Comparative analysis of forest stand structure and herb layer in managed and unmanaged sessile and Turkey oak dominated forests

Bölöni János (principal investigator)

Aims of the research

Typical habitat types in the hilly regions of the Carpathian Basin are dry-mesic oak forests dominated by *Quercus petraea* and *Q. cerris*, the total area of these forests reaches 135 000 ha today, which is 7% of the area covered by forests in Hungary. Both biodiversity conservation and commercial importance of these kinds of forests is high.
There was limited knowledge both on the managed, unmanaged (abandoned) and old-growth stands of dry-mesic oak dominated forests of Europe. The lack of knowledge was most striking on the variability of stand-structure, but it is also presented in structure of shrub and herb layer. These affect the fact that there is hardly any knowledge on the renewal and dynamics of dry-mesic oak forests under natural conditions.
The main aim of the project was to reduce the lack of knowledge on dry-mesic oak forests. We studied the most important characteristics of the overstory (richness, density, dominance, volume of living trees, amount of dead wood), the composition and density of shrub layer, the composition of the understory. Beside tree layer as environmental variable soil conditions and light were also measured and studied.
We analysed the difference in composition and structure of managed and unmanaged dry-mesic oak stands. We surveyed the dead wood conditions of dry-mesic oak forests in the Hungarian Carpathians. We studied the effect of stand age and management type on dead wood volume. We explored relationships between stand structure and composition of the herb layer. We specified the most important stand characteristics influenced composition of seedling and herb communities.

The research was done according to the plans between 01.01. 2013 and 31.12. 2016, and was ended at 31.12. 2017, because the supervisor asked for one year extension. The research unit of the project was Institute of Ecology and Botany, Centre for Ecological Research, Hungarian Academy of Sciences. The total budget of the project was 17 031 000 forint.
A project was started with tree researcher. Réka Ádám took considerable part in data analysis of herb layer. Péter Ódor and János Bölöni analysed data of tree layer. Later joined Réka Aszalós (data management, data analysis and publication) and László Somay (field survey, data management).

Our results we published firstly in scientific journals in English (Aszalós et al. 2017, Ádám et al. 2013, Bölöni et al. 2017). We edited a scientific report in Hungarian, which summarize the main findings and practical relevance of the project (Bölöni 2015, Aszalós et al. 2015, Ádám et al. 2015, Bölöni et al. 2015). The report can be downloaded free from the website of the research unit (http://www.okologia.mta.hu/MTA_OK_Tanulmanyai1) increasing the practical applicability of our result for forest managers and conservationists. A manuscript related to composition and structure of understory is under review (Ádám et al. 2018), even we intend a detailed paper related to composition and structure of overstrory (Bölöni et al. 2018).

