Wood Quality of *Quercus cerris* from Kosovo

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THESIS PRESENTED TO OBTAIN THE DOCTOR DEGREE IN FORESTRY ENGINEERING AND NATURAL RESOURCES

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2018

DEDICATION

This thesis is dedication to my parents, HALA and HETEM.

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This Thesis is my final work for the award of PhD in **Wood Quality of *Quercus cerris* from Kosovo**, at the Lisbon University. I wish to express my gratitude to all those who have supported, advised and assisted me in pursuing this research. Specifically, I would like to thank my supervisor, Dr. Helena Margarida Nunes Pereira and my co-supervisor Dr. Lina Maria Ribeiro Nunes for their continued and valuable support, professional guidance, and constructive feedback over the thesis-writing period, without which the production of this thesis would not have been possible.

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Last but certainly not least, I would like to express my appreciation to my wife Fatime, my son Dren and my daughter Ensara, for their understanding and support during this lonely journey of doctoral research.

ABSTRACT

Kosovo's forest products industry is a very important part of Kosovo's economy and within the present work data was collected through a survey of all sawmills in Kosovo and information gathering from the Ministry of Agriculture, Forestry and Rural Development of Kosovo. The forest resources and sawmill structure of Kosovo were analyzed and the availability of different species of wood in different regions of the country established.

In parallel, the study of one home grown wood species, *Quercus cerris*, was conducted in order to improve its use in sawmilling to produce value added wood components. For this purpose, ten *Quercus cerris* trees, grown in two sites in Kosovo, were felled and discs taken at different stem height levels. Relevant data for this species was obtained on stem quality, including heartwood, sapwood and bark development as well as ring analysis.

Chemical and durability characterization was also conducted together with the evaluation of density and Brinell hardness. *Quercus cerris* from Kosovo showed good potential as a timber species for the supply of stem wood to the saw-milling industry allowing good yields of heartwood-only sawn wood components. Taking into account the good technological properties measured together with the apparent low level of extracts and the low durability class against subterranean termites, interior or protected uses are highly recommended. The bark should also be considered for complementary valorization.

Furthermore, based on the worked developed, a curricular programme combining scientific and technological knowledge for industrial management, communication knowledge and creative work was developed in close cooperation with wood processing enterprises in Kosovo, and with the Kosovo Wood Processing Association. Recommendations were also provided for further development of the forest and sawmill industry.

Keywords: *Quercus cerris*, Kosovo, stem quality, heartwood, chemical analysis, insect durability.

Qualidade da madeira de *Quercus cerris* produzida no Kosovo

Resumo

A indústria de produtos florestais no Kosovo é uma parte muito importante da economia do país. Neste trabalho foram recolhidos dados através de um levantamento de todas as serrações do Kosovo e de informações do Ministério da Agricultura, Florestas e Desenvolvimento Rural. Foram analisados os recursos florestais e a estrutura da indústria de serração do Kosovo e foram estimadas as disponibilidades das diferentes espécies de madeira nas diferentes regiões do país.

Paralelamente, foi conduzido o estudo de uma espécie autóctone, *Quercus cerris,* para melhorar o seu uso em serração para produtos de madeira de maior valor acrescentado. Para este fim, foram abatidas dez árvores de *Quercus cerris,* cultivadas em dois locais no Kosovo, e foram retirados discos em diferentes níveis de altura do tronco. Obtiveram-se dados relevantes para esta espécie sobre a qualidade do tronco, incluindo desenvolvimento de cerne, borne e casca, bem como análise dos anéis de crescimento. Foi também realizada a caracterização química e de durabilidade assim como a avaliação de densidade e dureza de Brinell. O *Quercus cerris* do Kosovo mostrou um bom potencial para o fornecimento de toros de madeira para a indústria de serração, permitindo bons rendimentos de componentes de madeira de cerne. Recomenda-se o uso desta madeira em ambientes interiores ou protegidos tendo em conta as suas boas propriedades tecnológicas da madeira mas com um baixo teor de extrativos e uma classe de durabilidade baixa contra térmitas subterrâneas. A casca deverá também ser considerada como matéria prima para uma maior valorização.

Além disso, com base no trabalho desenvolvido, apresenta-se um programa curricular que combina conhecimento cíentifico e tecnológico para a gestão industrial, comunicação e trabalho criativo, desenvolvido em estreita colaboração com as empresas da fileira da madeira no Kosovo bem como com a

Associação que as representa. São ainda apresentadas recomendações para o desenvolvimento futuro do setor

Palavras-chave: *Quercus cerris*, Kosovo, qualidade da madeira, cerne, análise química, durabilidade aos insetos.

3.2. RESULTS

3.2.1. Forest resources and sawmill structure of Kosovo: State of the art and perspectives

3.2.2. Wood industry is an important factor for the Kosovo's development – the role of higher education

3.2.3. Stem quality of *Quercus cerris* trees from Kosovo for the sawmilling industry

3.2.4. Chemical characterization, hardness and termite resistance of *Quercus cerris* heartwood from Kosovo

Chapter 4 - Conclusions and Recommendations

CONCLUSIONS AND RECOMMENDATIONS

Chapter 1
Introduction and objectives

1.1 INTRODUCTION

Located in the heart of the Balkans, Kosovo represents a bridge between the several countries of South Eastern Europe. Through its unique geographical position and its liberal trade regime, Kosovo offers access to the interesting and growing markets of the Balkans and Central Europe, comprising 100 million potential customers. Forestry and forest products industry are important components of the country's economy. The annual value of wood products and other benefits arising from forests and related areas are estimated to be between approximately 50 and 75 million Euro, resulting in a contribution by the wood industry of between 1.8 % and 2.6 % to GDP (EICIKS, Investment Promotion Agency of Kosovo. 2008). Currently the wood products made in Kosovo include doors, window frames, furniture and various wood construction materials, while the manufacture of other products, such as fencing material, pallets, boxes, dimension and prefabricated components, is still limited.

Today the wood processing industry in Kosovo only uses round wood for producing lumber in sawmills and for firewood. The development of a wood products industry is recognized as an important component for enhancing the economic development of Kosovo. Not only are the various types of wood in Kosovo easily accessible in terms of quantity, but they are also available at competitive prices. Taking into consideration that wage levels in Kosovo are below the regional average and that the costs of inputs are competitive, one of the main advantages of the wood processing industry in Kosovo is its low cost. In particular, the wood industry therefore represents a good investment opportunity for those companies wishing to offer wood products to the regional market, manufactured at reasonable production costs.

However, the harvesting potential of Kosovo is to a large extent under-utilized. Forests cover 481 000 ha, representing 44.7% of the total area of the country, and are dominated by broadleaved trees, covering up to 93 % of the total forest area (Tomter *at al. 2013)*. The growing stock includes mainly *Fagus* and *Quercus spp* that account for 46% and 23% of the volume respectively. *Quercus cerris* is the major oak species with 4.28 billion m^3, followed by *Quercus petrea* with 3.67 billion m^3 and other oak species with 1.29 billion m^3. *Quercus cerris (*the Turkey oak*)*, is native to the southern central and southeastern Europe, extending into southwestern Asia (Danielewicz *et al.* 2014). It is a large, fast-growing deciduous tree, tolerating a range of soil types and able to quickly colonize open areas. It can withstand air pollution, is relatively tolerant to drought and has an attractive appearance, thereby often planted as an ornamental in urban areas (Sterry 2007; Preston *et al.* 2002). Moreover, it is useful for reforestation, erosion control and soil conservation as well as an agro-forestry species providing acorns and shoots for animals (Mert *et al.* 2016).

As regards the timber value of *Quercus cerris*, the wood has been used mainly for low-value applications, such as firewood and railway sleepers, and has not been considered for more demanding applications e.g. carpentry, due to low dimensional stability, low durability mainly of the sapwood (Giordano 1981) and difficult gluing (Lavisci *et al.* 1991). The possibility to use it in higher value products as raw material for construction has been investigated by Bajraktari *et al.* (2016), where they analyzed some mechanical and physical properties of *Quercus cerris* as well as the capacity of Kosovo forests to fulfill the needs for *Quercus cerris.* In this study Bajraktari *et al.* (2016) suggest that *Quercus cerris* in Kosovo showed good potential as a timber species for the supply of stem wood to the saw-milling industry. Furthermore, this study brings data on the heartwood and sapwood development within *Quercus cerris* trees grown in two sites in Kosovo, in view of increasing the value of its exploitation as a timber species for the sawmilling industry. It also includes an analysis of bark content anticipating its possible valorization under a full resource use approach.

The durability of *Quercus cerris* heartwood was also studied since biological deterioration of applied timber is often viewed as a limiting factor for its improved used in building. The natural durability of a wood species, defined as its inherent resistance to wood destroying agents, can vary with tree age, the geographical origin of the species, and the growing conditions. In the present work, the natural durability class for insect degradation was determined, as defined by EN350 (2016). Subterranean termites from the species *Reticulitermes grassei* (Clément) were used as models of insect degradation as they are accepted as the most dangerous insect species capable of degrading applied timber in Europe and elsewhere and in a changing climate scenario their risk is expected to be higher (Ewart *et al.* 2016). Tests were conducted according to EN 117 (2013) and the results obtained linked to the chemical analysis, density and Brinell hardness data obtained from paired test specimens.

1.2. OBJECTIVES

This work intends to contribute to the sustainable use of wood particularly in the Balkan region. For this goal, the main established objectives are:

- To evaluate the forest resources by determining the annual volumes of roundwood felled in the forests of Kosovo in relation to the amounts of timber available in the forest;
- To show and describe the sawmill structure in Kosovo;
- To study *Quercus cerris* as a model timber species with high technological potential including:
    - Evaluation of stem quality of *Quercus cerris* for the sawmilling industry regarding heartwood, sapwood and bark development as well as ring analysis and taper;
    - Evaluation of insect natural durability of *Quercus cerris* and its relation to chemical composition and some mechanical parameters.

1.3. THESIS STRUCTURE

Chapter 1 of this thesis provides a brief introduction to Kosovo's geographic position, distribution of forest area and particularly the coverage of Turkey oak (*Quercus cerris*) which is the main subject of study in this research. Furthermore chapter 1 provides aim and objectives of this thesis. Besides the introduction Chapter, this thesis is divided into three more Chapters.

Chapter 2, or State of the art chapter, provides a review of relevant literature of the Turkey oak wood. This chapter is mainly based on general characteristics of Turkey oak and on the properties of its wood namely on physical and mechanical properties.

Chapter 3 includes the original work carried out within this research work. It provides an explanation of the experimental work and general methodology used in this research including sample selection and analysis methods. Moreover, this chapter provides the results and discussion of the main findings from this research, organized as autonomous papers: (1) Forest resources and sawmill structure of Kosovo: State of the art and perspectives; (2) Wood industry is an important factor for the Kosovo's development – the role of higher education; (3) Stem quality of *Quercus cerris* trees from Kosovo for the sawmilling industry; and (4) Chemical characterization, hardness and termite resistance of *Quercus cerris* heartwood from Kosovo.

Finally, Chapter 4 concludes this thesis by fulfilling its aim and objectives and providing recommendation for future studies in sustainable use of Turkey oak wood.

Chapter 2
State of the art

2.1. GENERAL CHARACTERISTICS OF TURKEY OAK

2.1.1 Taxonomic classification and tree description

The *Quercus cerris* L., known by the common name of Turkey oak is a tree belonging to the family Fagaceae and the genus *Quercus*. Turkey oak represents section *Cerris*, a particular section within the genus *Quercus* which includes species for which the maturation of acorns occurs in the second year. This genus has about 531 classified species distributed throughout the Americas, Asia, Malaysia, Europe and North Africa (Uslu *et al.* 2011) and is one of the most important genera in the forest occupation in central and western Europe due to the diversity of species, ecological dominance and economic value (Stafasani and Toromani 2015).

The Turkey oak (*Quercus cerris*) is a hardwood that presents the taxonomic classification shown in Figure 2.1.

Figure 2.1. Taxonomic classification of the species *Quercus cerris*.

Quercus cerris L. is a large fast-growing deciduous tree species growing to 40 m tall with a trunk up to 1.5-2 m in diameter (Savill, 2013) and with a well-developed root system (Di Iorio *et al.* 2007). Turkey oak can live for around 120-150 years (Praciak, *et al.* 2013).

The bark is mauve-grey and deeply furrowed with reddish-brown or orange bark fissures (Gilman and Watson 1994). Compared with other common oak species, e.g. sessile oak (*Quercus petraea*) and pedunculate oak (*Quercus robur*), the Turkey oak wood is inferior, and only useful for rough work such as shuttering or fuelwood (Savill 2013). The leaves are dark green above and grey-felted underneath (Mitchell *et al.* 1974).

Figure 2.2. Turkey oak (*Quercus cerris*) forest

The leaves are variable in size and shape but are normally 9-12 cm long and 3-5 cm wide, with 7-9 pairs of triangular lobes (Mitchell *et al.* 1974). The leaves change the color from yellow to gold in late autumn and drop off or persist in the crown until the next spring, particularly on young trees. The twigs are long and pubescent, grey or olive-green, with lenticels. The buds, which are concentrated on the tip of the twigs, are egg-shaped and hairy and, typically, they are surrounded by long twisted whiskers. The flowers appear in April-May and are monoecious and wind-pollinated. The fruit is a large acorn stalkless, 2-3.5 cm long and 2 cm broad (Praciak, *et al.* 2013).
The acorn cup is densely covered with bristles (Figure 2.2.). Turkey oak acorns mature over a two-year period, but the acorn crop is abundant and it germinates readily and can be easily propagated (Savill 2013**,** Praciak *et al.* 2013).

Figure 2.3. Turkey oak (*Quercus cerris*) fruit and leaves

2.1.2 Geographical distribution

2.1.2.1. *Quercus cerris* in Europe

The geographical distribution range of *Quercus cerris* extends from southern Europe to Asia Minor. Across its distribution range, this wood species is predominantly present in the Balkan and Italian Peninsulas. The western limit of its natural range is France and its northern limit is in Germany, continuing eastward through Austria, Switzerland, eastern Czech Republic, Slovakia and Hungary (Praciak, *et al.* 2013). It is one of the 12 native oak species present in Albania. Also, in Bulgaria it occupies drier and moderately rich habitats in the plain and hilly regions (Yurukov and Zhelev 2001), where it forms large forests with other oak species (e.g. *Quercus frainetto*, *Quercus pubescens*) and other mixed broadleaves including field maple (*Acer campestre*), elm (*Ulmus minor*) Oriental hornbeam (*Carpinus orientalis*) and manna ash (*Fraxinus ornus*). It is equally important in Hungary, where it forms over 11% of the forested area (Solymos 1993). In Italy, it grows from sea level up to the Apennines and covers around 280 000 ha over the peninsula, frequently occurring together with Hungarian oak (*Q. frainetto*) (Bozzano and Turok 2003).

Turkey oak (*Quercus cerris*) is also widely distributed in Slovenia, most frequently in the sub-mediterranean regions of Kras, Brkini and Tolminsko, but it also grows on warm and dry steep slopes in the continental parts of the country (Bozzano and Turok 2003). In the case of a warming climate, the *Quercus cerris* species is expected to show a range shift to the North (Hlasny *et al.* 2011). Turkey oak is also present in other European countries including the UK and France, and it is also planted in North America, Ukraine, Argentina and New Zealand (Praciak, *et al.* 2013).

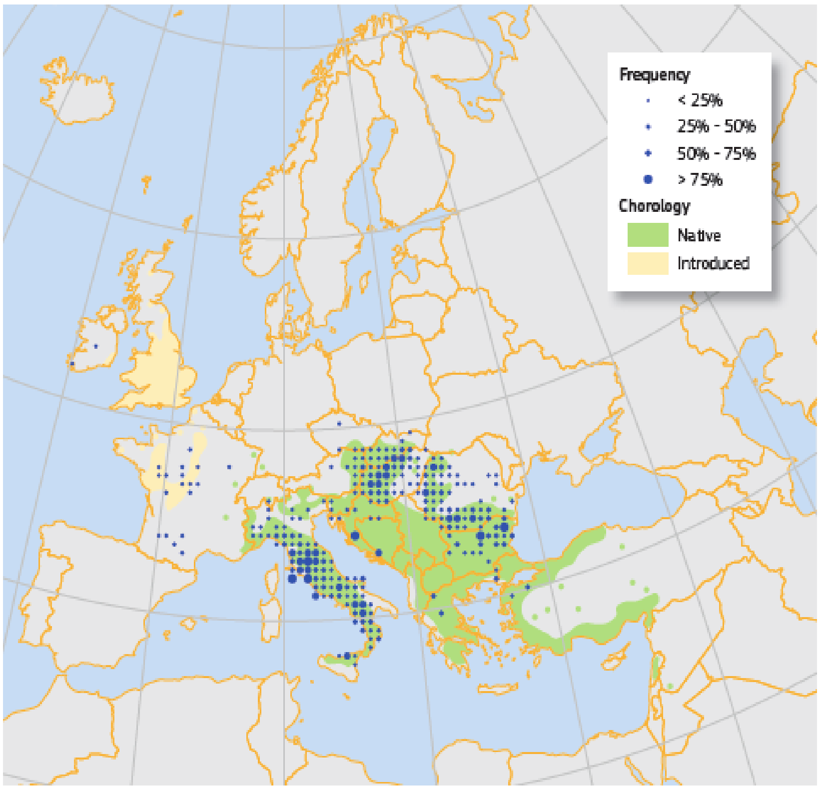

Figure 2.4. Plot distribution and simplified chorology map for *Quercus cerris* (from de Rigo *et al.* 2016)

Figure 2.4. represents the frequency of *Quercus cerris* occurrences within the field observations as reported by the National Forest Inventories (Jalas and Suominen 1976).
Turkey oak can be easily adapted to a variety of different site conditions. It is relatively tolerant to drought (more than the other oak species of the same region) (Praciak, et al 2013), air pollution and can grow in a wide range of soil types including weakly acid, or even shallow calcareous soils, as long as they are not too dry (Savill 2013). When the species is established, it develops a taproot and deep lateral root branches, helping it to remain windfirm (Praciak, *et al.* 2013). Moreover, it is a light demanding species but can grow under a light woodland canopy (Savill 2013). It has many pioneer characteristics, including good germination rates of seeds and fast early growth. It also has a high resprouting capacity, making it particularly suitable for coppicing and pollarding (Praciak, *et al.* 2013).
Over the last 400 years, the region in which oaks sections grow together has been dramatically expanded by widespread human planting in northern and western Europe of Turkey oak (Figure 2.5.). This introduction has triggered multiple invasions by a suite of host-alternating gallwasps, reaching northwards to Scotland and westwards to the northern slopes of the Pyrenees (Bozzano and Turok 2003). Genetic data show that all invading gallwasp populations have originated from within the native Balkan range of *Quercus cerris*, with no range expansion by Iberian peninsula populations (Bozzano and Turok 2003). In Iberia, cork oak (*Q. suber*) replaces *Quercus cerris*, and Iberian gallwasp populations have proven unable to make the host switch from *Q. suber* to *Quercus cerris* that is necessary for northwards range expansion.

