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OLD GROWTH FORESTS

Abandonment status and long-term monitoring of strict forest reserves in the Pannonian biogeographical region

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Abstract
The Pannonian region is situated in the Carpathian basin where forests have been used intensively for centuries. The article shows a map and a tabular overview of the forest reserves featured as forests "left for free development" of the region, and presents the most important stand structural characteristics of beech, mesophytic and thermophilous deciduous forests surveyed recently. The sampling points of six sites were selected to provide preliminary descriptive statistics according to the main types and abandonment status groups (recently managed, long abandoned and old-growth or primary stands) of these forests. In old-growth and primary stands the composition (list and mixture ratio of tree species) and stand structure characteristics [gap class distribution, stem density, distribution of relative crown classes and broad diameter at breast height (at 130 cm) classes, density of thick snags, and the amount of lying dead wood] proved to be similar to other European deciduous natural forests, while the abandoned and recently managed stands indicate that these forests are in a transitional stage towards natural ones.

Keywords: *Forest ecology, stand structure, temperate zone, deciduous forest, Hungary*

Introduction

The Pannonian region has been an optimal place for human life for a very long time. The forests of the landscape have all or almost all been used, transformed or altered by human activities. The medieval and early modern Hungarian forest management system – cutting, coppicing and grazing of woods – was similar to that in the rest of Europe (Szabó 2005), although considerable areas of forests still remained untouched (Fuchs 1861). The modern era was characterized by the increasing exploitation of forest resources and the decrease of wooded areas (Szabó 2008). As a consequence of the intensive land use in the densely populated areas, woodlands differed both from the recently managed forests and the old-growth forests as well at the end of nineteenth century. In general, these forests were very open, the age structure was relatively diverse, but the average age of the stands was low (20–50 years) and the volume was also rather low. Different from this is the history of woodlands situated far from settlements in the North Hungarian Mountains, where clearcutting, coppicing and grazing were not so common. Several closed, old, high forest-like stands or even virgin forest fragments could survive in the shelter of royal, church and noble demesnes (Czájlik & Pászty 2009).

New claims and the Forest Law introduced in 1879 caused radical changes in the approach and ways of forest use. The law ordered the management of private forests under state supervision to stop the further devastation and degradation of woodlands, and strictly prohibited grazing in forests. In the early twentieth century several propositions were put forward to the Minister of Agriculture to preserve

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fragments of virgin forest. Within several years, 20 virgin forest remnants were designated in the Carpathians by the Hungarian Royal Forest Directorate. The First World War and the following Treaty of Trianon had great influence on Hungarian forestry, because the state lost the high productive forests of the Carpathians. Therefore, an increased demand emerged for the hill and lowland deciduous forests of the region, which generally thrive under drier climatic conditions. The introduction of one-track cutting system caused significant reduction in forest structure and biodiversity on local and landscape scale even in most of the semi-natural forests of Hungary (Bartha et al. 2006).

The Hungarian Forest Reserve Program and Network was initiated by NGOs, researchers and ministerial stakeholders in the 1990s. The network consists of 63 forest reserves, which represent the most characteristic (semi-natural) forest types of Hungary and the Pannonian region (Czájlik & Standovár 1999; Horváth et al. 2001). The total extent of the strictly protected core areas is ~3600 ha, and each of them is surrounded by a protected buffer zone (~12,000 ha altogether). These forest stands have been withdrawn from management by law, are left for free development and free of any direct human intervention. The aims of the program are basically twofold: (a) to ensure the conservation of natural/semi-natural forest stands, (b) to get new sound knowledge about the biodiversity, stand structure and ecological processes of our representative forest ecosystems (Horváth et al. 2001).

At the European level, COST Action E4: "Forest Reserves Research Network" was initiated and set up in 1995. The aims of the action were to promote co-ordination among the participant countries and to focus research on "natural" forests (Parviainen et al. 2000). One objective was to develop a Europe-wide solid understanding of natural forests and strict forest reserves (SFRs) (Bücking et al. 2000), the other was to harmonize research methodology (Hochbichler et al. 2000). In the period of 1998–1999, during the realization of COST Action E4, we prepared a country-wide survey of the Hungarian forest reserves to get an overview of their habitat classification, stand structure and naturalness. After this, we published a book that lays down the theoretical and practical principles (Horváth & Borhidi 2002) and experiences of forest reserve research in Hungary. When elaborating the method of the long-term monitoring of forest stand structure, great emphasis was put on the components of natural stand structure such as varied mixture ratio and cohort structure, vertical stand structure, forms and stages of dead wood, and typical forest dynamic processes such as gap dynamics, natural forest development and regeneration (Oliver & Larson 1996; Frelich 2002). Some attributes of forest structure and dead wood proved to be good indicators of old-growth status and high species diversity, and therefore lent themselves well to be used for monitoring (Ódor et al. 2006; Burrascano et al. 2008; Blasi et al. 2010; Király & Ódor 2010).

The aim of present article is to give an overview of the forest reserves of the Pannonian biogeographic region, and to show the most important forest structural features of the major forest types based on the first results of the monitoring set off in 2005.

