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The dendrometric characteristics of oak woods in rural landscapes of the East Carpathians

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Abstract

The dendrometric characteristics are functions of tree age and ecological growth conditions. On relatively small areas of homogeneous sites, the stand age structure and the phytosocial interaction between the trees are the major factors influencing the stand characteristics. We hypothesise that the correlation between the basic dendrometric variables and tree age can be used as a yardstick discriminating silvopastoral oak woods from silvicultural stands managed for timber. The tree age, diameter at breast height (DBH), and height (H) were determined in 14 silvopastoral oak woods in the East Carpathian region, which were compared to the respective forest inventory data of 31 silvicultural oak stands. The correlation between DBH, H and their ratio – the slenderness index (*si*) and age of oaks – were very weak and insignificant compared to the conspicuous age effect on the dendrometric features in the forestry-grown stands, which can be explained by a more complex development dynamics and spatial structure of silvopastoral woods. The study implies that the habitat conditions and processes related to traditional husbandry are better harmonised with the intrinsic oak ecological adaptations than modern silvicultural treatments. Therefore, we advise to promote the revival of silvopastoralism in the Carpathian region as a cost-efficient way of perpetuating the rural ‘oakscape’, an outstanding bio-cultural landscape asset.

Keywords: slenderness index, height-diameter, oak, cultural landscape, agroforestry, cattle grazing, wood-pastures

Introduction

The slenderness index (*si*) is a quotient of a tree height (H) and diameter measured 1.3 m above the ground level (DBH, diameter at breast height) ratio, i.e., $H \times DBH^{-1}$. The index provides information about the trunk shape, being dependent on tree age (Kaźmierczak et al. 2008) and biological, or Kraft’s classes (Kaźmierczak and Stosik 2008). Considering a particular species and a given age class, a lower *si* value implies a higher tree taper, typical for trees with the lateral growth unconstrained by the competition of neighbouring trees. Such trees with low positions of their centres of gravity reveal firmer stability and resistance to strong winds. Therefore, the slenderness index is often used as a measure of a tree or stand stability (Wang et al. 1998, Peltola et al. 1999, Wilson and Oliver 2000, Hinze and Wessels 2002, Mezei et al. 2014, Kaźmierczak et al. 2015).

Various authors provide different *si* threshold values for tree resistance to wind damages, from 0.6 (i.e., trees are resistant if *si* < 0.6; Becquey and Riou-Nivert 1987) to 0.7 (Stępień 2014), and even to 0.8 (Burschel and Huss 1997 after Kaźmierczak et al. 2015, Pardé and Bouchon 1988 cited by Cucchi et al. 2005). Because of higher health and safety standards in urban areas, trees are considered resistant when their *si* < 0.5 (Mattheck 2002). However, according to Rust (2014), such a threshold value is hardly evidenced as a reliable measure predicting tree susceptibility to wind or snow damages. According to the researcher, there is no universal *si* threshold that might be used to assess a tree damage risk. Kaźmierczak and Stosik (2008) used the slenderness index as a measure of the bio-social position of trees, finding its correspondence with Kraft’s classes. The slenderness can be determined either through direct measurements or with theoretical models (Lu and Zhang 2013, Stankova and Diéguez-Aranda 2013).

The above-described features, as to most of the broadleaf species also pertain to European white oaks, including *Quercus robur* and *Q. petraea*. Their intensive vertical growth progresses until a certain age, after which it slows substantially. It has been observed that the oak stands established in the second half of the 20th century grew faster than those emerged one hundred years earlier. Therefore, within the same age classes, oaks are on average taller in the late 1900s than in late 1800s (Pretzsch et al. 2014). A similar pattern has been observed in pine forests. While some researchers explain this with the increased concentration of atmospheric CO_2, nitrogen deposition and climate warming (Jaworski 2003, Solberg et al. 2004, Sharma et al. 2012, Pretzsch et al. 2014), others attribute the change to the process of natural regeneration of degraded (through long-lasting nutrients take-off) habitats (e.g., Zang and Rothe 2013, Freschet et al. 2014). It should also be considered, however, that during the same time slot dispersed trees (such as wood-pasture oaks) would grow shorter and thicker (lower *si* value) and would develop wider crowns than their counterparts in dense forest.

The abandonment of traditional multifunctional use (including silvo-pastoralism) of woodlands in the Carpathian region has triggered the development of a dense shrub layer (e.g., *Corylus avellana*, *Padus avium*, *Sambucus nigra*) and succession of shade-tolerant species, in particular, hornbeam (*Carpinus betulus*) and beech (*Fagus sylvatica*), leading to the disappearance of semi-open oak woods. Such woods have undergone even faster decadence when, due to their typically low wood stock and low quality of timber, they had been deliberately subjected to silvicultural 'remodelling' aimed to improve the wood productivity, i.e., replacement with highly-stocked dense, mostly beech-fir (*Abies alba*) timber stands.

Perhaps the best known, still functioning relics of European silvopastoralism are oak-dominated wood-pastures, an important component of our biocultural legacy (Luick 2008, Bergmeier et al. 2010) and a key habitat of the European 'oakscape' (Bobiec et al. 2018). Very rich in biodiversity (Paltto et al. 2011, Öllerer 2012, Horák and Rebl 2013), they provide a wide range of ecosystem services (Bugalho et al. 2011, Garrido et al. 2017a, b, Torallba et al. 2018). According to estimates made by Plieninger et al. (2015), the habitats resembling wood-pastures still occupy ca. 200,000 km^2 of the EU territory, mostly in the Mediterranean region and in East European countries. The wood-pastures in Transylvania are the priceless sanctuaries of old oaks. Hartel et al. (2018) revealed that ancient oaks were present in 66% of the Transylvanian wood-pastures.

