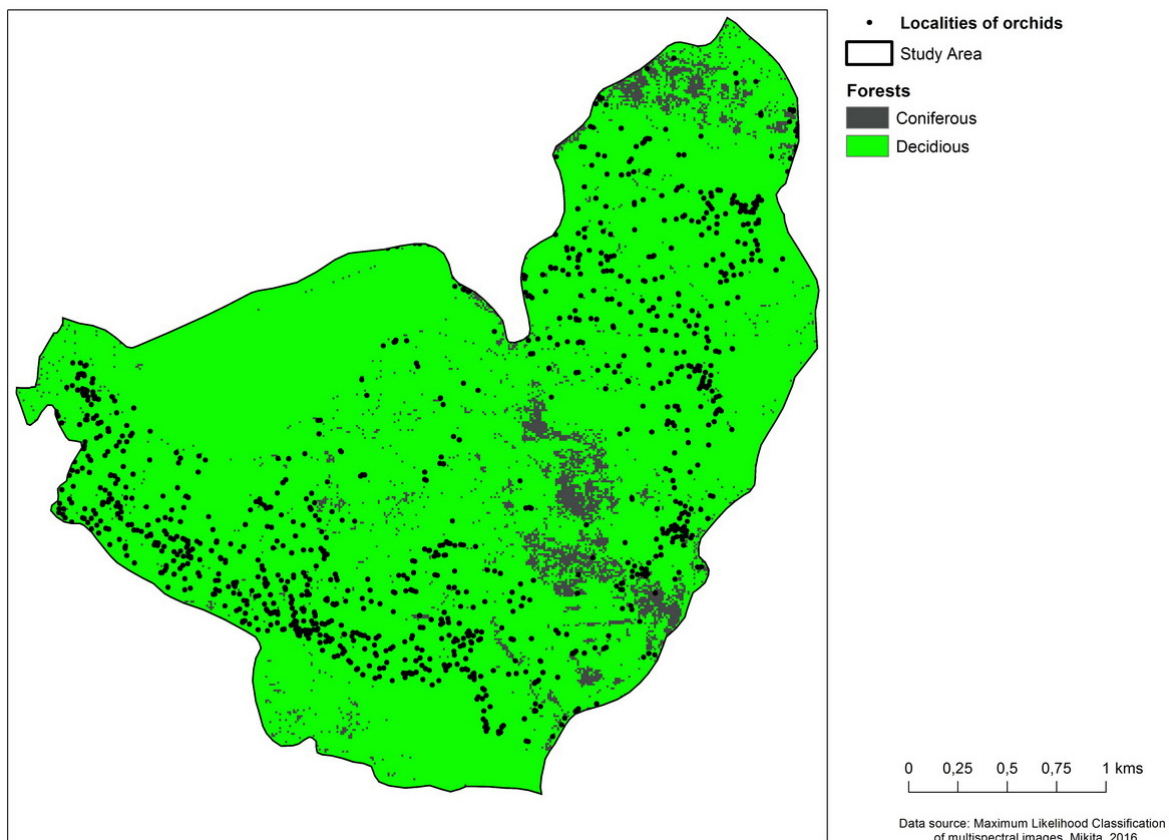


5: Relative occurrence of orchids depending on forest type. For explanation of abbreviations, see Materials and Methods.

the coincidence of orchids occurrence on basic forest types in relative numbers. This is shown in % in figure 5 below. Thus the forest type 3X *Corneto-Fagetum (xerothermicum)* on steep slopes in the southernmost part of the study area accounts for the highest portion (Fig. 5).

Orchids are relatively abundant in the Moravian Karst, the most important aspects being

the favourable geological structure of the site and suitable soil types. Orchids tend to favour an alkaline environment with a high proportion of limestone in the soil (Štěpánková *et al.* 2010). This hypothesis is confirmed by the recorded 340 sites with orchids in the 3W *Querceto-Fagetum calcarium* forest type, which is on limestone. In contrast, the 3K *Querceto-Fagetum acidophilum*, 2S *Fageto-Quercetum oligo-mesotrophicum* or



6: Locations of orchids in coniferous and deciduous forests.

3H *Querceto-Fagetum illim mesotrop* forest types were poor in orchid occurrence as is evident from Fig. 4.