Material and methods

Study area and forest types

The Pannonian region – 1 of the 10 biogeographical regions of Europe – is situated in the Carpathian basin, and is surrounded by the Alps, the Carpathians and the Dinaric Alps (EEA 2005). It was defined in the ecological interpretation of the Natural Vegetation Map of Europe (Bohn et al. 2003). The total area of Hungary belongs to this region, while other Central European countries, such as the Czech Republic, Slovakia, Ukraine, Romania, Serbia and Croatia belong here only in part. The centre of the basin is occupied by the Great Hungarian Plain, where forest steppe vegetation zone is characteristic due to the xero-thermic climatic conditions, according to Borhidi (1961). The rest of the region belongs to the temperate forest zone, which can be subdivided into oak, oak-hornbeam and beech-dominated forest belts (Niklfeld 1973; Zólyomi 1989). The Pannonian features of the vegetation are described by Fekete & Varga (2006), the Hungarian distribution maps of the forest types are given by Bölöni et al. (2008). We applied the European forest type description and nomenclature to classify our forest stands into the broad categories of EEA (2007):

- *Hemiboreal forest and nemoral coniferous and mixed broadleaved-coniferous forest* – Nemoral Scots pine forest (EEA code 2.2).
- *Mesophytic deciduous forest* – Pedunculate oak-hornbeam forest (EEA code 5.1); Sessile oak-hornbeam forest (EEA code 5.2); Maple-oak forest (EEA code 5.4); Maple-lime forest (EEA code 5.6); Ravine and slope forest (EEA code 5.8); other mesophytic deciduous forest (EEA code 5.9).
- *Beech forest* – Central European submountainous beech forest (EEA code 6.4); Carpathian submountainous beech forest (EEA code 6.5); Illyrian submountainous beech forest (EEA code 6.6).
- *Thermophilous deciduous forest* – Downy oak forest (EEA code 8.1); Turkey oak, Hungarian oak and Sessile oak forest (EEA code 8.2).

- *Mire and swamp forest* – Alder swamp forest (EEA code 11.2).
- *Floodplain forest* – Riparian forest (EEA code 12.1); Fluvial forest (EEA code 12.2).

Selected forest reserves

We selected six forest reserves in Hungary (see Table I for brief descriptions) to provide a preliminary overview of the structure of the most natural forest stands in the region (Figure 1).

Extensive survey of the forest reserve network

We carried out an extensive survey in 1998/1999 involving 15 experts who explored 1870 compartments of the forest reserve network. Each forest compartment was characterized on the basis of tree stand structure, botanical features and zoological microhabitats. Then, we evaluated the 63 reserves briefly and made proposals on the intensity level of future forest reserve researches (Horváth & Bölöni 2002).

The abandonment statuses of each compartment were classified in the following categories:

- *Recently managed* – secondary high forest, managed (cleaning) within 10–20 years, single-storey, even-aged, unmixed, homogeneous
- *Abandoned* – lately abandoned secondary forest, managed over 20 years ago, mixed, uneven-aged, structured and differentiated canopy, little dead wood, traces of former management.
- *Old second-growth* – old secondary forest, long abandoned, managed over 30–50 years ago, mixed, uneven-aged, multi-storey with gaps, dead wood of various stages of decay and a diverse pattern of patches.
- *Primary* or *old-growth forest* – ancient forest, managed only very long ago or never, multi-storey, uneven-aged, mixed, a patchwork of various development phases and gaps, a lot of dead wood of various stages of decay.
- *Successional forest* – old, spontaneous, successional forest where no management has ever taken place.

Hungarian legislation has guaranteed no forest management intervention in SFRs since 1991, and another 10 years have passed in free development of the forest stands since the extended survey. Therefore, we re-evaluated our earlier results in the light of new field experiences. In the case of forest reserves outside the country, we used literature and internet data for their classification.

Long-term monitoring approach

A grid network of permanent sampling points (SP) was developed and set up in the selected SFRs to gain information about the pattern and dynamics of the tree populations and stand structure. Four modules of standard thematic survey were interlinked in these SPs: stand structure (including standing and lying dead wood), sampling of shrub and regeneration layer, sampling of ground vegetation and site evaluation. The density of SPs was four SPs/hectare, which could normally be set as a regular grid of 50 × 50 m. We plan to re-survey these SPs in

Table I. Main characteristics of the forest reserves selected for stand structure analysis.

Site name (ID)	Conditions	Short description
Kőszegi-forrás (35)	A: 300–400 m T: 8.9°C P: 700 mm	Old, abandoned Illyrian beech and oak-hornbeam forests on a north-faced hillside with springs and gullies in the Mecsek hills (S-Hungary). Sandstone and limestone bedrock covered by deep brown forest soils.
Hidegvíz-völgy (46)	A: 450–520 m T: 8.5°C P: 750 mm	Abandoned old beech stand in the Sopron hills (NW-Hungary) on an S-SW slope. Some introduced spruce stands also present, but perishing in patches due to bark beetle destruction. Lessivated, acidic, non-podzolic brown forest soils with surface water gley, and colluvial soils, formed on gneiss and mica bedrock.
Szalafő (53)	A: 290–300 m T: 9.0°C P: 800–900 mm	Nemoral Scots pine forest abandoned over 50 years ago, successional transition towards an oak-hornbeam forest in the Őrség region (W-Hungary). Lessivated brown forest soils or brown forest soils with surface water gley, formed on loam and gravel bedrock.
Kékes-Észak (56)	A: 760–980 m T: 5.6°C P: 780 mm	Remnants of virgin beech and ravine forests in the Mátra Mountains (N-Hungary), on a steep rocky northern slope. Brown forest and colluvial soils formed on andesite bedrock.
Vár-hegy (59)	A: 300–669 m T: 7–9°C P: 700 mm	Old oak and beech dominated forests in the Bükk Mountains (N-Hungary). Four age classes of trees in relation to the forest history. Highly variable relief, predominantly limestone bedrock, various colluvial, brown forest and rendzina soils.
Haragistya–Lófej (70)	A: 400–600 m T: 9.1°C P: 660 mm	Young or mid-aged sessile oak-hornbeam forests, with dry oak (on ridges) and beech stands in the Gömör-Torna Karst (N-Hungary). Forest management abandoned in the 1980s. Limestone and dolomite bedrock, brown forest soils and brown or black rendzina soils.

ID, identity code; A, altitude in meters above sea level; T, mean annual temperature in Celsius; P, mean annual sum of precipitation in millimeter.

