Strict Forest Reserve Research in the Margin of the Carpathians, the Vár-hegy Case-Study

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Abstract Sixteen forest reserves are situated in the northern part of Hungary which belongs to the Carpathian region according to EURAC delimitation (Ruffini et al. 2006). These Hungarian forest reserves expand the natural forest remnant/forest reserve net of the Carpathians towards the lower hilly region, representing the deciduous beech and oak forest belts near their lower (xeric) distribution limits. This paper outlines the Hungarian forest reserves belonging to the Carpathian region and the preliminary results of current projects in the Vár-hegy Forest Reserve (Bükk Mts., Hungary) as a case study. The alteration of tree species composition was investigated here based on the reconstruction of forest history in the previous 130 years (management period) and analyses of forest stand inventory. In another project CO_2 sequestration changes of these forest stands were modeled since the clear-cutting in the 1880th and carbon stored in the forest ecosystem compartments was estimated. Our results show that the forest reserve stands are presently in a transition state from the managed forest towards a more natural mixed forest with several age-classes.

1 Introduction

Virgin and old-growth forest remnants play an outstand role in conserving the natural resources and the high level of biodiversity of the Carpathian region. Their first descriptions were published as early as in the nineteenth century (Fuchs 1861;

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Krauze 1898; Muzsnay 1899; Pulvermacher 1877). Conservation and research of old-growth forests have a long tradition in Central and Eastern European countries (Borlea 1999; Hort et al. 1999; Korpel 1995; Oszlanyi et al. 2004; Pruša 1985). As intensive forest management gained ground in the late twentieth century, the area of natural forests declined together with forest biodiversity. Consequently, natural forest remnants were shifted in the limelight once again and a European cooperation was initiated and set up in Europe, the COST Action E4: ‘Forest Reserves Research Network’ in 1995. The aims of the action were to promote co-ordination among countries and to focus research on ‘natural’ forests. The primary objectives were to create a European network of forest reserves, to collect ongoing research, to standardize research methodology and to create an accessible central data bank. The importance of the results from ‘natural’ forest research was highlighted for the application of ecologically oriented silviculture, for improved forest management and for the future planning of the forest protection network (Parviainen et al. 2000).

In Europe there are about 0.3 million ha of virgin forests (0.4 % of the total forest area) left in about 2500 strict forest reserves and other categories of protection in the temperate zone, mainly in the Balkan, Alpine and Carpathian geographic regions (Parviainen 2005). In the Carpathian region there are 217 virgin forest remnants or forest reserves situated in six countries: Czech Republic, Poland, Slovak Republic, Ukraine, Romania and Hungary (Barton 2010).

The designation of Hungarian Forest Reserve Network was launched in 1993. The aims of the Forest Reserve Program supervised by the State Secretary for Nature and Environment Protection are basically twofold: (a) to ensure the conservation of semi-natural forest stands, and (b) to get new sound knowledge, as natural development reference about the biodiversity, stand structure and ecological processes of our forest ecosystems (Horváth and Borhidi 2002). The total number of designated reserves in Hungary is presently 63. The northern part of Hungary belongs to the Carpathian region according to EURAC delimitation (Ruffini et al. 2006), see Fig. 1. Sixteen forest reserves are situated in the northern part of the country, see Table 1.

These reserves are the largest ones and represent the most characteristic (semi-natural) forest types of North Hungary. Forest reserve research has also been focused here, among others (Czájlik et al. 2003a, b, c; Kenderes et al. 2008; Ódor et al. 2006; Standovár et al. 2006). Here the main forest types are oak, oak–hornbeam or beech dominated mixed forests while in the upper belt of the Carpathians the majority of natural forest remnants are mixed fir-beech, or fir-spruce-beech stands. The Hungarian forest reserves expand the forest reserve net of the Carpathians towards the lower hilly region of the inner Carpathian Basin, both at the geographic and the vegetation level (Fig. 1.).