Forestry Management Analysis

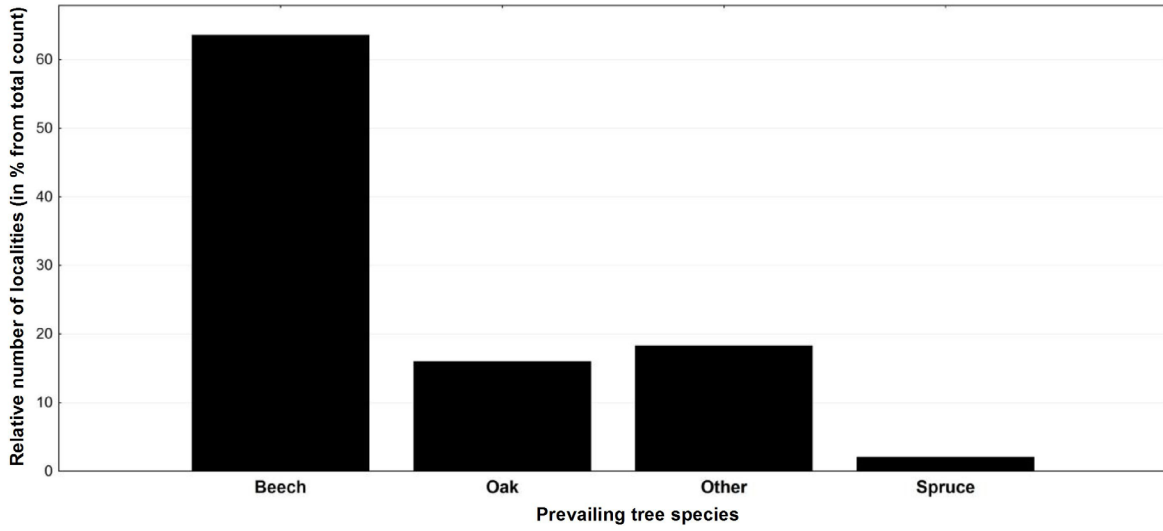
Most orchids were found on the south and south-west oriented slopes of the southern part of the study area between the villages of Kanice and Babice nad Svitavou (Fig. 1). The second maximum in orchids presence is found in the eastern part near the village of Březina. The lack of orchids in the north could be explained by different geology – greywackes and loamy sediments, but the lack of rare plants in the middle of the area is possibly connected with forestry – coniferous forest covers the central part of the study area (Fig. 6).

The greatest incidence of *Orchidaceae* locations was in broadleaved stands, having 1103 sites with orchids, which is 98 % of all recorded locations. In coniferous forests only 18 localities with orchids were found. In fact the most common forest in the studied area is the broadleaved one. Very few localities of orchids were recorded in places where spruce were planted after clear-cutting in the past (Fig. 7). The beech area makes up more than 60 % and oak forest nearly 20 %, as well as other broadleaved species. Fig. 10 shows that most orchids are more abundant at some distance from coniferous forest or even from individually distributed conifers.