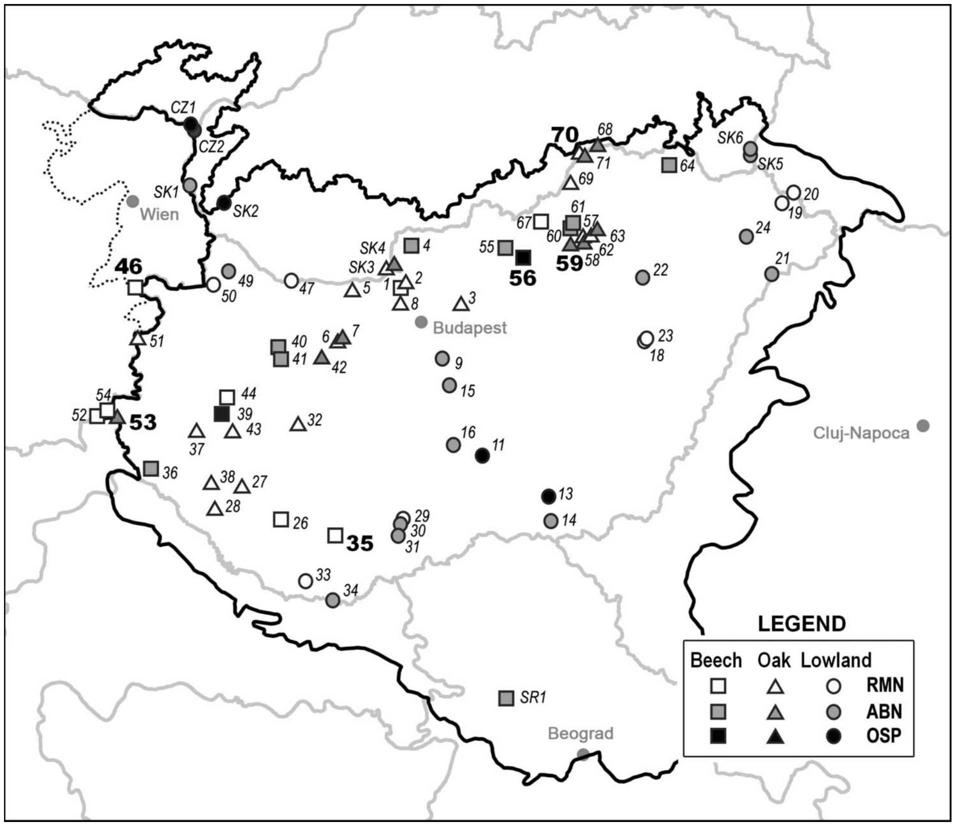

Figure 1. Overview map of the main forest types and abandonment statuses of forest reserves in the Pannonian biogeographical region. The delineation of the region on the western side is based on conservation policy considerations (ETC/BD 2006). Dotted line shows the real scientific judgement according to Kilian et al. (1994). Beech, beech-dominated forest; Oak, oak-dominated forest on hills/mountains; Lowland, lowland forest in the Pannonian region; RMN, recently managed; ABN, abandoned; OSP, old second-growth or successional, or primary/old-growth forests. Numbers refer to the IDs in Tables I and II.

10–15 years to follow up and evaluate natural changes in these forest stands. This approach is called FOREST + n + e + t – *the stand dynamic and ecological observation network of natural forests*.

Survey method of stand structure

We performed stand structure survey in each SP of the FOREST + n + e + t. There were three modules of data acquisition:

a. General description of forest stand, assessment of canopy closure, cover by layers, and gap extent within an area of 1–1.5 tree height around the SP:
   - *Gap size classes* – A gap is the absence of at least one crown dominant in size and position from the overstorey. The reasons may be withering, cutting or falling. The gap is not yet filled by neighbouring crowns or regenerating young trees. No gap or closed canopy (N0); a gap the size of one dominant crown (G1); a gap the size of two or three dominant crowns, or two or three gaps (G23); a gap larger than G23 or a collapse (GX).
   - Further characteristics not evaluated in this article are as follows: stand canopy closure; percentage cover of lower and upper canopies; percentage cover of shrub and regeneration layers.

b. Living and standing dead trees and shrubs were selected from the stands at each SPs by the combination of *circular plot sampling* [5 cm $\leq$ diameter at breast height (at 130 cm) (DBH) $<$ 25.2 cm, radius = 8.92 m, area = 250 m^2, tree factor = 40] and *horizontal point sampling* (DBH $\geq$ 25.2 cm, gauge constant $k = 2$, basal area factor = 2) to estimate the local stand parameters. The two subsets are additive:

$$\text{Sample} = \text{Subset}_{\text{circular plot}} + \text{Subset}_{\text{horizontal point}}$$

The number of stems (N) and the basal area (G) per hectare can be estimated by addition as follows:

$$N(\text{number/hectare}) = N_{\text{circular plot}} + N_{\text{horizontal point}}$$
$$\text{and } G(\text{m}^2/\text{hectare}) = G_{\text{circular plot}} + G_{\text{horizontal point}}$$

c. Assessment of trees in the sample. The following variables are recorded:

- *Species* – tree or shrub species
- *DBH* (cm) – living tree and standing dead wood
- *Crown position* – classification of relative crown position of each tree in the canopy after Kraft (1884). Dominant (Do): crown heightens above the average level of upper canopy, most of the crown receives direct sunlight; Co-dominant (Cd): crowns form a general level of canopy, about half of the crowns receive direct sunlight; Intermediate (In): crowns reach into the average level of canopy, but are quite crowded on the sides, crowns receive direct but much less sunlight; Suppressed (Su): crowns are entirely below the average level of canopy, do not receive any direct sunlight.
- Further characteristics not evaluated in this article are as follows: health status, dead wood decay phase, extraordinary tree form, presumable origin of the trees, canopy height.

