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BIOMASS PRODUCTION AND PRODUCTIVITY IN OAK FORESTS OF THE EASTERN CARPATHIANS IN RELATIONSHIP WITH STANDS AGE

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Abstract

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The results of the biomass production and productivity study of oak forest ecosystems in the Eastern Carpathians are presented. On the basis of data on structure and productivity of oak (*Quercus robur* L.) forests of different age (33,54, 75, 106 years old) in the Eastern Carpathians, the biomass fluctuation in the range of 120.5 – 239.8 t ha $^{-1}$ (dry weight) was found. Mass of stems and roots varied in the range of 66.9 – 146.5 and 27.9 – 45.4 t ha^{-1} respectively. The annual increment of biomass was 10.1 t ha^{-1}year $^{-1}$ in 106 years old and 14.0 t ha^{-1}year $^{-1}$ in 33 years old oak forests The ratio between the mass of leaves to mass of thin roots for the sampling areas was 3.5 – 4.0. Leaf area index changed from 4.3 ha ha^{-1} in the 33 years old oak forest stand to 3.3 ha ha^{-1} in 106 years old stand. Total leaf area index for tree and shrub layer changed from 7.3 to 4.2 ha ha^{-1} respectively. The leaf area index decreased with age of the oak forests. The results will be used to estimate realistically the potential biomass production and productivity of oak ecosystems in the Eastern Carpathians.

Introduction

Oak forests were formed in the Eastern Carpathians in the middle-Holocene (7800-3300 years B.P.). In this region as in whole continent of Europe the oak forests grow in the plane and foothills with worm climate. Since the historical time human civilisation developed in those places and the area of oak forests decreased under the influence of anthropogenic pressure. At present time the oak forests remained on the area of 120 000 ha in the Ukrainian Carpathians region and are important for soil protection and for water and climate regulations on this territory.

The tree species *Quercus robur* L. is dominant in the oak forest ecosystems of the Ukrainian Carpathians. These forest ecosystems represent complex horizontal and vertical struc-