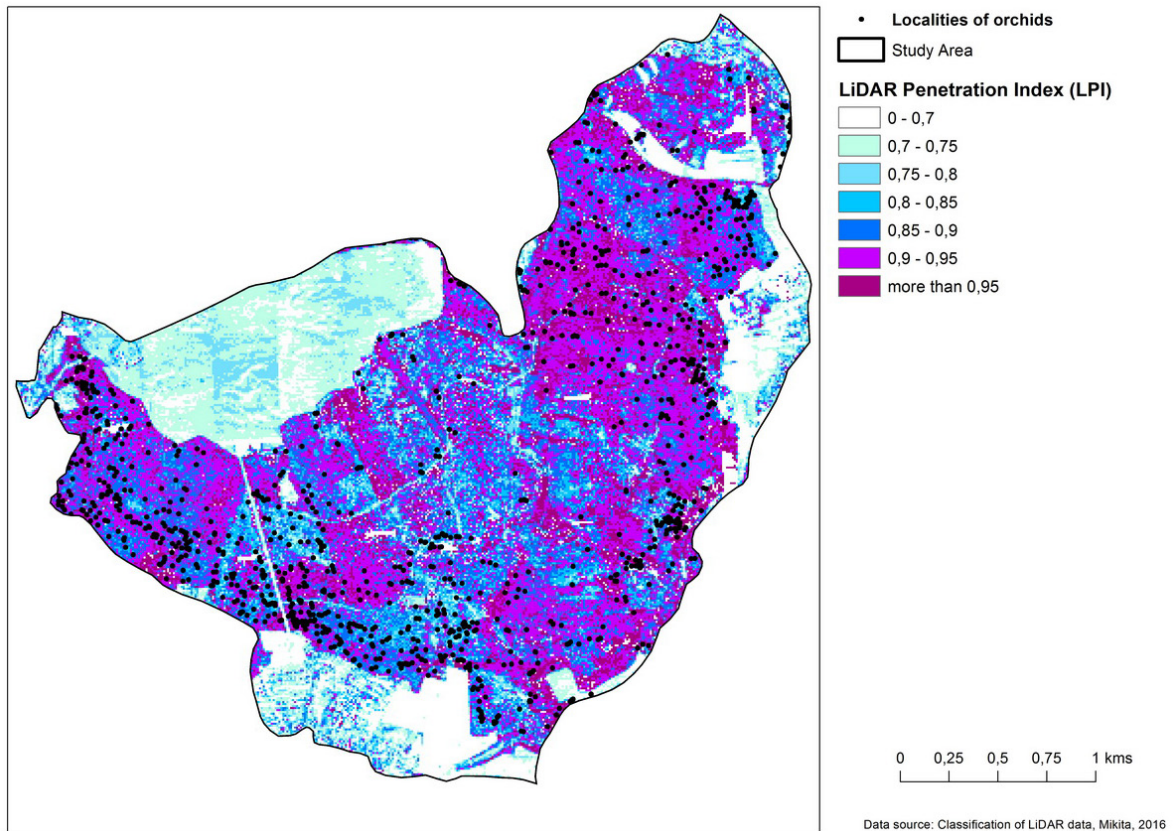
Although the studied orchids prefer a dense forest canopy, scattered light is also important.

The largest number of sites with *Orchidaceae* was recorded in forests with a high canopy density of forest vegetation (Fig. 8), but with good penetration by scattered light. Another analysis shows that forest road, forest edge and other open site give enough light to the surrounding forest (see figs. 9 and 10). In contrast, a very low incidence of orchids was recorded in places completely without forest such as clearings, cleared boundary lines and other places without tree vegetation. Therefore the importance of small-scale forest management with no clear-cutting is of high priority.

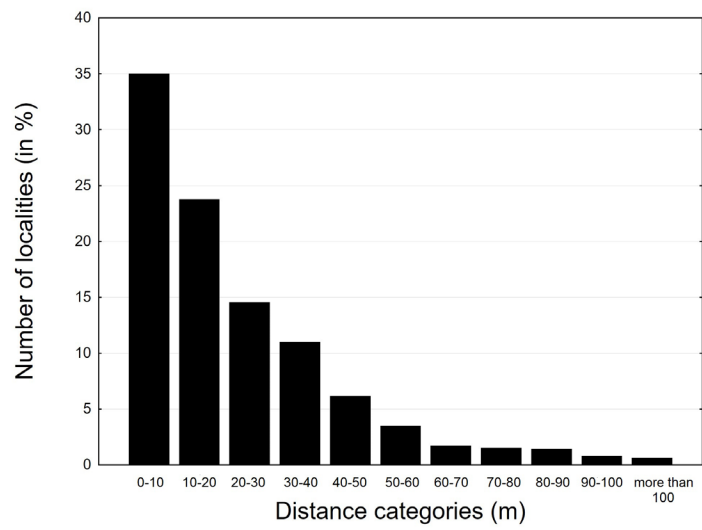
The largest number of orchid localities was recorded in forests with heights from 20 m to 25 m where there were over 300 recorded orchid localities with orchids (Fig. 11). In contrast the lowest number was recorded in forests from 5 m to 10 m, where there were fewer than 50 locations.