We hypothesise that the oak woods of silvopastoral origin, even long after abandonment, retain their structural and dendrometric characteristics discriminating them from sylvicultural timber stands. The difference should particularly pertain to the relation between oaks age and their dendrometric features. Therefore, we anticipate that the tree shape parameters are highly predictable in the managed stands, where sylviculture produces relatively even growing conditions, but not in the stands representing present or past oakscape, representing a far more heterogenous environment.

The aim of this study was to determine the effect of oak age on their height, diameter and slenderness index with respect to the management system. We hypothesized that results obtained may contribute to the development of robust criteria for identification of "wild" oak groves as indispensable components of the existing or future European oakscapes.

Materials and methods

The study was conducted in four landscape units (ca. 20-km^2 each in area) in the Carpathian region: in the Carpathian foothills (SE Poland, PL), in Cis-Carpathia (W Ukraine, UA), in the Southern Carpathians (Transylvania, Romania, RO), and in the Bukk Mountains representing the Carpathian basin (Hungary, HU). In each landscape unit, we identified oak (*Quercus robur* or *Q. petraea*) woods and groves neighbouring with grasslands. Selection criteria of woods for measurements were the following: (1) no obvious signs of sylvicultural treatment such as planting and thinning (selective exploitation of old trees without care of oak regeneration was not considered oak silviculture), (2) relatively uniform, on a particular area scale, stand physiognomy (oaks density, structure, etc.), and (3) spatial extent, allowing to locate at least one-hectare sampling unit. In total 14 plots were set for the stand mensuration: six in PL, five in UA, two in RO, and one in HU (Figure 1).

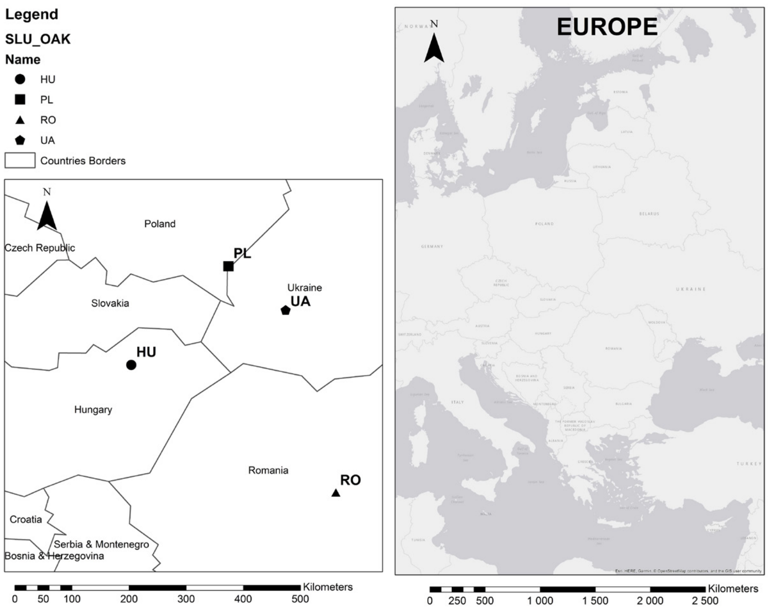

Figure 1. Locations of four landscape units studied

All studied landscape units are either currently used as wood-pastures (RO), or they are legacies of recently transformed sylvopastoral landscapes (HU, UA, PL) and witnessed by the local inhabitants (in Kalwaria Pacławska and Ivanivka) (see Table 1 for stand locations and basic description).

All oaks taller than 1.3 have been positioned and measured (DBH and height) with the Stork Field-Map set (Field-Map 2018). For other species, only the canopy layer trees (DBH ≥ 20 cm) were positioned and measured, whilst their share in lower layers was eye-assessed (Table 1).

The age of oaks was determined based on tree rings counts. In each stand 30 random trees, DBH ≥ 10 cm, were cored with the 5.2-mm Pressler wood borer at 1.3 m above the ground, a level considered as a tree recruitment baseline. To assess the whole age (as referred to the ground level) we applied a six-year correction corresponding to the median difference between the rings number on the ground level and on the 1.3 m level based on 59 pairs of wood discs extracted from young oaks in PL and UA landscape units. For instance, if the pith year of a wood core sample was 1910, the assumed tree age in 2015 was 105+6 years.

As a reference, 31 sylvicultural oak stands were selected from the Polish forests database (BDL 2020) in SE Poland. For the query, we applied the canopy composition criterion (oak share ≥ 50%) and stand age like their sylvipastoral counterparts (Table 2). Because of the common practice of establishing even-aged planted oak stands in production forests, the acquired stand age data were reliable. For the same reason, due to the homogeneous character of sylvicultural oak stands we referred to their average *si* values.