Ecologists agree that forests in the temperate zone will shift and alter due to the climate change. However the retreating low altitude/low latitude (xeric) limits of forests have been left largely unexplored until very recently (Mátyás 2010). Recent study indicates that climate change in Hungary may lead to drastic reduction in macroclimatically suitable sites for both beech and sessile oak forests in the next

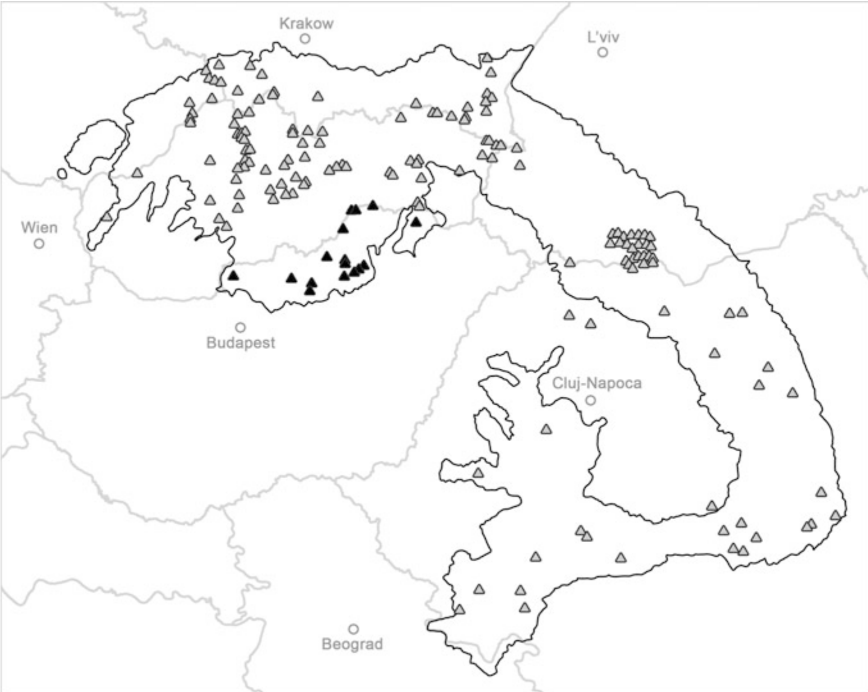

Fig. 1 Forest reserves or virgin forest remnants in the Carpathian region according to Barton (2010). *Black triangles* show the Hungarian ones. Delineation of the Carpathian region is based on Ruffini et al. (2006)

decades (Czúcz et al. 2011), however the actual pattern of forest cover strongly depends on the relief also. The border area of the deciduous forest and forest-steppe vegetation zone pass through Hungary (Borhidi 1961; Zólyomi 1967) see Fig. 2. Several forests reserves that are located in the southern part of Bükk Mts. (North Hungary) are close to the trailing edge of forest—forest steppe biome transition zone, hence suspected to strongly impact by climate change.

The total extent of the strictly protected core areas of the Hungarian forest reserves is cca. 3600 ha, each are surrounded by protected buffer zones (cca. 13.000 ha all together), comprising 0.8 % of the wooded land in Hungary. Most of the designated reserves have mature stands and they have been unmanaged since several decades (Mázsa et al. 2008). In the "Carpathian" part of the country 67 % of the area of strict forest reserves has developed spontaneously for at least 50 years or more (Fig. 3.). Although most Hungarian strict forest reserves were used and altered by human activities one exception is Kékes Forest Reserve. A recent forest historical study has proved that this site is a virgin forest remnant which had avoided exploitation, conversion and clearance as a manorial forest and hunting estate (Czájlik and Pászty 2009).

Table 1 Strictly protected forest reserves belonging to the Carpathian region in Hungary and their survey status

Name, location	Core area (ha)	Main forest type	Surveyed
Pogány-Rózsás, Börzsöny Mts.	91	Beech	
Csörgő-völgy, Mátra Mts.	51	Beech	
Kékes, Mátra Mts.	55	Beech	2005–2008
Hór-völgy, Bükk Mts.	61	Oak-hornbeam	
Kecskés-Galya, Bükk Mts.	87	Mixed sessile oak-turkey oak; downy oak	2010–2011
Vár-hegy, Bükk Mts.	94	Mixed sessile oak-turkey oak; downy oak; oak-hornbeam	2005–2008
Őserdő, Bükk Mts.	59	Beech	2008–2010
Leány-völgy, Bükk Mts.	57	Beech	
Paphárs-Kecskevár, Bükk Mts.	58	Mixed sessile oak-turkey oak; downy oak; oak-hornbeam	
Csókás-völgy, Bükk Mts.	144	Mixed sessile oak-turkey oak; downy oak;	
Nagy-sertéshegy, Eperjes-Tokaj Mts.	66	Beech	
Pataj, Heves hills	66	Beech	
Alsó-hegy, Aggtelek carst	113	Oak-hornbeam	
Haragistya-Lófej, Aggtelek carst	260	Beech, oak-hornbeam	2006–2010
Nagy-oldal, Aggtelek carst	234	Mixed sessile oak-turkey oak; downy oak; oak-hornbeam	
Kelemér-Serényfalu, Borsod hills	81	Oak-hornbeam	