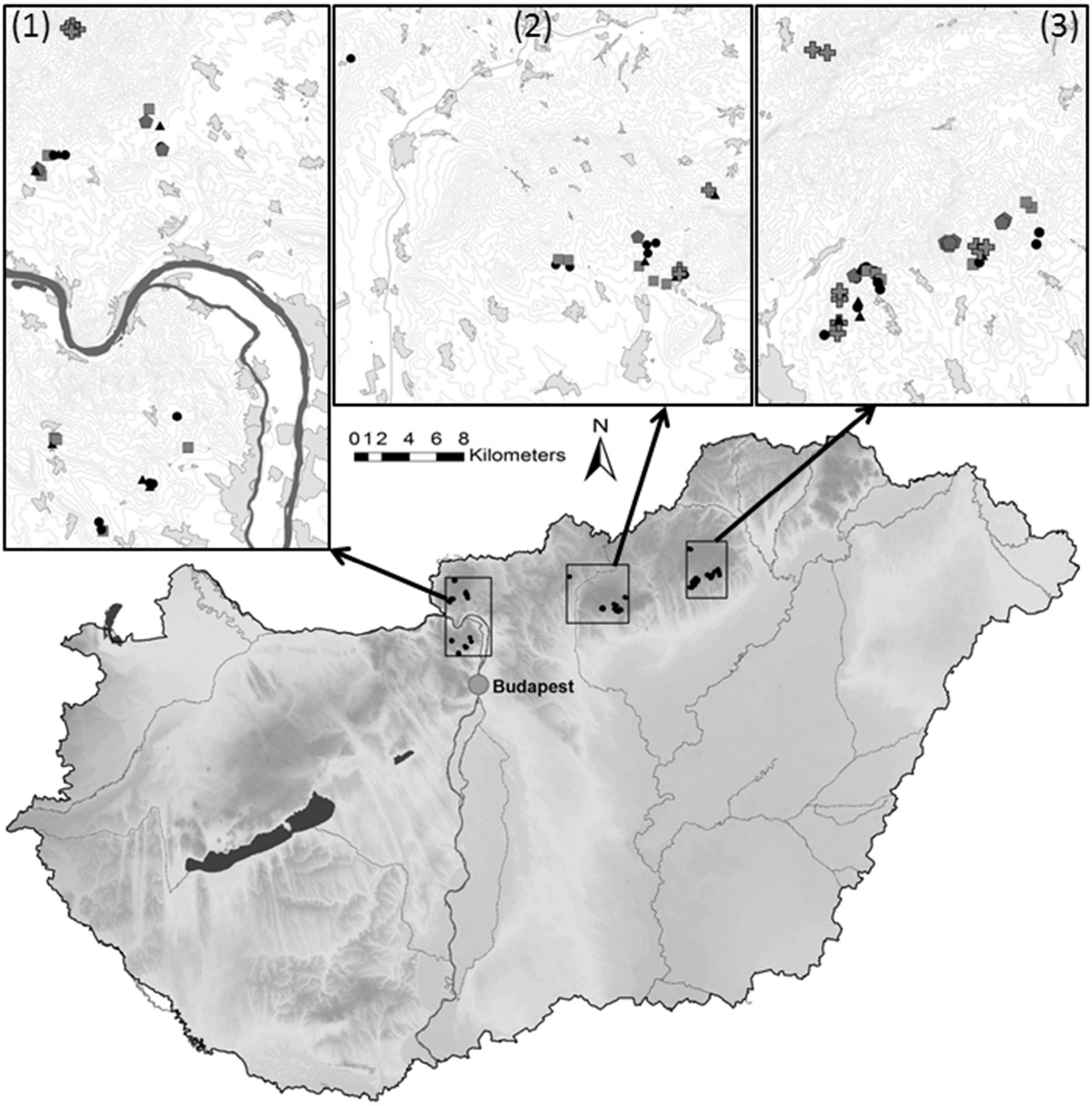
Summary of data collection

Before the start of the project we possessed stand structural data of a 3 ha sized plot of Vár-hegy Forest Reserve, which is an abandoned dry-mesic forest stand without management for 40 years. All tree individuals larger than 5 cm in diameter were mapped and measured within the plot, as well as dead wood individuals were also mapped. These data made possible the description of stand structural processes after abandonment. These data were analysed and published in the framework of the project.
During the data collection of the project we had 338 sampling plots in 100 forest supcompartments in three regions of the Hungarian Carpathians (Fig. 1). The investigated managed 40-119 years old stands were selected by a stratified random sampling from the Hungarian Forest Stand Database. We selected the unmanaged stands based on the following criteria: (1) dry-mesic *Quercus petraea-Q. cerris* dominated site, (2) older than 120 years, (3) highly protected conservation status or core area of forest reserve and (4) unmanaged for at least 30 years.
In case of stand structure we used a combined sampling method: trees between 5-25 cm diameter at breast high (DBH) were surveyed in a plot, while in the case of larger trees a point relascope sampling (Bitterlich sampling) with basal area factor 2 was used to identify trees added to the sample. In case of logs we used line-intercept method with 16 m long lines starting from the centre to 0^0, 120^0 and 240^0.
At each circular sampling plot (r=8.92 m, 250 m^2) we assigned 28 subplots 0.5 m^2 in size – along three concentric circles (r = 2, 5 and 8 m respectively) – where the species list of herbs and seedlings (arboreal species under 50 cm height) was recorded, thereby we obtained local frequency data on a scale ranging from 0 to 28 for all species.
We measured the canopy openness by spherical densiometer at four points, 5.6 m from the centre of the plot to north, east, south and west, facing to the cardinal directions. Soil samples were taken at three random points of each plot, where we excavated 500 cm^3 soil from 5x10 cm area, 10 cm depth. These individual samples were mixed and analysed together.