For each landscape unit, the linear regressions were calculated to examine the relationship between the oaks age and dendrometric variables, i.e., DBH, H and *si*. To compare the strength of relationships in sylvopastoral woods with ‘sylvicultural’ stands (where only average values of parameters for age classes were available), the ‘silvopastoral’ oaks have been grouped in

Table 1. Description of the studied stands physiognomy; coordinates mark stand centroid position (altitude [m])

PL1	N49.62085°/E22.71648° (407); 1.37 ha; NEE; narrow (40–65 m wide) wood track neighbouring with grassland; discontinuous canopy of old QURO and ABAL, CEAV, ACPS, and ACCA; dense COAV canopy preventing herbs, after experimental hazel removal (2013–15) development of abundant herb vegetation; oak tall saplings only at the edge of stand
PL2	N49.61114°/E22.70694° (470); 1.00 ha; S-SE; narrow (40–65 m wide) margin of forest neighbouring to N with crop-fields later turned to grassland; dense stand dominated by QURO and QUPE with admixture of ABAL and CEAV; closed tree canopy, poor undergrowth and herb layer, tall oak saplings only at the edge
PL4	N49.62490°/E22.69984° (400); 1.51 ha; (W) flat; forest “peninsula” near village, surrounded grasslands, former cropfieds; decimated in 1990s QURO-QUPE (+ single FASY) canopy (50% of oaks felled), part of oaks double-stem; dense FASY-CABE thicket, poor herb layer; few oak saplings found in the unfilled gap
PL5	N49.62963°/E22.69893° (395); 0.89 ha; SW; decimated in 1990s QURO canopy (80% of oaks felled) + FASY, ABAL and ACCA, near the village, along old path to the river, crop-fields and grasslands around; under sparse canopy dense thicket of COAV, CABE, FASY, ACCA and COSA; patchy remnants of grassland vegetation; abundant oak regeneration outside the stand on the abandoned pasture
PL6	N49.67616°/E22.64470° (405); 1.63 ha; flat; uneven discontinuous (Cc 50%), QURO (+ ABAL) canopy, apparently representing two distinct cohorts: the old one of 1800s and the younger one, established in early 1900s; after removal of the lower CABE layer in late 1980s a dense CABE + ABAL thicket preventing herbs development; no tall oak saplings found
PL8	N49.65807°/E22.73133° (326); 1.00 ha; undulated; canopy of mostly double-, or triple-stemmed QUPE (former oak coppicing, probably for tannin-rich bark); after 1950 transformed to high forest: removal of ca. 50% of oaks and introduction of FASY and PISY; Cc 100%; poor undergrowth and herb layer
HU1	N47.96742°/E20.47898° (320); 1.00 ha; S; semi-open QUPE (old, wide-crown trees); former pastured wood, abandoned ca. 25 yrs. ago; young generation of QUPE and QUCE; Cc 100%; QUPE regeneration in few gaps; poor herb layer
RO1	N46.130532°/E25.416336° (540); 5.71 ha; W; wood-pasture with scattered QUPE, wide-crowned trees (+ FASY, PYSP); heavy grazing pressure, few tall oak saplings
RO4	N46.17463°/E25.40802°; 1.65 ha (595); NW; irregular open ‘savannah’ wood dominated by QUPE (+ PYSP and BEPE); at spots dense shrub layer dominated by PRSP, CRMO, COSA, and ROSP; numerous oak saplings
UA1	N48.97770°/E24.12202° (425); 1.00 ha; flat; QURO semi-open canopy stand adjacent to pasture; in the part visited by cattle (ca. ½ of the area) regrowth of hazel controlled by occasional grass burning, abundant herb layer; further away released hazel over-shades depleting herb layer; relatively abundant short oak saplings; Cc 50%
UA2	N48.97903°/E24.12374° (425); 1.00 ha; flat; QURO stand (+ CEAV) adjacent to pasture and plough field; semi-open tree canopy, Cc 60%, dense COAV undergrowth, poor herb layer except COAV-canopy gaps, where oak tall saplings occur
UA3	N48.91885°/E24.11380° (413); 1.00 ha; flat; QURO-dominated savanna-like stand, Cc 40%, neighbouring with the abandoned agricultural land; evidence of frequent grass fires (charred tree stems and stumps); numerous tall oak saplings
UA4	N48.92101°/E24.12214° (420); 1.00 ha; flat; like UA3, except higher stand density (stock), more abundant shrub layer; older fire remnants; Cc 60%
UA5	N48.88592°/E24.09184° (482); 1.00 ha; like UA3

Note: flat/NSWE – (slope) exposure; ABAL – *Abies alba*, ACCA – *Acer campestre*, ACPS – *A. pseudoplatanus*, BEPE – *Betula pendula*, CABE – *Carpinus betulus*, CEAV – *Cerasus avium*, COAV – *Corylus avellana*, COSA – *Cornus sanguinea*, CRMO – *Crataegus monogyna*, FASY – *Fagus sylvatica*, FREX – *Fraxinus excelsior*, PIAB – *Picea abies*, PISY – *Pinus sylvestris*, POTR – *Populus tremula*, PRSP – *Prunus spinosa*, PYSP – *Pyrus* sp., QUPE – *Quercus petraea*, QURO – *Q. robur*, ROSP – *Rosa* sp., TICO – *Tilia cordata*; Cc – Canopy cover; ‘+’ – admixture; BF – Białowieża Forest.

10-years-wide age classes, for which the mean values of dendrometric parameters were calculated and Spearman's correlation coefficients between the 10-years-wide age classes and H, DBH and *si* were determined. For the analyses, we used Statistica 13 software package (Dell 2015).