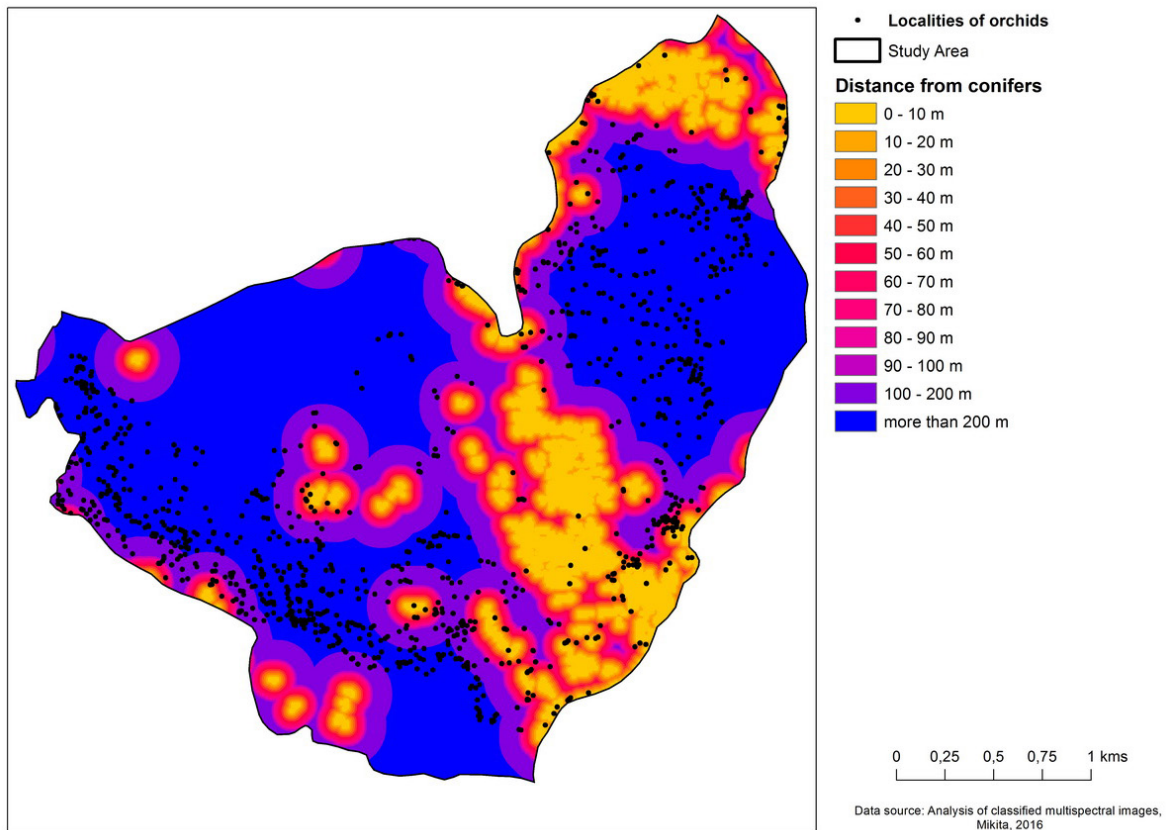
7: Relative occurrence of orchids in forest stands with different prevailing tree species.