d. Lying dead wood estimation with line intercept sampling method (Ståhl et al. 2001). We established three sampling lines (9 m long each, $L = 27$ m) radiating from the center of the SP in the directions of 0 (North), 120 and 240 degrees. Each interception of the sampling line and any lying dead wood (width ≥ 5 cm, longer than 0.5 m) made a record. The following data were recorded: *species* – if applicable, *diameter* (d in cm) where the line crossed the piece, and *decay phase*. The volume of lying dead wood material per hectare (V_{ldw}) was calculated as follows:

$$V = \frac{\pi^2 \sum d^2}{8L}$$

Data analyses

Of the FOREST + n + e + t SPs established in the six forest reserves, we picked the ones that belonged to the categories of "mesophytic deciduous forest", "beech forest" and "thermophilous deciduous forest". We omitted open downy oak stands lower than 10 m on extremely dry sites. The following SPs were used in our analyses: Kőszegi-forrás, 96 SPs; Hidegvíz-völgy, 75 SPs; Szalafő, 33 SPs; Kékes, 210 SPs; Vár-hegy, 373 SPs; Haragistya-Lófej, 325 SPs; altogether, 1112 SPs. We assigned the extensive survey abandonment statuses to the SPs. For further analyses, we created a forest type, abandonment status and stand structure dataset. We used database functions for the calculation of sums according to the two aspects and for the descriptive statistics (mean, standard deviation, minimum and maximum).

Results

The SFRs belonging to the Pannonian biogeographical region are listed in Table II, their major features are indicated. We also prepared an overview map of these reserves (Figure 1). Sixty-three of the region SFRs are found in Hungary, 6 in Slovakia, 2 in the Czech Republic and 1 in Serbia (not assigned as forest reserve, but protected as national park). Ukraine, Romania and Croatia do not have any forest reserves within the Pannonian region. The examined 72 SFRs cover altogether ~4370 ha, of which 10 (~840 ha, 19%) belong for the most part to the "mesophytic deciduous forest" type, 18 (~900 ha, 21%) to the "beech forest" type, 17 (~1590 ha, 36%) to the "thermophilous deciduous forest" type, 27 (~1020 ha, 23%) to the lowland, mostly floodplain or mire and swamp forest type (Table II). Several forest reserves can be considered as virgin forests or rather virgin forest fragments (Cahnov-Soutok, Ranšpurk, Kékes, Šúr, ~123 ha, 3%), there is a spontaneous succession forest, three belong to old second-growth forests (~167 ha, 4%), while most woodlands are either old, abandoned forests that have been cultivated for some time (33, ~2030 ha, 47%) or younger woodlands abandoned recently (31, ~1965 ha, 45%).

Results of the analysis of the stand structure and tree composition dataset according to forest type are given in Figure 2. This shows the mixture ratio of the main trees (basal area was considered at DBH ≥ 5 cm, including shrubs), the mean and standard deviation of the number of woody plant species (S) by SPs. The number of woody species is relatively high for all forest types: 25 trees and 6 shrubs + 4 introduced trees for beech forests (429 SPs from 6 SFRs), 23 trees and 11 shrubs + 4 introduced trees for mesophytic deciduous forests (466 SPs from 5 SFRs), 20 trees and 7 shrubs + 1 introduced trees for thermophilous deciduous forests (217 SPs from 3 SFRs) of altogether 45. Five of the six forest reserves: Hidegvíz-völgy (Norway spruce and larch), Szalafő (Norway spruce), Kőszegi-forrás (larch, Scots pine, black pine, red oak), Kékes (spruce and larch) and Haragistya – Lófej (Scots pine, black pine) suffer from some non-native (fortunately non-invasive) tree species due to earlier introduction by forest management. The mean number of tree species per SPs is 3.3 ± 1.8 in beech stands, while it is almost twice greater: 5.4 ± 2.1 and 5.4 ± 2.3 in mesophytic and thermophilous deciduous forest stands, respectively (Figure 2). In general, these results reflect a high diversity of mixture ratio and species composition.

Stand structure characteristics for the same forest type and abandonment status groups are given in Table III. The distribution of forest stands according

Table II. Forest type, abandonment and monitoring status of strict forest reserves in the Pannonian biogeographical region.