Data analysis

For Vár-hegy Forest Reserve main stand structural characteristics of living trees (distribution of tree layer based on tree species, diameter, basal area, height and their combination) as well as dead wood variables were described. Spatial pattern of the tree layer were analysed by Ripley's K statistic with isotropic edge correction.
In the landscape scaled investigation stem number, basal area, volume of living and dead trees, density of shrub layer per hectare were calculated. Canopy closure and species composition, richness and exponential Shanon-Wiener diversity were also computed in each plot. Diameter distribution of living and dead trees was calculated.
In the case of tree layer the effect of age on the derived variables was analysed by general linear mixed models using age as a fixed and region as a random effect. The most important analysed derived variables are density, basal area, volume of living and standing dead trees, volume of downed dead trees, volume of total dead wood, species richness and diversity of tree layer, dead wood volume over 30 cm in diameter, range of diameter distribution, number of large living trees. In case of significant fixed (age) effects the differences between the age classes were analysed by Tukey HSD multiple comparisons.
In case of understory, herbaceous species and seedlings were analysed together, rare species were eliminated from the analyses. The effect of the three variables, light, soil pH and stand heterogeneity on the understory species composition was explored by redundancy analysis (RDA), using mountain ranges as covariables. Analyses were carried out with R 3.1.2.

Fig. 1
Study sites in three regions of the Hungarian Carpathians (1 – Pilis, Visegrádi-hegség, Börzsöny; 2 – Mátra and Kelet-Cserhát; 3 – Bükk).
Legend: Black triangles = 40-59 years old stands, black dots = 60-79 years old stands, grey squares = 80-99 years old stands, grey pentagons = 100-119 years old stands, grey crosses = unmanaged 120-165 years old stands.



Results related to composition and structure of living trees (Aszalós et al. 2015, 2017; Bölöni et al. 2018)

Based on results from the 3 ha site in Vár-hegy Forest Reserve four decades of non-intervention created a stand with two main, compositionally relatively poor layers instead, a canopy layer dominated by *Q. petraea*, and a sub-canopy layer dominated by *A. campestre*. According to the results of the Ripley's L-statistics, the thin diameter class (5-20 cm) of trees were highly aggregated at all examined scales. The thick class (diameter >20 cm) of the tree layer showed a segregated pattern between 20 and 70 meters.

Our results indicated that three to four decades of abandonment of a mature dry-mesic oak forest is rather short time to generate a more diverse forest composition and structure in these site conditions. The dense regeneration and shrub layer and the upsurgence of admixing species indicate the shift towards the uneven-aged and compositionally more diverse old-growth oak forest state. Among the structural forest features the dead wood had similar values as old-growth forests.
In the landscape scaled investigation strong dominance of the oak species was determinant in the tree layer (Tab. 1). Stem number, basal area, relative density and relative basal area of non-oak species in tree layer were low, especially in managed, 60-119 years old stands. Younger, 40-59 years old stands contained relatively more non-oak species, but these species was extracted during the thinnings. Unmanaged stands over 120 years old contained the highest relative basal area of admixed tree species (5%), but dry-mesic old-growth forests dispose 10-40% of the basal area. We presume that this measure of oak-dominance and especially the almost total absence of admixing species with larger diameters are not natural in dry-mesic oak forests of the Hungarian Carpathians, but is the effect of the direct human preference on oak species (primarily *Quercus petraea*) in the last centuries. Evidently, the actions of the shelter wood system of the systematic forest management of the last 150-200 years – planting, spacing, thinning – played leading role of the overwhelming oak dominance in Central European commercial forests, which aimed at to maximize the ratio of the principal tree species in the canopy layer.
However, the shrub layer was dominated by associate tree and shrub species and density of oaks was low. The results of our study support that, if open space is not created by humans or other disturbance factors, like fire or wind, there is little chance for the oak forest to regenerate. This conclusion is in accordance with the several other authors'.