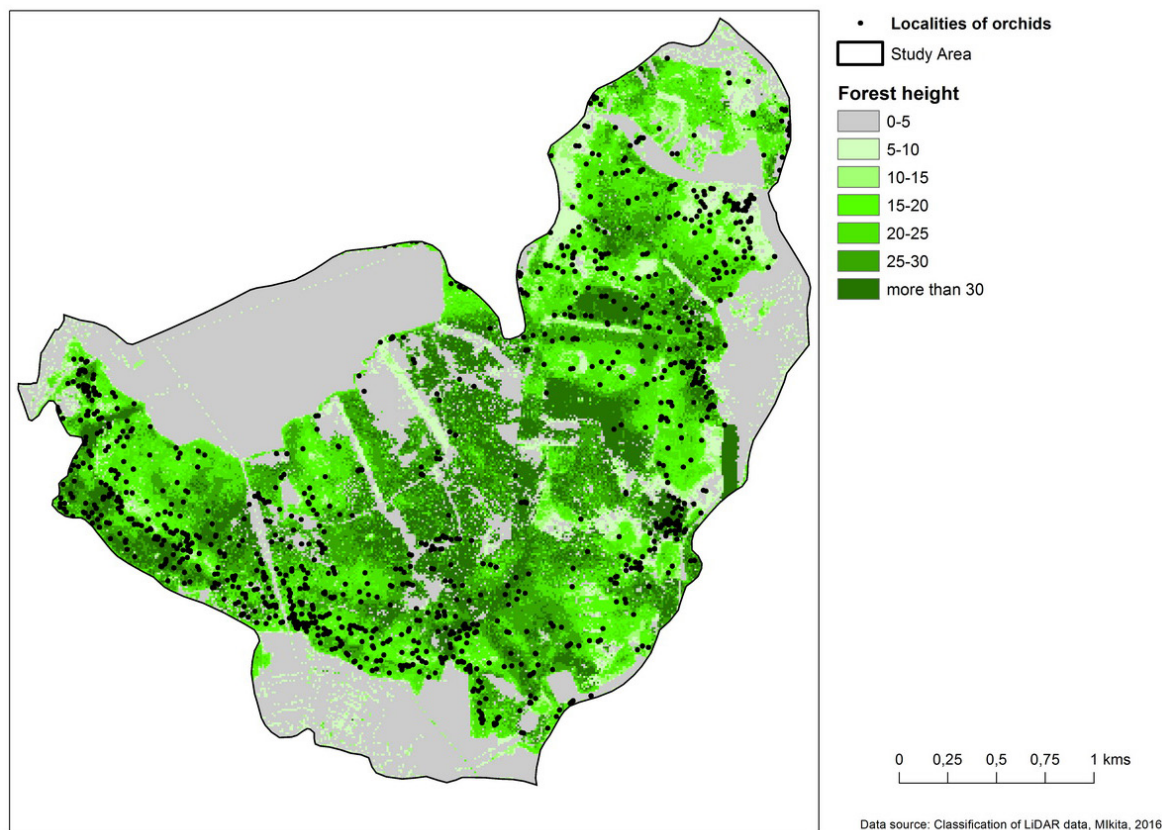
8: Locations of orchids in LPI categories (canopy density relationship).



9: The occurrence of orchids in distance categories from clear-cuts and forest roads in %.



10: Locations of orchids in distance categories from conifers.



11: Locations of species in forest height categories.

DISCUSSION

The *Orchidaceae* family is preferentially present in deciduous forests with beech, as shown on map of figures 6 and 7, where there have been over 600 orchid localities, while in spruce coniferous forests only 18 orchid localities have been found. This is probably due to the highly acidic pH of fallen needles which acidifies the upper part of the soil, and which the orchid plants find unsuitable (Dykyjová, 2003). Interesting results were also found when comparing the relationship between the occurrence of orchids and the distance from coniferous forests. Within a distance of 100 m from coniferous stands a low incidence of orchids was observed, so the coniferous forests seems to have a negative influence on orchids.

Conifers are very rare in the Moravian Karst's natural vegetation; *Picea abies* is indigenous only in the coldest valleys of the northern part of the Moravian Karst (Štefka *et al.* 1999) while *Abies alba* naturally occurs in the colder valleys of the central and northern part of the Moravian Karst. *Pinus sylvestris* grows naturally in a mixture with *Quercus petraea* on steep slopes of the dry and usually acidic habitat of the area (Drahany Upland), but is rare in the Moravian Karst. Other conifers which were found in the research area, *Larix decidua* and *Pseudotsuga menziesii*, are not autochthonous here. The litter of coniferous forests, especially

spruce, larch and Douglas fir, causes acidification of the upper horizons of the soil which is unfavourable for orchids as they are dependent on cooperation with mycorrhizal fungi (Dykyjová, 2003).

The occurrence of orchids is highly dependent on age or height of trees. The largest number of orchids grew in stands from a height of 15 m with a maximum number of locations at a height of the tree canopy of between 20-25 metres. This can be explained by the fact that in young forest stands there is a lack of light. This is confirmed by the LPI histogram, where the highest incidence of orchids was recorded in the stands with a closed canopy but with partial penetration of diffuse sunlight. In contrast, the sites with full canopy and places without forest stands, as seen from the LPI histogram, are not very suitable for orchids. This hypothesis that the majority of plants from the *Orchidaceae* family prefer light broadleaved forests in the Moravian Karst is supported by the histogram, which shows the occurrence of orchids near roads and cleared boundary lines. According to this histogram nearly 400 locations with orchids were recorded at a distance up to 10 m from roads and cleared boundary lines and with increasing distance the incidence declined.