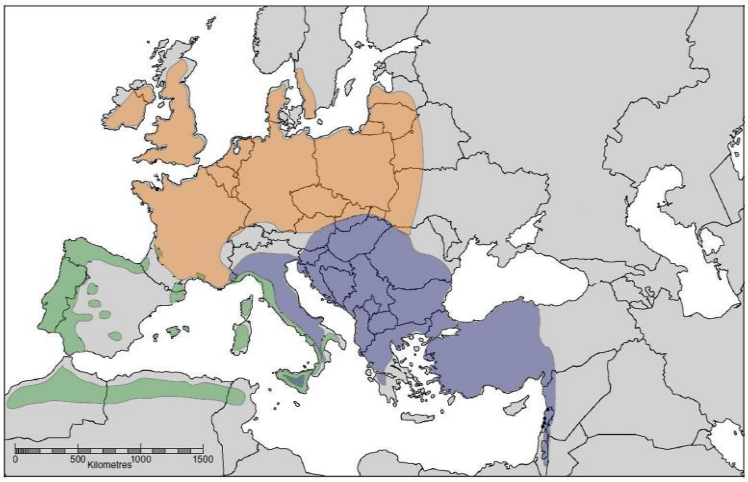

Figure 2.5. Map indicating the major European *Quercus* section cerris oak distributions. Green shading indicates the native distribution of *Q. suber*, blue the native distribution of *Quercus cerris*, and orange the introduced distribution of *Quercus cerris* (adapted from Nicholls *et al.* 2010)

2.1.2.2. *Quercus cerris* distribution in Kosovo

Forests in Kosovo are distributed around its state borders; however more dense forests are concentrated along northern and western part of Kosovo's borders.

The forest area composition is comprised by 449,400 ha of broadleaved species, 23,800 ha of coniferous species, and 7,800 ha pf mixed forests. In terms of ownership, around 180 800 ha, or 38 % of Kosovo's forest is classified as privately owned, and 295,200 ha, or 62 % is classified as public forest. Approximately 44 % of its total area is covered by forests which counts up to 481,000 ha. Growing stock of trees with diameter at breast height >= 7 cm stands at 40.5 million m^3, which is about the same as ten years ago. Amongst the trees, *Fagus* species contribute 46 % of the volume, whereas *Quercus* species represent 23 %. The mean growing stock in Kosovo is 84 m^3/ha.

Annual increment over bark of trees with diameter (dbh) ≥ 7 cm is estimated at 1.55 million m^3 – 1.32 million of broadleaves and 0.23 million of coniferous trees.

Land use distribution in Kosovo was measured and calculated by Tomter *et al.* (2013) based on classification of 3,453 sample plots. Most of the land use in Kosovo is covered by forests with around 481,000 ha or 44.7 % of its total area (Figure 2.6.).

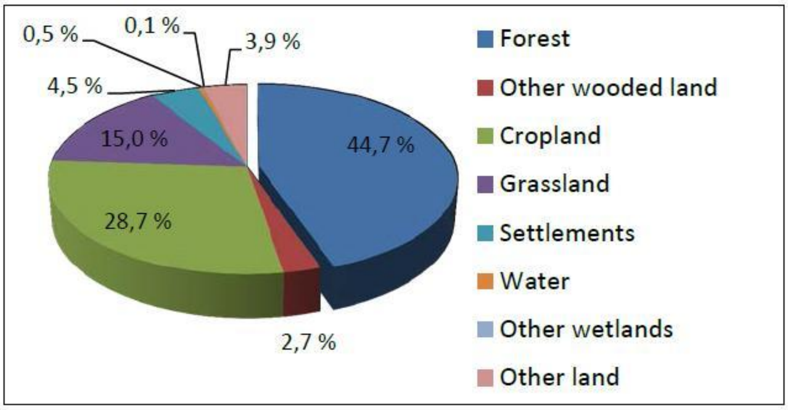

Figure 2.6. Land use classes in Kosovo (% of total land area)

Source: Tomter S. M., Bergsaker E., Muja I., Dale T. and Kolstad J. 2013. Kosovo National Forest Inventory 2012. Kosovo Ministry of Agriculture, Forestry and Rural Development/Norwegian Forestry Group

This area is followed by cropland which constitutes around 309,000 ha, or 28.7 % of the total Kosovo area. Another significant portion is comprised by grassland which constitutes around 161,000 or 15 % of its total area. In addition, there are other land use classes such as settlements, water, other wooded land, and other land which constitute a small portion of Kosovo's total area.

In Kosovo the forest age distribution by forest composition and age class explains the history of the forest, how it has been regenerated, how it has developed over the years, and also, how it probably will look in the future, i.e. future harvesting potential. Knowledge about age distribution can also provide information about biodiversity and the forest's recreational values. The major part of the forest area in Kosovo belongs to the age class between 0 to 80 years old.

Growing stock, expressed both in cubic meters and stocking levels (m^3/ha), is an important indicator for assessing sustainable forest management. Growing stock in Kosovo's forests that belong to broadleaves species is distributed as following (Table 2.1.): *Quercus cerris* 4,282,000 m^3, *Querus petrea* 3,669,000 m^3 and other *Quercus* species 1 292,000 m^3; and *Fagus* species 18,524,000 m^3, other broadleaves 6,750,000 m^3. On the other hand, growing stock of forests that belong to coniferous species is distributed as following: *Abies alba* 1,573,000 m^3, *Picea abies* 1,840,000 m^3, and *Pinus* species 2,502,000 m^3.

Table 2.1. Growing stock in forest by main tree species (dbh >= 7 cm) (1 000 m^3)

Tree species	2012
Quercus cerris	4 282
Querus petrea	3 669
Other *quercus* sp.	1 292
Fagus sp.	18 524
Other broadleaves	6 750
Undefined broadleaves	0
Abies alba	1 573
Picea abies	1 840
Pinus sp.	2 502
Other conifers	77
Total	**40 508**

Source: Tomter S. M., Bergsaker E., Muja I., Dale T. and Kolstad J. 2013. Kosovo National Forest Inventory 2012. Kosovo Ministry of Agriculture, Forestry and Rural Development/Norwegian Forestry Group

According to Tomter *et al.* (2013), the growing stock of the most valuable tree species for the high forest is either stable or increasing. Taking into consideration that the forest area is fairly stable this indicates that annual increment is balanced by annual harvesting and natural losses. Most of the growing stock in Kosovo is concentrated in forests compared to other wooded land. For example, around 5,992,000 m^3 of coniferous species and 34,516,000 m^3 of broadleaves species are grown in forests.

Moreover, growing stock in forest by tree species group and diameter class (Table 2.2.) indicates that the large scale short rotation coppice forestry contributes to broadleaves big share of growing stock in diameter class 10-20 cm and 30-50 cm, whereas growing stock in forest by tree species and diameter class indicates that *Fagus* species have the biggest share of growing stock, comprising 18,524,000 m^3 or 45.7 % from the total growing stock in Kosovo forests. In terms of diameter class, *Fagus* species biggest share stands in diameter class 30-50 cm.

Table 2.2. Growing stock in forest by tree species and diameter class (1,000 m^3)

Tree species	Diameter class						Total
	7-10	10 -20	20 -30	30 -50	50 -70	70 -	
Quercus cerris	592	1 686	923	872	127	83	4 282
Querus petrea	365	1 539	880	644	169	72	3 669
Other quercus sp.	245	646	164	57	143	37	1 292
Fagus sp.	494	2 559	3 077	6 244	3 840	2 311	18 524
Other broadleaves	883	2 274	1 233	1 246	372	742	6 750
Abies alba	34	216	364	660	183	117	1 573
Picea abies	45	286	487	829	193	0	1 840
Pinus sp.	28	181	468	1 195	472	159	2 502
Other conifers	2	10	8	57	0	0	77
Total	**2 688**	**9 397**	**7 604**	**11 804**	**5 499**	**3 521**	**40 508**

Source: Tomter S. M., Bergsaker E., Muja I., Dale T. and Kolstad J. 2013. Kosovo National Forest Inventory 2012. Kosovo Ministry of Agriculture, Forestry and Rural Development/Norwegian Forestry Group

Another important metric which indicates the elevation levels of the trees is the growing stock in forest by tree species and elevation above sea level (Table 2.3.). The oak species are mainly growing between 500 and 1,000 m above sea level.

Table 2.3**.** Growing stock in forest by tree species and elevation class (1,000 m^3)

Tree species	Elevation class						Total
	<500	500-750	750-1 000	1 000-1 250	1 250-1 500	>=1 500	
Quercus cerris	316	2 027	1 538	383	18	0	4 282
Quercus petrae	169	913	2 224	326	11	25	3 669
Other Quercus sp.	52	570	655	13	0	2	1 292
Fagus sp.	67	630	3 415	7 083	5 238	2 090	18 524
Other broadleaves	901	1 259	2 411	1 593	328	257	6 750
Abies alba	0	0	8	216	586	762	1 573
Picea Abies	0	16	10	92	277	1 446	1 840
Pinus sp.	109	127	4	69	254	1 938	2 502
Other conifers	49	1	22	5	0	0	77
Total	**1 663**	**5 543**	**10 287**	**9 780**	**6 712**	**6 520**	**40 508**

Source: Tomter S. M., Bergsaker E., Muja I., Dale T. and Kolstad J. 2013. Kosovo National Forest Inventory 2012. Kosovo Ministry of Agriculture, Forestry and Rural Development/Norwegian Forestry Group

The average growing stock in Kosovo forest is 84 m^3/ha. In Europe as a whole, the average growing stock is 105 m^3/ha, which is less than the world's average of 130 m^3/ha. Some Central European countries have forests with high productivity yielding stocking levels up to 250 m^3/ha. In all European regions the growing stocks have increased steadily during the past 20 years. The increase is due to both increases in forest area and stocking levels (Tomter *et al.* 2013). Turkey oak in Kosovo is in location see as in figures 2.7. & 2.8.

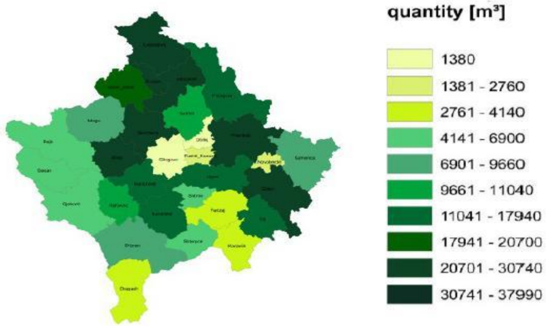

Figure 2.7. Allocation of in Kosovo (light green – low quantity, dark green – high quantity)
The needs for Turkey oak in Kosovo in different districts.

Source: Bajraktari A, Petutschnigg A, Ymeri M, Canda Z, Korkut S, Nunes L, Pereira H (2014) Forest resources and sawmill structure of Kosovo: State of the art and perspectives. Drvna Industrija 65 (4): 323-327. doi: 10.5552/drind.2014.1343

Figure 10. Oversupply and undersupply of oak in Kosovo (blue oversupply, red undersupply)

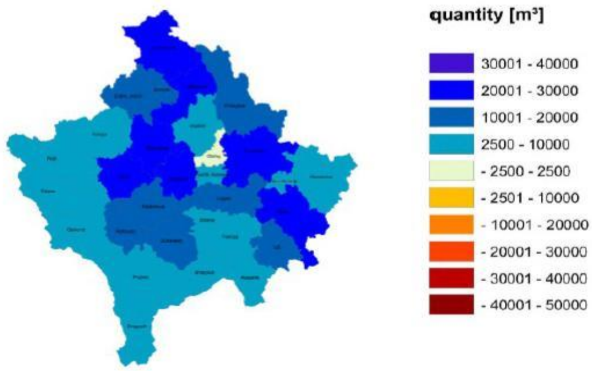

Figure 2.8. Oversupply and undersupply of oak in Kosovo (blue oversupply, red undersupply)

Source: Bajraktari A, Petutschnigg A, Ymeri M, Canda Z, Korkut S, Nunes L, Pereira H (2014) Forest resources and sawmill structure of Kosovo: State of the art and perspectives. Drvna Industrija 65 (4): 323-327. doi: 10.5552/drind.2014.1343

2.2. TURKEY OAK WOOD

2.2.1. Anatomical properties

The wood species are divided into two large groups, the hardwoods and the softwoods. Each of these groups has a characteristic anatomical arrangement, which also influences the wood properties (Tsoumis 1991, Carvalho 1996).

The resinous ones have a wood with homoxylated structure, constituted almost by a type of elements that are doubly in charge of the support and transport functions - vertical tracheids. The wood of the hardwoods is of heteroxylated structure, predominating two fundamental types of histological elements: the vessels, responsible for the circulation of the sebaceous liquids and the fibers with the transport paper (Carvalho 1996, Lauw 2011), only present in hardwoods (Tsoumis 1991). Oak wood is mostly ring porous, having large earlywood vessels and small latewood vessels. Earlywood vessels are distinctly larger in diameter than latewood vessels and are usually arranged in tangential bands of one to four cells. Fiber types in oak wood are libriform fibers and fiber tracheids. Libriform fibers have apparent simple pits and fiber tracheids have bordered pits with lenticular to slit-like apertures (Panshin and de Zeeuw 1980).

There are also other important components that are part of the constitution of wood: the rays and the parenchyma. Rays of oak are one of its best known distinctive features. Broad oak-type (compound) rays produce much of the figure for which oak wood is known. Compound rays are 12-30 or more cells wide and may be hundreds of cells high in the tangential-longitudinal plane. Latewood vessels are surrounded by light-colored, thin-walled paratracheal axial parenchyma. Vasicentric tracheids are also found in this tissue and are identical to axial parenchyma in cross-section. Similar earlywood conjunctive tissue contains more vasicentric tracheids and less parenchyma. Axial parenchyma (also called longitudinal parenchyma) also occurs apotracheally, often forming tangential bands in the latewood fibrous tissue.

There is extensive available literature on the macroscopic and microscopic characteristics of commercial oak species (Panshin and de Zeeuw 1980) but a lack of information was noted for Turkey oak wood though studies on its cork forming bark have been conducted in the last years (Leite and Pereira 2017).

Quercus cerris has a heteroxylated structure (Carvalho 1997) with mostly solitary vessels: initially with a pronounced elliptic shape and with a larger radial axis, with dimensions of 250 to 300 μ for 150 to 210 μ and constituting a band of 3 to 4 elements, the vessels gradually diminish in size, maintaining the same shape, but disposing in uniseriate chains. The parenchyma is metatraquial in tangential discontinuous and aggregate, diffuse and very abundant. The rays are of two types: broad, as it happens in oaks in general, with multiple cells of height (frequently exceeding 5000 μ) and wide (1000 to 1500 μ), with characteristic intercalar fibers; and narrow, unisserized or with 2 to 3 cells, in 1 to 2 rows of the body, and 3 to 30 cells of height (150 to 300 μ). The fibers are liberiform (Carvalho 1997).

Porosity varies in the different *Quercus* species, many species have ring porosity (e.g. *Quercus cerris*, *Quercus robur, Q.rubra or Q. pyrenaica*) while others have diffuse porosity (*Q. ilex*). *Q. suber* on the other hands shows semi-diffuse porosity. The porosity type influences the behavior of species subject to external factors. For example, Cherubini *et al.* (2003) reported higher competitiveness of *Q. suber* (semi diffuse porosity) when compared to *Quercus cerris* (ring porosity, Figure 2.9) under drought conditions as *Quercus cerris* is more prone to dehydration.