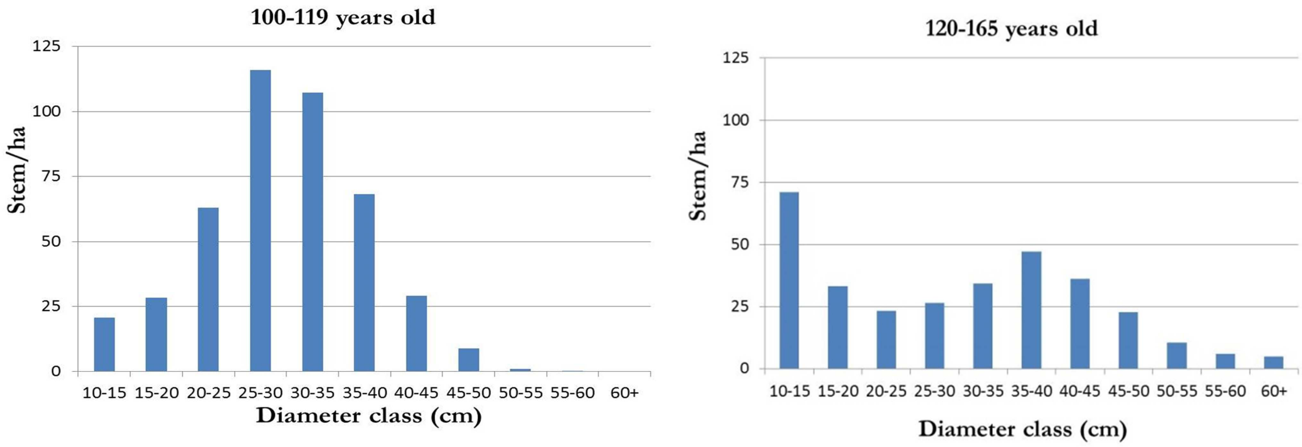
Table 1
Composition, density and basal area of living trees of the tree layer with DBH >10 cm.

Stand age in 2010, years	40-59	60-79	80-99	100-119	120-165	40-59	60-79	80-99	100-119	120-165
species	relative density, %					relative basal area %				
Quercus petraea	71.7	83.0	66.8	61.7	61.1	72.9	82.2	70.0	70.4	63.1
Q. cerris	23.7	14.6	27.4	28.9	20.6	22.8	16.9	28.1	26.3	29.7
Acer campestre	0.4	0.5	1.6	0.2	9.1	0.2	0.2	0.5	0.0	1.9
Q. pubescens	0.5	0.2	0.6	4.3	1.6	0.4	0.1	0.3	2.0	1.7
Sorbus torminalis	0.6	0.7	1.2	4.0	2.8	0.5	0.3	0.4	1.0	1.6
Fraxinus excelsior	0.8	0.0	0.0	0.5	0.7	1.1	0.0	0.0	0.2	0.7
Carpinus betulus	0.2	0.5	0.5	0.3	0.9	0.1	0.1	0.2	0.1	0.4
A. palatanoides	0.0	0.0	0.0	0.0	0.6	0.0	0.0	0.0	0.0	0.4
Tilia platyphyllos	0.1	0.0	0.0	0.0	0.3	0.1	0.0	0.0	0.0	0.2
Cerasus avium	0.0	0.1	0.4	0.0	0.9	0.1	0.0	0.1	0.0	0.2
Cornus mas	0.0	0.0	0.4	0.0	0.3	0.0	0.0	0.1	0.0	0.0
Pyrus pyraster	0.1	0.2	0.1	0.0	0.2	0.1	0.0	0.0	0.0	0.0
Crataegus monogyna	0.0	0.0	0.1	0.0	0.3	0.0	0.0	0.0	0.0	0.0
F. ornus	1.5	0.1	1.0	0.0	0.0	1.1	0.0	0.2	0.0	0.0
others	0.3	0.1	0.0	0.0	0.6	0.5	0.0	0.0	0.0	0.3
density, stem/ha	1185	632	436	443	317					
basal area, m^2/ha						26.00	27.51	27.66	32.53	27.27

Others: *Acer pseudoplatanus, Cerasus mahaleb, Corylus avellana, Cotinus coggygria, Fagus sylvatica, Malus sylvestris, Pinus sylvestris, Sorbus aria, S. domestica, Tilia cordata, Ulmus glabra*

The diversity of tree species was higher in unmanaged stands over 120 years old, than in managed 40-119 years old stands. All variables describing structure of stands indicated, that diversity of structure grows with stand age. Range of mean diameter and the diversity of diameter distribution were least in managed 40-59 years old stands and the highest in unmanaged stands older than 120 years. Unmanaged stands has at least 10 times higher density of veteran trees with a diameter > 30 cm, than managed stands. Diameter classes of woody stems of the tree layer (DBH ≥ 10 cm) showed normal distribution in managed stands, while it maintained bimodal shape, indicating the absence of the medium sized-trees in unmanaged stands over 120 years old (Fig 2).