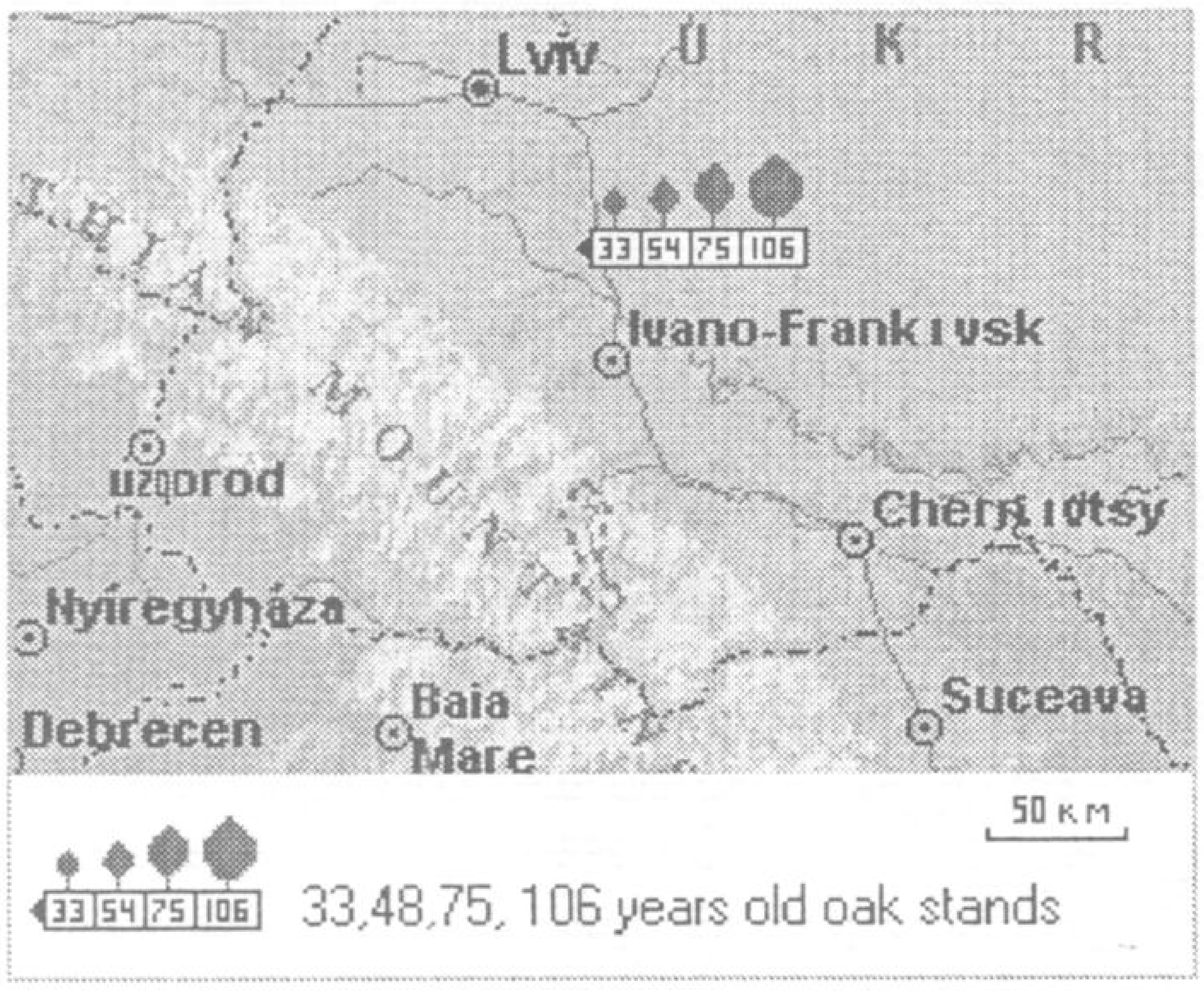

Fig. 1. Location of research plots.