Tree ring analysis is considered as a powerful tool for the identification of the most important relations between the tree radial growth and the climate (Begum *et al.* 2013). Some dendrochronological studies have been conducted with *Quercus cerris* that reported Turkey oak has sensitive to local climatic conditions and different altitudes (Stafasani and Toromani, 2015).

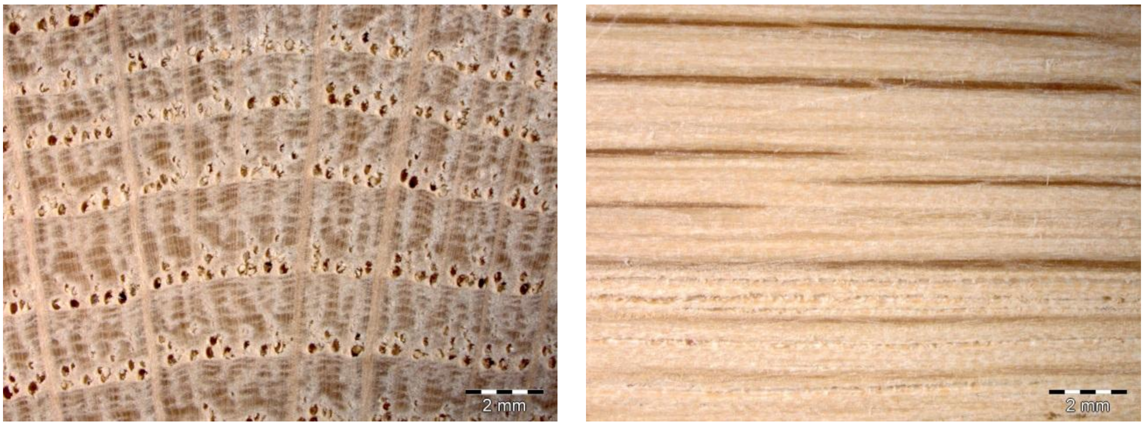

Figure 2.9. Transversal and tangential sections of *Quercus cerris* (from Duboçak, Kosovo)

2.2.2. Physical-chemical properties

Turkey oak wood shares many characteristics of other oaks but it's generally perceived as having lower quality (de Rigo *et al.* 2016). The wood is regarded as prone to cracking, with low dimensional stability and low durability particularly when compared to other oaks (Ferrari *et al.* 2013). Difficult gluing (Lavisci *et al.* 1991) and staining due to the presence of certain extractives (Todaro *et al.* 2013) were also referred as problems. Strong colour differences between the dark heartwood and the light and large sapwood (Figure 2.10) also contribute to the low-quality image of the timber. The high sapwood content (approximately half of the total diameter) can also be linked with the general perception of low durability.

Figure 2.10. Cross sectional discs of *Quercus cerris* from Duboçak (KD) and Blinaja (BB), Kosovo, showing heartwood and sapwood colour differences

Some studies were recently conducted to improve the wood properties and to homogenize surface color by using heat and steaming treatments (Todaro 2012, Todaro *et al.* 2012, 2013, Tolvaj and Molnart 2006). In parallel, Stanfest *et al.* (2012) characterized the colour of *Quercus cerris* from Kosovo and found significant differences between the colour parameters (L*, a* and b*) of Turkey and pedunculated oaks (*Quercus robur*) of similar origin (Figure 2.11.).

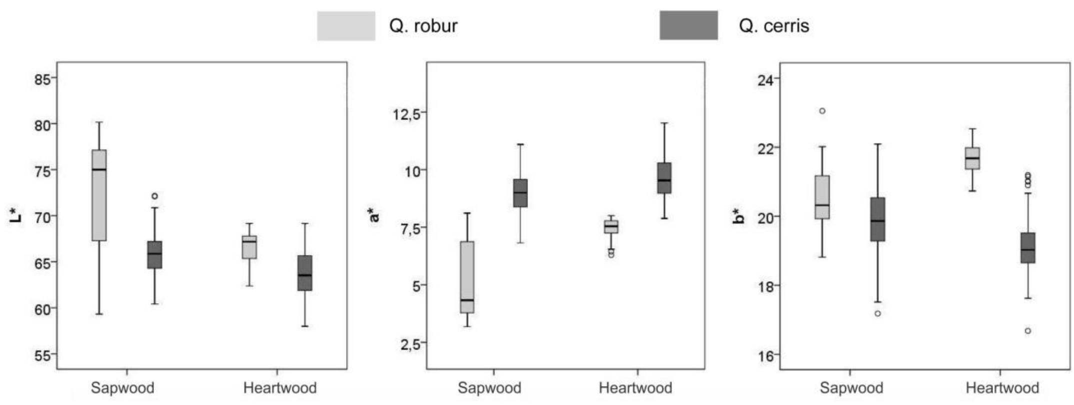

Figure 2.11. Comparison of wood species Pedunculate oak and Turkey oak separated by sapwood and heartwood, and the color values L*, a* and b* (from Standfest *et al.* 2012)

The interaction between the relative humidity and the wood balancing moisture of the heartwood and sapwood of *Quercus cerris* was also studied by the same authors (Stanfest *et al.* 2012a) as well as the comparative swelling behavior of Turkey and pedunculated oaks (Table 2.4.).

Table 2.4. Estimated mean and standard deviation (in parentheses) of linear and differential swelling of Turkey oak and pedunculate oak samples divided by heartwood and sapwood (from Standfest *et al.* 2012)

	Linear swelling (%)			**Differential swelling (%/%)**	
Wood type	**Axial**	**radial**	**Tangential**	**radial**	**tangential**
Quercus. cerris Heartwood	0,28 (0,19)	4,33 (0,51)	9,83 (0,85)	0,26 (0,03)	0,58 (0,04)
Quercus cerris Sapwood	0,27 (0,18)	4,19 (0,59)	9,45 (0,79)	0,25 (0,03)	0,56 (0,04)
Quercus robur Heartwood	0,29 (0,15)	2,74 (0,30)	4,63 (0,43)	0,18 (0,02)	0,31 (0,03)
Quercus robur Sapwood	0,32 (0,10)	2,66 (0,56)	4,47 (0,36)	0,17 (0,04)	0,29 (0,03)

2.2.3. Mechanical properties

Until recently not a lot of scientific information was available on the mechanical properties of Turkey oak and knowledge of the species relied mainly on anecdotal information reducing its use to low-value applications. Since this oak may represent an important forest resource in its natural habitat or in areas where it was introduced (de Rigo *et al.* 2016) the possibility to use it as raw material for construction has been investigated in the last years. Some initial work attempting to finger joint the Turkey oak wood for non-structural products like furniture, cladding, fencing and joinery, reported again gluing difficulties (Karastergiou *et al.* 2006, Molnár *et al.* 2006).

In the case of Kosovo, Standfest and co-workers (2012 b) evaluated the mechanical properties of Turkey oak and compared the results with those of pedunculate oak (*Quercus robur*). The results demonstrated the good quality of this wood, and the data were a valuable first tool to assist decision making in relation to the use of Turkey oak in the construction and furniture industries (Standfest *et al.* 2012).

The densities determined for the two sites studied (Table 2.5) were significantly higher in Turkey oak, 0.86g/cm³ (heartwood) and 0.81 g/cm³ (sapwood), when compared to pedunculate oak , 0.63g/cm³ (heartwood) and 0.62 g/cm³ (sapwood), and also higher than previously reported by Molnár *et al.* (2006), 0.75 g/cm³. A significant difference in the flexural strength and modulus of elasticity between Turkey oak and pedunculated oak was also found.

The Brinell hardness was tested according to two test methods and carried out in each of the 3 main cutting directions. Turkey oak material had a significantly higher Brinell hardness than the pedunculate oak. The compressive strength parallel to the fibers was also higher on Turkey oak.

Table 2.5. Mean, standard deviation and test statistics of the investigated properties of the two different oak woods. Comparison between *Quercus cerris* and *Quercus robur*; values marked with * have statistically no difference in mean values; values marked with ** are significantly different (from Standfest *et al.* 2012b)

	Heartwood		**Sapwood**	
Group	***Quercus cerris***	***Quercus robur***	***Quercus cerris***	***Quercus robur***
Properties	Mean (Standard deviation)		Mean (Standard deviation)	
Density [g/cm³]	0,86 (0,04)**	0,63 (0,05)**	0,81 (0,05)**	0,62 (0,07)**
Bending [N/mm²]	128,88 (15,87)**	74,26 (13,56)**	126,15 (14,65)**	65,94 (13,10)**
Modulus of elasticity [N/mm²]	12058,29 (1894,40)**	9268,04 (1238,68)**	12631,32 (1716,45)**	7783,85 (1675,99)**
Hardness axial EN 1534 [N/mm²]	63,39 (6,90)**	45,23 (6,73)**	61,84 (6,81)**	51,28 (8,57)**
Hardness radial EN 1534 [N/mm²]	41,11 (7,05)**	26,23 (9,83)**	38,44 (6,14)**	26,37 (5,05)**
Hardness tangential EN 1534 [N/mm²]	39,92 (6,33)**	22,17 (7,68)**	36,66 (5,12)**	22,36 (4,13)**
Hardness axial [N/mm²]	69,56 (5,22)**	47,48 (7,04)**	67,65 (5,66)**	50,53 (8,79)**
Hardness radial [N/mm²]	39,64 (5,44)**	25,49 (9,37)**	34,95 (4,95)**	24,63 (4,61)**
Hardness tangential [N/mm²]	35,23 (3,46)**	20,72 (6,33)**	32,72 (3,54)**	20,56 (4,55)**
Compression strength ‖ [N/mm²]	53,98 (4,59)**	39,35 (6,45)**	54,88 (4,48)**	34,67 (3,06)**
Compression strength ⊥ [N/mm²]	26,69 (2,53)**	15,81 (5,42)**	25,19 (3,01)**	14,67 (2,49)**

As computer systems are increasingly applied to the selection of materials during the development of a product, Ashby diagrams were also created for the comparison of the two types of wood (Standfes *et al.* 2012). Ashby diagrams can be used to compare materials based on different properties depending on the objective of the material search. When looking for light-weight materials, either the density versus the bending strength or the density versus the modulus of elasticity is plotted (figure 2.12). The higher density of the Turkey oak is associated with higher bending strengths and higher modulus of elasticity. The illustration also shows straight lines with different slopes. These lines are required for the material selection and are chosen according to the procedure according to Ashby (2005) depending on the load and the geometry of the respective product.

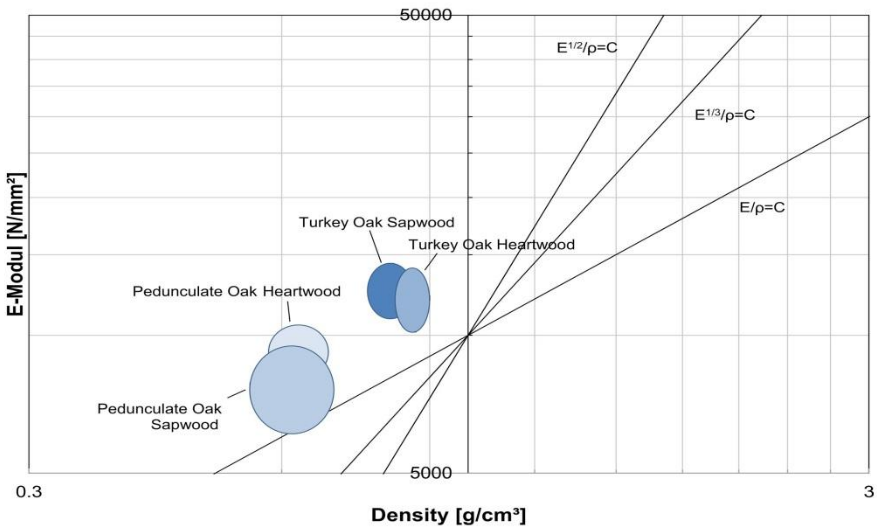

Figure 2.12. Ashby chart for Density and Modulus of Elasticity (from Standfest *et al.* 2012)

2.2.4. Durability

Wood as a natural material is not immune to deterioration. However, this process relies on the exposure to a specific environment for a sufficiently long period of time. The length of this period varies significantly with timber species, environmental conditions, the degree and the type of exposure (Cruz *et al.* 2015). Although the exact lignocellulose degradation mechanisms are still under intense research (Cragg *et al.* 2015) the main agents of deterioration insects, fungi and marine wood borers, which use wood as a source of food and/or shelter. The survival of these organisms depends on the existence of specific requirements such as moisture, temperature and oxygen.

On the other hand, wood can be used in many different exposure situations, particularly with respect to hydrothermal environmental conditions that affect the type and speed of material degradation by the biological agents. The moisture content of wood is therefore at the base of the use classes of application described in the European standard EN 335 (2013). The probability of deterioration depends not only on the biological agents but also on the location of the piece of wood being used in construction. In addition to these factors, the service life of the material is also linked to its natural durability, understood as the natural resistance of wood to the attacks by living organisms (fungi, insects and marine borers) and to its impregnability, to the extent that it determines the viability of giving it added protection.

If the use class is correctly estimated (Table 2.6) and if the wood is properly prepared and utilized, also subjected to preservative treatment when necessary, the likelihood of severe cases of biological degradation is very low.

Table 2.6. Use classes for the application of solid wood (from Cruz *et al*. 2015)

Use class	General service situation	Description of exposure to wetting in service (wood moisture content in %)	Occurrence of biological agents (geographical variations are possible)
1	Interior, covered	Dry 20 % maximum	Beetles
			Termites
2	Interior, or under cover, not exposed to the weather. Possibility of water condensation	Occasionally >20 %	Beetles
			Termites
			Disfiguring fungi
			Brown rot
3	Exterior, above ground, exposed to the weather	Occasionally or frequently >20 %	Beetles
			Termites
	3.1 Limited wetting conditions		Blue stain fungi
	3.2 Prolonged wetting conditions		Brown rot
			White rot
4	Exterior in ground and/or fresh water	Predominantly or permanently >20 %	Beetles
			Termites
			Blue stain fungi
			Brown rot
			White rot
			Soft rot
5	In salt water	Permanently >20 %	Marine borers (=UC4, for elements outside the water)

Since the biological deterioration of applied timber is often viewed as a limiting factor for its improved used in building to know the natural durability, defined as its inherent resistance to wood destroying agents, of a less know wood species is extremely relevant. The natural durability can vary widely depending on tree age, geographical origin, and growing conditions. Decay resistance also varies within the stem e.g. it tends to increase radially from pith to the heartwood-sapwood boundary and longitudinally from crown to base (Stirling *et al.* 2015), and is typically connected to the wood chemical composition, in particular, with the extractives present (Daniels and Russell 2007; Gierlinger *et al.* 2003; Pâques and Charpentier 2015). Nevertheless, the reasons of resistance to decay may not be directly translated into resistance to insect attacks; for instance, Taylor *et al.* (2006) found no link between extractives and termite durability in *Thuja plicata* and *Chamaecyparis nootkatensis*, and Stirling *et al.* (2015) confirmed the findings for *Thuja plicata*. Density and hardness are also typically referred as influencing the natural resistance of wood to termite attack (Esenther 1997; Peralta *et al.* 2004; Arango *et al.* 2006; França *et al.* 2016).

As already referred, the wood of Turkey oak is commonly described as easily prone to biodegradation and has conditioned its use for construction (Bajraktari *et al.* 2014). Nevertheless, in Europe, EN350 (2016) classifies the wood as "moderately durable" against decay fungi and subterranean termites. Data for wood boring beetles is insufficient to allow a classification but the sapwood is not resistant to *Trichoferus holosericeus*. The sapwood is classified as "big" and "easily treated"; the heartwood is "extremely difficult to treat". Further studies to clarify the natural durability of this timber will allow recommendations for its improved use.

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Chapter 3
Experimental work

3.1. GENERAL METHODOLOGY

3.1.1. Characterization of Kosovo forest wood supply and sawmill industry

The main objectives of this task are to evaluate the forest resources by determining the annual volumes of round wood felled in the forests of Kosovo in relation to the amounts of timber available in the forest and to describe the sawmill structure in Kosovo when possible relating the present state of the art of the wood industry with the new technical University of Ferizaj.

Forests in Kosovo are managed by the Kosovo Forest Agency, part of the Ministry of Agriculture, Forestry and Rural Development and the reports conducted or existing in this organism have formed the basis of the present work (Anon 2018 a, b, Luma and Bajraktari 2008, Bajraktari 2009, Bajraktari e. al. 2009, Ukaj and Abazi 2009) together with local surveys conducted in the country.

3.1.2. Characterization of *Quercus cerris* sampling sites

Two sampling stands of *Quercus cerris* were defined in Kosovo: Blinaja and Duboçak Figure 3.1. These two regions, around 50 km apart, were chosen because of the high density of this species in the forest. Both stands are naturally regenerated and unmanaged. From each sampling area, five trees, free of visible signs of decay, were randomly selected, felled in November 2014 and processed as described below.

