Veteran trees and saproxylic insects in the floodplains of Lower Morava and Dyje rivers, Czech Republic

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1. Introduction

Veteran trees are usually large, senescent trees bearing numerous specific microhabitats. They are considered to be key features supporting biodiversity in wooded landscapes of Central Europe as well as temperate and boreal regions in general (Fischer, Stott, & Law, 2010; Hall & Bunce, 2011; Lindemayer et al., 2014; Lindemayer, Laurance, & Franklin, 2012; Manning, Fischer, & Lindemayer, 2006; Read, 2000; Sebek et al., 2016; Sittonen & Ranius, 2015; Vodka, Konvička, & Čížek, 2009). These trees mostly grow in open woodlands, including wooded meadows and pastures. They host a wide spectrum of endangered and protected organisms, including mainly insects and lichens, but also bats, birds and other taxa (Hartel et al., 2014). Owing to natural disturbances (e.g. windthrows or fires) (Adámek, Bobek, Hadincová, Wild, & Kopecký, 2015; Hültberg, Gaillard, Grundmann, & Lindbladh, 2015; Niklasson et al., 2010) and grazing of large herbivores (Bengtsson, Nilsson, Franc, & Menozzi, 2000; Vera, 2000) European forests have at least partly been open for most of their Holocene history. These natural processes have gradually been replaced by human activities such as coppicing and wood pasture (Rackham, 1998; Szabó, 2009; Szabó, Müllerová, Suchánková, & Kotečka, 2015). The open canopy conditions that are required for trees to reach large diameters and veteran state have thus endured until modern times.

The intensification of agriculture and forest management, however, led to the abandonment of traditional silvicultural practices between the eighteenth and twentieth centuries. They were replaced by intensive forestry cultivating mainly even-aged, closed-canopy forests often managed within a clearcut silvicultural system. Open woodlands thus rapidly turned into closed-canopy forests (Bürgi, 1999; Hédl, Kopecký, & Komárek, 2010; Kopecký, Hédl, & Szabó, 2013). Remaining open woodlands containing veteran trees have been preserved mainly in some hunting parks and game reserves, parks and tree alleys (Horak et al., 2014; Jonsell, 2012). Open woodlands have mostly disappeared from protected areas where a non-interventionist management regime prevails. Today, they are isolated, fragmented and still in decline (Miklín & Čížek, 2014); the same applies to solitary and veteran trees (Čížek & Hauck, 2008). Given the importance of open woodlands and veteran and solitary trees for biodiversity (Dolek et al., 2009; Horak et al., 2014; Ramírez-Hernández, Micó, de los Ángeles Marcos-García, Brustel, & Galante, 2014; Spitzer, Konvička, Tropek, Tuf, & Tufová, 2008), nature conservation management should focus on their
preservation and restoration. Knowledge of landscape history and land use changes together with detailed mapping of the present state is thus crucial for designing effective conservation management measures and goals.

In this paper, we present results of an extensive mapping survey of solitary and veteran trees and several saproxylic insect species associated with such trees on 14,600 ha of the floodplain woodlands along the lower reaches of the Dyje and Morava rivers in the south-east of the Czech Republic. High concentrations of solitary and veteran trees in the area are a result of traditional silvicultural practices that have locally been abandoned over the past two centuries. Shifts in the forest management have led to increased canopy closure and the decline of solitary and veteran trees that are crucial to the survival of numerous endangered species (Miklín & Čížek, 2014). Our results should serve as one of the sources for nature conservation and forestry administration of the area.