Fig. 2
Diameter distribution in 100-119 years old and in 120-165 years old stands



Results related to dead wood (Aszalós et al. 2015, 2017; Bölöni et al. 2015, 2017)

The density and volume of dead wood is considered a useful structural indicator of the sustainability and maintenance of biodiversity in forests. Results related to dead wood were already published both in Hungarian (Bölöni et al. 2015) and in English (Bölöni et al. 2017). In 40-99 years old managed stands, we found very low quantities of dead wood (under 15 m^3/ha) regardless of stand age, a finding similar to that reported for managed dry-mesic oak forests elsewhere in Europe. One hundred years of stand development can be considered a threshold for large wood recruitment in these systems. Above this age both less intensively managed and the unmanaged stands are capable of recruiting relatively high volume of dead wood (36.9 and 45.1 m^3/ha respectively).
Dead wood accumulation in the studied unmanaged stands approximates, but does not reach the dead wood volume of old-growth dry-mesic oak forests. The volume of total dead wood found in unmanaged stands older than 120 years (45 m^3/ha) is in the lower half of the range of similar old-growth or abandoned dry-mesic oak forests, which are dominated by canopy trees over 110-150 years. Abandoned and old-growth mesic oak forest stands have 2-5 times more dead wood – usually exceeding 100 m^3/ha – than dry-mesic oak forests with a similar history and structure. The density of large dead wood (diameter > 30 cm) is very low in managed 40-119 years old dry-mesic oak forests in the Hungarian Carpathians, large-diameter downed dead trees are totally absent from the stands younger than 100 years, due to the general forest management regime, like in other managed oak forests in Europe.
Our results support a conclusion that after cessation of management, a relatively short period – approximately 20-30 years – is enough to produce dead wood volumes and biomass similar to old-growth forests, provided that the stand was at least 80 year-old at the time of the abandonment. Dead wood appears to be one of the first structural features that regenerate after cessation of intensive forest management based on our results and previous research. Furthermore, the low rate of decayed dead wood indicates the influence of former intensive forest management. The volume of well-decayed dead wood is considerably low even in the stands abandoned at least 30 years ago. Three decades of non-intervention were not enough time interval for the development of high volume of well-decayed dead wood.

Result related to understory (Ádám et al. 2013, 2015, 2018)

Forest understory has a key role in the functioning of forest ecosystems. We conclude that different factors affect the occurrence of herbaceous and seedling species. The herb species composition of the understory is mainly influenced by canopy openness, stand structure and shrub layer density. The most important factors affecting the occurrence of seedling species were shrub density, mean diameter of trees and tree species diversity. According to our results, the canopy openness and the soil pH are more influential in determining the species composition of the understory, than stand heterogeneity. Stand heterogeneity has a bit lower, but still significant impact on the understory. Thirteen of the 19 studied arboreal species showed significant relationship with canopy openness, 12 with soil pH and 9 with stand heterogeneity.

Seedling species usually avoided open areas with acidic soil. Sessile oak seedlings showed unique response to the studied variables, which was different from other seedlings. This species preferred moderately open areas with homogeneous stand structure and acidic soil and sessile oak dominated stands with relatively large tree size, homogeneous stand structure and low tree diversity. The two specific subordinate tree species (*Acer campestre*, *Fraxinus excelsior*) and most of the shrub species correlated positively with soil pH and preferred stands with high tree diversity and heterogeneous stand structure. In the case of arboreal species, the proximity of the propagule source has great importance.

In case of herbaceous species the canopy openness and the soil pH were more important stand characteristics than the stand heterogeneity. Herbaceous species showed various responses to the studied stand characteristics, however, some response combinations were completely missing. None of the studied 79 herb species preferred acidic soil with heterogeneous stand structure or with closed canopy, and they avoided homogeneous stands with relatively neutral soil. Considering the half-shaded areas, two types of herbaceous understory can be observed. The first type can be found in homogeneous stands with acidic soil and sessile oak dominance in the overstory. In these forests the typical herbaceous species are *Campanula persicifolia*, *Carex digitata*, *Festuca heterophylla*, *Poa nemoralis* and *Veronica chamaedrys.* The second undestorey type occurs in half-shaded, structurally heterogeneous forests with relatively neutral soil conditions. The characteristic species of these stands are *Bromus ramosus*, *Scutellaria altissima,* and *Viola reichenbachiana.*

The community-level responses of species were similar to the results of individual models, the latter can help to get a more complete picture of oak forest organization. According to our results based on the species composition of the understory, two types of dry-mesic oak forests can be divided: 1) a sessile oak dominated type with acidic soil and 2) a mixed type on more neutral soil conditions. The sessile oak dominated type has usually more homogeneous stand structure, than the mixed type, which is often characterized by dense shrub layer, multi-layered overstory.