ID	Site name	Area (ha)	Main forest type (EEA codes for more details)	Abandonment status	Monitoring[a]
Hungary (Horváth & Bölöni, 2002)					
1	Pilis-oldal	45	Beech forest (6.5, 8.1, 5.9)	Recently managed	
2	Prédikálószék	27	Oak forest (8.2, 5.9)	Recently managed	
3	Nagy-Istrázsa-hegy	45	Maple-oak forest (5.4, 5.2, 8.2)	Recently managed	2012–. . .[b]
4	Pogány-Rózsás	91	Beech forest (6.5, 5.8)	Abandoned	
5	Gerecse, Száz-völgy	50	Oak-hornbeam forest (5.2, 5.9, 8.2)	Recently managed	
6	Meszes-völgy	46	Ravine and slope forest (5.8, 5.2, 8.1)	Recently managed	
7	Juhdöglő-völgy	26	Oak forest (8.1, 6.4, 8.2)	Abandoned	2012–. . .[b]
8	Kisszénás	41	Oak forest (8.1, 5.2)	Recently managed	
9	Ócsai turjános	22	Alder swamp forest (11.2)	Abandoned	
11	Nagybugaci ősborókás	76	Poplar-juniper steppe woodlands	Successional	
13	Sasér	20	Floodplain forest (12.2)	Old second-growth	
14	Maros, hullámtér	21	Floodplain forest (12.2)	Abandoned	
15	Kunpeszéri Tilos-erdő	19	Oak forest (8.1)	Abandoned	
16	Közös-erdő	29	Floodplain forest (12.2)	Abandoned	
18	Farkas-sziget 2.	8	Floodplain forest (12.2)	Recently managed	
19	Bockereki-erdő	60	Oak-hornbeam forest (5.1, 11.2, 12.2)	Recently managed	
20	Dédai-erdő	20	Oak-hornbeam forest (5.1)	Recently managed	
21	Fényi-erdő	59	Floodplain forest (12.2, 8.1)	Abandoned	
22	Tilos-erdő	22	Oak forest (8.1)	Abandoned	
23	Farkas-sziget 1.	24	Floodplain forest (12.2, 8.1)	Recently managed	
24	Baktai-erdő	28	Oak-hornbeam forest (5.1, 8.1)	Abandoned	
26	Ropolyi-erdő	58	Beech forest (6.6, 5.2)	Recently managed	
27	Dávodi-erdő	52	Oak-hornbeam forest (5.1, 12.1)	Recently managed	
28	Baláta-tó	92	Oak-hornbeam forest (5.1, 11.2)	Recently managed	
29	Buvat, Keszeges-tó	85	Floodplain forest (12.2)	Recently managed	
30	Dél-Veránka, Sasfok	55	Floodplain forest (12.2)	Abandoned	
31	Kádár-sziget	51	Floodplain forest (12.2)	Abandoned	
32	Vaskereszt	32	Oak forest (8.1, 8.2)	Recently managed	
33	Bükkhát	36	Floodplain forest (12.2, 5.1)	Recently managed	
34	Matty	32	Floodplain forest (12.2)	Abandoned	
35	Kőszegi-forrás	33	Beech forest (6.6, 5.2)	Recently managed	2009–2011
36	Vétyem	31	Beech forest (6.6)	Abandoned	
37	Remetekert	32	Beech forest (6.4, 5.2)	Recently managed	
38	Csörnyeberek	25	Floodplain forest (12.1, 12.2, 5.1)	Recently managed	
39	Tátika	88	Beech forest (6.4, 5.8, 5.2)	Old second-growth	(1994)[c]
40	Tóth-árok	58	Beech forest (6.4, 8.1, 5.2)	Abandoned	
41	Som-hegy	104	Beech forest (6.4, 5.9)	Abandoned	
42	Burok-völgy	129	Oak forest (8.1, 8.2, 5.8, 5.9, 6.4)	Abandoned	
43	Virágos-hegy	47	Oak forest (8.1, 8.2, 5.2)	Recently managed	
44	Fehér-sziklák	39	Beech forest (6.4, 5.2)	Recently managed	
46	Hidegvíz-völgy	20	Beech forest (6.4, 5.2)	Recently managed	2005
47	Erebe-szigetek	64	Floodplain forest (12.2)	Recently managed	
49	Dombosház	83	Floodplain forest (12.2, 11.2)	Abandoned	
50	Bikafej	76	Pioneer willows	Recently managed	
51	Hosszú-völgy	38	Beech forest (6.4)	Recently managed	
52	Szabó-völgy	27	Beech forest (6.4)	Recently managed	
53	Szalafő	13	Oak-hornbeam forest (5.2, 6.4)	Abandoned	(1981)[c] 2005
54	Pap-erdő	20	Beech forest (6.4)	Recently managed	
55	Csörgő-völgy	51	Beech forest (6.5, 5.2, 11.2)	Abandoned	
56	Kékes-Észak	55	Beech forest (6.5, 5.8)	Primary forest	(1993)[c] 2005
57	Hór-völgy	61	Beech forest (6.5, 8.1, 5.2)	Recently managed	
58	Kecskés-galya	87	Oak forest (8.1, 8.2)	Abandoned	2010–2011
59	Vár-hegy	94	Oak-hornbeam forest (5.2, 8.1, 8.2, 6.5)	Abandoned	2005–2009
60	Őserdő	59	Beech forest (6.5, 5.8)	Old second-growth	2009–2011
61	Leány-völgy	57	Ravine and slope forest (5.8, 5.9, 6.5)	Abandoned	
62	Paphárs-Kecskevár	58	Oak-hornbeam forest (5.2, 8.1)	Recently managed	
63	Csókás-völgy	144	Oak forest (8.1, 6.5, 5.8, 8.2)	Abandoned	
64	Nagy-sertéshegy	66	Beech forest (6.5, 5.2)	Abandoned	
67	Pataj	66	Beech forest (6.5, 5.2)	Recently managed	
68	Alsó-hegy	113	Oak-hornbeam forest (5.2, 6.5)	Abandoned	

(continued)

Table II. (*Continued*).

ID	Site name	Area (ha)	Main forest type (EEA codes for more details)	Abandonment status	Monitoring[a]
69	Kelemér–Serényfalu	72	Oak-hornbeam forest (5.2, 8.2)	Recently managed	
70	Haragistya–Lófej	260	Oak-hornbeam forest (5.2, 6.5, 5.9, 8.1)	Recently managed	2005–2006
71	Nagy-oldal	224	Oak forest (8.1, 5.2, 6.5, 5.9)	Abandoned	
Slovakia (Korpeľ 1995; www.pralesy.sk; uzemia.enviroportal.sk)					
SK1	Horný les	11	Floodplain forest (12.2)	Abandoned	
SK2	Šúr	29	Floodplain forest (12.2)	Primary forest	1972, 1987, 1992, . . .
SK3	Burdov (Kováčovské kopce)	364	Oak forest (8.1, 8.2, 5.2)	Recently managed	
SK4	Leliansky les	199	Oak-hornbeam forest (5.2)	Abandoned	
SK5	Latorický luh	15	Floodplain forest (12.2)	Abandoned	
SK6	Botiansky luh	41	Floodplain forest (12.2)	Abandoned	
Czech Republic (www.pralesy.cz)					
CZ1	Ranšpurk (Lanžhot)	22	Floodplain forest (12.1, 5.1)	Primary forest	1973, 1994, 2006
CZ2	Cahnov-Soutok (Lanžhot)	17	Floodplain forest (12.2)	Primary forest	1973, 1994, 2006
Serbia (no forest reserve assigned yet)					
SR1	National Park Fruška Gora	–	Beech forest (6.4, 5.2)	Abandoned	

[a]We only consider here stand structure inventories according to the FOREST + n + e + t approach in Hungary. [b]FOREST + n + e + t inventory is planned to perform. [c]A preliminary survey was done (unpublished private draft minute). ID, identity code (same as numbers and codes on Figure 1).