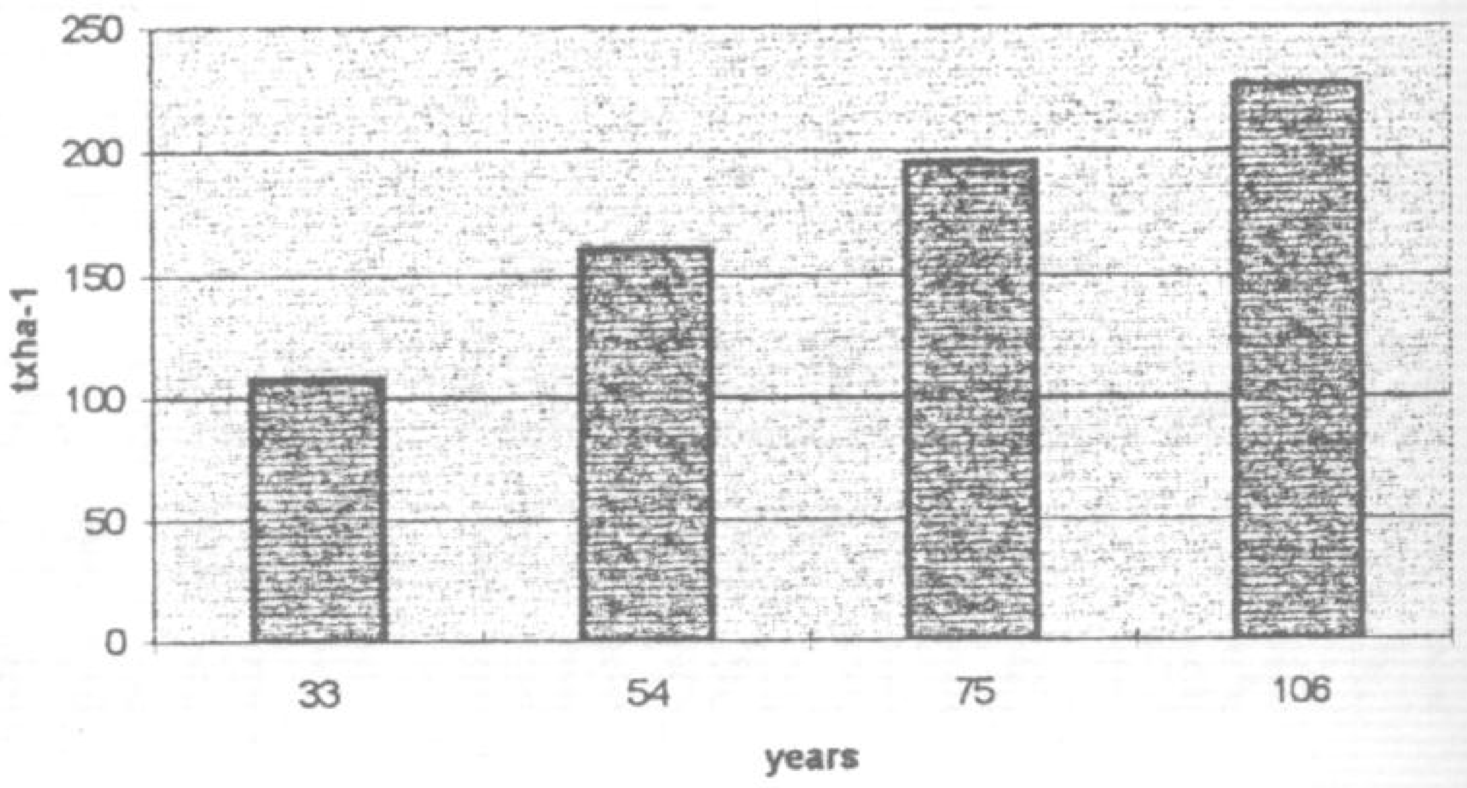

Fig. 2. Total biomass of oak forests in the examined stands.

ture with an important role of shrub and herb layers in the aspects, for example, of water regulation, or productivity.

At present the oak forests have a small stand density that has negative influence on the biomass production and productivity of oak forest ecosystems. The stand density of oak forests decreased during the last decades. As a result of this the productive function of oak forest ecosystems decreased too.

The estimation of biomass in the Ukrainian part of the Eastern Carpathians was scarcely published in western literature while the results on forest production in the Carpathian arch in Poland (Medwecka-Kornas et al., 1974), Slovakia (Biskupský, Oszlányi, 1975; Biskupský, 1981; Oszlányi, 1978, 1994, 1995a, 1997, 1999; Benčat', 1990) and Hungary (Jakucs, 1981), are world–wide known.

Oak forests in the Eastern Carpathians reached lower biomass than the oak forests in Belgium (Duvigneaud et al., 1971; Kestemont, 1971), Slovakia (Oszlányi, 1977), France (Lossaint, Rapp, 1978), United Kingdom (Sykes, Bunce, 1970), Russia (Bazilevich, Rodin, 1975; Goryshina, 1974) and in lower part of Poland, close to Eastern Carpathians (Medwecka-Kornas et al., 1974).

Our study has been carried out in order to investigate the biomass production and productivity in oak forests of the Eastern Carpathians in relationship with stands age.

Objects and methods

Stationary sampling plots were situated in the Ukrainian part of the Eastern Carpathian foothills (Fig. 1) at the altitude of 330-360 m a. s. l. on the soddy podzolic soils in the Dnister river basin ($49^0 16'$ N, $24^0 25'$ E). Plots were located in oak forests dominated by *Quercus robur* L. of different age (33, 54, 75, 106 years old stands) and belong to pure eutrofic oak forests according to classification of Golubets, Malinowskij (1967).

The analyses were performed inside the 2000 m^2 (40 m x 50 m) areas. The number of trees was determined within each plot. Every tree was numbered for easy identification. The breast height (1.3 m aboveground on the

T a b l e 1. Basic dendrometrical data on trees with d.b.h. equal to or exceeding 8 cm

Forest type	Tree species	Age (years)	Diameter at breast height		Height	
			Variation span [cm]	Arithmetic Mean [cm]	Variation span [cm]	Arithmetic mean [cm]
Eutrofic Oak forest	*Quercus robur*	106	31.0-60.0	42.8	22.0-36.0	28.9
Eutrofic Oak forest	*Quercus robur*	75	23.0-46.0	32.5	17.0-23.0	20.0
Eutrofic Oak forest	*Quercus robur*	54	15.0-44.0	22.9	16.0-23.0	18.7
Eutrofic Oak forest	*Quercus robur*	33	9.0-24.0	12.4	7.0-15.0	11.4

uphill side of the tree) was permanently marked around each trunk with a point. In all trees the trunk diameter at breast height (d.b.h.) and height were measured (Table 1). In the category of trees of d.b.h. equal and above 8 cm, there were 225, 166,158, and 116 trees within the 33, 54, 75, 106 years old stands respectively.