Orchids probably prefer soil with plenty of calcium, but equally important is plenty of diffuse light penetrating the forest, which is provided by

broadleaved forest in the 2nd and 3rd vegetation zone (*Fagi-Querceta* and *Querci-Fageta*). Only part of the area consists of coniferous forest and beech forest of the 4th vegetation zone (*Fageta*).

These facts should be taken into account when managing forests with rare plant species, to which orchids belong. Forest management should prioritise small scale shelterwood and selective systems, where the new young forest grows under the protection of the bigger trees above. Domestic broadleaved species should be preferred. They are autochthonous and rare plants prosper under their protection. This type of management does not open

the way to direct sunlight, does not use clear-cutting and only a minimum of planted non-native conifer species in small groups are used. Such management is called Dauerwald (Möller, 1922) and is applied in part of the Křtiny Training Forest Enterprise. It should be also noted that the investigated area has long been used for forestry. Although Dauerwald is not applied in our study area, the occurrence of orchids and other rare plants in such amounts indicates the sustainability of forestry here, which brings both economic effects and contributes to the preservation of biodiversity.

CONCLUSION

This study has deepened knowledge of the occurrence of orchids in the central part of the Moravian Karst and uncovers the connections between this and forest management. Orchids rarely grow in coniferous monocultures but grow in both nature reserves with no logging (Čihadlo Nature Reserve and Březinka Nature Reserve), and outside those areas where shelterwood logging has traditionally been used.

The studied area of 853 ha occupies the 3rd vegetation zone with a predominance of the *Querci-Fageta* on limestone forest type where *Fagus sylvatica* prevails. The botanical survey recorded 13 species of orchids at 1,121 sites with a total of 2,599 individual plants, which includes the endangered species *Epipactis greuteri* with 4 plants, *Orchis purpurea* with 26 plants, *Epipactis leutei* with 28 plants and *Cephalanthera rubra* with 119 plants.

Ninety-three per cent of the research area is formed by deciduous forest with a predominance of oak (*Quercus petraea*) and beech (*Fagus sylvatica*). Coniferous forest with spruce-dominated areas makes up only seven per cent. Most orchids were found in deciduous forests even when we take into account relative numbers to total study area, whereas in areas with a predominance of conifers these rare species do not usually grow (only on 18 locations). Most orchids grow in beech dominated forest (more than 60 %) and forest dominated by other deciduous species (more than 30 %). More than 600 sites where species of orchid were found were forests with *Fagus sylvatica* dominance. The highest incidence of these plants was observed on limestone, which is the most common bedrock in the study area.

Orchids are found mainly in forests with an average tree height of 20 to 30 metres (600 sites), where a part of the diffused sunlight penetrates. Most sites (nearly 400 orchid sites) were recorded at a distance within 10 m from roads and cleared boundary lines, which provides plenty of diffused sunlight. These plants prefer light forests which is also a commonly published fact. Forest management using shelterwood or selective methods that use natural regeneration of native broadleaved trees and which prevails in the territory of the Křtiny Training Forest Enterprise, contribute to the preservation of rare species such as the studied orchids.

Acknowledgements

This paper was prepared within the research project "The Red Book of Woody Plants of the Czech Republic, The Red Book of Threatened Species of the Floodplain Forests of the Dolní Morava Biosphere Reserve and The Red List of Threatened Species of Training Forest Enterprise Křtiny: EHP-CZ02-OV-1-012-2014".

REFERENCES

- ACKERMANN F. 1999. Airborne laser scanning of present status and future expectations. *ISPRS Journal of Photogrammetry and Remote Sensing*, 54(1): 64–67.
- BATOUŠEK, P. 2005. *The key to determining the species Epipactis Zinn growing in the Czech Republic* [In Czech: *Klíč k určování druhů rodu Epipactis Zinn rostoucích na území České republiky*]. Brno: Exprint – Kocián spol. s r. o.
- CARLEER, A. and WOLFF, E. 2004. *Exploitation of Very High Resolution Satellite Data for Tree Species Identification*. *Photogrammetric Engineering and Remote Sensing*, 70(1): 135–140.