to gap classes is given in percentage, while the distribution of relative crown classes and broad DBH classes are expressed as the relative number of trees. Stem number per hectare is also given (N). We used two indicators to describe dead wood conditions in the reserves: the density of thicker snags (mean, standard deviation and min/max number of snags thicker than 25 cm per hectare) and the amount of lying dead wood (mean, standard deviation, and min/max estimated volume of lying dead trees per hectare). The data of Table III show some tendencies regarding stand structure. Significant decrease can be seen in stem number (*N*) along the "abandonment gradient" from recently managed to old-growth or primary status for all three forest types, especially for beech stands. In parallel with this, the distribution of DBH classes is apparently shifted towards thicker trees. We found that trees with a DBH > 40 cm gave 10–25% contribution in the old-growth and primary stands. On the contrary, these values varied between 2% and 3% in the recently managed stands. The largest beech achieved a breast diameter of 166 cm (Kőszegi-forrás reserve), while the breast diameter of the largest sessile oak exceeded 100 cm (Vár-hegy reserve). The distribution of crown classes indicates a varied and well-differentiated canopy structure. The higher ratio of suppressed categories in old-growth or primary forests indicates increasing proportion of multilayer stands. The distribution of gap classes shows the clear tendency of gap structure becoming more varied following abandonment: old-growth or primary stands have the largest and most diverse gap structure (G1, G23 and GX) in all three forest types. As regards snag density and the amount of lying dead wood, local standard deviation is very high, but the tendency is similar: the average amount of thick snags and lying dead wood becomes ever larger towards the category of old-growth or primary stands.

Discussion

In Central Europe, most virgin and natural forests are found in the alpine and continental biogeographical regions (Parviainen 2005; Barton 2010; Marchetti & Blasi 2010). The majority of these forests are beech, mixed fir-beech or fir-spruce-beech up to the timberline in remote and mountainous areas. The Pannonian ecoregion, however, is characterized by lowland swamp and floodplain forests, steppe woodlands, oak-dominated thermophilous and mesophytic forests, and submontane forests. Very few of these forests are virgin, successional or old-growth (8 of 72), since most of them had been managed before designation, then left for free development. It has been shown that the abandonment of forest activities could be an effective strategy to reach natural status and to restore the natural processes and structures of forest stands (Meyer & Schmidt 2011), although the recovery of managed forests is a slow process (Vandekerkhove et al. 2009). Some important indicators of old-growth characteristics can develop within several decades after the abandonement of management (Meyer 1999, 2005). These are the broad diameter distribution of the trees, the presence of large living trees, tree and canopy differentiation, the fine scale spatio-temporal occurrence of canopy gaps, and the accumulation of dead wood. Other attributes, like the biological senescence of old trees, the dominance of strongly decayed large snags and logs, the inverted J-shaped