Table 2. Mean age and dendrometric parameters of oaks in the stands studied

Plots	Age [years]	H [m]	DBH [cm]	$si = H \times DBH^{-1}$
PL1	112	22	74	0.30
PL2	80	21	39	0.54
PL4	174	25	87	0.29
PL5	156	22	85	0.26
PL6	168	24	59	0.41
PL8	138	22	49	0.45
UA1	103	20	57	0.35
UA2	86	19	60	0.32
UA3	74	14	30	0.47
UA4	70	15	31	0.48
UA5	45	13	26	0.50
HU1	121	15	56	0.27
RO1	102	18	86	0.21
RO4	102	15	62	0.24
04-08-1-05-202c*	52	16	21	0.76
04-08-1-01-190f	55	18	20	0.90
04-08-1-01-161f	52	19	20	0.95
04-08-1-01-161A	42	15	14	1.07
04-08-1-02-43c	70	25	32	0.78
04-08-1-02-42b	75	26	37	0.70
04-08-2-14-276h	72	26	34	0.76
04-08-2-09-181a	77	25	38	0.66
04-08-2-09-188c	77	24	38	0.63
04-22-2-04-57f	73	25	38	0.66
04-22-2-11-149d	102	27	55	0.49
04-22-2-11-145f	102	27	46	0.59
04-09-1-03-52f	102	28	49	0.57
04-09-1-03-67c	143	28	66	0.42
04-09-1-03-78a	106	27	50	0.54
04-09-1-03-48c	106	28	49	0.57
04-09-1-03-47a	120	29	56	0.52
04-09-1-03-53b	101	27	50	0.54
04-09-1-03-57h	101	26	45	0.58
04-09-1-04-103f	77	26	33	0.79
04-09-1-03-80d	71	26	35	0.74
04-22-2-01-267b	77	28	39	0.72
04-22-2-01-216f	102	27	44	0.61
04-22-2-12-247c	103	28	44	0.64
04-15-2-06-91c	101	29	46	0.63
04-09-2-07-12b	125	28	62	0.45
04-09-2-11-138d	105	29	42	0.69
04-13-2-12-49h	138	32	57	0.56
04-13-2-12-49d	138	31	59	0.53
04-13-2-12-67c	143	28	65	0.43
04-13-2-12-56d	131	29	57	0.51

Note: * – forest address in state forests in Poland; – managed oak stands (MF).

Results

The wood mean oaks DBH varied from 39 to 87 cm in the Carpathian foothills and from 26 to 60 cm in Cis-Carpathia, with the mean height ranging from 21 to 25 m in the former and from 13 to 20 m in the latter. The slenderness index oscillated between 0.26 and 0.54 and between 0.32 and 0.50, respectively. The mean oaks age in the foothill woods ranged from 80 to 168 years and in the Cis-Carpathian woods – from 45 to 103 years. The age of the managed (sylvicultural) stands varied from 70 to 143 years, with mean DBH, H, and *si* in the ranges of 32–65 cm, 24–32 m and 0,43–0,78, respectively. All parameters of the woods, including the Transylvanian wood-pasture and the former wood-pasture oak grove in the Bukk Mts. are collated in Table 2. The Carpathian foothill and the Transylvanian stacks had significantly thicker oaks than the Cis-Carpathian stack and the collection of managed stands. As expected, grown purposely in high densities oaks in managed stands were, on average, taller (median 27 m) than their counterparts in other stacks, though not significantly with regard of the Carpathian foothills (median 24 m). The most conspicuous was a sharp difference in stem slenderness of silvopastoral oaks (overall mean Si = 0.39) and their counterparts grown in dense managed stands (mean Si = 0.64) (Figure 2).

In contrast to the sylvipastoral woods, where H and DBH revealed none or very weak correlation with oaks age, both parameters were strongly correlated with the age classes in the managed stands (Figures 3, 4). That lack of or very weak correlation between tree age and their den-

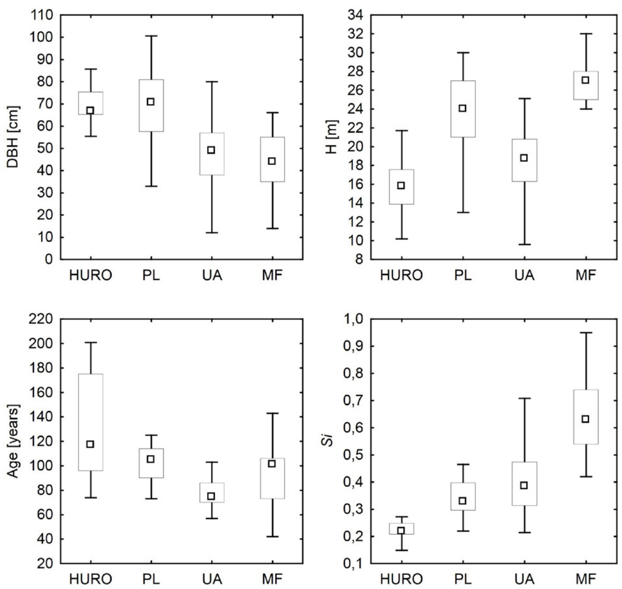

Figure 2. The comparison of four parameters from the oak assemblages

Medians – inter-quartile ranges – min/max; HURO – the Bukk Mts., Hungary, and Transylvanian wood-pastures; PL – Polish Carpathian foothills' marginal oak woods; UA – Ukrainian marginal woods; MF – managed oak stands.

drometric characteristics is a common feature of the marginal Carpathian and Cis-Carpathian woods and in the wood-pasture woodlands of Transylvania and the Bukk Mts. (Figures 3–5). Similarly, the silvipastoral woods differ from the managed timber stands in the very poor response of *si* values to tree age. Although in all considered