Basing upon mean dendrometrical characteristics (d.b.h., height, length and width of crown, biosociological position) 18 sample trees were chosen for destructive analysis at the end of vegetation period (August-September). Each fallen sample tree was divided into the trunk and the crown. The trunk ended at the point where its thickness equalled the half of the basal width of the first live branch from below.

The fresh weight was ascertained first of all. Then, following the determination of dry matter percentage in the samples (after desiccation at 105 ^{0} C), the dry matter weight was calculated in the lower, medium and upper thirds of the trunk. The dry matter of the branches (0-1.5, 1.5-3.0, 3.0-5.0, 5.0-7.0, 7.0-10.0, 10.0-15.0 and 15.0-20.0 cm thick), and of leaves in the lower, medium and upper thirds of the crown was calculated as well.

The degree of the stand density was calculated as the ratio of the crown covered area to the stand area (only trees of diameter at breast height of 8 cm and more were considered).

The total contact surface was calculated as the sum of surfaces of particular fractions of the forest biomass. As regards the tree stems the surface was measured directly using model trees. For thin branches up to 1.5 cm the surface was determined indirectly by measuring the surface of a weighed subsample and calculating of surface to mass ratio (Molczanov, Smirnov, 1967).

The ratio of leaves biomass to the biomass of twigs 0-1.5 cm thick was calculated for the three vertical crown thirds. Samples of leaf biomass were weighed and dried, then their one–side surface was assessed by means of the photoplanimeter. The leaf area of the sample trees and of all trees per 1 ha was next calculated. The leaf area index for the shrub layer was assessed using the data on number of individuals per 1 ha, their average ground-collar thickness and height and average number of leaves on 1 average individual were measured. After photoplanimetry of samples, the calculation per 1 ha was performed.

A procedure of calculating the belowground biomass (root biomass and structure in trees, shrubs and herbs) involved digging out the trees and taking soil monoliths. On each sample plot in the vicinity of two average model trees the 12 monoliths have been taken (below and above on the slope near the tree). The size of monoliths was 0.5 x 0.5 m. Monoliths were sampled near the stem, in the middle and at the end of the radius of the alimentation area of the tree. Further the soil was taken from the layers of 10 cm up to the depth of 150 cm. Roots were dug out and sorted by diameters of below 0.5, 0.5-1.0, 1.0-5.0, 5.0-10.0, and over 10.0 mm and species affiliation was done according to Lohmus, Oja (1983). Roots of ground flora were sampled from 20 pits 50 x 50 x 60 cm giving the fine root biomass.

Annual increment of stems and branches was investigated according to Molczanov and Smirnov (1967) and that of roots according to Rodin (1968).

The litter fall was collected on the sampling areas in 20 litter traps, 50 x 50 x 30 cm, placed 25 cm above the ground surface. The traps were emptied once a month. The biomass of the ground vegetation layer was estimated on 25 plots of 1 m^2 within each sampling area. Values of particular biomass fractions varied within 2-10% of the mean.

Results

The total dry biomass of oak forests varied within close limits increasing proportionally to forest age (Fig. 2). In the 33 years old oak stand the total biomass reached 120.5 and in a 106-years old–239.8 t ha^{-1}.

The main share of biomass was concentrated in the stems (from 55.5% in 33 years to 61.1% in 106 years), roots (from 23.2% in 33 years to 18.9% in 106 years) and branches (from 8.1% in 33 years to 13.4% in 106 years old stands). The percentage of the biomass leaves was not so high and changed from 2.7% in 33 years to 1.2% in 106 years old stands. In shrub layer the share of biomass changed from 9.8% in 33 years to 2.9% in 106 years old oak stand and in the herb layer from 0.7% in 33 years old to 2.5% in 106 years old stand. As it was shown, the share of stems, branches and herb biomass increased proportionally to forest age but this tendency is not true of roots, leaves and shrubs, the percentage of these components decreased with age.

