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ESTIMATION OF PHYTOMASS, PRODUCTION, AND CARBON SEQUESTRATION IN WARM CONTINENTAL OAK FORESTS AND MONTANE BEECH FORESTS OF MACEDONIA

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Abstract — Phytomass and production of a Quercetum frainetto-cerris macedonicum xerothermic oak ecosystem in Galichica National Park and a Calamintho grandiflorae–Fagetum montane beech ecosystem in Mavrovo National Park were investigated at research stations in the field. Detailed data on phytomass and production were obtained for aboveground and belowground parts; for tree, shrub, and herb layers; and for perennial and annual organs. The areas of warm continental and montane belts and the percentage of forested area were used to assess the area of these two types of forests in Macedonia.

An estimation of phytomass, production, and carbon sequestration was performed for the total territory of Macedonia. These data were adjusted in the light of biomass of the accumulated forest floor and CO_2 assimilation and dissimilation.

Key words: Forest ecosystems, biomass, phytomass, production, carbon sequestration

INTRODUCTION

After an absence of about 30 years from scientific research, forest biomass appears to be regaining its historical significance (Zianis and Mencuccini, 2004). Estimation of tree biomass is needed both for sustainable planning of forest exploitation and for studies on the energy and nutrients flows in ecosystems. It also allows estimation of global climate change impacts on forest ecosystems.

The autotrophic component of ecosystems is a unique producer of organic matter by virtue of its capacity for photosynthesis. Autotrophic organisms perform storage of energy, which provides conditions for survival of heterotrophic organisms. The fluxes of matter and energy in forest ecosystems are thereby determined. The main result of the activity of autotrophs is accummulation of phytomass. Generally, phytomass surpasses the biomass of animals and microorganisms. This is especially true of forest ecosystems with high productivity of wood as the main resource for human needs.

The present paper is based on the results of complex ecosystem research conducted in a Hungarian and Turkey oak forest ecosystem (Quercetum frainetto-cerris macedonicum Oberd. emend. H-t) in Galichica National Park and a montane beech forest (Calamintho grandilorae-Fagetum Em) in Mavrovo National Park. As a result of this work, we were able to estimate phytomass, production, and carbon sequestration in the indicated warm continental oak and montane beech forests of Macedonia.

THE FOREST FUND IN MACEDONIA

The forest fund in Macedonia consists of diverse tree species and different forest phytocoenoses formed as a result of mountainous relief and specific evolution (Filipovski et al., 1996).

Hungarian and Turkey oak ecosystems (Quercetum frainetto-cerris) are distributed in the area with a warm continental climate area. Most of these ecosystems are distributed in Western Macedonia (the Polog, Kichevo, Debar, Belchishta, Izdeglabje, Struga, Ohrid, Prespa, and Pelagonija valleys). In the Povardarie region (along the Vardar River) and eastern parts of Macedonia, there are small areas covered by such forest ecosystems above the continental—sub-Mediterranean oak belt (Carpinetum orientalis macedonicum Rudski and H-t). Hungarian and Turkey oak forests are distributed at altitudes of from 400 to 900 m a.s.l. The Belchishta, Ohrid, Struga, and Prespa valleys have lower parts at 700-850 m a.s.l. and are characterized by high precipitation: 600-900 mm annually (Filipovski et al., 1996). Evapotranspiration in the warm continental belt ranges from 622 to 701 mm and on average is higher than annual precipitation. The summer period is characterized by drought in all of the afore mentioned valleys. All characteristics of the climate are summarized in the climate diagrams of Walter (Fig. 1).

However, valleys near the large lakes are warmer due to the influence of Mediterranean climate. In the valleys at higher altitudes, the Hungarian and Turkey oak ecosystem is the first altitudinal oak belt. Vast areas of oak ecosystems have been transformed from high-stemmed to low-stemmed forests by human activities.