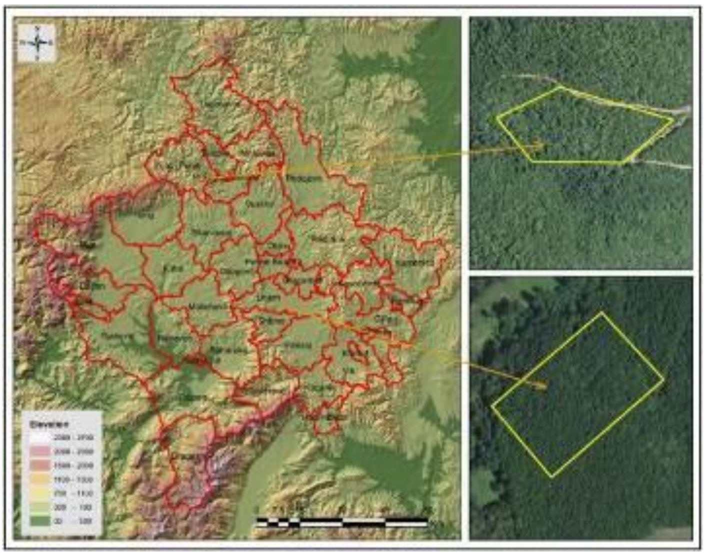


Figure 3.1. Sampling sites: Duboçak (top right) and Blinaja (bottom right)

Source: Author

3.1.2.2. Blinaja

Blinaja is characterized as a homogenous region with mountainous relief, with relatively small differences in elevation (697 m - 650 m). It is located between 20° 59′ 6′′E and 20^0 59′ 15′′E and 42^0 30′ 31′′N and 42^0 30′ 38′′N.

The climate is a mixture of moderate continental climate and continental climate. In a large part of Blinaja, the vegetation is delayed for 10-15 days compared with Dukagjini valley, and 2-5 days compared with Kosovo valley, which means that spring is also delayed by such an amount of time. Mountain barriers that lie on the northern side of Blinaja hinder penetration of cold mass; however, as a result of Blinaja River valley which runs towards the Sitnica River, makes an interaction with warm and humid mass coming from the Kosovo valley. These features clearly indicate that Blinaja has a continental climate with cold and humid winters and with warm and dry summers.

The annual average air temperature is 11.3 °C, highest during July when it goes up to 21.4 °C, while the lowest is in January with average temperature -1.7 ^{0}C. During the vegetation period the average air temperature is 17.4 °C (Meteorological Institute of Pristina, 2017). Yearly average atmospheric precipitation is 609.8mm, with the highest amount occurring in November with 87.1 mm rainfall, followed by May with 67.2 mm (Precipitation Station Pristina, 2017). The winds dominate from the north-west (NW) and south (S) with average speed of 2.4 m/s, and 2.7 m/s respectively. Sunlight in this region falls continuously from sunrise until sunset. The position of the plot in Blinaja lays 5% towards West, 85% towards North-West, and 10% towards North. Because of the slope position of this plot, most of the time the sunlight falls on the angle of 45^0.

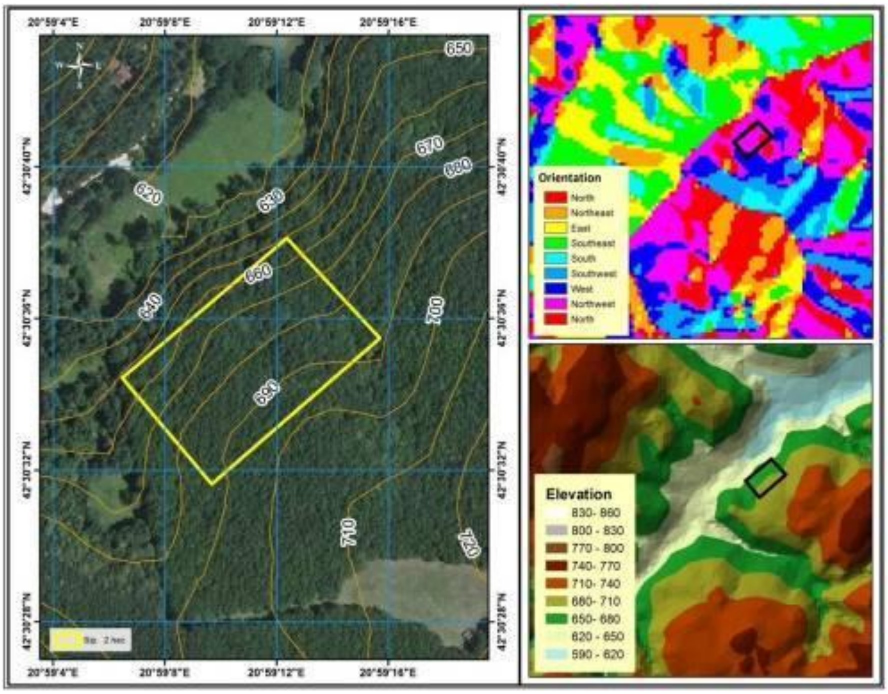


Figure 3.2. Geographic coordinates, site orientation and altitude in Blinaja

Source: Author

The hydrographic network of this region is poorly developed and derives from the Blinaja River with its branches. The Blinaja River is a branch of Sitnica River and belongs to the Black Sea basin. Figure 3.3. represents a part of the river Blinaja with the location of the sampling plot.

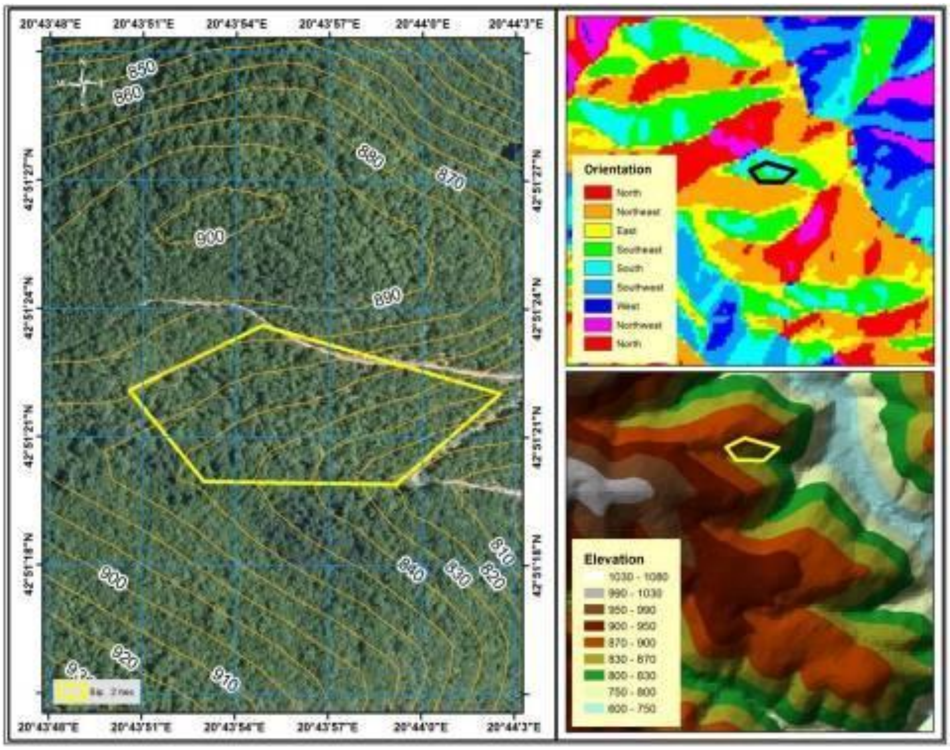
Figure 3.3. River Blinaja and location of the sampling plot

Source: Author

3.1.2.2. Duboçak

The geographic position of the plot in Duboçak is also characterized as a homogenous region with mountainous relief, with relatively small differences in elevation (885 m - 817 m), in which new geological formations are prevailing. The plot is located between 20º 43′ 50′′E and 20º 44′ 02′′E and 42º 51′ 20′′N and 42º 51′ 23′′N.

The climate is similar to the one described for Blinaja. In a large part of Duboçak, the vegetation is delayed for 10-15 days compared with Dukagjini valley, and 2-5 days compared with Kosovo valley, which means that spring is also delayed for such amount of time. Mountain barriers that lie on the northern side of Duboçak impede penetration of cold mass, however, as a result of Klina River valley which runs towards the Drini i Bardhë River, makes an interaction with warm and humid mass coming from the Dukagjini valley.



Fugure 3.4. Geographic coordinates, parcel orientation and altitude in Duboçak

Source: Author

On the other hand, during the winter period, Klina River valley enables penetration of easy and fast cold continental air masses from the northern part.

This region has an annual average air temperature of 10.4 ºC. The average monthly temperature is highest during July /20.7 ºC) and lowest in January (-1.5 ºC). During the vegetation period the average air temperature goes up to 16.7ºC ((Meteorological Institute of Pristina, 2017). Yearly average atmospheric precipitation in this region is 604.8 mm, whereas the highest amount of atmospheric precipitation occurs in November (83.1 mm), followed by May (65.2 mm) (Precipitation Station Skenderaj, 2017). The winds dominate from the north (N), north-west (NW) and south (S). with average speed of 2.6 m/s, 2.8 m/s, and 2.8 m/s respectively. During the summer, the winds usually come from Mokna, which brings high temperatures, particularly during the nights. Sunlight in this region falls continuously from sunrise until sunset. The position of the plot in Duboçak lays 70% towards South, whereas 30% of the area lies towards South-east direction. Because of the slope position of this plot, most of the time the sunlight falls on the angle of 90º.

The hydrographic network of this region is poorly developed. This network is created from Klina River and its branches. Klina River is a left branch of Drini i Bardhe River and belongs to the Adriatic Sea basin. Figure 3.5 represents a part of the Klina River and the location of the plot.

Figure 3.5. River Klina and location of the sampling plot

Source: Author

3.1.3. Sampling and marking of trees

From each sampling area (Blinaja and Duboçak) five healthy trees were cut. Each tree was marked immediately after felling and shipped to the base workshop where further processing was done. Figure 3.6. shows a field view of the Blinaja plot on the day the trees were felled.

Figure 3.6. Blinaja plot. General view and tree cutting
Source: Author

Figure 3.7. & 3.8. Details of marking of the felled trees (B = Blinaja; D = Duboçak)
Source: Author

Table 3.1. General characterization data of the sampled sites (from the 10 felled trees)

Plot	Average diameter (mm)	Initial date	Final date	Average number of years	Heartwood average number of years	Sapwood average number of years
Blinaja	243.95	1946	2014	67	44	22
Duboçak	214.31	1932	2014	77	55	22

Source: Author

Test materials were obtained from each felled log based on the tree height Table 3.2. From each tree, four 50 mm thick disks were taken at breast height (1.3 m) and every two meters up to the total length of the trunk. The logs between the first four levels of sampled disks were converted to boards about 2 m long (1.2 m for the first level) and 25 mm o thickness Figure 3.6, 3.7 & 3.8. A total of 240 disks and 90 boards was obtained.

Table 3.2. Total tree high and trunk length of the felled trees.

Plot	Blinaja					Duboçak				
Tree	KBI	KBI	KBI	KBI	KBI	KDI	KDI	KDI	KDI	KDI
Total tree high (m)	18.0	16.5	17.3	17.8	19.2	16.6	16.4	14.9	15.5	18.2
Trunk length (m)	10.7	11.0	11.10	10.8	10.7	11.0	11.1	11.2	11.0	11.1

Source: Author

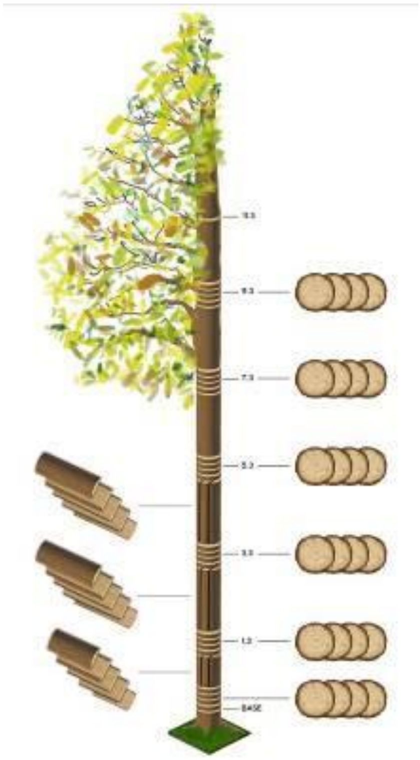


Figure 3.9., 3.10. & 3.11. General sampling plan of the felled trees and aspect of the disks and boards
Source: Author

In order to avoid possible errors all samples were marked as they were cut. Each disk and board was marked with a simple code based on the sampling area, tree number and trunk part. For example, the code KB1 / 1.3 / I, represent the sample taken from Blinaja where "KB1" represents Kosovo Blinaja tree 1, "1.3" represents the log from which the disk was cut, and "I" represents the consecutive number of the disk.

All samples were dried in a conventional chamber of a local company. Wood drying was done in order to reduce the moisture content (MC) to approximately 12% and allow safe transport to Portugal for further testing. After the target MC was achieved the wood was kept at room temperature for some months and in due time transported by road to Lisbon, Portugal.

Blinaja and Duboçak stands were harvested to produce logs for the sawmilling industry. At the time of felling, the trees were randomly selected in each stand and characterized by measuring total height and diameter at 1.3 m above ground (d.b.h., as the mean of two crossed diameters). Tree age was approximately 70 to 90 years, respectively at Blinaja and Duboçak.

Cross-sectional discs were taken at different stem height levels: base, 1.3 m, 3.3 m, 5.3 m, 7.3 m and 9.3 m. The stem discs were dried in-door under well ventilated conditions. For measurement of stem components and ring analysis, the discs surface was smoothed by sanding. In all cases the annual rings were distinct and the heartwood was clearly distinguished visually from the sapwood.

The surface image of the stem discs was acquired with an image analysis system that includes a digital 7 mega pixels in macro stand solution set on an acquisition Kaiser RS1 Board with a controlled illumination apparatus, connected to a computer using AnalySIS® image processing software (Analysis Soft Imaging System GmbH, Münster, Germany, version 3.2). The images allowed the clear distinction between heartwood and sapwood, and in the bark between phloem and rhytidome.

The areas of each component were determined, and their proportion was calculated. The average radius of heartwood was calculated considering it as a circle, and the radial width of sapwood, phloem and rhytidome were calculated considering that their respective areas represented circular crowns. Taper of stem wood and heartwood was calculated as the difference between radii at the various height levels and calculated per unit of stem length.

The width of annual rings was measured from pith to bark along two opposite radii at 1.3 m stem height using the same image analysis system. The arithmetic mean of the measurements was used in the calculations.

Statistical analysis was made using an analysis of variance including as factors of variation the site, the stem height level and their interaction.

For stem quality characterization, cross-sectional discs were taken at different stem height levels: base, 1.3 m, 3.3 m, 5.3 m, 7.3 m and 9.3 m and the logs between the first four discs converted to boards. The boards were dried indoor under well ventilated conditions and used to obtain the necessary test specimens for further testing. Unless otherwise described, the test specimens were obtained from the second log, just above the 1.3 m level.

Here are some pictures taken during the experimental work

3.2. RESULTS

3.2.1. Forest resources and sawmill structure of Kosovo: State of the art and perspectives

In this paper, the forest resources and sawmill structure of Kosovo are analyzed and the availability of different species of wood in different regions of the country is presented.

The results of this study indicate that there is a low quantity of wood available for felling in the central region of Kosovo. Beech wood resources are widely spread in all districts of Kosovo, and Oak wood is mostly concentrated in northern and eastern regions of Kosovo. As regards the softwoods available for felling, they are only abundant in high quantities in the western part of the country.

3.2.2. Wood industry is an important factor for the Kosovo's development – the role of higher education

This paper presents the role of higher education in meeting the highest contemporary needs for students of wood processing studies in building new competences, combining scientific and technological knowledge for industrial management, communication knowledge, creative work, project management, team work, etc. The scientific work and research methods provided in this study, offers a baseline for students to gain the ability for practical projects. The recommendation of this study stands that the study process should be more closely with industrial practices and scientific analyses of all practical parts in economical context. Furthermore, this study indicates that Kosovo forests represents a relatively good potential for development of wood sector in domestic market, as well as for exports of wood products, and for foreign investments.

3.2.3. Stem quality of *Quercus cerris* trees from Kosovo for the sawmilling industry

This paper provides the data from the study of the heartwood, sapwood and bark development within *Quercus cerris* trees grown in two sites in Kosovo. The results of this study indicate that Heartwood was present in all the trees, decreasing from the tree base upwards, with the heartwood profile following closely that of the stemwood. Heartwood proportion was 53% and 43% until 5 m of height in the two sites. The radial width of sapwood was higher at stem base and afterwards approximately constant at

32 mm. Taper was low at an average 3.3 mm m^{-1} between 3.3 and 7.3 m of stem height. Bark represented on average 16.4% of the total stem cross-section and contained a substantial proportion of rhytidome. *Quercus cerris* in Kosovo showed good potential as a timber species for the supply of stem wood to the saw-milling industry allowing good yields of heartwood-only sawn wood components.

3.2.4. Chemical composition and termite resistance of heartwood of *Quercus cerris*

In this paper, the heartwood of *Quercus cerris* taken from 70-90 year-old trees grown in two sites in Kosovo was studied regarding resistance to termite attack, chemical composition and hardness. The sample heartwood contained only 6.7% extractives, with a small content of tannins. The wood density was on average 0.81 at 12% moisture content and Brinell hardness 36.2 N mm^{-2}. The results of this study indicate that the heartwood of *Quercus cerris* taken from 70-90 year-old trees is not durable against subterranean termites and therefore not suitable for external use in ground contact unless adequately protected. Nevertheless, *Quercus cerris* wood showed adequate hardness and density for interior uses like flooring for domestic and commercial applications with moderate use.