1.1. Study area and species

Solitary and veteran trees were mapped in the floodplains along the lower reaches of the Morava (March) and Dyje (Thaya) rivers in the very south-eastern part of the Czech Republic (Figure 1(a)). With an average yearly temperature of ~9.6°C and rainfall of ~500 mm, the study area belongs to one of the warmest and driest localities of the Czech Republic. Out of 146 km² covered by the study, 60.1% are forests and 39.9% are grasslands and arable land (Miklín & Hradecký, 2016a). Pedunculate oak (Quercus robur), narrow-leaved ash (Fraxinus angustifolia), hornbeam (Carpinus betulus) and field maple (Acer campestre) prevail in the forests. The study area can be divided into three parts based on forestry management units, namely (i) Dyje floodplain (north-western part of the area between the Nové Mlýny dam and Břeclav town along the Dyje river), (ii) Tvrdoňicko (north-eastern part of the area between Lanzhot and Hodonín towns along the Morava river) and (iii) Soutok (part to the south of Lanzhot town along both the rivers to their confluence) (Figure 1(b)). Flat terrain of the alluvial landscape (149–184 m a.s.l.) was strongly influenced by regular flooding, enhanced by human impact over the last two millennia (Kadlec et al., 2009), and long-lasting human presence (Dresler & Macháček, 2013). The contemporary landscape thus has to be understood as a mosaic of natural and semi-natural ecosystems, and its biodiversity has been partially dependent on human management. Due to its importance, the study area is covered by both national and international forms of nature conservation and protected areas. The Lower Morava UNESCO Biosphere Reserve covers the whole area, while its parts are recognised within the NATURA 2000 system (Soutok – Podluží and Niva Dyje Sites of Community Importance; Special Protection Areas of Soutok-Tvrdoňicko, Lednice fishponds and Pálava), Triilateral Ramsar Site Floodplains of the Morava-Dyje-Danube Confluence, or several state reserves.

2. Methods

The mapping of solitary and veteran trees took place from 2006 to 2015. All solitary trees of a diameter in breast height (DBH) > 40 cm were recorded outside closed-canopy stands. All trees apparently older than the surrounding stand and trees with veteran characteristics (e.g. trees with hollows or a partly dead trunk, see Read, 2000) were recorded in the forests. The following data were recorded for each tree: (i) coordinates (measured with a global positioning system receiver in WGS84 coordinate system, afterwards converted into the national S-JTSK system); (ii) species; (iii) DBH of the trunk; (iv) health condition of the tree (1 – healthy, 2 – ca. one-third of the tree crown dried, 3 – ca. one-half of the tree crown dried, 4 – ca. two-thirds of the tree crown dried, 5 – dead tree, log or stump).

Moreover, the presence of the following mostly endangered and protected species was registered: (i) the hermit beetle (Osmoderma barnabita), (ii) the great capricorn beetle (Cerambyx cerdo), (iii) jewel beetle (Eurythyrea quercus), (v) jet ant (Lasius fuliginosus) and (vi) velvety tree ant (Liometopum microcephalum). The hermit beetle (i) inhabits hollows of various broad-leaved trees in Europe (Ranius et al., 2005). The great capricorn beetle (ii) inhabits mainly large, old oaks growing outside closed-canopy conditions (Buse, Ranius, & Assmann, 2008). The jewel beetle (iii) inhabits bare and dry, but hard wood of old oaks (Bílý, 2002). All the three species prefer sun-exposed trees. The jet ant (v) is a common species nesting in hollowed tree trunks. Among the mapped species, it is the only one that is neither endangered nor protected. The velvety tree ant (vi) also nests in tree trunks, it prefers large trees and is considered endangered (Schlaghamersky & Omelkova, 2007) The species (i–iii) are ‘target species’ of the Sites of Community Importance. The presence of adult individuals or their remains, larvae and larval frass indicates the presence of (i). Characteristic exit holes indicated the presence of (ii) and (iii). Individuals walking on a tree served as a proof of presence of (v) and (vi). Among these data – visualised on the maps – several other characteristics usable for further analyses were recorded, for example, tree habitats or estimation of percentage without bark. Some other species including the Rosalia longicorn (Rosalia alpina) or Stag beetle (Lucanus cervus) were mapped in a related project in selected localities. All the data were processed and maps created using Esri ArcGIS (Desktop and Online) software.
3. Results

In total, 11,596 trees were mapped within the study area, with oaks (mainly pedunculate oak) being the most frequent species (63.2%), followed by narrow-leaved ash (*F. angustifolia*; 9.7% share) and willows (*Salix* spp.; 8.8%) (Table 1). The great capricorn beetle was recorded on 2988 oaks, the hermit beetle on 254 trees (53.1% willows and 39.0% oaks), *E. quercus* jewel beetle on 332 oaks, *L. microcephalum* ant on 1397 trees (90.0% were oaks), and *L. fuliginosus* ant on 627 trees (50.1% on oaks and 18.2% on willows). Hollows were recorded on 2610 trees (51.5% were oaks and 25.7% willows).

Average DBH of all recorded trees was 97 cm. The highest average trunk diameters were those of poplars (*Populus* spp. 105 cm), willows and oaks (both 101 cm). In total, 756 trees with DBH > 150 cm were recorded, 582 of them were oaks. The largest recorded tree was a pedunculate oak with a 260-cm DBH (Table 2).