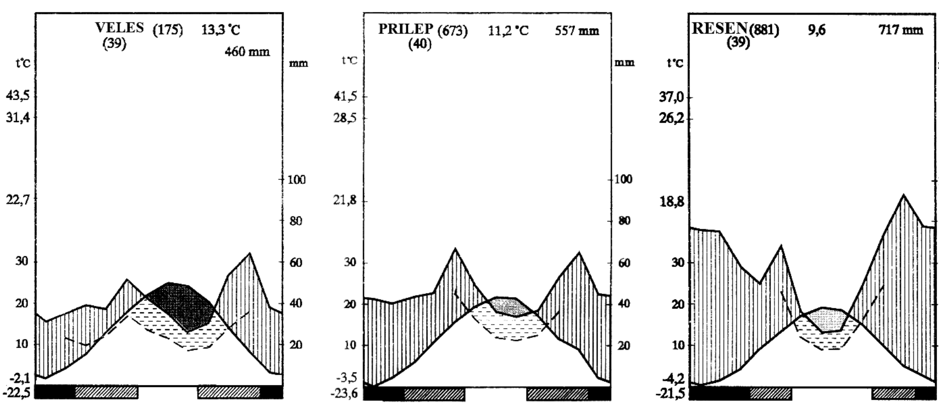

Fig. 1. Climate diagrams of Walter for Veles (a), Prilep (b), and Resen (c) (Filipovski et al., 1996)

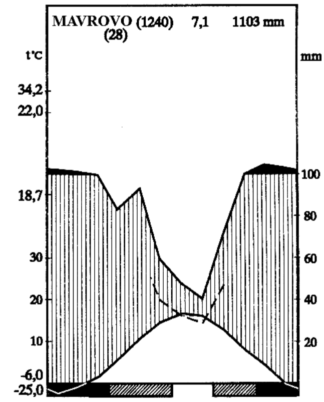

Fig. 2. Climate diagram of Walter for Mavrovo (Filipovski et al., 1996).

Hungarian and Turkey oak ecosystems are widely distributed on the Balkan Peninsula (Southern Romania, Northern Bulgaria, and Serbia). In this area, it is described as Quercetum confertae-cerris moesiacum Rud, 49. All of these forest ecosystems (described as different associations and sub-associations) extend up to the Adriatic, Black Sea, and Aegean Coasts. In Macedonia, they occupy the belt above sub-Mediterranean oak ecosystems (Rizovski, 1983).

Montane beech forests (Calamintho grandiflorae-Fagetum Em) are developed in the montane continental region. They can be found on all of the mountain massifs in Macedonia above the piedmont (sub-montane) beech forests at altitudes of 1300 to 1650 m a.s.l. This region is under the influence of continental and mountainous conditions, resulting in a more humid and colder climate. Montane beech forests are developed in the most favorable hydrothermic conditions in Macedonia. These areas have high precipitation (1044-1103 mm) and reduced evapotranspiration (534-544 mm). The given characteristics are presented on the climate diagram for Mavrovo (Fig. 2).

Table 1. Forest structure in Macedonia (unpublished data of Public Enterprise "Macedonian Forests").

Forest structure	Surface (ha)
High-stemmed forests	**262730**
Even-aged	95883
Uneven-aged	166907
Low-stemmed forests	**642863**
Low-stemmed	557592
scrubs	77567
shrubland	6099
pseudomaquis	1605
TOTAL	905655

Montane beech forests have climazonal distribution. The dominant tree species is European beech (*Fagus sylvatica* L.), which is shade-tolerant and thus prevails over other tree species. However, Macedonian fir (*Abies borisii-regis*), Norway maple (*Acer platanoides*), and Wych elm (*Ulmus glabra*) can also be found in these forests. The soils are mainly neutral or moderately acidic.

Forests in Macedonia cover an area of 947,653 ha and have a wood volume of 74,343,000 m^3 and annual increment of 2.02 $m^3 \cdot ha^{-1}$ (First National Communication to UNFCCC). The approach taken by foresters to estimation of these national resources differs markedly from the ecosystem approach. Forestry records contain only wood increment statistics without any data on phytomass of belowground organs. The lack of data on phytomass and production, annual litter fall, forest floor characteristics, litter decomposition, and mineral cycling was the main incentive for some ecologists to undertake activities designed to apply the ecosystem approach in the study of forest ecosystems. The establishment of research stations for field investigations resulted in more precise information about the phytomass and production of oak and beech ecosystems in Macedonia (Grupche et al., 1983; Grupche and Melovski, 1999; Hristovski, 2007).