- DYKYJOVÁ, D. 2003. *Ecology of Orchids in Central Europe* [in Czech: *Ekologie středoevropských orchidejí*]. České Budějovice: Kopp.
- FAHRIG, L. 2003. Effects of habitat fragmentation on biodiversity. *Annu Rev Ecol Evol Syst*, 34: 487–515.
- FOLEY, et. al., 2005. *Global consequences of land use*. *Science*, 309: 570–574.
- GRULICH, V. 2012. Red List of vascular plants of the Czech Republic: 3rd edition. *Preslia*, 84: 631–645.
- HANNAH, L., CARR, J. and LANKERANI, A. 1995. *Human disturbance and natural habitat: a biome level analysis of a global data set*. *Biodivers. Conserv.*, 4: 128–155.
- JELÍNEK, P. 2008. *The decrease of orchid species populations in the Křtiny region*. In: *Landscape in the context of global changes* [In Czech: *Úbytek vstavačovitých druhů rostlin v okolí obce Křtiny: In Krajina v kontextu globálních změn*]. Brno: Mendelova zemědělská a lesnická univerzita v Brně, Ústav lesnické botaniky, dendrologie a geobiocenologie.
- JATIOVÁ, M. and ŠMITÁK, J. 1996. *The occurrence and protection of orchids in Moravia and Silesia* [In Czech and German: *Rozšíření a ochrana orchidejí na Moravě a ve Slezsku: Verbreitung und Schutz der Orchideen in Mähren und Schlesien*]. Třebíč: Arca JiMfa.
- JERSÁKOVÁ, J. and KINDLMANN, P. 2004. *Management of orchid habitats* [In Czech: *Zásady péče o orchidejové stanoviště*]. České Budějovice: Kopp.
- JEŽEK, Z. 2003. *Encyclopaedia of Orchids* [In Czech: *Encyklopedie orchidejí*]. 1st edition. Čestlice: Rebo Productions CZ, spol. s r. o.
- KUBÁT, K. et. al. 2002. *Key to the Flora of the Czech Republic* [In Czech: *Klíč ke květeně České republiky*]. Praha: Academia.
- MIKITA, T., KLIMÁNEK, M. and CIBULKA, M. 2013. Evaluation of interpolation methods of airborne laser scanning to detect trees and measuring their heights [In Czech: *Hodnocení metod interpolace dat leteckého laserového skenování pro detekci stromů a měření jejich výšek*]. *Zprávy lesnického výzkumu*, 58(2): 99–106.
- MUSSELMAN, K. N., MARGULIS, S. A. and NOAH P. M. 2013. Estimation of solar direct beam transmittance of conifer canopies from airborne LiDAR. *Remote Sensing of Environment*, 136: 402–415.
- MÖLLER, A. 1922. *Der Dauerwaldgedanke. Sein Sinn und seine Bedeutung*. Wilhelm Bode, Kommentierter Reprint, mit Einführung und Glossar, Degreif, Oberteuringen, 1992. Berlin: Springer.
- PLÍVA K. 1971. *The typological system of the Forest Dendrometry Institute in the Czech Republic*. [In Czech: *Typologický systém ÚHÚL*.] Brandýs n/L.: ÚHÚL.
- PROCHÁZKA, F. and VELÍSEK, V. 1983. *Orchids in our countryside* [In Czech: *Orchideje naší přírody*]. 1st Edition. Praha: Academia.
- RIMBACH, R. et. al., 2013. Effects of logging, hunting, and forest fragment size on physiological stress levels of two sympatric ateline primates in Colombia. *Conserv. Physiol.*, 1(1): cot031.
- ŠTEFKA, L. and MULLER, J. 1995. *Mapping of rare and endangered plant species in the Moravian Karst Protected Landscape Area* [In Czech: *Mapování vzácných a ohrožených druhů rostlin v Chráněné krajinné oblasti Moravský kras: mapové podklady*]. Blansko: Správa Chráněné krajinné oblasti Moravský kras.
- ŠTEFKA, L. et. al. 1999. *The management plan of the protected area Vývěry Punkvy National Nature Reserve* [In Czech: *Plán péče o chráněné území Národní přírodní rezervace Vývěry Punkvy*]. Blansko: Agentura ochrany přírody a krajiny České republiky.
- ŠTĚPÁNKOVÁ, J. et. al., 2010. *Flora of the Czech Republic 8*. [In Czech: *Květena České republiky 8*.] Praha: Academia.
- VANĚČKOVÁ, L. and VAŠÁTKO, J. 1992. *Mapping of rare and endangered plant species in the Moravian Karst Landscape Protected Area: maps* [In Czech: *Mapování vzácných a ohrožených druhů rostlin v Chráněné krajinné oblasti Moravský kras: mapové podklady*]. Blansko: Správa Chráněné krajinné oblasti Moravský kras.
- VANĚČKOVÁ, L. et. al., 1997. *Plants of the Moravian Karst and its surroundings* [In Czech: *Rostliny Moravského krasu a okolí*] Blansko: Nadace Moravský kras.
- VIEWEGH, J., KUSBACH, A. and MIKESKA, M. 2003. Czech forest ecosystem classification. *Journal of Forest Science*, 49: 74–82.
- ZLATNÍK, A. 1956. An outline of forest typology on the basis of geobiocenology and Czechoslovak forest distribution by groups of forest types [In Czech: *Nástin lesnické typologie na biocenologickém základě a rozlišení československých lesů podle skupin lesních typů*]. In: POLANSKÝ, B. (Ed.) *Pěstění lesů*. Praha: Státní zemědělské nakladatelství.