In total, 54.1% of the trees were classified as healthy, while 18.8% were dead (Table 3). Nearly half of the oaks were healthy, while 25.3% were dead and at least half of the crown was dead in 8.5% of the oaks. Unsurprisingly, tree health on average worsened with increasing DBH (Figure 2). In total, 68.6% of trees with DBH < 75 cm were classified as healthy, whereas only 20.4% of trees with DBH > 150 cm. As many as 39.0% of the trees with DBH > 150 cm and only 11.3% of those with DBH < 75 cm were dead. Generally, there are some differences in health among tree species. The health state of oaks, for example, was worse than that of ash, most likely owing to the lower average DBH of the latter.

Analysis of the spatial distribution of the trees revealed several clearly pronounced hotspots (Figure 3). In general, the western part of the study area (along the Dyje river) is densely covered. Tree hotspots include (see Figure 1(b) for location) the Křivé jezero National Nature Reserve (with the highest share of willows), the area of Lednický Chateau park (park around Lednice Chateau), Kančí obora near the town of Břeclav, open woodlands and meadows with solitary trees around Pohansko and Lány Chateaus, and the east-central part of the Soutok game reserve. In the floodplain of the Morava river (Tvrdonicko), the only site rich in veteran trees concerns meadows near Mikulčice in the north-eastern part of the study area. The hotspots of mapped insect species (Figure 4) are mostly identical with those of the trees. Individual hotspots also differed for tree health. The oaks in Lednice Chateau park, for example, were generally in better health conditions than the oaks on the meadows in...
Table 1. Mapped veteran and solitary trees and insect species.

| Tree Species          | Total (Trees (pc)) | % | Narrow-leaved ash (F. angustifolia) (F. angustifolia) | % | Willows (Salix spp.) (Salix spp.) | % | Elm (Ulmus spp.) (Ulmus spp.) | % | Poplars (Populus spp.) (Populus spp.) | % | Hornbeam (C. betulus) (C. betulus) | % | Horse chestnut (Aesculus hippocastanum) (Aesculus hippocastanum) | % | Lime tree (Tilia spp.) (Tilia spp.) | % | Field Maple (A. campestre) (A. campestre) | % | Pears (Pyrus spp.) (Pyrus spp.) | % | Alder (Alnus spp.) (Alnus spp.) | % | Malus (Malus spp.) (Malus spp.) | % | Pines (Pinus spp.) (Pinus spp.) | % | other/not specified (other/not specified) | % |
|-----------------------|--------------------|---|-----------------------------------------------------|---|-----------------------------------|---|---------------------------------|---|------------------------------------|---|-----------------------------------|---|-----------------------------------|---|---------------------------------|---|---------------------------------|---|---------------------------------|---|---------------------------------|---|---------------------------------|---|---------------------------------|---|---------------------------------|---|
| Oaks (Quercus spp.)   | 11,596 (11,596)    | 63.22 | 1129 (1129) | 9.74 | 1019 (1019) | 8.79 | 674 (674) | 5.81 | 534 (534) | 4.61 | 250 (250) | 2.16 | 235 (235) | 1.96 | 151 (151) | 1.27 | 147 (147) | 0.56 | 65 (65) | 0.24 | 28 (28) | 0.12 | 14 (14) | 0.04 | 14 (14) | 0.12 |
| Narrow-leaved ash (F. angustifolia) (F. angustifolia) | 2988 (2988) | 100.00 | 2988 (2988) | 100.00 | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Willows (Salix spp.) (Salix spp.) | 254 (254) | 38.98 | 99 (99) | 0.39 | 135 (135) | 53.15 | 6.30 (6.30) | 0.39 | 32 (32) | 0.39 | 1 (1) | 0.07 | 1 (1) | 0.07 | 1 (1) | 0.07 | 6 (6) | 0.14 | 2 (2) | 0.00 | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Elm (Ulmus spp.) (Ulmus spp.) | 332 (332) | 100.00 | 332 (332) | 100.00 | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Poplars (Populus spp.) (Populus spp.) | 1397 (1397) | 89.98 | 1257 (1257) | 75.74 | 155 (155) | 10.77 | 7.47 (7.47) | 0.38 | 30 (30) | 1.90 | 23 (23) | 1.52 | 9 (9) | 0.55 | 6 (6) | 0.39 | 3 (3) | 0.14 | 2 (2) | 0.10 | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) | 0 (0) |
| Hornbeam (C. betulus) (C. betulus) | 327 (327) | 60.08 | 38 (38) | 6.06 | 114 (114) | 18.18 | 21 (21) | 5.74 | 36 (36) | 30 (30) | 7 (7) | 30 (30) | 7 (7) | 4 (4) | 0.62 | 17 (17) | 2.65 | 5 (5) | 0.78 | 42 (42) | 6.78 | 5 (5) | 0.78 | 42 (42) | 6.78 |
| Horse chestnut (Aesculus hippocastanum) (Aesculus hippocastanum) | 15 (15) | 5.41 | 25.67 (25.67) | 0.81 | 3.10 (3.10) | 0.25 | 4.25 (4.25) | 0.25 | 5.21 (5.21) | 0.25 | 2.61 (2.61) | 0.25 | 1.72 (1.72) | 0.25 | 1.76 (1.76) | 0.25 | 0.19 (0.19) | 0.01 | 0.00 (0.00) | 0.00 (0.00) | 0.00 (0.00) | 0.00 (0.00) | 0.00 (0.00) | 0.00 (0.00) | 0.00 (0.00) | 0.00 (0.00) |