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Forest Resources and Sawmill Structure of Kosovo: State of the Art and Perspectives

Šumski resursi i struktura pilana u Republici Kosovo: stanje i perspektiva

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ABSTRACT • *Kosovo, located in the heart of the Balkans, was formerly a part of Yugoslavia. The breakup of Yugoslavia led not only to the creation of new countries and borders; it also had a huge impact on the transportation and availability of raw materials and goods. Kosovo's forest products industry has been greatly affected by the country's current political and legal environment. The creation of new boundaries, combined with trade constraints between Kosovo and some neighboring countries, has changed the amount and type of available wood raw material. Although the forest products industry is a very important part of Kosovo's economy, this change in distribution has had a negative impact on the sawmill structure of the country. To better understand the current state of Kosovo's forest products sector, data was collected through a survey of all sawmills in Kosovo and through information gathered from the Ministry of Agriculture, Forestry and Rural Development of Kosovo. In this paper, the forest resources and sawmill structure of Kosovo are analyzed and the availability of different species of wood in different regions of the country is presented. Based on these findings, recommendations are provided for further development of the forest and sawmill industry.*

Keywords: *forest resources, sawmills, Kosovo*

SAŽETAK • *Kosovo, koje se nalazi u srcu Balkana, nekad je bilo dio Jugoslavije. Raspad Jugoslavije nije doveo samo do stvaranja novih država i granica; to je također imalo velik utjecaj na transport i dostupnost sirovina i roba. Kosovska industrija drvnih proizvoda uvelike je pod utjecajem trenutačnoga političkog i pravnog okruženja*

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u zemlji. Nastajanje novih granica, u kombinaciji s trgovinskim ograničenjima između Kosova i nekih susjednih zemalja, promijenilo je količinu i vrstu dostupne drvne sirovine. Iako je industrija drvnih proizvoda vrlo važan dio gospodarstva Kosova, ta promjena u distribuciji negativno je utjecala na strukturu pilana u zemlji. Radi boljeg razumijevanja trenutačnog stanja drvnog sektora Kosova, prikupljeni su podaci od svih pilana na Kosovu, i to anketiranjem i dobivanjem informacija od Ministarstva poljoprivrede, šumarstva i ruralnog razvoja Kosova. U radu su analizirani šumski resursi i struktura pilana Kosova te opisana dostupnost različitih vrsta drva u različitim dijelovima zemlje. Na temelju tih nalaza, dane su preporuke za daljnji razvoj drvne industrije i pilanarstva Kosova.

Ključne riječi: *šumski resursi, pilane, Kosovo*

1 INTRODUCTION
1. UVOD

Kosovo, a former part of Yugoslavia and a newly formed independent country, is a landlocked country located in the heart of the Balkan Peninsula. Of the country's total surface area of 10 887 km², approximately 42 % is covered by forests (Luma and Bajraktari, 2008). Therefore, forestry and forest products industry are important components of the country's economy.

However, the recent political changes regarding new countries and borders have significantly influenced transport and availability of goods and raw materials. Companies formerly conveniently located near abundant raw material sources (e.g. forests) may now be burdened with transport costs and challenging complications due to the need of crossing borders.

Today the wood processing industry in Kosovo only uses roundwood for producing lumber in sawmills and for firewood. The export of logs is negligible (Bajraktari, 2009) and there are no other primary wood working industries (e.g., pulp & paper or wood based panel industry) located in the country. However, the development of a wood products industry is recognized as an important component for enhancing the economic development of Kosovo. The sawmill structure of Kosovo has not been investigated in detail. This is essential to enable future developments and to support an effective and efficient use of wood resources in Kosovo.

This paper presents the results of a research analysis conducted to understand the situation and structure of forest resources and sawmill industry in Kosovo. The following objectives were defined: 1) to determine the annual roundwood volume felled in the forests of Kosovo in relation to the amounts of timber available in the forests; 2) to describe the sawmill structure in Kosovo; and 3) to analyze the balance between potential supply and processing demand. The understanding of such questions provides the basis for future targets and activities of the Ministry of Agriculture, Forestry and Rural Development of Kosovo (MAFRD), and will encourage efforts to strengthen the country's sawmill industry.

2 METHODS AND MATERIALS
2. METODE I MATERIJALI

2.1 Wood resources from Kosovo forests
2.1. Drvna sirovina iz kosovskih šuma

Data related to Kosovo's current wood resources and use of roundwood were collected using the 2003 data of a forest inventory compiled by the Food and Agriculture Organization of the United Nations (FAO, 2003). This report indicates that Kosovo's total forest area is approximately 460 800 ha. Of the total forest area, approximately 353 400 ha (77 % of the total) are broadleaf forests, 19 200 ha (4 %) are dominated by softwoods, and 88 200 ha (19 %) were not investigated due to risks associated with military mines. Additional information obtained from a 2008 project conducted by the United States Agency for International Development (USAID), which also addressed forest resources in Kosovo, was used and annual roundwood fellings were estimated (Kaciu *et al*., 2008).

The annual felling allowance for each wood species in Kosovo is currently set by the Ministry of Agriculture, Forestry and Rural Development (MAFRD). The felling allowance for 2008 was divided by three main groups of wood species: beech (*Fagus sylvatica* subsp. *moesiaca*) with 436 000 m³; oaks (*Quercus spp.*) with 341 000 m³; and softwoods (*Abies alba*, *Picea abies*, *Pinus heldreichii*, etc.,) with 123 000 m³ (MAFRD, 2008). The total allowance for each species is divided between all the districts of Kosovo.

The potential log resource is defined as the amount of logs with a small end diameter above 7 cm and was calculated according to the felling allowance and the MAFRD data (Bajraktari *et al*., 2009). The quality of the logs was not considered in this analysis.

2.2 The structure of Kosovo sawmill industries
2.2. Struktura pilanske industrije Kosova

According to a study conducted by the Ministry of Trade and Industry of Kosovo (MTI, 2008), the amount of lumber imported into Kosovo is much higher than the amount exported. In 2006, the difference amounted to 223 797 m³. The study also indicated that Kosovo's forests were capable of supplying a log volume of 693 000 m, which is much higher than currently felled and cut in sawmills. However, specific information about the sawmill structure was not given.

To gather additional data about the structure of sawmill industries, the following information for all the 143 registered sawmills (Ukaj and Abazi, 2009) in Kosovo was collected via telephone interviews:
- the cutting technology used (in Kosovo only frame saws and band saws are in use)
- the annual log breakdown divided into the above mentioned groups of wood species.

The results were analyzed separately for 30 districts of Kosovo.

2.3 Comparing wood resources and sawmill demand
2.3. Usporedba resursa drvne sirovine i zahtjeva pilana

The amount of available roundwood resources and the amount of wood demanded by various sawmills were compared for each district. The difference between total log supply and demand was calculated for the three groups of wood species. This calculation was used to determine the regions with oversupply and undersupply and a map highlighting this balance was created.

The information obtained will be used to describe the current state of the sawmill industry in Kosovo and to determine future opportunities for establishing or re-orienting manufacturing enterprises to optimally utilize the available roundwood resources.

3 RESULTS
3. REZULTATI

3.1 Wood resources per district and wood species
3.1. Resursi drvne sirovine prema distriktu i vrsti drva

Figure 1 shows the geographical distribution of availability of wood resources per district and by groups of species in Kosovo, as given by the felling allowances (MAFRD, 2008).

Overall, there is a low quantity of wood available for felling in the central region of Kosovo (mainly in the districts of Obiliq, Fushe Kosove and Gllogovc).

Beech wood resources are widely available in all the remaining districts of Kosovo, except for the ones located in the southern region where there is a smaller amount available for felling.

Although oaks are common wood species in the country, the data show that the southern and western regions have a significantly lower quantity than the northern and eastern regions.

As regards the softwoods available for felling, they are only abundant in high quantities in the western part of the country (the districts of Gjakove, Peje and Istogu), while in the east and especially in the southeast of Kosovo there are almost no softwoods allowed for felling (Figure 1).

3.2 Sawmill structure
3.2. Struktura pilana

Out of a total of 143 sawmills in Kosovo, 106 sawmills work with a frame saw and 37 with a band saw (74 % and 26 %, respectively). Figure 2 shows the breakdown per district for the two technologies in relation to the amount of processed wood. It can be seen that operations using frame saws are concentrated in the western districts (Deqan, Peje and Istogu), while those using

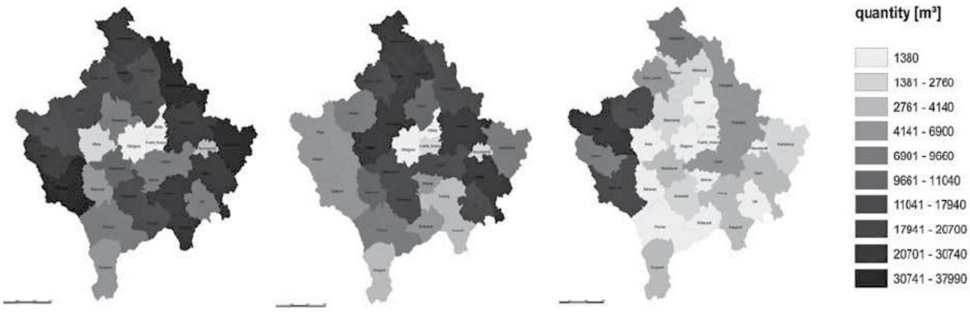

Figure 1 Allocation of beech (left), oak (middle) and softwood (right) in Kosovo (light green – low quantity, dark green – high quantity)
Slika 1. Alokacija bukve (lijevo), hrasta (sredina) i mekih vrsta drva (desno) na Kosovu (svjetlozeleno – mala količina, tamnozeleno – velika količina)

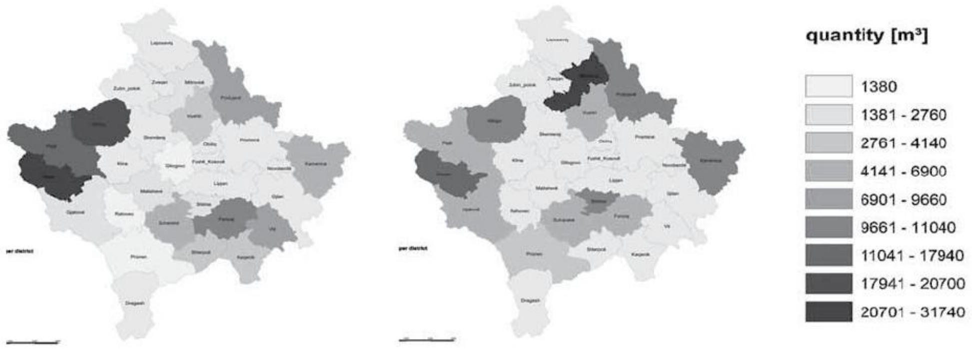

Figure 2 Timber cut with frame saw (left) and band saw (right) in Kosovo
Slika 2. Raspiljivanje trupaca pilama jarmačama (lijevo) i tračnim pilama (desno) na Kosovu

Figure 3 Breakdown of beech (left), oak (middle) and softwood (right) in sawmills in Kosovo
Slika 3. Raspodjela bukovih trupaca (lijevo), hrastovih trupaca (sredina) i trupaca mekih vrsta drva (desno) u pilanama na Kosovu

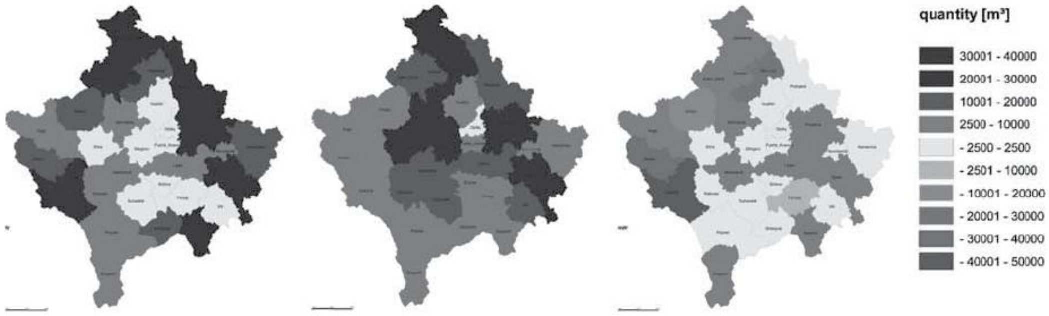

Figure 4 Oversupply and undersupply of beech (left), oak (middle) and softwood (right) in Kosovo (blue oversupply, red undersupply)
Slika 4. Prevelika i premala ponuda bukovih trupaca (lijevo), hrastovih trupaca (desno) i trupaca mekih vrsta drva (desno) na Kosovu (plavo – prevelika ponuda, crveno – premala ponuda)

band saws are concentrated in the eastern districts with a very high concentration in Mitrovice. Most log processing takes place in the regions located in the east and west of Kosovo, with significant amounts being processed in the districts of Ferizaj, Shtime and Suhareke (amounting to more than 21 000 m³).

As regards the breakdown of processed timber by species, the data is shown in Figure 3. It can be seen that for beech and oaks, processing is distributed throughout the country without a high concentration in one specific region. This is different for softwood sawmilling and it seems that the sawmills in the western region, including the districts of Peje, Istogu, Deqan and Mitrovice, have a focus on cutting softwoods. The frame saw mills are also mainly concentrated in the western region in the districts of Peje, Istogu and Deqan. This indicates that these frame saw mills have specialized in cutting softwoods, while the sawmills in Mitrovice mainly use band saws to cut softwoods.

3.3 Comparison of supply and demand
3.3. Usporedba ponude i potražnje

The balance between the potential wood supply (allowable cuts, Figure 1) and the industrial wood demand (sawmill processed wood, Figure 3) was calculated and the undersupply and oversupply of wood resources was determined for each district and species (Figure 4).

The supply of beech and oak sawlogs sufficiently meets the demands of sawmills in all of Kosovo's districts. However, the situation is different for softwoods. There is a need for additional softwood supply especially in the districts of Deqan, Mitrovice and Istogu. In total, there is a softwood undersupply of approximately 15 000 m³ in Kosovo. This negative balance is met by imports, and currently softwoods are predominately imported from Montenegro.

In former times, softwood was also imported from Serbia with a large quantity going to the district of Mitrovice. However, softwood imports from Serbia have not been available since 1999 due to the border closing for log imports. Log imports are possible from Montenegro and Albania, and therefore the districts near these countries (Deqan and Istogu) have a higher share in the softwood supply.

4 DISCUSSION AND CONCLUSIONS
4. RASPRAVA I ZAKLJUČAK

It is evident from the results that one of the country's major forest management tasks should be the efficient management of softwood resources to meet the continuous demand of the sawmill industry.

The softwood sawmill industry of Kosovo has drastically changed due to the breakup of Yugoslavia. Sawmills located in districts like Mitrovice, that were near large supplies of softwoods, are no longer optimally located. On the contrary, numerous sawmills were established in the last 10 years in the districts of Deqan and Istogu, showing that the sawmill industry is reacting to the new resource location. The efficient management of this resource may, therefore, support the development of a thriving wood products industry and enhance the economy of Kosovo. At the forest level, and given the deficit of national softwoods for the processing industry, attention should be focused on development plans and silvicultural management options for an increased softwood production.

This study also shows that sawmills processing beech and oaks are located over the country and that there is a potential supply surplus allowing the increase of production of sawn products from beech and oaks. However such a production increase only makes sense if two factors converge: i) a market need for the sawn wood; and ii) an effective supply of quality logs. The present study did not investigate the quality of the potential available logs and further research is needed in this area. In fact developing log grading rules and increasing the availability of high quality logs are two of the main objectives of MAFRD that has already started to increase thinning in Kosovo's forests in order to accomplish these objectives. A careful and cooperative approach between the wood products market, wood industry and forest services is certainly a key issue for a balanced forest-to-consumer chain.

The lack of wood-fiber based industries (e.g., wood-based panel production or pulp industries) is also an important topic for the value optimization of the wood chain that requires the cooperation of the forest raw-material supplier (MAFRD) and the forest products industry. Currently, by-products like wood shavings or sawdust do not have a market and their use as an energy resource is virtually non-existent. The creation of markets for by-products could further enhance the economic development of the country and a full resource valorization. Awareness of emerging uses, such as those based on biorefinery approaches to value residual biomass, should also be scrutinized. A recent example is the potential valorization of *Quercus cerris* bark (an oak species of Kosovo) through its cork component to be used as insulation material in the form of expanded cork agglomerates in the construction industry (Sen *et al.*, 2012).

An important topic not covered in this research is the impact of the use of firewood in Kosovo. This paper only focused on sawmills because of the complexity of obtaining information on firewood (e.g. illegal firewood cutting or missing census). However, understanding the amount of the use of firewood in Kosovo is also an important element for improving the whole forest sector and will be a focus of this research group in the future.

In conclusion, this paper discusses the current state of wood supply and demand of Kosovo's sawmill industry and represents a basis for implementation of policies and activities in this field. Numerous research and policy questions remain to be answered, but our belief is that solving them stepwise and with an integrated sectorial approach will be crucial for successfully reconstructing and developing Kosovo's economy.