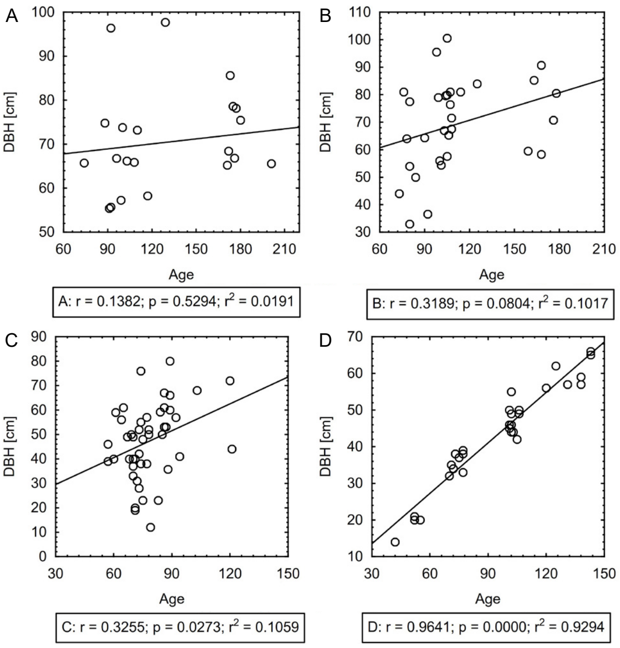

Figure 3. Correlation of oaks DBH with age

A – the Bukk Mts., Hungary, and Transylvanian wood-pastures; B – Polish Carpathian foothill marginal oak woods; C – Ukrainian marginal woods; D – managed oak stands; r_s – Spearman's rank correlation coefficient, r^2 – the coefficient of determination; neither linear regression line was drawn nor r^2 was calculated for the managed oak stands, where instead of actual oaks age, the 10-yr age classes were used.

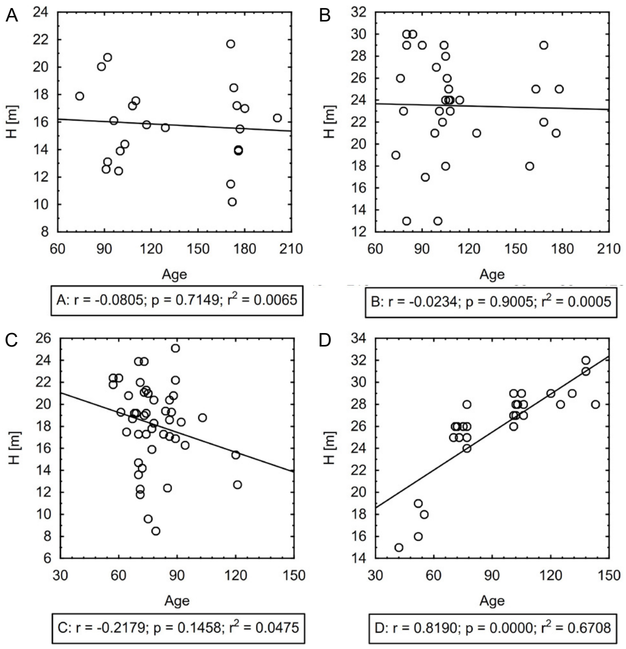

Figure 4. The correlation of oak height with age

See explanations for Figure 3.

cases the correlation was negative, with a very small r^2, one cannot tell that in semi-open woods the slenderness of oaks declines with age (Figure 5).

In a similar manner to DBH and H, the negative association of *si* with oak age was very weak in sylvopastoral woods, but strong in the managed stands (Figure 3–5).

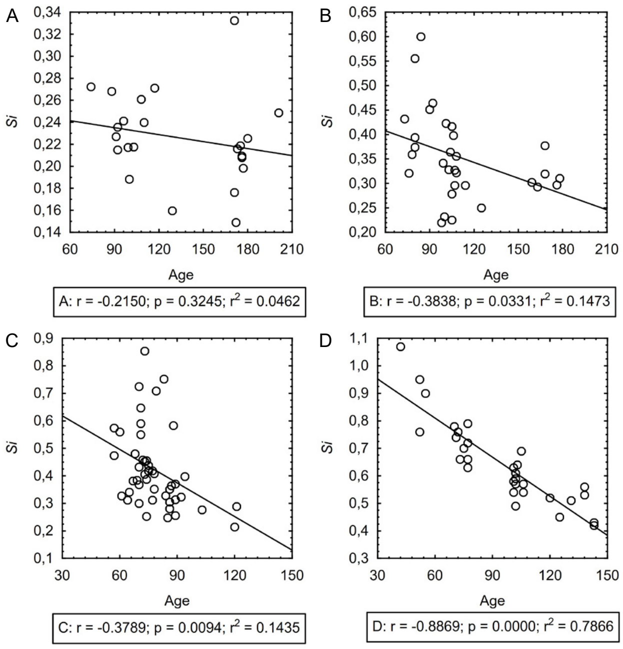

Figure 5. The correlation of the slenderness index of oaks with age

See explanations for Figure 3.

Discussion

Regarding the managed oak stands in SE Poland, the presented results correspond with earlier studies from other parts of Poland. For instance, it was found that in managed oak stands in Wielkopolskie Lakeland (W Poland) *si* in oaks decreased from 1.2 at 10 years to 0.72 at 120 years of age (Kaźmierczak et al. 2008). In Niepołomicka Forest near Cracow, S Poland, the mean oak *si* was 0.81 at the age of 67 (Orzeł 2007), being an intermediate value between the one from Wielkopolskie Lakeland (0.93 according to Kaźmierczak et al. 2008) and the one from SE Poland managed forests in the present study (0.74; Figure 6).