The main part of biomass was concentrated in the tree layer of the oak forests (Table 2). The biomass of stems increased with age 2.2 times and the root biomass was 1.6 times higher in a 106-years old forest as compared to that of 33-years old stand. At the same time

T a b l e 2. Biomass production of tree layer in oak forests in the Ukrainian Carpathians

Components	Biomass t/ha			
	Age of stand , years			
	33	54	75	106
Stems	66.9±1.2	101.9±2.1	124.0±2.8	146.5±3.2
Branches	9.7±0.4	20.4±1.1	26.2±1.2	32.1±1.4
Leaves	3.3±0.2	2.8±0.1	3.0±0.1	2.9±0.1
Roots	27.9±1.2	35.4±1.4	42.5±2.0	45.4±2.2
Total	107.8	160.5	195.7	226.9

the branches biomass increases with age was as high as more than 3.3 times. Only the leaf biomass remained at the same level. Accordingly the ratio of the aboveground biomass to the belowground one grew with the tree age from 2.9 for 33 years to 4.0 for 106 years old stands.

Thin roots (less than 0.5 mm) are of major importance in the matter exchange between soil and plants. In oak forests thin roots reached 1.6-3.4 % of the total roots biomass and the proportion of thin roots decreased with the stand age. The ratio of leaves to thin roots equalled 3.5-4.0.

The shrub and herb layers are very interesting for future study of water and energy transformations in the oak ecosystems. They have different tendencies in accumulation of organic matter with age. The biomass of the shrub vegetation decreased with forest age 1.9 times: in the 33 years old forest the percentage of biomass of the shrub layer reached 9.8% and in 106-years old only 2.9% of total forest biomass. The biomass of the herb layer increased with age 6.8 times, from 0.9 t ha^{-1}in the 33 years old forest to 6.0 t ha^{-1} in 106-years old stand. The biomass of the herb layer depended on the quality of light penetrating under trees. In conditions where the share of grass cover was 40-50 % of the ground surface and the herb biomass was 0.9-1.4 t ha^{-1} whereas in altered stands, where the stand density of forest was 0.6, the total biomass of the herb layer amounted to 6.0 t ha^{-1} .

The annual increment of biomass in oak forests varied from 14.0 ±0.4 t $ha^{-1}year^{-1}$ in 33 years old to 10.1 ±0.3 t $ha^{-1}year^{-1}$ in 106 years old oak stands. On the other hand the increment of lower layers of plants (shrubs and herbs) increased with age, for example, their contribution to the total annual increment of oak forests attained 17-40%. The distribution of increments in different fractions of biomass in oak forest stands is depending on the forest age dynamics. From 33 to 106 years the share of stems in annual production decreased from 39 to 24% and of roots from 19 to 10%. The share of leaves increased from 28 to 50% and that of current twigs from 5 to 8 % respectively. Only the increment of branches was at the same level.

The total contact surface of the aboveground part of oak forests plays a very important ecological role, for example, in the transformation of water and energy in the forest ecosystem. The total contact surface was 15.1 $ha \cdot ha^{-1}$ in the 33 years old forests, 16.4 $ha \cdot ha^{-1}$ in 54 years old, 16.1 $ha \cdot ha^{-1}$ in the 75 years old and 10.4 $ha \cdot ha^{-1}$ in 106 years old forest. At the same time 49.7-22.6% of this was in the shrub layer. In this instance the 33 years and 106 years old stands have the surface of the tree layer greater than the surface of the shrub layer (65.3% and 34.7%; 77.4% and 22.6% respectively). For the medium age stands the percent of the tree and shrub surface was similar (50.3% and 49.7% for 54 years old stand and 50.6% and 49.4% for 75 years old stand respectively). It is worth noting that 82-89 % of the total surface consisted of leaves of tree and shrub species. This informs us about their important role in transformation functions in oak forest ecosystems. Oak forest stands have the high leaf area index, measured by one-side surface of leaves per 1 ha. Leaf area index changed from 4.3 $ha \cdot ha^{-1}$ in the 33 years old oak forest stand to 3.3 $ha \cdot ha^{-1}$ in 106 years old stand. Total leaf area index for tree and shrub layer changed from 7.3 in 33 years old stand to 4.2 in 106 years old stand, considerably decreasing with age in the oak forests.