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Research Article

Wood Industry is an Important Factor for the Kosovo's Development– The Role of Higher Education

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Abstract

Kosovo is relatively small place with 10870 km^2 where 44.7% of its territory is covered with trees. To date, Kosovo has passed through three important phases of economic development; the first phase was the emergency one after war, the second phase was privatization of social enterprises and the third phase was sustainable development. The after war period was very important for this sector because it has passed through a reconstruction process, privatization and development and become part of the internal and foreign markets. Positive developments in the field of wood industry led to the number of work places offered in this field are increasing; also requirements for specialized workforce and qualification workers are increasing. This is the reason why today's study programs of wood industry are addressing these issues. One of the study programs that is applied in many European Universities and beyond in the wood program at The University of Applied Sciences in Ferizaj. The University of Applied Sciences in Ferizaj is the only high institution in Republic of Kosovo that for 40 years offers Kosovo's students, and widely, opportunity to study in wood industry. Based on high expertise of this institution and the achieved results, together with experts of this industry, along with relevant Kosovo institution and private enterprises as well as in cooperation with western universities, the faculty presented a new study offer. This offer meets the highest contemporary needs and is compiled together with wood processing enterprises in Kosovo, and with Kosovo Wood Processing Association. Also this study project is fully equivalent with European Universities and is comparable to University of Applied Sciences Salzburg, Austria and University of Applied Sciences Rosenheim, Germany. This curriculum offers students to built new competences, combining scientific and technological knowledge for industrial management, communication knowledge and creative work. Furthermore, during studies a special time will also devoted to building management competences as: project management, team work, etc. However, the scientific work and research methods, working with projects from the start of study, means that students not only that will study but they will also gain the ability for practical projects, and this fact makes these practical projects to be very complexes and more interdisciplinary in high study semesters. Orientation of this curriculum in projects is focused in a way that the study process should be more closely with industrial practices and scientific analyses of all practical parts in economical context. The fact that Kosovo approximately has 44.7% of all area that are covered with trees represents a relatively good potential for development of this sector domestic market, and on the other side potential for exports of wood products. This sector can be very attractive for foreign investments and can generated new jobs.

Keywords: *Wood industry, development, curriculum, forest.*

Introduction

Located in the heart of the Balkans, Kosovo represents a bridge between the several countries of South Eastern Europe. Through its unique geographical position and its liberal trade regime, Kosovo offers instant access to the interesting and growing markets of the Balkans and Central Europe, compromising 100 million potential customers.

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Currently the harvesting potential of Kosovo is to a large extent under-utilized. Not only are the various types of wood in Kosovo easily accessible in terms of quantity, but they are also available at competitive prices.

Taking into consideration that wage levels in Kosovo are below the regional average and that the costs of inputs are competitive, one of the main advantages of the wood processing industry in Kosovo is its low cost. In addition to basic labor available at low rates, there is also a large pool of highly skilled workers available at a reasonable cost.

Given its central position in the Balkans and its liberal trade regime, Kosovo offers potential investors a favorable place from which products can be exported, free of any customs duties to the CEFTA and EU-markets. In particular, the wood industry therefore represents a good investment opportunity for those companies wishing to offer wood products to the regional market, manufactured at reasonable production costs.

Currently Kosovo enjoys a higher demand for finished wood products than local businesses can satisfy. In addition to export opportunities therefore, fulfilling local market needs offers a huge potential.

Forests and related areas cover approximately 44.7% of the total surface of Kosovo and represent a resource of special importance for the Kosovo economy (Bajraktari, A *et al.* 2011) (Figure 1).

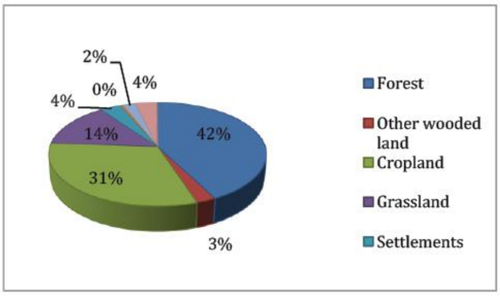

Figure 1 Land of Kosovo in percentage (%)

The annual value of wood products and other benefits arising from forests and related areas is estimated to be between approximately 50 and 75 million Euro, resulting in a contribution by the wood industry of between 1.8 percent and 2.6 percent to GDP. The wood sector is also an important employment provider in Kosovo. The livelihood of between 8 and 10 percent of the population depends upon the forestry and wood industries (EICIKS, Investment Promotion Agency of Kosovo. 2008).

Apart from its use solely for heating purposes, forestry represents an important input for the domestic wood processing industry. Until 1989, this sector was rated among the most significant export sectors. Kosovo used to export wood products as far away as the US and several European countries, in addition to its traditional markets in the former Yugoslav republics.

Currently the wood products made in Kosovo include doors, window frames, furniture and various wood construction materials, while the manufacture of other products, such as fencing material, pallets, boxes, dimension and prefabricated components, is still limited.

Although the domestic production currently caters solely to the Kosovo market, with a limited (and insignificant) number of products being exported to Albania and Macedonia, the industry has enough capacity not only to meet the domestic demand, but also to expand into export markets. Owing to its vast experience and expert knowledge in wood processing, the Kosovar wood industry is particularly well suited to the manufacture of hand-made luxury products. In addition, most sawmills in Kosovo only saw logs into rough, mixed grade lumber, and do not appear to recognize, or have not yet explored, the potential value of waste products from lumber production, i.e. sawdust and wood chips.

Faculty of Technical Applied Sciences in Ferizaj is academic part of the University of Prishtina, its objectives are advanced studies and scientific researches in applied academic disciplines of Mechanical Engineering with profile: Artificial Processing Materials Techniques (plastic masses), and discipline of Design and Wood Technology with profile: Interior Design and Wood Technology.

Academic studies of the Faculty are concentrated in Bachelor studies with practical work, based on concept of European Universities for Applied Sciences. The curriculums are based and implemented according to Bologna System, where every course is estimated on credits attained by student. The number of credits and individual work is presented on the table of curriculum of corresponding departments.

The Faculty goals are concentrated on country work force needs, training, and study of professionals all the time, giving the best offers for local partners. Practical work in the Faculty support and create advanced standards in scientific researches for effective utilizing self-funded revenues, having effective cooperation on studies in national, regional, and international level, adapting to international standards, and finally integration to European Higher Education, which is represented by European Community.

The mission of our institution is alongside teaching students during studies, having cooperation with local and international partners, through mobilization of students and professors by utilizing of material resources, comparing with local economical needs and gradual advancing of teaching quality

Industrial policy in the forestry sector

Forests and related surfaces in Kosovo are managed by the Kosovo Forests Agency, part of the Ministry of Agriculture, Forestry and Rural Development. According to the principles of the Law on Forests, this agency is responsible for preserving the biodiversity of forests while providing a valuable yield. The Kosovo Forest Agency is therefore the sole authority in charge of compiling and implementing long-term forest development plans, carrying inventory, assigning annual harvesting allowances and issuing permits and licenses in order to undertake harvests.

Another body, the Kosovo Association of the Private Forest's Owners, promotes its members' interests, facilitates the trade of wood, and provides assistance to others to ensure the development of the private forests.

Last but by no means the least important is the Association of Wood Processors of Kosovo, a trade association which fosters the development of the processing industry by helping the wood processors to implement new technologies and know-how, as well as to find new markets and expand exports.

Through the efforts and engagement of the members of this rich institutional environment of the wood Industry, Kosovo has started to implement various incentives to further promote and facilitate primary and secondary wood production. Recently, the Government of Kosovo approved a zero tariff rate for the imports of machinery and capital goods related to this sector, while further negotiations for the exemption of wood raw material from VAT and customs policy are currently taking place. Furthermore in cooperation with several international institutions, the Government is implementing various programs to increase the quality, know-how and economic results of this industry (EICIKS, Investment Promotion Agency of Kosovo. 2008).

Primary wood production

The primary production of wood in Kosovo is dominated by public forests. Of a total forest area of 464,800 ha, as much as 278,880 ha (or 60 percent) is under public ownership, while the remainder of 185,920 ha is split between approximately 120,000 private forest owners (FAO. 2003).

The total standing volume of wood is estimated at 53 million m³. Of the total volume, 40.4 million m³ of trees have a diameter greater than 7 cm. Broadleaved forests predominate, covering 90 percent of the area. Oak and beech are the main species (FAO. 2003) (Figure 2).

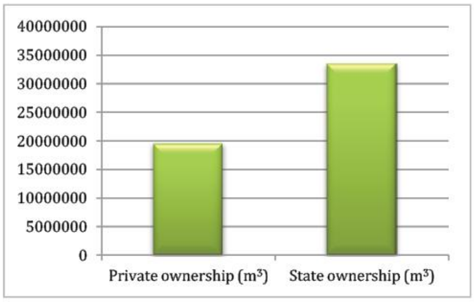

Figure 2 Forests volume by ownership

The annual increment of forests is calculated to be 1.30 million m³. Thus, based on international standards, the annual felling allowance is 900,000 m³, corresponding to 77 percent of the annual increment. Of this figure, about 700,000 m³ can be harvested in high forest and about 200,000 m³ in low forest areas. These figures are gross and additionally include tops, bark and larger branches (Bajraktari, A. *et al.* 2011) (Figure 3).

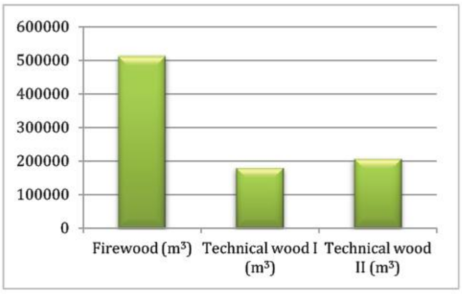

Figure 3 Annual harvesting in m³

Depending on the quality of the harvested wood, a relatively high percentage can be used by the processing industry. Of the total annual felling allowance, 43 percent is categorized as technical wood (class1 and 2), while the remainder is used for heating purposes (FAO. 2003).

With a high capacity for supply, the Kosovo wood primary production can, to a certain extent, cover the demands of the local processing industry. Furthermore, owing to low wood prices per mı wood produced in Kosovo will become an important item in foreign trade.

In addition to wood, the Kosovo forests are well endowed with non-wood products such as mushrooms, berries and herbs. The growth of these species is continuously increasing, mainly due to the low degree of environmental pollution and adequate treatment by the rural population.

Wood types in Kosovo are: beech (fagus), oak (quercus), other broadleaves, abies alba (fir), pinus abies, pinus ssp, other coniferous (FAO. 2003).

Wood processing industry

According to the Ministry of Trade and Industry, 1480 enterprises are registered as wood processors in Kosovo. The Association of Wood Processors accounts for some 80 of the most important companies, employing more than 3,000 workers (EICIKS, Investment Promotion Agency of Kosovo. 2008).

According to the data available, six (6) companies have turnover ranging from 1 to 6 millions €. All other companies have declared a turnover under 1 million €.. Of the 80 companies who are AWPK members, 50% are manufacture furniture and the remaining 50 % make doors and windows.

Finished products represent more than 75 % of production while semi – finished products make up less than 25%.

Owing to a sufficient availability of inputs, Kosovar wood processing companies mostly use beech (Fagus), Oak (Quercus) and other broadleaves in their production. The majority of these processors produce furniture, doors, and windows. As a subset of the secondary manufacturing sector, there are also several enterprises engaged in cutting or milling lumber.

During the past eight years, Kosovo's wood processing industry has experienced some significant changes. Owing to better organization and satisfactory service-providing clusters, producers were able to increase the quality and product range, and expanded into foreign markets. Currently, Kosovar wood processors supply home and hotel furniture to companies in Germany, Netherlands, Switzerland, as well as other neighboring markets (Kaciu S. Jahanica, V. Aliu, F. 2008).

According to the Kosovo Customs Service, the total amount of imported wood products from 2005 till 2010 is presented (FIGURE 4). In the next figure is presented also the export of wood products (Figure 5) (Kosovo Customs Service Reports. 2006-2011).

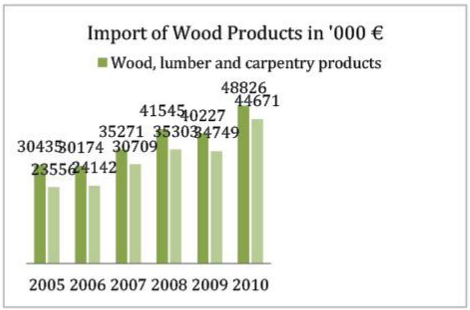

Figure 4 Import of wood products from the year 2005 till the year 2010

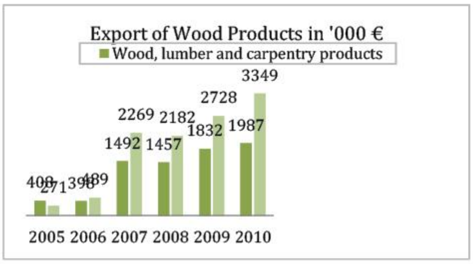

Figure 5 Export of wood products from the year 2005 till the year 2010

Conclusion

This represents a relatively good potential for development of this sector within the country, and on the other side generated exports of wood products. It can be very sustainable sector for drawback of invested assets and can generated new jobs.

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STEM QUALITY OF *QUERCUS CERRIS* TREES FROM KOSOVO FOR THE SAWMILLING INDUSTRY

Quercus cerris is an important species in the forests of Kosovo with a potential high economic value, although there is little information on the stem quality for the saw milling industry. This study brings data on wood properties particularly on heartwood, sapwood and bark development within Q. cerris trees grown in two sites in Kosovo, where mature trees were felled and discs taken at different stem height levels.

The average radial growth rate was 1.21 and 1.76 mm yr^{-1} for both sites. Heartwood decreased from the tree base upwards with a proportion of 53% and 43% until 5 m of height in the two sites. The radial width of sapwood was higher at stem base (on average 44 mm) and afterwards approximately constant at 32 mm. Taper was low at an average 3.3 mm m^{-1} between 3.3 and 7.3 m of height. Bark represented on average 16.4% of total stem cross-section and contained a substantial proportion of rhytidome (51% of the total bark area proportion at stem base and 41% at 9.3 m).

Q. cerris in Kosovo showed good potential as a timber species for the supply of stem wood to the saw-milling industry allowing good yields of heartwood-only sawn wood components. The bark should also be considered for complementary valorization.

Keywords: *Quercus cerris*, heartwood, sapwood, bark, ring width, growth rate, taper

Introduction

Quercus cerris, the Turkey oak, is native to the southern central and southeastern Europe, extending into southwestern Asia [Danielewicz *et al.* 2014]. It is a large, fast-growing deciduous tree, tolerating a range of soil types and able to quickly colonize open areas. It can withstand air pollution, is relatively tolerant to drought and has an attractive appearance, thereby often planted as an ornamental in urban areas [Sterry 2007; Preston *et al.* 2002].

The Turkey oak may represent an important forest resource in its natural habitat regions or in areas where it was introduced [de Rigo *et al.* 2006]. It is useful for reforestation, erosion control and soil conservation [Mert *et al.* 2016] as well as a potential cork provider [Sen *et al.* 2011, 2016].
As regards the timber value of the species, the wood has been used mainly for low-value applications, such as firewood and railway sleepers, and has not been considered for more demanding applications e.g. carpentry, due to low dimensional stability, low

durability mainly of the sapwood [Giordano 1981] and difficult gluing [Lavisci *et al.* 1991]. The color differences between the dark heartwood and the light sapwood and their irregular margins also contribute to under-valuate the species but some studies were recently made to improve the wood properties and to homogenize surface color by using heat and steaming treatments [Todaro 2012; Todaro *et al.* 2012, 2013; Tolvaj and Molnart 2006]. Other properties of Turkey oak wood were also investigated e.g. density and moisture [Monaco *et al.* 2011], and bending strength [Karastergiou *et al.* 2005].

Overall there is little information on the Turkey oak wood, namely regarding the species stem quality for the saw milling industry e.g. the within-tree development of heartwood and ring width. In general heartwood has higher natural durability and aesthetic value, and is therefore preferred for wood products [Pereira *et al.* 2003]. The development of heartwood and the sapwood was not characterized for *Quercus cerris*. This is an information of interest for stem quality evaluation for use in sawmilling for the production of wood components [Sousa *et al.* 2013].

This study brings data on the heartwood and sapwood development within *Quercus cerris* trees grown in two sites in Kosovo, in view of increasing the value of its exploitation as a timber species for the sawmilling industry. It also includes an analysis of bark content anticipating its possible valorization under a full resource use approach.

In Kosovo, forests cover 481 000 ha, representing 44.7% of the total area of the country, and are dominated by broadleaved trees, covering up to 93 % of the total forest area [Tomter *at al.* 2013]. The growing stock includes mainly *Fagus* and *Quercus* spp that account for 46% and 23% of the volume respectively. *Quercus cerris* is the major oak species with 4.28 billion m^3, followed by *Quercus petrea* with 3.67 billion m^3 and other oak species with 1.29 billion m^3. The national forest inventory from 2002 estimated the annual allowable cut around 900 000 m^3/year gross, of which 55% is fuelwood [Mitchell 2009]. However, in the past decade, the annual allowable cut calculated and legally available for harvesting through the current system of forest management planning was under 200 000 m^3/year [Harou and Hajredini 2009]. Due to the country' recent history, exact statistical data on timber harvesting is still scarce and difficult to obtain.