However, in either case, whether in Wielkopolskie Lakeland, in Niepołomicka Forest, or in the managed oak stands of the present study, the oaks slenderness index was substantially higher than that of the similar age oaks in sylvopastoral woods in the Carpathian foothills, in Cis-Carpathia, in the Bukk Mts. and in Transylvania. Those differences were observed in the age range of 60–150 years. The only exception was PL8 (average age 136 years) with the mean *si* = 0.46, i.e., almost equal to the mean of five managed stands of similar ages (126, 131, 137, twice 144 years, see Table 2), *si* = 0.48. Unlike

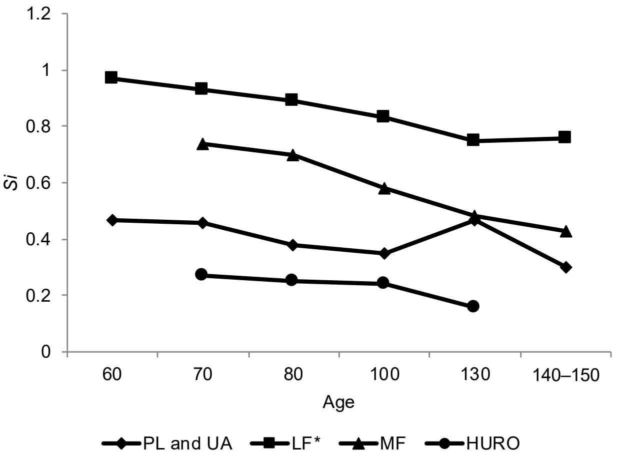

Figure 6. The dependence of oaks slenderness on age in the selected oak woods

See explanations for Figure 2; * data from Kaźmierczak et al. (2008).

all other considered stands emerged from seeds, PL8 is a lapsed *Q. petraea* coppice, creating a dense stand comparable with the forests managed for timber. Therefore, it was excluded from the correlation analyses. Despite the lower technical quality of oak timber in silvopastoral woods (lower *si* values) than in the managed stands (longer branchless trunks, fewer gnarls and knags), the former deserve restoration and conservation. Due to the canopy openness, tree age and shape variability, they have a higher potential to develop multiple ecosystem services such related to forest recreation.

The most 'classic' examples of wood-pasture were RO1 and RO4 in Harghita county (Photo 1, 2), Romania, both grazed by cattle from May to October. Open *Q. petraea* wood HU in the Bukk Mts., Hungary, has been abandoned ca. 25 years ago, which made the wood filled with a relatively dense undergrowth of *Q. petraea* and *Q. cerris*.

The countryside of the Carpathian foothills in SE Poland until World War Two was several-fold more densely populated than today. While most of the rich soils were tilled, marginal woods were used as communal pastures of numerous cattle (Affek 2015). Because of war, most of the inhabitants of the borderland between Poland and the then Ukrainian Soviet Republic have been forcefully displaced, and most of the former pastured woods were acquired by the State Forest Holding. Regardless of the husbandry decline, the Forest Act of the early 1970s has imposed a universal ban on any livestock grazing in forests. As a result, the PL studied stands can be considered "shadow" pastured woods retaining "silvopastoral" oaks (usually only part of them), but as habitats being entirely transformed into dense-canopy communities with very poor herb layer.

In that respect, the Cis-Carpathian woods are a very different case. Until the late 1970s, they were used as treed meadows, where after the hay harvest grazed by cattle. Later, despite a substantial decline of livestock, some of such marginal oak woods are still occasionally grazed. However, the most important factor, sustaining their semi-open character are frequent spring grass fires spreading into woods from the neighbouring abandoned plough land, where local people burn the dry herbal biomass to improve the transform them into pastures. In such a way the woody undergrowth (mainly of hazel) is kept under control and the lush grassy vegetation develops under scattered oak stands (Ziobro et al. 2016) (Photo 3).

The presented data confirm the hypothesis that silvopastoral habitats provide more diverse, heterogenous growth conditions to oaks than those in dense timber

Photos 1, 2. Working wood-pastures in Transylvania

Photo 3. Cattle grazing on the margin of the oak wood in Ukraine

stands. Therefore, as expected, oaks ageing in silviculture-led stands result in a more unequivocal H and DBH response than if they were subjected to uneven conditions of silvopastoral habitats. In addition, open or semi-open grown oaks cease their height increase earlier than their forest counterparts exposed to the competition from their neighbours. Therefore, the H/DBH ratio would react to tree age with a different dynamic than in high timber stands, which complies with the findings of Gafta and Crişan (2010).

Our findings prove the process of silvopastoral woods being much more complex, influenced by far more variegated habitats than the development of timber high stands following the strict silvicultural regime. While in the former case the tree recruitment is usually extended in a time interval of several mast years, the oak silviculture routinely applies dense planting of even-aged future stands. As a result, small lots of silvopastoral oak woods represent a much wider range of age and stronger variability of parameters than larger sylvicultural stands. The study implies that the drivers leading to the establishment of silvopastoral woods are better harmonised with the intrinsic ecological adaptations of oaks than modern sylvicultural treatments.

With the oaks planting in clear-cut areas being the only oak regeneration technique applied in the region, we assumed the average H and DBH values of the stands provided by the forestry database (Table 2). Because of the common practice of establishing even-aged planted oak stands in production forests, the acquired age data of the stands were reliable. For the same reason, due to the homogeneous character of sylvicultural oak stands, we referred to the average values of dendrometric parameters of the stands.

Conclusions

The legacies of oak silvopastoral woods in South-Eastern Poland, Western Ukraine and in the Hungarian upland, as well as the grazed Romanian wood pastures, reveal a much weaker correspondence between the age of oaks and their dendrometric parameters (DBH, H and their quotient, *si*, the slenderness index) than sylvicultural high timber stands.

All examined oak woods are characterized by the lower average slenderness index of oak trees than the analyzed sylvicultural high timber stands. This may prove the natural origin of the oaks growing in these oak woods and the sylvipastoral use of this area in the first decades of life of these oaks.