Table 2. Trunk diameters of mapped veteran and solitary trees.

| Diameter | Total (Oaks (Quercus spp.)) | % | Narrow-leaved ash (F. angustifolia) (F. angustifolia) | % | Willows (Salix spp.) (Salix spp.) | % | Elm (Ulmus spp.) (Ulmus spp.) | % | Poplars (Populus spp.) (Populus spp.) | % | Horse chestnut (Aesculus hippocastanum) (Aesculus hippocastanum) | % | Lime tree (Tilia spp.) (Tilia spp.) | % | Field Maple (A. campestre) (A. campestre) | % | Pears (Pyrus spp.) (Pyrus spp.) | % | Alder (Alnus spp.) (Alnus spp.) | % | Malus (Malus spp.) (Malus spp.) | % | Pines (Pinus spp.) (Pinus spp.) | % | other/not specified (other/not specified) | % |
|----------|-----------------------------|---|-----------------------------------------------------|---|-----------------------------------|---|---------------------------------|---|------------------------------------|---|-----------------------------------|---|---------------------------------|---|---------------------------------|---|---------------------------------|---|---------------------------------|---|---------------------------------|---|---------------------------------|---|---------------------------------|---|
| Under 75 cm | 27.3 | 22.8 | 28.3 | 24.2 | 43.2 | 18.4 | 47.2 | 76.2 | 47.7 | 55.1 | 80.0 | 89.3 | 64.3 | 80.0 | 42.9 | 76–100 cm | 31.6 | 30.8 | 38.4 | 32.2 | 29.7 | 29.6 | 42.4 | 21.3 | 34.4 | 37.4 | 16.9 | 7.1 | 28.6 | 20.0 | 42.9 | 101–150 cm | 34.5 | 38.4 | 32.0 | 34.1 | 25.2 | 43.4 | 10.4 | 2.6 | 17.2 | 6.8 | 1.5 | 3.6 | 7.1 | 0.0 | 7.1 | 151 cm and more | 6.5 | 8.0 | 1.2 | 9.5 | 1.9 | 8.6 | 0.0 | 0.0 | 0.7 | 0.7 | 1.5 | 0.0 | 0.0 | 0.0 | 7.1 | 8.0 | Maximum (cm) | 97 | 101 | 90 | 101 | 84 | 105 | 76 | 67 | 79 | 75 | 63 | 61 | 68 | 61 | 87.0 | Total number of trees (pc) | 11,596 | 7331 | 1129 | 1019 | 674 | 534 | 250 | 235 | 151 | 147 | 65 | 28 | 14 | 5 | 14 |
Pohansko and Lánya despite similar land cover condition (both places were classified by Miklín and Hradecký (2016a) as open woodlands).