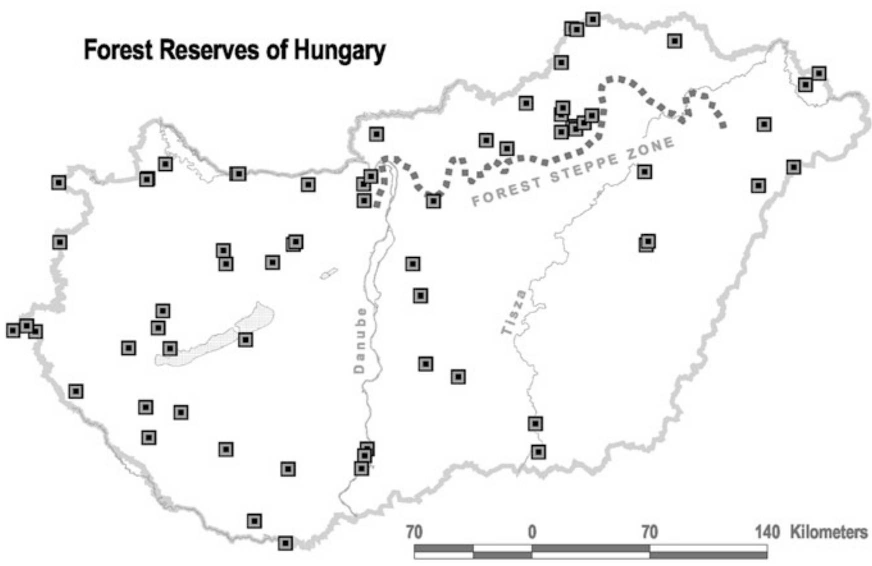

Fig. 2 Overview map of the Hungarian forest reserve network. *Dashed line* shows the border of the forest steppe zone

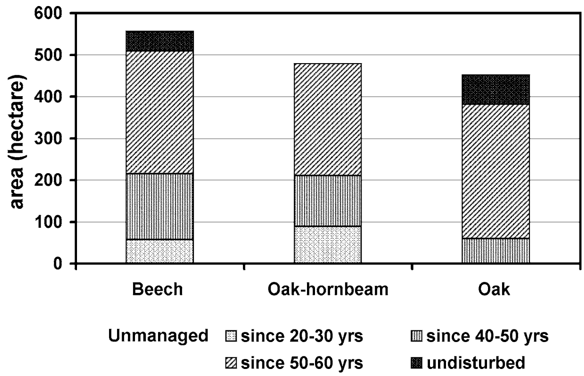

Fig. 3 Present management status of 16 strict forest reserves by main forest types belonging to the Carpathian Region based on a nationwide survey in 1998. Oak = several types of mixed oak forest from mesic to dry, dominated by *Quercus petraea*, *Q. cerris* or *Q. pubescens*

The research team of the Centre for Ecological Research of the HAS coordinates the survey of the Hungarian forest reserves, and carries out more detailed research in the Vár-hegy Forest Reserve (Bükk Mts., Hungary). This paper shows the preliminary results of current projects in the Vár-hegy Forest Reserve as a case study. The following projects are run in the Vár-hegy Forest Reserve:

- reconstruction of forest history in the previous 130 years (management period) based on land-use history documents and analyses of forest stand structure;
- study of fine scale stand dynamic processes: alteration of canopy species composition after a large scale oak decline in the 1970/1980s;
- modeling the CO_2 sequestration changes/development of these forest stands since natural regeneration after clear-cutting in the 1880th and estimation of carbon stored in the forest ecosystem compartments.