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References

Affek, A. 2015. Spatially explicit changes in land ownership through 3 socio-political systems: A case study from south-east Poland. *Geographia Polonica* 88(3): 519–530. https://doi.org/10.7163/GPol.0032.

BDL. 2018. Bank Danych o Lasach. Biuro Urządzania Lasu i Geodezji Leśnej [Forest Data Bank. Forest Management and Geodesy Office]. Sękocin Stary, ul. Leśników 21, 05- 090 Raszyn. URL: https://www.bdl.lasy.gov.pl/portal/ (in Polish and English).

Becquey, J. and Riou-Nivert, P. 1987. L`existence de zones de stabilite des peuplements. Consequences sur la gestion [The existence of "zones of stability" of the stands. Management consequences]. *Revue Forestière Française* 39: 323–334 (in French with English summary).

Bergmeier, E., Petermann, J. and Schröder, E. 2010. A geobotanical survey of wood pasture habitats in Europe: diversity, threats and conservation. *Biodiversity and Conservation* 19(11): 2995–3014.

Bobiec, A., Reif, A. and Ollerer, K. 2018. Seeing the oakscape beyond the forest: a landscape approach to the oak regeneration in Europe. *Landscape Ecology* 33(4): 513–528. https://doi.org/10.1007/s10980-018-0619-y.

Bugalho, M.N., Cladeira, M.C., Pereira, J.S., Aronson, J. and Pausas, J.G. 2011. Mediterranean cork oak savannas require human use to sustain biodiversity and ecosystem services. *Frontiers in Ecology and the Environment* 9(5): 278–286. https://doi.org/10.1890/100084.

Burschel, P. and Huss, J. 1997. Grundriss des Waldbaus [Ground plan of the silviculture]. Parey Buchverlag, Berlin, 487 pp. (in German).

Cucchi, V., Meredieu, C., Stokes, A., De Coligny, F., Suarez, J. and Gardiner, B.A. 2005. Modelling the windthrow risk for simulated forest stands of Maritime pine (*Pinus pinaster* Ait.). *Forest Ecology and Management* 213(1-3): 184–196. https://doi.org/10.1016/j.foreco.2005.03.019.

Dell. 2015. Statistica, an advanced analytics software package, version 13. Dell Inc., Round Rock, Texas, USA. URL: www.dell.com.

Field-Map. 2018. IFER – Monitoring and Mapping Solutions, Ltd., Čs. armády 655, 254 01 Jilove u Prahy, Czech Republic. URL: http://www.ifer.cz, https://www.field-map.com.

Freschet, G.T., Ostlund, L., Kichenin, E. and Wardle, D.A. 2014. Aboveground and belowground legacies of native Sami land use on boreal forest in northern Sweden 100 years after abandonment. *Ecology* 95(4): 963–977. https://doi.org/10.1890/13-0824.1.

Gafta, D. and Crişan, F. 2010. Scaling allometric relationships in pure, crowded, even-aged stands: do tree shade-tolerance, reproductive mode and wood productivity matter? *Annals of Forest Research* 53(2): 141–149.

Garrido, P., Elbakidze, M., Angelstam, P., Plieninger, T., Pulido, F. and Moreno, G. 2017a. Stakeholder perspectives of wood-pasture ecosystem services: A case study from Iberian dehesas. *Land Use Policy* 60: 324–333. https://doi.org/10.1016/j.landusepol.2016.10.022.

Garrido, P., Elbakidze, M. and Angelstam, P. 2017b. Stakeholders' perceptions on ecosystem services in Östergötland's (Sweden) threatened oak wood-pasture landscapes. *Landscape and Urban Planning* 158: 96–104. https://doi.org/10.1016/j.landurbplan.2016.08.018.

Hartel, T., Hanspach, J., Moga, C.I., Holband, L., Szapanyos, Á., Tamáse, R., Hováth, C. and Réti, K.O. 2018. Abundance of large old trees in wood-pastures of Transylvania (Romania). *Science of the Total Environment* 613–614: 263–270. https://doi.org/10.1016/j.scitotenv.2017.09.048.

Hinze, W.H.F. and Wessels, M.O. 2002. Stand stability in pines: an important sylvicultural criterion for the evaluation of thinnings and the development of thinning regimes: management paper. *Southern African Forestry Journal* 196(1): 37–40. https://doi.org/10.1080/20702620.2002.10434616.

Horák, J. and Rébl, K. 2013. The species richness of click beetles in ancient pasture woodland benefits from high level of sun exposure. *Journal of Insect Conservation* 17(2): 307–318.

Jaworski, A. 2003. Zmiany tendencji wzrostowych głównych lasotwórczych gatunków drzew w Europie i obszarach górskich Polski oraz ich przyczyny. Część II. Przypuszczalne przyczyny zmian tendencji wzrostowych [Changes in growth trends of the main forest tree species in Europe and mountain regions in Poland and possible causes. Part II. Possible causes of changes in growth trends]. *Sylwan* 147(7): 69–74 (in Polish with English abstract).

Kaźmierczak, K. and Stosik, M. 2008. Analiza wybranych cech przestrzeni wzrostu pojedynczego drzewa na przykładzie 135-letniego drzewostanu dębowego [Analysis of selected features of the growth space of a single tree on the example of a 135-year-old oak stand]. *Sylwan* 152(2): 3–9 (in Polish with English abstract).

Kaźmierczak, K., Pazdrowski, W., Mańka, K., Szymański, M. and Nawrot, M. 2008. Kształtowanie się smukłości pni dębu szypułkowego (*Quercus robur* L.) w zależności od wieku drzew [Forming slenderness of pedunculate oak stems (*Quercus robur* L.) in dependence of age of trees]. *Sylwan* 152(7): 39–45 (in Polish with English abstract).