The results of the mapping are presented in an online map (http://goo.gl/oeBgtn) created with ArcGIS Online (ESRI, 2016) allowing users to combine several layers and zooming over the map (see the instructional video in Supplementary material). Among data from the mapping, an orthophotomap (used as a basemap) and land cover data (from the years 1938 and 2009 adopted from Miklín and Hradecký 2016a with simplified categories) are available. Tree data are separated into layers by individual species (except for elms, which are popular with amateur entomologists as they host a large number of rare species), using visual variables of colour (five categories according to tree health) and size (matching trunk diameter). A pop-up window for each tree contains information on the date of mapping, presence of the great capricorn beetle, tree health (categorised as per colour) and trunk diameter (in cm). It is also possible to visualise the density of all the mapped trees on a heat map (DeBoer, 2015). The same visualisation is used for species data (holloows, great capricorn beetle, hermit beetle, jewel beetle, L. microcephalum and L. fuliginosus ants). For conservation reasons, the data on the website map are not available as point symbols to prevent precisely identify their location. Nevertheless, they provide a good overview of priority areas for veteran trees and their associated biota.

Several series of detailed maps were printed on the basis of the online map presented in the paper for the national nature conservation administration and majority forest owner company, for example, maps of the distribution of selected species or maps of the distribution of solitary and veteran trees. These maps were prepared as atlases with several dozens of map sheets covering the whole area at a detailed scale (1:5000) (see the Main map for examples).

4. Discussion and conclusions

The herein presented information demonstrates that the target area is rich in veteran trees, pointing to their hotspots and the hotspots of associated organisms that were the subject of mapping.

Solitary and veteran trees are keystone features supporting the biodiversity of wooded landscapes. The larger a tree is, the greater its importance (Lindhe, Lindelöw, & Åsenblad, 2005). In the mapped area, tree veterans are crucial not only for the mapped endangered and protected beetles, but also for a wide range of other organisms including lichens, birds and insects (Sebek et al., 2016; Vondrák et al., 2016). The number of the trees is, however, in long-term decline, which increases the risk of extinction for their associated biota (Čížek & Hauck, 2008).
It is difficult to estimate the age of a tree from its DBH as the increment growth depends on numerous regional and local factors such as climate, water and nutrient availability, and current and past canopy closure (Altman et al., 2013). In a recent study based on extensive coring, however, the largest oaks in the study area were estimated to be up to 400 years old (Altman, Doležal, & Čížek, 2016).

Miklín and Hradecký (2016b) found an effect of current and past land cover on the distribution of veteran trees and their associated insect species. The areas classified as open woodlands today showed higher numbers of tree veterans. Yet in a closed forest, there were more veteran trees if a particular stand was open in 1938 than if it was closed. This points to the importance of open canopy conditions for the existence of veteran trees. Only in open or semi-open conditions do oaks reach large dimensions preferred by, for example, saproxylic beetles (Altman et al., 2013). Open grown-up tree veterans are preferred even after canopy closure due to changes in forest management (Miklín & Čížek, 2014). A substantial increase in canopy closure in woodlands of the area during the past century has thus threatened the existence of veteran trees and their associated biota in two ways. First, it decreases survival of existing tree veterans; second, it prevents younger trees from gaining veteran tree characteristics. An exceptionally high rate of logging over the past three decades has posed another threat to the biodiversity of the area (Miklín & Čížek, 2014).

Since all except one of the mapped insect species are protected by law, the maps presented in the paper offer evidence needed by conservation authorities and already serve as a base for management decisions.
Figure 3. Density of mapped trees within a hexagon net (in trees per ha; regular hexagons with side length 300 m and area 23.4 ha), in trees per ha; (a) all species, (b) oaks (*Quercus* spp.), (c) narrow-leaved ash (*F. angustifolia*), (d) willows (*Salix* spp.), (e) Elm (*Ulnus* spp.) and (f) Poplars (*Populus* spp.).

Figure 4. Density of trees inhabited by mapped insect species within a hexagon net (in trees per hectare, regular hexagons with side length 300 m, area 23.4 ha), in trees per ha; (a) great capricorn beetle (*C. cerdo*), (b) hollows, (c) hermit beetle (*O. barnabita*), (d) jewel beetle (*E. quercus*), (e) *L. microcephalum* ant, and (f) *L. fuliginosus* ant.
Software
All the processing and analyses of mapped data as well as paper maps were carried out using Esri ArcGIS (9.3 to 10.2). The online map was created in ArcGIS Online. For design of printed maps, Adobe Creative Suite (InDesign, Photoshop and Illustrator) was used. The instructional video was recorded using with Active Presenter 6 (Free edition).

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