Discussion

Oak forests are distributed in the lower parts of the Eastern Carpathians but their area decreased under the influence of anthropogenic pressure. These forests do not reveal high accumulation of organic matter and following Bazilevich and Rodin (1975) they were estimated as belonging to class VII.

We compared also our results with those from geographically close areas. We found that oak forests in the Eastern Carpathians accumulate less biomass than forests in neighbouring areas. For example, in Poland, the total dry biomass was 275.9 $t.ha^{-1}$ in 100 years old oak-hornbeam forest in Ispina (Medwecka-Kornas et al., 1974). In Slovakia the oak-hornbeam forests represented 237.7 $t.ha^{-1}$ of dry tree biomass (Biskupský, 1981), similarly as in Hungary, where 65 years old oak forest has 238.5 $t.ha^{-1}$ of the dry biomass (Jakucs, 1981). The dry biomass was high in Belgium, 355.4 $t \cdot ha^{-1}$ in 120 years old (Duvigneaud et al., 1971) and 213.3 $t \cdot ha^{-1}$in 66 years old (Kestemont, 1971) forests. In the Caucasus, the average biomass of oak forests was 182 t ha^{-1} and the productivity was 10.7 t · ha^{-1} (Aliev, Gasanov, 1974; Gasanov, 1980). The total aboveground biomass at the stand age of 29 years was 175.5 t· ha^{-1} in oak forests (type group *Carpineto-Quercetum*) on the alluvial soil in the Nitra river valley in Czechoslovakia. The highest part belongs to trunk biomass (86.1% as fresh matter and 87.3% as dry matter; Tokar, 1987). In our research plots the highest proportions relative to trunk mass were 55.5% in the 33 years old stand, and 61.1% in the 106 years old one.

Noteworthy is the observation on a faster increase with age of aboveground biomass as compared to the belowground one and on the ratio of leaves to thin roots. The ratio of leaves to thin roots was 2 times higher than in beech forests in the Ukrainian Carpathians (Kozak, Holubets, 1997). The leaves are that portion of the ecosystem in which the transformation of solar energy into organic substance takes place. Thus the leaves biomass is one of the very important characteristics of the forest ecosystems.

In oak forests the biomass of branches increased more intensively with age (3.3 times). The total biomass of stems for this period increased 2.2 and that of roots 1.6 times. Interesting is that the absolute amounts and percentage only of shrub biomass decreased with age in the examined oak forests.

In oak forests the share of lower layers of plants (shrubs and herb) increased with age, for example, their contribution to total annual biomass increment of oak forests attained 17-40%. The distribution of increment in different fractions of biomass in oak forest stands is depending on forest age. From 33 to 106 years the share of stems in annual production decreased from 39 to 24% and of roots from 19 to 10%. The share of leaves increased from 28 to 50% and that of current twigs from 5 to 8 % respectively. Only the increment of branches was at the same level.

The annual increment of biomass in oak forests was very high (14.0 ±0.4 t $ha^{-1}year^{-1}$ in 33 years old to 10.1 ±0.3 t $ha^{-1}year^{-1}$ in 106 years old oak stands), considerable higher than the annual increment of 36-50 years old artificial hornbeam forest in the similar conditions in the Ukrainian Carpathians. As a matter of fact the annual increment in hornbeam forests was 8.2±0.1-9.6±0.2 t $ha^{-1}year^{-1}$. To compare: in Poland, in 100 years old oak-hornbeam forest in Ispina (Medwecka-Kornas et al., 1974) the total primary productivity of stem wood, stem bark, branches and foliage was 7.4 $t.ha^{-1}.year^{-1}$ and in the Caucasus, the productivity was *10.7* $t \cdot ha^{-1}$ *(Aliev, Gasanov, 1974; Gasanov, 1980).*

The total surface of the aboveground part of oak forests was very high. This implies the important role of the surface in the functioning (transport of water) of oak forest ecosystems. This contact surface in the forest under study was even higher than the surface of aboveground biomass in 24, 57, and 74 years old oak forests in the Telerman forest district in Russia amounting to 9.0, 10.2, 9.1 $ha \cdot ha^{-1}$ respectively (Vatkovskyi, 1978).