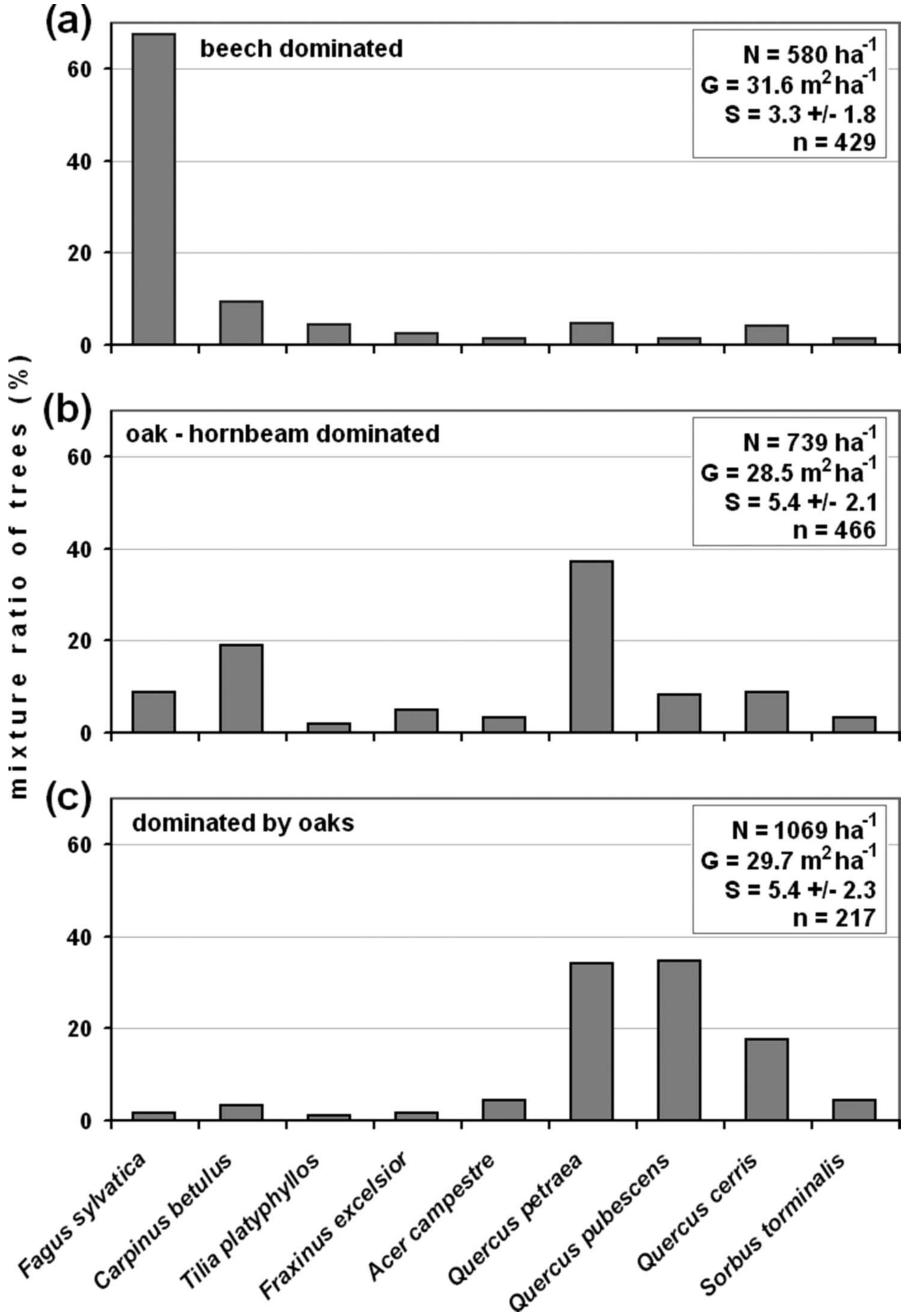

Figure 2. Compositional key features surveyed in beech-dominated stands (a), mesophytic deciduous forest stands (b), and oak-dominated thermophilous deciduous forest stands (c) of strict forest reserves. The mixture ratio of main trees can be seen on diagrams, while all the other trees and shrubs (DBH $\geq$ 5 cm) are listed as follows: *Acer platanoides* L. (a, b, c), *Acer pseudo-platanus* L. (a, b, c), *Betula pendula* Roth (a, b), *Castanea sativa* Mill. (introduced: a, b), *Cerasus avium* (L.) Mönch (a, b, c), *Cornus mas* L. (a, b, c), *Cornus sanguinea* L. (a, b, c), *Corylus avellana* L. (a, b, c), *Cotinus coggygria* Scop. (b, c), *Crataegus monogyna* Jacq. (a, b, c), *Crataegus oxyacantha* L. (b, c), *Euonymus europaea* L. (b), *Fraxinus ornus* L. (a, b, c), *Juniperus communis* L. (remnant of former grazing: a, b, c), *Larix decidua* Mill. (introduced: a, b), *Malus sylvestris* (L.) Mill. (b, c), *Picea abies* (L.) Karsten (introduced: a, b), *Pinus nigra* Arnold (introduced: b, c), *Pinus sylvestris* L. (a, b), *Populus tremula* L. (a, b), *Prunus spinosa* L. (b), *Pyrus pyraster* Burgsd. (a, b, c), *Quercus robur* L. (a, b, c), *Quercus rubra* L. (introduced: a, b), *Sambucus nigra* L. (a, b), *Sorbus aria* (L.) Cr. (a, b, c), *Sorbus aucuparia* L. (a), *Sorbus domestica* L. (c), *Staphylea pinnata* L. (a, b), *Tilia cordata* Mill. (a, b, c), *Tilia tomentosa* Mönch (a), *Ulmus glabra* Huds. (a, b, c), *Ulmus minor* Mill. (a), *Viburnum lantana* L. (b). *N*, number of stems per hectare; *G*, sum of the basal area per hectare; *S*, number of the woody species per SPs (mean $\pm$ standard deviation); *n*, number of cases (SPs).

distribution of DBH and the small-scale mosaic of various developmental phases (Leibundgut 1993; Korpeľ 1995) require much more time to develop (Vandekerkhove et al. 2005; Heiri et al. 2009; Marchetti et al. 2010; Meyer & Schmidt 2011). Vandekerhove et al. (2009) and Meyer and Schmidt (2011) put special emphasis on comparing the accumulation and quantity of dead wood. The quantity of total lying dead wood was found to be very small in managed forests. For example, it was less than 10 $m^3 \cdot ha^{-1}$ in boreal forests (Siitonen 2001), and varied between 3 and 30 $m^3 \cdot ha^{-1}$ in the European beech zone (Christensen et al. 2005). On the contrary, lying and standing dead wood was found to comprise 10–37% of total above-ground wood stock in virgin or old-growth forest stands. For example, 90–120 $m^3 \cdot ha^{-1}$ was measured in the central and southern parts of the boreal region (Siitonen 2001), 100–150 $m^3 \cdot ha^{-1}$ in European beech forests (Saniga & Schütz 2002; Christensen et al. 2005) and 67 $m^3 \cdot ha^{-1}$ in a mixed beech and silver fir forest with low intensity of silviculture (Motta et al. 2010). Further, Rahman et al. (2008) reported 44–95 $m^3 \cdot ha^{-1}$ of lying dead wood in various oak-hornbeam forest types in the Lange-Leitn Natural Forest Reserve (Austria), and $\sim$50 $m^3 \cdot ha^{-1}$ in the oak-dominated Boky forest reserve in Slovakia (Saniga & Schütz 2002). Our results corroborate these findings well, since we measured a mean of 53 $m^3 \cdot ha^{-1}$ (beech), 83 $m^3 \cdot ha^{-1}$ (mesophytic) and 58 $m^3 \cdot ha^{-1}$ (oak dominated) of total lying dead wood for primary or old-growth forests, and a mean of 26 $m^3 \cdot ha^{-1}$ (beech), 20 $m^3 \cdot ha^{-1}$ (mesophytic) and 16 $m^3 \cdot ha^{-1}$ (oak dominated) of total lying dead wood for recently managed stands (Table III). Intermediate values were found for lately abandoned stands. Another important indicator of forest naturalness is the density of snags, which was found to be 19 ha^{-1} of DBH $\geq$ 25 cm in mature spruce forests of the sub-alpine vegetation zone (Bütler & Schlaepfer 2004), and 12–13 ha^{-1} of DBH $\geq$ 30 cm in the Białowieża deciduous stands (Czeszczewik 2009). The values of DBH $\geq$ 30 cm varied between 1 and 13 ha^{-1} in five beech-dominated forest reserves in Switzerland (Heiri et al. 2009), and a mean of 19 snags ha^{-1} was estimated in primary beech forest remnants in the Apennines (Piovesan et al. 2005). We have found similar values (8–19 snags ha^{-1} of DBH > 25 cm) for all forest types in the primary, old-growth or lately abandoned reserves. Note, however, that Piovesan et al. (2005) reported mostly higher snag densities (14–115 snags ha^{-1}) of various *Fagus* stands in the world.