According to data of the Public Enterprise "Macedonian Forests", the area of oak and beech ecosystems is almost equal. Oak forests occupy 283,050 ha, beech forests 226,016 ha. However, low-stemmed forests (including Quercetum frainetto-cerris macedonicum) predominate in the forest fund and occupy 557,592 ha (Table 1). High-stemmed forests occupy 262,730 ha. Low-stemmed forests (including shrublands and pseudomaquis) occupy 642,863 ha. Table 1 shows that montane beech forests are dominant in the high-stemmed forests.

The greatest deficiency of these data is the absence of precise areas of separate oak and beech ecosystems. This is an obstacle in the estimation of phytomass, production, and carbon sequestration for oak and beech ecosystems.

On the basis of the known areas of separate climate-vegetation-soil regions in Macedonia (Filipovski et al., 1996), an attempt is made below to estimate the areas covered by the Hungarian and Turkey oak ecosystem and the montane beech ecosystem.

Area of the warm continental region is 704,000 ha. According to the PE "Macedonian Forests", the forest cover is 27.5%, which gives an area of 193,574 ha for the Hungarian and Turkey oak ecosystem (Table 6).

According to the PE "Macedonian Forests", the forest cover in the montane beech region is 36.7%. The total area of montane beech regions is 269,000 ha. Thus, the calculated area of the montane beech ecosystem is 98,723 ha.

PHYTOMASS AND PRODUCTION

Investigations of phytomass and production in Hungarian and Turkey oak ecosystems were initiated within the framework of the Man and Biosphere (MAB) project in 1979. The research station established in Galichica National Park was the first of its kind in Macedonia. It occupies a representative area which enables us to draw relevant conclusions for similar ecosystems at other localities in Macedonia. We accepted the principle of MAB which says that the investigation of undisturbed natural ecosystems can provide knowledge indicating how these complex ecological units should be managed in order to maintain the state of both natural and altered ecosystems.

The research station in the beech ecosystem in Mavrovo National Park was established in 1996 (Grupche and Melovski, 1999). It was organized in a manner similar to that in the oak forests of Galichica National Park.

The Hungarian and Turkey oak ecosystem (Quercetum frainetto–cerris macedonicum Oberd. em. H-t 1959) is characterized by the presence of many Mediterranean elements. The tree layer is dominated by Hungarian oak (*Quercus frainetto*), while Turkey oak (*Quercus cerris*) is represented by 1.3% (Grupče et al., 1995). The density of trees is 1241 ha^{-1}. Age of the ecosystems is 40-50 years. The coverage is 80%, with LAI of 4.92. The shrub layer is poorly developed. It has phytomass of 530 $kg{\cdot}ha^{-1}$ and participates with 0.3% in the total phytomass. Hungarian oak is also dominant in the shrub layer (72.01%). The herb layer has phytomass of 242.91 $kg{\cdot}ha^{-1}$. With respect to phytomass, the dominant species is *Carex bryzoides* (24.16%), followed by *Trifolium medium* and other *Trifolium* species (12%), *Festuca heterophylla* (8.51%), *Lathyrus venetus* (9.07%), and *Pteridium aquilinum* (4.60%).

These two ecosystems are very similar, except for LAI in the oak ecosystem (Table 2), which is almost double that of the beech ecosystem (Table 4). However, the beech ecosystem has a forest floor with twice as much phytomass due to the accumulation of litter at higher altitudes and climatic conditions.

Table 2. Stand parameters in the Hungarian and Turkey oak ecosystem in Galichica National Park.

Density (trees, ha^{-1})	*Q. frainetto*	1241
	Q. cerris	16
Age of the stand (years)	*Q. frainetto*	40-50
Average DBH (cm)	*Q. frainetto*	15,.0
	Q. cerris	19.95
Average height (m)	*Q. frainetto*	14.90
	Q. cerris	18.12
LAI (ha/ha)	tree layer	4.41
	upper third of crown	3.17
	middle third of crown	0.73
	lower third of crown	0.36
	shrub layer	0.38
	herb layer	0.13
	total	4.92
Forest floor biomass (t/ha^{-1})		10.89

Table 3. Stand parameters and aboveground phytomass in the Hungarian and Turkey oak ecosystem (Quercetum frainetto–cerris macedonicum Oberd. em. H-t 1959) in the Veles foothill area.