2 Materials and Methods

2.1 *Case Study Site: The Vár-hegy Forest Reserve*

The Vár-hegy Forest Reserve is located in the south-western part of the Bükk Mts., approximately 10 km far from the town of Eger. Its geographical coordinates are: lat./long 47°54′N; 19°57′E. The 94 ha strictly protected core area comprises the upper one-third of the hill at elevations from 326 to 669 m a.s.l. The relief and the microclimate are highly diverse. The soil type composition of the area is varied, variations of rendzina and brown earths being the most characteristic (Bidló et al. 2004). The following Natura 2000 habitat types are the most important in the core area:

- 91H0 Pannonian woods with *Quercus pubescens* on the steep southern-south-eastern ridges with shallow soil,
- 91M0 Pannonian-Balkanic turkey oak—sessile oak forests on southern slopes,

- 91G0 Pannonic woods with *Quercus petraea* and *Carpinus betulus* on hilltops and fresh sites,
- 9130 *Asperulo-Fagetum* beech forests—at higher elevations with north-eastern exposition.

3 Methods of Reconstructing Forest History, Forest Inventory and Assessing Tree Age Classes

We collected forest use and forest management history documents of Vár-hegy area from the Heves county Archive and from the management plan archive of Heves county Forestry Board. Management plans and land-register maps dating from 1887, 1896, 1907, 1953, 1963, 1976, 1986, 1995 and 2006 were collected and other descriptions from the late nineteenth century (Gesztes 1887; Borovszky 1896–1914; Anonymus 1953–2005). Data from historical forest management plans and maps referring to the upper third of the Vár-hegy hill—the present area of the forest reserve—were considered in this study. Based on the documents we separated four historical period of regeneration of existing trees and regarded it as assessed four different age classes.

In the strict forest reserve area a fine scale stand survey was performed. The inventory concept was based on the COST E4 guidelines (Hochbichler et al. 2000) and earlier Hungarian experiences (Czájlik 2002). The methodology, infrastructure and service together are called "FOREST+n+e+t"—*monitoring network of forest stand dynamics and ecology* (Horváth et al. 2009). FOREST+n+e+t is a 50 × 50 m grid system of permanently marked field sampling points, where we perform forest stand structure, vegetation and soil inventory modules. We surveyed Vár-hegy Forest Reserve between 2005 and 2008 in cca. 400 sampling points. The stand survey methodology in the grid points combines fixed-area circular plot (R = 8.92 m), and horizontal point sampling according to (Bitterlich 1952) for standing trees, and line transect sub sampling methods for lying dead wood. For the surveyed trees (DBH > 5 cm) the following information was provided: position, species, DBH, height of selected trees, social status and health categories, decomposition stadium. This method samples the forest stand by a fine scale (50 × 50 m), while the traditional forestry inventory provides average data for management units which area size varies from 2 to 15 ha.

In this grid system about 8400 individual trees were sampled. Each single tree was ranked into cohorts according to their diameters at breast height (DBH) and social status categories. We regarded the different cohorts by size and history as assessed different age classes. We calculated the number of trees per hectare according to both tree species and assessed age groups by averaging the sampling points for the patch area.

4 Modeling of CO_2 Sequestration and Estimation of Carbon Stored in Different Pools

Based on the results of detailed site and stand survey, and historical forest management maps, we classified and subdivided the core area of the reserve into 28 different patches. Each of them could be considered homogenous according to the recent stand structure and forest use history. We have adapted a cohort-based carbon sequestration model, called CO2FIX 3.1 (Schelhaas et al. 2004) to reconstruct the development of each stands. We have developed, compared and evaluated several scenarios to simulate the carbon sequestration of the patches in the past 125 years, from 1880 (clearcutting and natural regeneration) to 2005 (stand survey) (Balázs et al. 2008). In this paper we calculated and used tree proportion of stands by assessed age categories (same as above) to evaluate forest changes, stand volume and tree species proportion by living and dead wood for the CO_2 sequestration model.