In the literature the ecological studies on productivity included the leaf area index. Some of them concerned broad-leaved (Benčať, 1990; Oszlányi, 1977, 1994, 1995b, 1999,Tokár, 1987) and coniferous (Vose, 1988) forests. Oak forest stands in the Ukrainian Carpathians have a high leaf area index (7.3 $ha \cdot ha^{-1}$ in the 33 year old oak forest stand), however the leaf area index decreased with age of the stand. Among others, leaf area index is considered as a very valuable characteristics in ecological studies. It is necessary to say that the total leaf area index in oak forests is one of the highest in the region, due to the situation, that the development and illumination of tree crowns was optimal. In our studies the leaf area index of both tree and shrub layers was assessed. The shrub layer forms a very important part of the oak forest ecosystems and therefore it can not be omitted.

Conclusions

In the Eastern Carpathians oak forests did not reveal high accumulation of organic matter. They accumulate less biomass than forests in the neighbouring areas.

The total dry biomass of the examined oak forests increased proportionally to forest age. Biomass of branches increased with age more than 3.3 times, that of stems 2.2 times, and of roots 1.6 times. Only the leaf biomass remained on the same level whereas the biomass of the shrub vegetation decreased with age 1.9 times. The share of branches, stems, and grasses biomass increased proportionally to forest age contrarily to the situation of roots, leaves and shrubs, the percentage of these components decreasing with age. The relation of the aboveground biomass to the belowground one showed faster increase with age of the aboveground biomass than of the belowground one. The main part of this mass was accumulated in stems, lesser proportion was accumulated in roots and in branches. The share of tree leaves and of grass being much lower. The proportion of thin roots decreased with the age of a stand.

The distribution of increments in different fractions of biomass in oak forest stands was depending on forest age. From 33 to 106 years the share of stems and of roots in the annual production decreased, whereas that of leaves and current twigs increased. Only the increment of branches was at the same level. In oak forests the increment of lower layers of plants (shrubs and plants) increased with age, their contributions to the total annual increment of oak forests attained high values.

Oak forest stands have the high leaf area index, however decreasing with forest age.This is an important indicator of the functioning of the oak forest communities as regards the cycling of matter.

Translated by the authors

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Kozak I., Holubets M.: **Produkcia a produktivita biomasy vo vzťahu k veku porastov v dubovom lese vo Východných Karpatoch.**

V práci predkladáme výsledky štúdia produkcie a produktivity biomasy v dubovom lesnom ekosystéme vo Východných Karpatoch. Na základe údajov o štruktúre a produktivite dubových (*Quercus robur* L.) lesov rôzneho veku (33, 54,75, 106 rokov) vo Východných Karpatoch sme zistili kolísanie biomasy v medziach 120.5 – 239.8 t ha^{-1} (sušina). Biomasa kmeňov a koreňov sa pohybovala medzi 66.9 – 146.5 a 27.9 – 45.4 t ha^{-1} . Ročný rast biomasy bol 10.1 t ha^{-1} rok^{-1} v 106-ročných a 14.0 t ha $^{-1}$ rok^{-1} v 33-ročných dubových lesoch. Na študijnej ploche pomer medzi biomasou listov a tenkých koreňov bol 3.5 – 4.0. Index listovej plochy sa menil od 4.3 ha ha^{-1} v 33-ročnom dubovom lese do 3.3 ha ha $^{-1}$ v 106-ročnom poraste. Celkový index listovej plochy pre stromovú a krovinovú etáž sa pohyboval od 7.3 do 4.2 ha ha $^{-1}$. Index listovej plochy rástol s vekom dubových lesov. Výsledky výskumu možno využiť na reálne určenie potenciálnej produkcie a produktivity biomasy v dubovom ekosystéme Východných Karpát.