The increasing quantity of dead wood correlates well with the increasing amount of gaps in the canopy. We have found a low frequency of gaps in the recently managed stands (14% of G1 class). Values in the old-growth or primary stands were much higher and proved to be 66%, 89% and 100% in beech, mesophytic and oak-dominated stands, respectively (Table III). Our findings on the gap frequency of old-growth stands coincide with the results of a recent study, which showed that gaps comprised 2.5–7.7% of the total area in a beech-dominated old-growth reserve (Kenderes et al. 2008). If the area of a single gap (G1) is taken as $\sim$80 m^2, and that of G2 and GX are taken as $\sim$150 and 300 m^2, respectively, then the total share of gaps can be estimated at roughly 5%. Similarly, Meyer (2005) reported an average gap size of $\sim$100 m^2 in beech-dominated forest reserves in Lower Saxony, and a ratio of 3–8% 30 years after a heavy storm in 1972.

Another possibility for the quantification of the vertical differentiation of forest structure is the comparison of the relative crown class distribution of trees. In the recently managed stands, the co-dominant crowns reach a high frequency. We measured 58%, 42% and 41% frequency values in beech, mesophytic and oak-dominated forests, respectively. These figures are considerably smaller in the old-growth or primary stands with more complex canopy structure, where the corresponding figures proved to be 44%, 22% and 24%, respectively (Table III). In conjunction with this, the proportion of the suppressed trees was found to be much higher in the old-growth or primary stands, than in recently managed stands indicating a more natural, multi-layered canopy (i.e., Korpeľ 1995; Bartha et al. 2006; Burrascano 2008). The structure of DBH distribution was not evaluated in detail in this work (but see Piovesan et al. 2005; Heiri et al. 2009). However, it is worth mentioning that higher proportion of large trees occurred in the old-growth or primary stands.

There are 18 native tree species, which occur in all of the three forest types and further 8 natives at least in one. It represents a moderately high tree diversity in this region compared with European examples (Svenning & Skov 2007).

In conclusion, our results indicate that the most natural stands examined in this study show a stand structure similar to that of other European deciduous natural forests (Saniga & Schütz 2002; Christensen et al. 2005; Gilg 2005; Heiri et al. 2009; Blasi et al. 2010; Müller & Bütler 2010; Meyer & Schmidt 2011). The abandoned or recently managed stands of the Hungarian forest reserves are in a transitional state towards becoming natural ones.

At the same time, these woodlands are subject to strong secondary impacts. Grazing and browsing pressure by game is far too high throughout the region (Milner et al. 2006; Molnár et al. 2008; Kenderes et al. 2008; Hédl et al. 2010), which considerably modifies or even blocks natural regeneration (Mayer & Tichy 1979; Ammer et al.

Table III. Structural key features surveyed in the beech-dominated stands (a), mesophytic deciduous forest stands (b), and oak-dominated thermophilous deciduous forest stands (c) of strict forest reserves.

	Distribution of GAP classes of SPs (%)				Distribution of relative CROWN classes (relative number of tree, %)				Distribution of DBH classes (relative number of tree, %)				N	Snag density (number of trees/hectare)	Volume of lying dead wood ($m^3 \cdot ha^{-1}$)
Abandonment status	NO	G1	G23	GX	Do	Cd	In	Su	5–20 cm	20–40 cm	40–60 cm	>60 cm	(tree/hectare)	DBH > 25 cm	D ≥ 5 cm
Beech forest stands (number of cases: 174 + 166 + 89 = 429)															
Old-growth or primary	34	26	25	14	1	44	11	44	50	24	16	9	353	8 ± 13.4 (0–75)	53 ± 78.2 (0–508)
Lately abandoned[a]	49	25	12	14	3	41	17	38	56	34	9	2	614	14 ± 35.2 (0–280)	30 ± 43.0 (0–322)
Recently managed[b]	86	14	0	0	2	58	16	23	64	34	2	0	963	4 ± 12.3 (0–64)	26 ± 57.4 (0–416)
Mesophytic deciduous forest stands (number of cases: 105 + 323 + 38 = 466)															
Old-growth or primary[c]	11	58	27	5	6	22	11	61	69	20	9	1	722	12 ± 17.6 (0–100)	83 ± 85.3 (0–433)
Lately abandoned[d]	29	32	33	6	1	36	12	50	61	32	6	1	712	13 ± 28.7 (0–280)	24 ± 34.8 (0–274)
Recently managed[e]	83	14	0	0	2	42	12	44	69	29	2	0	1018	7 ± 14.9 (0–64)	20 ± 18.3 (3–75)
Thermophilous deciduous forest stands (number of cases: 26 + 178 + 13 = 217)															
Old-growth or primary	0	27	69	4	0	24	4	72	71	19	9	1	841	19 ± 17.7 (0–55)	58 ± 54.4 (5–224)
Lately abandoned[f]	11	38	45	6	1	41	11	47	69	29	2	0	1100	9 ± 19.5 (0–144)	19 ± 27.5 (0–199)
Recently managed	NA	NA	NA	NA	2	41	13	45	71	25	3	0	1117	5 ± 13.8 (0–45)	16 ± 18.7 (0–70)

[a]Number of cases of GAP classes was 111, due to 55 missing data. [b]Number of cases of GAP classes was 50, due to 39 missing data. [c]Number of cases of GAP classes was 83, due to 22 missing data. [d]Number of cases of GAP classes was 208, due to 115 missing data. [e]Number of cases of GAP classes was 6, due to 32 missing data. [f]Number of cases of GAP classes was 95, due to 83 missing data. NO, closed canopy (no gap); G1, a gap the size of one dominant crown; G23, a gap the size of two or three dominant crowns; GX, larger gap or collapse; Do, dominant tree; Cd, co-dominant tree; In, intermediate tree; Su, suppressed, overtopped tree.

2010). Climate change is also an increasing threat for zonal forest types (Mátyás 2010; Czúcz et al. 2011). Due to all the above facts and factors, forest reserves and forest reserve research face new challenges in the Pannonian biogeographical region.

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