The development of a wood products industry is recognized as an important component for enhancing the economic growth of Kosovo. Today the wood industry only uses roundwood for producing lumber in sawmills (over one hundred mills located over the country) and for firewood. A production increase of sawn products from beech and oaks is possible given the potential supply surplus but will require an effective availability of quality logs [Bajraktari *et al.* 2014] as well as a sustainable production of fuelwood [Bouriaud *et al.* 2014].

The overall objective is to enrich the raw-material supply to the wood industry and to improve the economic and technological performance of *Quercus cerris* trees for quality timber products.

The main objective is the assessment of the stem quality of *Quercus cerris* trees, through the study of tree growth and ring width, heartwood and sapwood variation, bark development and, taper.

Material and methods

The data regarding the location and tree are displayed in table 1.

Table 1

The study was based on 10 mature trees of *Quercus cerris* L. sampled from two stands in Blinaja and Duboçak, in Kosovo.

Both stands were harvested to produce logs for the sawmilling industry. The trees harvested on both sites were cut into logs for the sawmillig industry. At the time of felling, the trees were randomly selected in each stand and characterized by measuring total height and diameter at 1.3 m above ground (d.b.h., as the mean of two crossed diameters). Tree age was approximately 70 to 90 years, respectively at KB and KD.

Cross-sectional discs were taken at different stem height levels: base, 1.3 m, 3.3 m, 5.3 m, 7.3 m and 9.3 m. The stem discs were dried in-door under well ventilated conditions. For measurement of stem components and ring analysis, the disc surface was smoothed by sanding. In all cases the annual rings were distinct and the heartwood was clearly distinguished visually from the sapwood.

The surface image of the stem discs was acquired with an image analysis system that includes a digital 7 mega pixels in macro stand solution set on an acquisition Kaiser RS1 Board with a controlled illumination apparatus, connected to a computer using AnalySIS® image processing software (Analysis Soft Imaging System GmbH, Münster, Germany, version 3.2). The images allowed the clear distinction between heartwood and sapwood, and in the bark between phloem and rhytidome.

The areas of each component were determined, and their proportion was calculated. The average radius of heartwood was calculated considering it as a circle, and the radial width of sapwood, phloem and rhytidome were calculated considering that their respective areas represented circular crowns. Taper of stemwood and heartwood was calculated as the difference between radii at the various height levels and calculated per unit of stem length.

The width of annual rings was measured from pith to bark along two opposite radii at 1.3 m stem height using the same image analysis system. The arithmetic mean of the measurements was used in the calculations.

Statistical analysis was made using an analysis of variance including as factors of variation the site, the stem height level and their interaction. All the analyses were done in RStudio version 3.1.2. (R Core Team, 2014).

Results and discussion

Figure 1

The sampled *Quercus cerris* trees were representative of the wood supply to the saw milling industry in Kos ovo. The stem showed distinct tree rings that were visible to the naked eye. The wood is ring porous (Fig. 1) with wide pores in the earlywood in comparison with the small pores in latewood, that allowed distinct ring boundaries and an easy ring counting and measurement. The heartwood was clearly out-singled from the sapwood by a darker brown color. In the bark, it was possible to make the distinction between the phloem and the rhytidome in the cross-section; the rhytidome showed large longitudinal running fissures (Fig. 1).

Tree growth and ring width

The within-tree variation of radial growth is exemplified in Fig. 2 for both sites, by plotting the cumulative radial dimensions measured along the stem as a function of tree height.

Figure 2

The radial growth measured at breast height in the trees from the two sites is shown in Fig. 3 as the mean ring width from pith to bark. The cambial ages attained on average 66 and 80 years at breast height respectively in KB and KD. Overall there was a radial variation of ring width with a steadily decrease along the first 15 rings and maintaining afterwards a rather constant mean value in spite of the inter-annual fluctuations.

Figure 3

Table 2 displays data, for both sites, on mean annual ring width, mean annual ring for the initial growth in the first 20 years from pith, and mean annual ring for the mature growth in the 45 to 65 years of cambial age.

In both sites, the mature growth rate was similar, but the initial growth was considerably higher at KB than at KD.

Table 2

The radial variation of the annual growth rate found here for *Quercus cerris* was similar to previous reports for the same species: a growth rate of 2.2- 2.9 mm in the first 15 years and 1.5 -1.7 mm afterwards until 25 years [Manetti 2002]. For 45-58-year-old *Quercus cerris* trees sampled in Italy, the mean annual radius increment was 2.3 mm [Corona *et al.* 1995]. The values are also similar to those reported for other oaks: Corcuera *et al.* [2006] found a radial ring width decrease from approximately 1.6 mm to 0.5 mm for a cambial age of 35-41 years in *Quercus pyrenaica*; Sousa *et al.* [2013] reported a decrease of ring width from 2.8-1.2 mm to 1.5-1.0 mm for cambial ages of 30-40 years for *Quercus faginea* while widths between 1.5 mm and 1.9 mm were reported for *Quercus petraea* and *Quercus robur* [Degron and Nepveu 1996; Zhang *et al.* 1993]. Tree ring width in *Quercus suber* also showed a decrease with cambial age from an average of 3.3 mm in the beginning of cambial activity to an average of 1.1 mm at 26 years of age [Leal *et al.* 2008].

In spite of the radial variation of ring width found in the sampled *Quercus cerris* trees, the overall variation was of small magnitude and therefore the stem showed considerable homogeneity. This is indicative that the within-tree variation of properties will not be detrimental to product value.

Heartwood and sapwood variation

Heartwood was present in all the trees until the maximal sampling height of 9.3 m. The vertical development of heartwood (Fig. 4) was similar in all the trees, decreasing from the tree base upwards, with the heartwood profile following closely that of the stemwood. The variation of the heartwood diameter was highly significant in relation to site and height level ($P<0.001$) but not to their interaction. The heartwood diameter was related to tree diameter at any height level (Fig. 4); in fact, the diameter of heartwood in *Quercus cerris* was strongly correlated with stem diameter ($R^2=0.83$ and 0.88 in KB and KD, p

Figure 4

<0.0001). This result shows the possibility of modelling heartwood dimensions in *Q. cerris* standing trees by measurement of tree diameter.

The correlation of heartwood diameter with tree diameter has been reported for several species e.g. *Acacia melanoxylon* [Knapic *et al.* 2006], *Eucalyptus globulus* [Gominho and Pereira 2000, 2005], *Pinus pinaster* [Pinto *et al.* 2004] and *P. canariensis* [Climent *et al.* 2003].

Table 3

The proportion of heartwood in the total stemwood cross-section remained stable in the lower part of the stem until about 5 m of tree height, after which it decreased to the upper height levels (Table 3). There was a difference between the sites in the average heartwood proportion with the trees from KB showing more heartwood than the trees from KD: the average proportion until 5 m of height was 53% and 43% respectively.

The radial width of sapwood was higher at the stem base, where it represented on average 44 mm (Table 3) and afterwards was approximately constant at 32 mm. There were no significant differences in sapwood development between the trees of both sites (Fig. 4) but the analysis of variance showed that site (P = 0.005) and height level (P<0.001) were significant factors of variation but not their interaction.

The within-tree axial variations of heartwood and sapwood are in agreement with previous results for most species [Hillis 1987] e.g. for *Quercus faginea* [Sousa *et al.* 2007]. The results also corroborate the theoretical background that, heartwood formation is a cumulative process that increases during tree growth, as required by the physiological conditions of the species, to maintain an approximately constant sapwood width [Bamber 1976]. In the case of the sampled *Quercus cerris* trees, the sapwood area (at 1.3 m) averaged 199.30 cm^2 in KB, and 191.86 cm^2 in KD (Table 3) while the average sapwood width of 3-4 cm is similar to values reported for other oaks e.g. *Quercus faginea* (2-5 cm) [Sousa *et al.* 2013], *Quercus petraea* (2 cm) [Granier *et al.* 1994] and *Quercus robur* (3 cm) [Čermák *et al.* 1991]. The relatively small radial dimension of sapwood of *Quercus cerris* trees allows the production of sawnwood components that are mostly constituted by the more valuable heartwood.

Bark development

Table 4

Bark represented on average 16.4% of the total overbark stem cross-section, with slightly higher values for the trees of KD in relation to KB (Table 4). The mean bark proportion decreased from base to the bh level; it remained constant until the upper sampled level in KB representing 14% of the total area, while in KD it increased along the tree from 16% at bh to 20% at 9.3 m. Within the tree, the bark thickness was highest at stem base (14.4 mm and 13.2 mm in KB and KD respectively, Table 4).

The analysis of variance of bark thickness showed a significant influence of stem height level (P=0.451) but not of site or their interaction. The analysis for bark proportion showed that site (P<0.001), stem height level (P=0.005) and their interaction (P=0.020) were significant factors of variation. This can be explained by the fact that there is a difference in age between the two sites.

The bark structure showed that the rhytidome proportion was highest at the stem base where it represented on average 51% of the total bark area (Table 4). Rhytidome proportion decreased for the upper tree levels; at 9.3 m, it represented on average 41% of the total bark area.

The analysis of variance of the proportion of rhytidome in the bark showed a highly significant effect of stem height level (P<0,001) and a significant effect of site (P=0.366) and their interaction (P=0.346).

Bark development in trees is a cumulative process and the formation of rhytidome is age dependent. This explains the fact that the bark thickness was highest at stem base and contained the highest proportion of rhytidome.

Taper

Table 5

Stemwood taper and heartwood taper for the different logs are summarized in Table 5. Taper was highest for the butt log especially from base to 1.3 m height and higher for the trees in KB than in KD (25 vs. 18 mm m^{-1}). The central logs showed a very small taper e.g. from 3.3 to 7.3 m taper averaged 2.8 and 3.9 mm m^{-1} respectively in KB and KD. The heartwood showed similar taper values, namely for the tree base (Table 5).

Overall the stems had a small conicity and very low taper values which stresses the stem quality of *Quercus cerris* for sawn wood components with potential low material loss from stem edges. The values compare favorably in relation to e.g. *Quercus suber* stems with an average 24 mm m^{-1} taper [Bembenek *et al.* 2013, Knapic *et al.* 2011]. Moreover, lower taper may facilitate mechanized harvesting of hardwoods. In the case of better trunk quality (lower taper), we can expect higher accuracy of bucking and lower damage to the outer layer of roundwood [Bembenek *et al.* 2015].

Conclusions

Quercus cerris trees grown in Kosovo showed good potential as a timber species for the supply of stemwood to the saw-milling industry. The growth rates were like those of other oaks and the stems showed an overall low radial heterogeneity of ring width as well as a very low taper.

The *Quercus cerris* trees contained a substantial proportion of heartwood and the sapwood width was on average 4 cm with small axial variation, therefore allowing potential good yields of heartwood-only sawnwood components. The bark content was high especially in the lower part of the stem where it included a high proportion of rhytidome, and should therefore be considered for complementary valorization.

The wood of *Quercus cerris* showed suitable characteristics for the production of lumber in sawmills, hence contributing to a possible further enhancement of the wood products industry in Kosovo.

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Table 1. Data regarding location and trees

	Site KB	Site KD
Coordinates	42^{0}30′31′′- 42^{0}30′38′′ N and 20^{0}59′06′′-20^{0}59′152″ E, at 650-697m of altitude	42^{0}51′20′′- 42^{0}51′23′′ N and 20^{0}43′50′′-20^{0}44′02″ E, at 817-885 m of altitude
Climate	moderate continental climate and continental climate	
Annual average air temperature	11.3 ^{0}C (-1.7 ^{0}C - 21.4 ^{0}C)	10.4 ^{0}C (-1.5^{0}C - 20.7^{0}C)
Average annual precipitation	609.8 mm	604.8 mm
DBH (average)	243.9 mm	214.3 mm
Total tree height (m)	17.8 m	11.1 m

Table 2. Tree growth variables for *Quercus cerris* trees (mean ± standard deviation) from two sites KB and KD in Kosovo measured at 1.3 m height: RW - mean annual ring width; IRW - mean annual ring for the initial growth in the first 20 years from pith; MRW - mean annual ring for the mature growth in the 45 to 65 years of cambial age;

	Annual growth rate (mm yr^{-1})	
	Site KB	Site KD
RW	1.76 (0.57)	1.21 (0.49)
IRW	2.22 (0.62)	1.23 (0.55)
MRW	1.34 (0.28)	1.16 (0.36)

Table 3. Variation along the tree height of *Quercus cerris* trees at two sites (KB and KD): total stemwood cross-sectional area (cm^2), heartwood proportion and sapwood width. Mean (standard deviation).

Height level	Site KB			Site KD		
	Cross-section wood area (cm^2)	Heartwood proportion (% of wood area)	Sapwood width (mm)	Cross-section wood area (cm^2)	Heartwood proportion (% of wood area)	Sapwood width (mm)
Base	756.9 (122.7)	52.5 (5.9)	42.5 (5.4)	511.3 (181.6)	40.7 (8.6)	46.3 (13.3)
1.3 m	469.9 (75.1)	57.2 (5.7)	29.7 (3.6)	333.8 (86.5)	43.2 (7.8)	35.6 (8.7)
3.3 m	407.2 (59.5)	54.4 (6.6)	29.7 (3.9)	281.2 (77.2)	43.9 (9.8)	32.2 (9.6)
5.3 m	371.4 (65.8)	51.2 (6.9)	30.9 (4.6)	234.0 (73.9)	41.1 (11.8)	31.6 (10.2)
7.3 m	333.3 (66.6)	48.1 (7.7)	31.3 (4.4)	196.9 (66.2)	37.0 (11.5)	34.4 (10.1)
9.3 m	285.9 (61.4)	43.6 (9.3)	32.7 (5.1)	155.9 (64.5)	25.6 (11.9)	35.1 (11.2)

Table 4. Variation along the tree height of *Quercus cerris* trees at two sites (KB and KD) of bark proportion, thickness, and rhytidome content. Mean ± standard deviation.

Height level	Site KB			Site KD		
	Bark (% of total stem area)	Bark thickness (mm)	Rhytidome (% of bark)	Bark (% of total stem area)	Bark thickness (mm)	Rhytidome (% of bark)
Base	16.8 (3.0)	14.4 (2.2)	53.5 (3.2)	18.2 (2.4)	13.2 (2.6)	49.4 (6.0)
1.3 m	14.4 (1.0)	10.0 (1.8)	52.8 (4.2)	16.3 (1.2)	9.6 (0.8)	46.6 (5.1)
3.3 m	14.1 (0.9)	8.9 (1.1)	47.8 (3.9)	16.9 (1.1)	9.0 (0.8)	45.6 (5.9)
5.3 m	14.1 (0.4)	8.6 (1.0)	43.5 (5.9)	18.1 (1.5)	8.9 (0.6)	46.0 (8.4)
7.3 m	14.4 (0.4)	8.2 (0.9)	41.1 (4.4)	18.8 (1.6)	8.5 (1.1)	43.9 (5.7)
9.3 m	14.6 (1.0)	7.9 (1.2)	40.6 (5.4)	20.1 (1.1)	8.0 (1.3)	41.7 (2.7)

Table 5. Stemwood and heartwood taper, in mm/m, between different stem height levels (mean ± standard deviation) of *Quercus cerris* trees in two locations (KB and KD). In Kosovo

Height level	Stemwood taper (mm/m)		Heartwood taper (mm/m)	
	Site KB	Site KD	Site KB	Site KD
Base - 1.3 m	25.1 (2.3)	18.0 (8.4)	15.1 (2.8)	12.9 (8.9)
1.3 m - 3.3 m	4.2 (0.7)	4.2 (1.2)	4.2 (0.5)	2.8 (0.9)
3.3 m - 5.3 m	2.6 (1.3)	4.2 (2.2)	3.2 (0.9)	3.7 (2.2)
5.3 m - 7.3 m	2.9 (1.3)	3.6 (0.5)	3.1 (0.8)	3.6 (0.9)
7.3 m - 9.3 m	3.0 (1.7)	4.5 (0.8)	3.7 (0.7)	5.7 (1.2)