Density	29840
Age of the stand (years)	
Average DBH (cm)	2.85
Average height (m)	2.29
Aboveground phytomass	43

Table 4. Stand parameters in the beech forest ecosystem in Mavrovo National Park (Hristovski, 2007).,

Density	1200
Age of the stand (years)	26-80
Average DBH (cm)	16
Average height(m)	20-25
LAI (ha/ha^{-1})	8.18
Forest floor biomass (t/ha^{-1})	20.58
Forest floor carbon (t/ha^{-1})	8.79

Table 5. Phytomass and production in oak and beech ecosystems of Macedonia.

Parameters	Beech ecosystem	Oak ecosystem
	Mavrovo	**Galichica**
Biomass (t/ha)	346.7	236.6
Biomass aboveground	297.7	189.6
Total aboveground	297.6	188.8
% branches in trees	29.6	13.2
shrub layer – total	0.084	0.53
herb layer - total	0.009	0.243
Total belowground	57.75	47.02
NPP (t/ha)	19.7	11.09
Net aboveground production (ANPP)	13.75	8.91
Net belowground production (BNPP)	5.91	2.175
R/S	0.19	0.23
BNPP/ANPP	0.43	0.24
NPP:LAI	2.41	2.52

Differences of phytomass and production between these two ecosystems are presented in Table 5. The oak ecosystem in Galichica NP is a low-stemmed forest, while the beech ecosystem in Mavrovo NP is a high-stemmed forest.

The oak ecosystem in Galichica NP and beech ecosystem in Mavrovo NP are different from the oak ecosystem in the Veles foothill area (Table 3). The oak ecosystem around Veles is young, with small DHB and low height. It is a degraded, shrub-like forest that experiences extremely arid conditions during the summer.

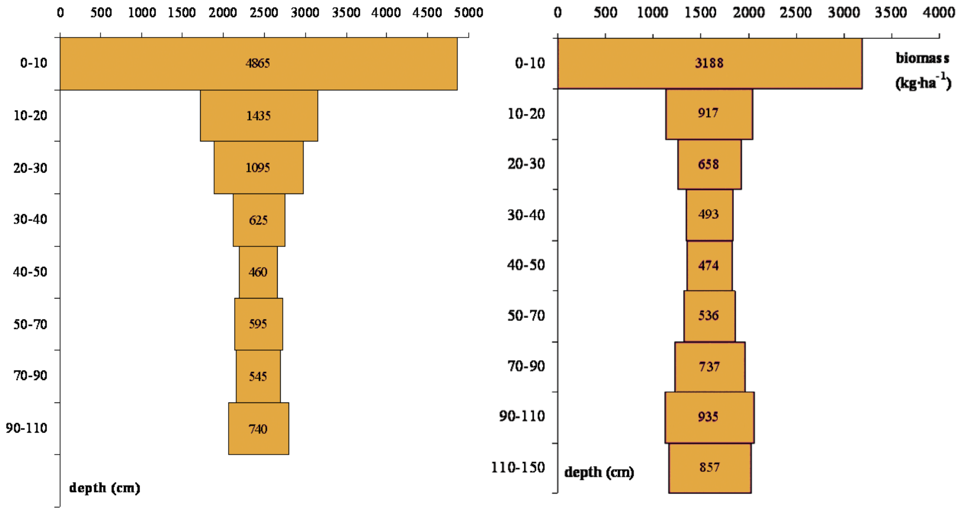

Fig. 3. Fine root (<1 mm) mass distribution by depth in the oak ecosystem in Galichica NP (a) and beech forest in Mavrovo NP (b) (after Grupche et al., 1989, 1995; and Hristovski, 2007).

According to Hristovski (2007), the R/S ratio is higher in the oak ecosystem in Galichica NP (0.23) than in beech ecosystem in Mavrovo NP (0.19). This underlines the xero-thermophyllic nature of the Hungarian and Turkey oak ecosystem, which is further confirmed by the distribution of fine roots (Fig. 3). Ecologically active soil water in the oak ecosystem in Galichica NP during August and September of 1987 and 1988 up to a depth of 1 m was very scarce. Thus, the water supply of tree species must rely on trophic roots reaching greater depths. However, reliance on the water of deeper soil horizons is also evident in the case of the beech ecosystem (Fig. 3b).