5 Selected Results

5.1 Stand Structure Changes in the Past 130 Years from the Beginning of the Planned Management of the Forest Reserve

5.1.1 Forest History

According to a title deed dating from 1261 the area had been an estate of the Episcopate in Eger from the thirteenth century until World War II. Later it was nationalized, and gained increasing nature conservation importance. The first management plan of the forest dates from 1887. Before that time, irregular cuttings were made to fulfill the needs of the manorial estate in terms of charcoal burning, lime burning, fire wood, and timber for the extensive agricultural estates. Most of the present reserve area was cut around 1880 (Gesztes 1887), however, some old seed dispersing trees have remained from the ancient forest stand. Although some of these old specimens were cut around the 1920s, those that were hard to approach survived. These old sessile and Turkey oak trees are mostly hollow, broken in the trunk or lying deadwood. The dominant 120–130 years old stand of the present core area of the forest reserve was regenerated around 1875–1885, comprising coppice oak to a greater and beech to a lesser extent (Borovszky 1896; Gesztes 1887). The aim of forest management according to the management plan was to ensure the dominance of sessile oak and to supplant Turkey oak and beech through tending cutting. Today, sessile oak trees, especially those of coppice origin, are declining forming the majority of deadwood in the reserve. The first management plan of the nationalized forest concerns the period between 1953 and 1963. During World War II uncontrolled wood trade and illegal cuttings must have prevailed, as urgent replacement plantings were ordered in the management plan. The present middle-aged, 55–70 year-old cohort of trees is evidence for the natural regenerative capacity of the late forest, as it originates from the replacement plantings and regeneration plantings of the 1950s and also from natural regeneration following illegal cuttings during the war period. The last management action in the forest reserve ordered by the management plan took place in the late 1960s. Clearcuttings were postponed according to the management plan in the 1960–1970s, being afraid of browsing damage of the over-populated game. As a result, the coppice oak stand of the reserve survived and matured. Later the most significant changes were the formation of the Bükk National Park Directorate in the 1980s and the designation of the area as a forest reserve in 1993. Beside the problems caused by the high amount of game, the disease causing oak decline throughout Europe appeared in the Vár-hegy stand as well in the 1970–1980s (Szepesi 1997). Consequently, sanitary cutting was performed in some stands in the 1980s. Since then, the forest has been left for free development.

5.1.2 Assessed Age Classes of Canopy Forming Trees

On the base of forest history and stand survey four regeneration period and assessed age classes were recognised for the main tree species—*Quercus petraea, Q. cerris, Q. pubescens, Carpinus betulus, Fagus sylvatica, Fraxinus excelsior* and *Acer campestre*. These are: more than 160 years old cohorts (AGE > 160): the existing remnants of old seed dispersing trees prior to the management system, AGE-130: the dominant 130 years old cohorts—mainly sessile oaks most of them with coppice originated around the first management plan (1880), AGE-60: the middle-aged cohorts originated from natural succession and replacement planting after the irregular cuttings around the World War II., and AGE-30: the young cohorts filling the gaps and openings after the oak decline of the 1970–1980s.

We found that the dominant canopy forming cohorts (AGE-130) and the age group of old seed dispersing trees (AGE > 160) are composed mainly of sessile oak, downy oak and Turkey oak. Old oak stands are apparently opening up and producing gaps (Mázsa et al. 2009). The ratio of oak species is less in the cohort originated in the World War II (AGE-60). This age class has a balanced mixture ratio of oak, hornbeam and other mixing species comprising about the same proportion, coupled by the appearance of field maple. The species composition shifting dominance towards hornbeam, common ash and field maple, especially in the young age group (AGE-30). The tree species composition of the four age classes shows a remarkable decrease in all oak species, but first of all in *Quercus petraea* in the middle-aged and young age classes, see Fig. 4. Parallel with the increasing role of natural succession (around World War II, and after the oak decline from the 1980s), the proportion of *Fraxinus excelsior*, *Acer campestre*, *Carpinus betulus* and other associate species has increased.

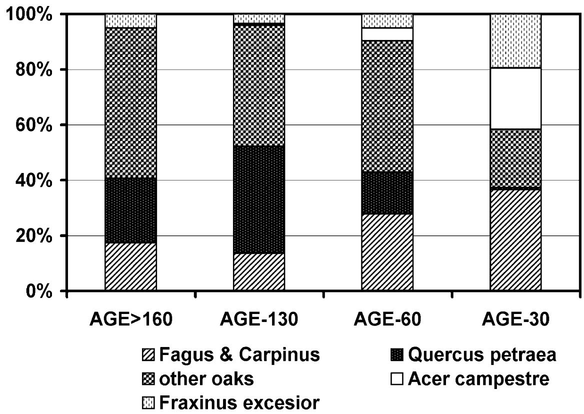

Fig. 4 Proportion of main tree species by age classes based on the average density for *Fagus sylvatica*, *Carpinus betulus*, *Quercus petraea*, other oaks as *Q. pubescens*, *Q. cerris*, *Acer campestre* and *Fraxinus excelsior* (Mazsa et al. 2009)

This change is conspicuous for *Quercus petraea*. Although the stand has been left for free development for about 30–50 years, the ratio of sessile oak is small in the regeneration layer and even smaller in the shrub layer. Gaps opening after the dieback of oak trees are colonized spontaneously mostly by common ash, field maple and hornbeam saplings. Similar shift in tree composition was found in the long-term study of Turkey oak—sessile oak woodlands in the frameworks of the closely located Síkfőkút Project (Kotroczó et al. 2007).