Kaźmierczak, K., Borzyszkowski, W. and Korzeniewicz, R. 2015. Slenderness of 35-year-old pines from a dominant stand as an indicator of a stand stability. *Forestry Letters* 108: 32–35.

Lu, J. and Zhang, L. 2013. Evaluation of structure specification in linear mixed models for modelling the spatial effects in tree height-diameter relationships. *Annals of Forest Research* 56(1): 137–148.

Luick, R. 2008. Transhumance in Germany. Report to European Forum on Nature Conservation and Pastoralism (EFNCP). 16 pp. Available online at: http://www.efncp.org/download/Swabian_Alb_F_F_Download.pdf. Accessed: September 3, 2018.

Mattheck, C. 2002. A new failure criterion for non-decayed solitary trees. *Arboricultural Journal* 26(1): 43–54. https://doi.org/10.1080/03071375.2002.9747317.

Mezei, P., Grodzki, W., Blaženec, M. and Jakuš, R. 2014. Factors influencing the wind-bark beetles' disturbance system in the course of an *Ips typographus* outbreak in the Tatra Mountains. *Forest Ecology and Management* 312: 67–77. https://doi.org/10.1016/j.foreco.2013.10.020.

Orzeł, S. 2007. A comparative analysis of slenderness of the main tree species of the Niepolomice Forest. EJPAU 10(2), #13. Available online at: http://www.ejpau.media.pl/volume10/issue2/art-13.html. Accessed: September 3, 2018.

Öllerer, K. 2012. The flora of the Breite wood-pasture (Sighisoara, Romania). *Brukenthal Acta Musei* 7(3): 589–604.

Paltto, H., Nordberg, A., Nordén, B. and Snall, T. 2011. Development of secondary woodland in oak wood-pastures reduces the richness of rare epiphytic lichens. *PLoS ONE* 6, e24675. https://doi.org/10.1371/journal.pone.0024675.

Peltola, H., Kellomäki, S., Väisanen, H. and Ikonen, V.P. 1999. A mechanistic model for assessing the risk of wind and snow damage to single trees and stands of Scots pine, Norway spruce, and birch. *Canadian Journal of Forest Research* 29(6): 647–661. https://doi.org/10.1139/x99-029.

Plieninger, T., Hartel, T., Martín-López, B., Beaufoy, G., Bergmeier, E., Kirby, K., Montero, M.J., Moreno, G., Oteros-Rozas, E. and Van Uytvanck, J. 2015. Wood-pastures of Europe: geographic coverage, social-ecological values, conservation management, and policy implications. *Biological Conservation* 190: 70–79. https://doi.org/10.1016/j.biocon.2015.05.014.

Pretzsch, H., Biber, P., Schütze, G. and Bielak, K. 2014. Changes of forest stand dynamics in Europe. Facts from long-term observational plots and their relevance for forest ecology and management. *Forest Ecology and Management* 316: 65–77. https://doi.org/10.1016/j.foreco.2013.07.050.

Rust, S. 2014. Analysis of regional variation of height growth and slenderness in populations of six urban tree species using a quantile regression approach. *Urban Forestry and Urban Greening* 13(2): 336–343. https://doi.org/10.1016/j.ufug.2013.12.003.

Sharma, R.P., Brunner, A. and Eid, T. 2012. Site index prediction from site and climate variables for Norway spruce and Scots pine in Norway. *Scandinavian Journal of Forest Research* 27(7): 619–636. https://doi.org/10.1080/02827581.2012.685749.

Solberg, S., Andreassen, K., Clarke, N., Tørseth, K., Tveito, O.E., Strand, G.H. and Tomter, S. 2004. The possible influence of nitrogen and acid deposition on forest growth in Norway. *Forest Ecology and Management* 192(2-3): 241–249. https://doi.org/10.1016/j.foreco.2004.01.036.

Stankova, T.V. and Diéguez-Aranda, U. 2013. Height-diameter relationships for Scots pine plantations in Bulgaria: optimal combination of model type and application. *Annals of Forest Research* 56(1): 149–163.

Stępień, E. 2014. Stabilność lasu i drzewostanów, metody szacowania oraz znaczenie w gospodarowaniu zasobami leśnymi [The stability of woods and forests – the principles and importance of assessing the sustainability of forest and forestry]. *Studia i Materiały CEPL* 39(2A): 70–79 (in Polish with English abstract).

Wang, Y., Titus, S.J. and LeMay, V.M. 1998. Relationships between tree slenderness coefficients and tree or stand characteristics for major species in boreal mixedwood forests. *Canadian Journal of Forest Research* 28(8): 1171–1183. https://doi.org/10.1139/x98-092.

Wilson, J.S. and Oliver, C.D. 2000. Stability and density management in Douglas-fir plantations. *Canadian Journal of Forest Research* 30(6): 910–920. https://doi.org/10.1139/x00-027.

Zang, C. and Rothe, A. 2013. Effect of nutrient removal on radial growth of *Pinus sylvestris* and *Quercus petraea* in Southern Germany. *Annals of Forest Science* 70(2): 143–149. https://doi.org/10.1007/s13595-012-0238-8.

Ziobro, J., Koziarz, M., Havrylyuk, S., Korol, M., Ortyl, B., Wolański, P. and Bobiec, A. 2016. Spring grass burning: an alleged driver of successful oak regeneration in sub-Carpathian marginal woods: a case study. *Prace Geograficzne* 146: 67–88. https://doi.org/10.4467/20833113PG.16.018.5548.