Total phytomass in the oak ecosystem in Galichica NP is 237 $t{\cdot}ha^{-1}$. This value is in accordance with the normal phytomass of broad-leaved forests (Whittaker and Woodwell, 1968, 1969; Lossaint and Rapp, 1971; Papp, 1985). Temperate continental oak forests have phytomass of 175 $t{\cdot}ha^{-1}$ (Art and Marks, 1971). Oak forests of the Russian plain with similar age (40-50 years) have very similar phytomass (Mina, 1955). Aboveground organs have phytomass of 189.6 $t{\cdot}ha^{-1}$, while the belowground phytomass is 47.02 $t{\cdot}ha^{-1}$. The quantity of carbon is 118.5 $t{\cdot}ha^{-1}$. Annual production of the oak ecosystem in Galichica NP is 11.09 $t{\cdot}ha^{-1}$. Annual carbon accummulation in the aboveground and belowground phytomass is 5.5 $t{\cdot}ha^{-1}$.

The phytomass of the montane beech forest in Mavrovo NP (355.27 $t{\cdot}ha^{-1}$) is greater than that of the oak ecosystem in Galichica NP. This can be explained by the uneven age of the trees (26-80 years), favorable hydrothermic conditions, and species characteristics (Rozanova, 1960). The belowground phytomass is 57.75 $t{\cdot}ha^{-1}$, and it participates with 16.2% in the total phytomass. Aboveground phytomass is 297.7 $t{\cdot}ha^{-1}$, which consists of 70% wood and the rest of branch biomass (Hristovski, 2007). This ecosystem is similar to the one in the Sredna Stara Planina Mountains in Bulgaria (Marinov et al., 1983).

The presented data represent the first quantified indicators of the extent of phytomass in the Quercetum frainetto-cerris macedonicum oak ecosystem in Galichica NP and the Calamintho grandiflorae-Fagetum montane beech ecosystem in Mavrovo NP. They allow quantification of processes in the given forest ecosystems and their potential production of organic matter, mineral fluxes, and response to increased CO_2 concentrations.

Knowledge of belowground and aboveground phytomass provides a basis for estimation of carbon quantities and possible increase of carbon sequestration due to increased CO_2 concentrations (Chojnacky and Heath, 2002; Ziannis et al., 2005). Most of the annual increment is accummulated in the tree stems, which was also recorded for other beech ecosystems (Le Goff et al., 2004).

Investigation of forest ecosystems nowadays is focused on climate change (increases of temperature and CO_2) because primary production is expected to increase as well (Dittmar et al., 2003; Bascieto et al., 2004). This implies that carbon sequestration might surpass the carbon released through respiration.

According to Hristovski (2007), carbon sequestration is 4202.4 $kg \cdot ha^{-1} \cdot y^{-1}$ aboveground and 2157.9 $kg \cdot ha^{-1} \cdot y^{-1}$ belowground, which gives a total of 6.4 $t \cdot ha^{-1} \cdot y^{-1}$. The quantity of carbon in phytomass of the beech ecosystem is 175.5 $t \cdot ha^{-1}$.

These data show that the studied oak and beech forests accumulate large quantities of carbon, which is of great significance for mineral fluxes and illustrates the consequences of climate change.

Knowledge of primary production is important because accumulation of organic matter occurs parallel with the process of litter production. Produced litter (dead organs or whole plants) forms the forest floor. The role of the forest floor is very important and comparable to that of the living part of the forest ecosystem. The forest floor biomass is 20.58 $t \cdot ha^{-1}$ in the beech ecosystem in Mavrovo NP and 10.89 $t \cdot ha^{-1}$ in the oak ecosystem in Galichica NP.

The biomass accumulation ratio (ratio between biomass and primary production - BAR) for the beech ecosystem is 18.94. This shows that the investigated beech ecosystem is young and will continue to increase its phytomass (Hristovski, 2007). A similar value was recorded for the oak ecosystem in Galichica NP (21.33).

PHYTOMASS IN HUNGARIAN AND TURKEY OAK ECOSYSTEMS AND MONTANE BEECH ECOSYSTEMS OF MACEDONIA

The role of macroproducers in the two ecosystems is played by tree species, which are dominant in tree layers of the ecosystems. They occupy the greatest volume in the atmosphere and pedosphere, produce the bulk of organic matter, fix and accumulate the largest quantities of solar energy, and involve the largest quantities of nutrients and water in cycling processes. In addition, they influence the mobility, composition, humidity and temperature of the air, and alter chemical and physical characteristics of the soils. Meso- and microproducers (shrubs and herbs) are less effective and less important in these processes. Accordingly, Sukachev (1964) called macroproducers the macrotransformers of solar energy.