Appendix

Abbreviations

- 1J – *Carpineto-Aceretum saxatile* – Hornbeam-Maple
 1X – *Corneto-Quercetum (xerothermicum)* – Cornelian Cherry-Oak
 2A – *Aceri-Fagetum-Quercetum lapidosum* – Stony-colluvial Maple-Beech-Oak
 2B – *Fagetum-Quercetum mesotrophicum* – Nutrient-rich Beech-Oak
 2C – *Fagetum-Quercetum subxerothermicum* – Water-deficient Beech-Oak
 2D – *Fagetum-Quercetum acerosum deluvium* – Enriched-colluvial Beech-Oak
 2H – *Fagetum-Quercetum illimerosum mesotrophicum* – Loamy Beech-Oak
 2K – *Fagetum-Quercetum acidophilum* – Acidic Beech-Oak
 2S – *Fagetum-Quercetum oligo-mesotrophicum* – Nutrient-medium Beech-Oak
 2X – *Corneto-Fagi-Quercetum (xerothermicum)* – Cornelian Cherry-(Beech)-Oak
 2Z – *Fagetum-Quercetum humile* – Scrub Beech-Oak
 3A – *Tilii-Querceto-Fagetum acerosum lapidosum* – Stony-colluvial Lime-Oak-Beech
 3B – *Querceto-Fagetum mesotrophicum* – Nutrient-rich Oak-Beech
 3D – *Querceto-Fagetum acerosum deluvium* – Enriched-colluvial Oak-Beech
 3H – *Querceto-Fagetum illimerosum mesotrophicum* – Loamy Oak-Beech
 3J – *Tilieto-Aceretum saxatile* – Lime-Maple
 3K – *Querceto-Fagetum acidophilum* – Acidic Oak-Beech
 3L – *Fraxineto-Alnetum alluviale* – Ash-Alder
 3N – *Querceto-Fagetum lapidosum acidophilum* – Stony-acidic Oak-Beech
 3S – *Querceto-Fagetum oligo-mesotrophicum* – Nutrient-medium Oak-Beech
 3W – *Querceto-Fagetum calcarium* – Limestone Oak-Beech
 3X – *Corneto-Fagetum (xerothermicum)* – Cornelian Cherry-Oak-Beech
 4A – *Tilieto-Fagetum acerosum lapidosum* – Stony-colluvial Lime-Beech
 4D – *Fagetum acerosum deluvium* – Enriched-colluvial Beech
 4G – *Querceto-Abietum piceosum paludosum mesotrophicum* – Nutrient-medium wet Oak-Fir
 4S – *Fagetum oligo-mesotrophicum* – Nutrient-medium Beech
 4V – *Fagetum fraxinosum humidum* – Moist to wet Beech
 4W – *Fagetum calcarium* – Limestone Beech
 4X – *Fagetum dealpinum (xerothermicum)* – Dealpine Beech

Contact information

Alois Procházka: all.procha@seznam.cz
 Tomáš Mikita: tomas.mikita@mendelu.cz
 Petr Jelínek: jelen@mendelu.cz