Our results showed, that way of forest management has high importance for biodiversity. We recommend that management for biodiversity should also maintain higher density and volume of dead wood in these forests. As old-growth dry mesic forests contain approximately 50 m^3 DW per hectare on average, we recommend to leave at least the half of that, 25-30 m^3/ha, in case of these habitat types for the benefit of biodiversity.

The very low frequency of large standing and downed dead trees could be enhanced by active conservation management by the felling and girdling of large-diameter trees, or in case of absence of large trees, by importing large downed dead trees. Retention of approximately 10-15 m^3/ha DW over 30 cm in diameter is recommended in protected dry-mesic oak forest sites, with 5-10 stem/ha standing dead tree density as a minimum target, to achieve biodiversity conservation targets.

In order to preserve the plant community of dry-mesic oak forests we need to create light rich, sessile oak dominated stands with sparsely standing trees and heterogeneous, species-rich patches with developed shrub layer as well.

References

Ádám R, Ódor P, Bidló A, Somay L, Bölöni J, 2018. The effect of light, soil pH and stand heterogeneity on understory species composition of dry-mesic oak forests in the Hungarian Carpathians. (under review)

Ádám R, Ódor P, Bölöni J, 2013. The effects of stand characteristics on the understory vegetation in Quercus petraea and Q. cerris dominated forests, Community Ecology 14, 101-109.

Ádám R, Ódor Péter, Bölöni J: Állományjellemzők hatása a gyepszint fajösszetételére cseres-kocsánytalan tölgyes erdőkben. In Bölöni J (szerk.), Tanulmányok a félszáraz tölgyesek ökológiai viszonyairól. MTA Ökológiai Kutatóközpont, Tihany, pp. 9-18., 2015

Aszalós R, Horváth F, Mázsa K, Lengyel A, Bölöni J, 2014. Erdőszerkezeti és fajösszetétel-változási tendenciák középhegységi cseres-tölgyesben 35 év felhagyás után. IX. Magyar Természetvédelmi Biológiai Konferencia, absztrakt, p. 28.

Aszalós R, Horváth F, Mázsa K, Ódor P, Lengyel A, Kovács G, Bölöni J, 2015: A faállomány-szerkezet és összetétel változása egy középhegységi cseres-tölgyesben négy évtizedes felhagyás után. In Bölöni J (szerk.), Tanulmányok a félszáraz tölgyesek ökológiai viszonyairól. MTA Ökológiai Kutatóközpont, Tihany, pp. 19-29.

Aszalós R, Horváth F, Mázsa K, Ódor P, Lengyel A, Kovács G, Bölöni J, 2017. First signs of old-growth structure and composition of an oak forest after four decades of abandonment. Biologia 72, 1264-1274.

Bölöni J, Ódor P, Ádám R, Keeton WS, Aszalós R, 2017. Quantity and dynamics of dead wood in managed and unmanaged dry-mesic oak forests in the Hungarian Carpathians. Forest Ecology and Management 399, 120-131.

Bölöni J, (szerk.), 2015. Tanulmányok a félszáraz tölgyesek ökológiai viszonyairól. MTA Ökológiai Kutatóközpont, Tihany.

Bölöni J, Ádám R, Aszalós R, Ódor P, 2015. Holtfa az észak-magyarországi kezelt és felhagyott cseres-kocsánytalan tölgyesekben. In Bölöni J (szerk.), Tanulmányok a félszáraz tölgyesek ökológiai viszonyairól. MTA Ökológiai Kutatóközpont, Tihany, pp. 31-45.

Bölöni et al., 2018. Composition and structure of managed and unmanaged dry-mesic oak forests in the Hungarian Carpathians. (manuscript)