The importance of macroproducers is demonstrated by estimated values of net primary production (belowground and aboveground) and carbon sequestration (Table 6).

The total phytomass in Hungarian and Turkey oak ecosystems of Macedonia was estimated to be 2146 kt. Total phytomass in the country's montane beech forests is similar (1940 kt), although they occupy an area twice as small. Annual carbon accumulation is 1073 kt in the investigated oak ecosystem and 970 kt in the beech ecosystem. Assimilated CO_2 is 3934 kt in the oak and 3556 kt in the montane beech forest. The quantity of carbon in the forest floor is 1021 kt in the oak and 1016 kt in the beech forest (Table 6). All of these figures underline the role of the forest fund in mineral cycling and the biocenological role of living organisms in forest ecosystems.

Annual carbon sequestration is estimated to be 652 and 828 kt·y^{-1} for the oak and beech ecosystems, respectively (Table 6). Estimates indicate that 3377 and 3751 kt·y^{-1} of CO_2 are sequestered from the atmosphere. The annual release of CO_2 through respiration was estimated at 2456 and 2728 kt·y^{-1}, respectively.

Table 6. Estimation of phytomass, production and carbon sequestration in a Hungarian and Turkey oak ecosystem (Quercetum frainetto-cerris) and a montane beech ecosystem (Calamintho grandiflorae-Fagetum) in Macedonia.

Parameters	Quercetum frainetto-cerris	Calamintho grandiflorae-Fagetum
Total surface (ha)	193574	98723
Phytomass (kt)	45800	34227
Aboveground phytomass (kt)	36702	29390
Belowground phytomass (kt)	9102	5701
Net-primary production	2147	1945
Aboveground net primary production (kt)	1725	1357
Belowground net-primary production (kt)	421	583
Annual carbon assimilation (kt·y^{-1})	1073	970
Annual carbon sequestration (kt·y^{-1})	921	1023
Aboveground annual carbon sequestration (kt·y^{-1})	652	828
Belowground annual carbon sequestration (kt·y^{-1})	270	195
Annual carbon assimilation (kt·y^{-1})	3927	3550
Carbon accumulated in the forest floor (kt)	905	868

CONCLUSIONS

Investigation of phytomass and production of forest ecosystems provides detailed information about processes transpiring in forest ecosystems.

Phytomass production in the studied Hungarian and Turkey oak ecosystem (Quercetum frainetto-cerris macedonicum) is 237 $t{\cdot}ha^{-1}$, 189.6 $t{\cdot}ha^{-1}$ of which is aboveground and 47.02 $t{\cdot}ha^{-1}$ belowground phytomass. Annual net primary production is 11.09 $t{\cdot}ha^{-1}{\cdot}y^{-1}$.

Phytomass of the montane beech forest (Calamintho grandiflorae–Fagetum) is 347 $t{\cdot}ha^{-1}$ (297 $t{\cdot}ha^{-1}$ is aboveground and 57.75 $t{\cdot}ha^{-1}$ belowground). Annual net primary production (19.7 $t{\cdot}ha^{-1}{\cdot}y^{-1}$) is higher than that of the oak ecosystem.

Values of total phytomass of the investigated Hungarian and Turkey oak ecosystem and montane beech forest in Macedonia are 45800 and 34,227 kt, respectively. Aboveground phytomass values of these two ecosystems are 36,702 and 29,390 kt, respectively. The belowground phytomass was estimated to be 9102 and 5701 kt, respectively.

Total net primary production is 2147 and 1945 $kt{\cdot}y^{-1}$ for the Hungarian and Turkey oak and montane beech ecosystems, respectively. Aboveground net primary production is 1725 and 1357 $kt{\cdot}y^{-1}$, respectively, belowground 421 and 583 $kt{\cdot}y^{-1}$.

Assimilation of CO_2 was estimated at 3927 and 3550 $kt{\cdot}y^{-1}$ for the Hungarian and Turkey oak ecosystem and the montane beech ecosystem, respectively.

Total reserves of carbon in the forest floor comprise 905 kt in the oak ecosystem and 868 kt in the beech ecosystem.

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