6 Carbon Sequestration of Vár-hegy Forest Reserve

According to our simulations, the overall amount of carbon accumulated in all living biomass (including living roots), total dead biomass (lying and standing dead trees, fine woody debris, litter and dead roots), carbon increments of soil (the starting carbon pool of soil was not considered), thinned wood products of the core area of Vár-hegy Forest Reserve is 18600 ± 720 tons per 94 ha at the end of the model simulation. The mean value is 200 ± 10 tons per hectare which is comparable to a countrywide average of managed forest in Hungary. Figure 5 shows the calculated carbon sequestration during the simulated 125 years (from 1880 to 2005). After clear cutting, the seed dispersing cohort provide a low initial stock, then carbon accumulation is increasing continuously. From the 1970s, a drop can be observed which turns again into an intensive increasing period from the 1990s. This is caused by the oak decline and after that the increment of the younger generations (AGE-60 and AGE-30). The enclosed pie chart presents the proportional distribution of living (L), dead (D) biomass, soil carbon increment (S) and carbon content of removed wood product (W) compartments of the system in 2005.

In case of partitioning these results by age groups of living biomass, we can find that the remnant trees (AGE > 160) store 6 %, dominant old trees (AGE-130)

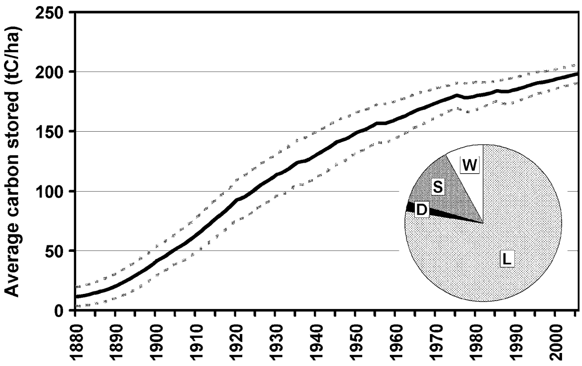

Fig. 5 Overall carbon sequestration of the Vár-hegy core area in the simulated period (1880–2005). *Thick black line* is the average of the results of different scenarios; *broken line* is the standard deviation. The pie chart inserted shows the proportion of carbon accumulated in different pools: living biomass (L), dead biomass (D), increments in the soil (S) and harvested wood products (W) summarized at the end of the simulated period

store 76 %, middle-aged trees (AGE-60) store 13 % and young trees (AGE-30) store 4 % of the total sequestered carbon. The amount of carbon stored of not-dominant cohorts is remarkable (23 % of total), which imply also to transition stage of the forest to a near-natural one.

7 Conclusion

The importance of forest reserve research, as was highlighted Europe-wide by the COST Action E4, lies in the hypothesis that by understanding the processes that take place in natural forests we get closer to the establishment and later switching to nature-oriented silviculture (Parviainen et al. 2000). This idea was later questioned by Brang (2005). He stated that research on virgin forests has had important implications on managed forests only in topics which objects could be studied only in virgin forests, such as nurse logs as a seedbed for tree seedlings or the maximum age and size of the trees. In several other cases like competitive interactions between tree species or forest dynamics after abandonment, managed forest, or a combination of managed and virgin forest should be studied (Brang 2005).

Our researches point out that study of recently established forest reserves which were designated only 20 years ago may answer questions beyond current forest management issues. Our results show that forest reserve can serve as reference area for the natural succession of abandoned woodlands under changing climate and forest management or reference area of carbon cycle in semi-natural forests. We believe that the natural forest remnants and forest reserves of various types and history form an outstanding network in the Carpathian region, the study of which could contribute to answering questions in the field of nature conservation, ecosystem functioning, climate change and restoration ecology.

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