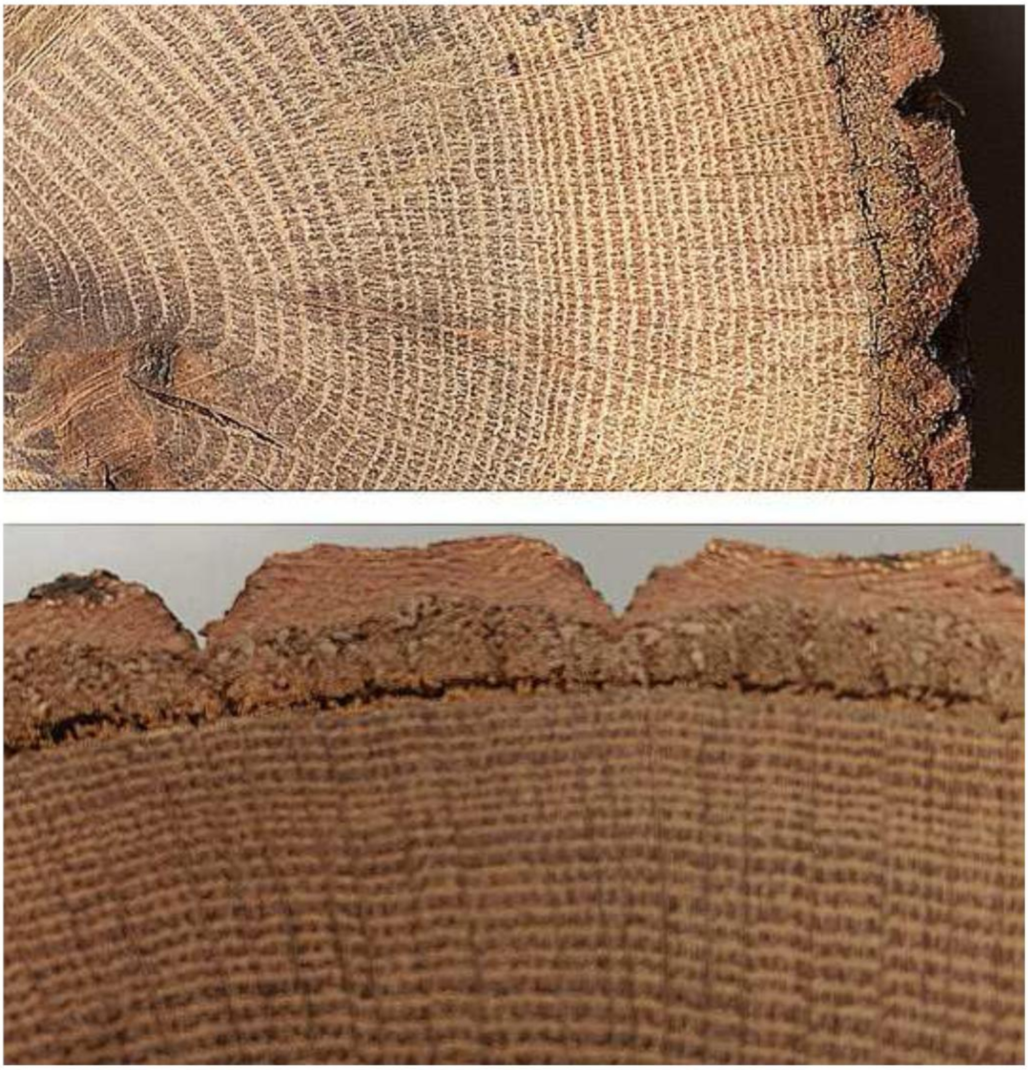

Figure 2

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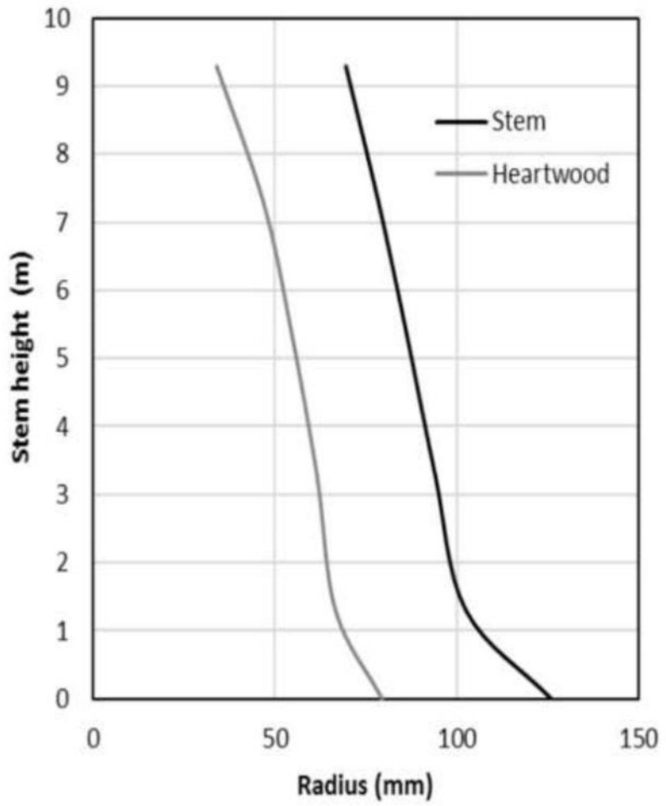

Figure 3

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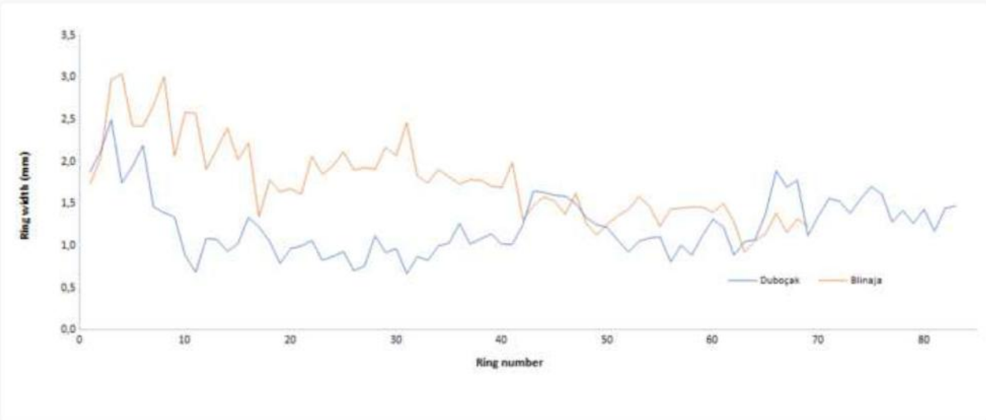

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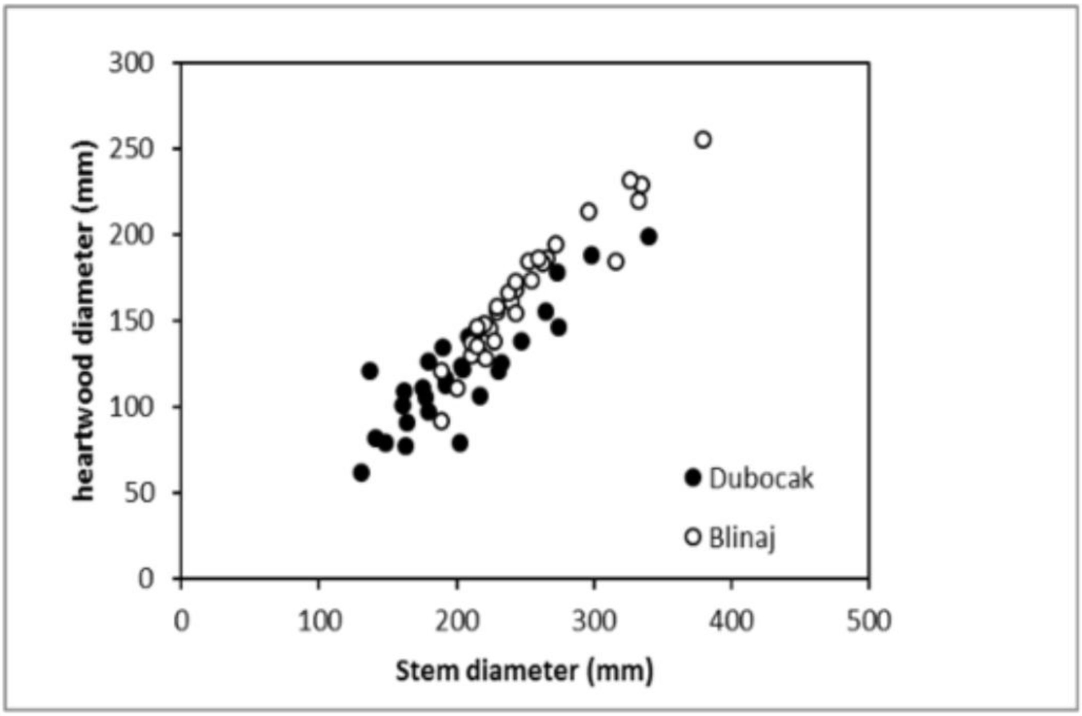

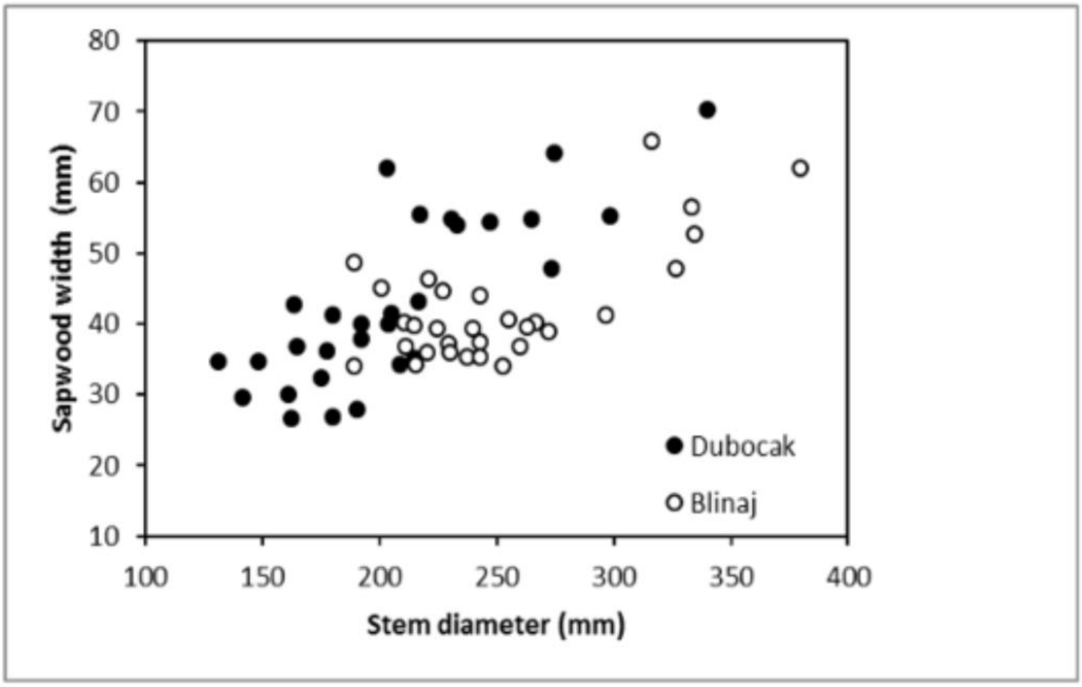

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CHEMICAL CHARACTERIZATION, HARDNESS AND TERMITE RESISTANCE OF *QUERCUS CERRIS* HEARTWOOD FROM KOSOVO

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ABSTRACT

Quercus cerris, the Turkey oak, is an oak species native to southern central and southeastern Europe, extending into southwestern Asia. It is present in a large extent in the forests of the Republic of Kosovo, and at present used mainly for bio-energy. The potential use of *Q. cerris* wood for construction and higher value wood products has been investigated in the last years. However limited information is available on wood characteristics and performance, mainly regarding chemical composition and durability. The heartwood of *Q. cerris* taken from 70-90 year-old trees grown in two sites in Kosovo was studied regarding resistance to termite attack, chemical composition and hardness. The heartwood contained only 6.7% extractives, with a small content of tannins. The wood density was on average 0.81 at 12% moisture content and Brinell hardness 36.2 N mm^{-2}. It was classified as not durable against subterranean termites and therefore not suitable for external use in ground contact in termite areas unless adequately protected. Nevertheless, *Q. cerris* wood showed adequate hardness and density for interior uses like flooring for domestic and commercial applications with moderate use.

Keywords: Brinell hardness, chemical analysis, density, *Reticulitermes grassei,* wood extractives.

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INTRODUCTION

For centuries, European oaks have provided highly valued timber for carpentry, furniture making, construction and ship building. However, except for a few of the oak species e.g. *Quercus robur* and *Q. petreae*, the knowledge on the technological properties of other species is still sparse. This is the case of *Quercus cerris*, the Turkey oak, a species native to southern central and southeastern Europe, extending into southwestern Asia (Danielewicz et al. 2014).

Q. cerris is present in the forests of the Republic of Kosovo, which cover 42% of the country area and harbor a great potential in biomass for energy purposes and good quality timber for construction mainly from European beech (*Fagus sylvatica*) and oaks, with relevance to Turkey oak (*Q. cerris*) (Bajraktari et al. 2014). *Q. cerris* is one of the most used wood species in the country although mainly for bio-energy (Bouriaud et al. 2014).

The possibility of using *Q. cerris* wood for construction and in higher value wood products has been investigated in the last years (Bajraktari et al. 2014; Standfest et al. 2012a, b). The potential of *Q. cerris* bark as a cork provider was also studied especially regarding one variety in Turkey, *Q. cerris x cerris*, that has a thick bark with high cork content (Sen et al. 2011, 2016). Several authors have attempted wood modification processes (heat and steaming treatments) to improve the wood dimensional properties and to homogenize surface color (Todaro et. al. 2012, 2013). Other wood properties were also investigated e.g. density and moisture (Monaco et al. 2011), and bending strength (Karastergiou et al. 2005). However, there is still limited information on *Q. cerris* wood characteristics and performance, mainly regarding chemical composition and durability.

The biological deterioration of applied timber is often viewed as a limiting factor for its improved used in building. The natural durability of a wood species, defined as its inherent resistance to wood destroying agents, can vary widely depending on tree age, geographical origin, and growing conditions. Decay resistance also varies within the stem e.g. it tends to increase radially from pith to the heartwood-sapwood boundary and longitudinally from crown to base (Stirling et al. 2015), and is typically connected to the wood chemical composition, in particular, with the extractives present (Daniels and Russell 2007; Gierlinger et al. 2003; Pâques and Charpentier 2015). Nevertheless, the reasons of resistance to decay may not be directly translated into resistance to insect attacks: for instance, Taylor et al. (2006) found that the total wood extractives amount was important but alone could not explain termite durability in *Thuja plicata* and *Chamaecyparis nootkatensis*, and Stirling et al. (2015) confirmed the findings for *Thuja plicata*. Density and hardness are also typically referred as influencing the natural resistance of wood to termite attack (Esenther 1997; Peralta et al. 2004; Arango 2006; França et al. 2016).

In the present work, the natural durability class for insect degradation, as defined by EN350 (2016) (Table 1), was determined for *Q. cerris* heartwood from mature trees at harvest age grown in Kosovo. Subterranean termites from the species *Reticulitermes grassei* were used as models as they are accepted as the most dangerous insect species capable of degrading applied timber in Europe and elsewhere and their risk is expected to be higher in a changing climate scenario (Ewart et al. 2016). Tests were conducted according to EN 117 (2013) and the results obtained linked to the chemical analysis, density and Brinnel hardeness data obtained from paired test specimens.

Table 1. Wood durability classes to attack by subterranean termites according to EN350 (2016).

Durability Class	Description	Attack level
DC D	Durable	≥ 90 % "0 or 1" and max 10 % "2"; no "3" or "4"
DC M	Moderately durable	< 50 % "3, 4"
DC S	Not Durable	≥ 50 % "3, 4"

MATERIALS AND METHODS

Site characterization and sampling

Ten mature *Quercus cerris* L. trees were randomly selected and harvested from two naturally regenerated and unmanaged stands in the Republic of Kosovo: Blinaja (KB), located at 42°30'31''N – 42°30'38''N and 20°59'06''E – 20°59'15''E at 650-697 m of altitude, and Duboçak (KD) at

42°51’20”N - 42°51’23”N and 20°43’50”E - 20°44’02”E at 817-885 m of altitude. Both sites belong to a mixture of moderate continental and continental climates with 11.3ºC (KB) and 10.4ºC (KD) annual average air temperature, and 609.8 mm (KB) and 604.8 mm (KG) average annual precipitation.

The trees were randomly selected in each stand and characterized by measuring total height and diameter at 1.3 m above ground (d.b.h., as the mean of two crossed diameters). Tree age was approximately 70 and 90 years, respectively at KB and KD.

For stem quality characterization (Bajraktari et al. submitted) cross-sectional discs were taken at different stem height levels (base, 1.3 m, 3.3 m, 5.3 m, 7.3 m and 9.3 m) and the logs between the first four discs were converted to boards. The boards were dried indoor under well ventilated conditions and the test specimens were taken from the heartwood. Unless otherwise described, the test specimens were obtained from the second log (1.3 m - 3.3 m).

Chemical analysis

Chemical summative analysis included determination of ash, soluble extractives in dichloromethane, ethanol and water, Klason and acid-soluble lignin, and the monomeric composition of polysaccharides. A total of 12 test specimens from the heartwood (6 from KB and 6 from KD) with 50 x 25 x 15 mm were individually analysed following procedures adapted from TAPPI standard methods (TAPPI, 2004).

The test specimens were ground with a knife mill (Retsch SM200), sieved (Retsch ISO9001) and the 40-60 mesh fraction was kept for analysis. The ash content was determined by incinerating 1.0 g of the sample at 525º overnight and weighing the residue (TAPPI 15 os-58).

The determination of extractives was adapted from TAPPI 204 cm-97, using a Soxhlet system with dichloromethane, ethanol and water during 6 h, 16 h and 16 h respectively. The extractives solubilized by each solvent were determined by mass difference of the solid residue after drying at

105ºC. The lignin content was determined in the extracted samples by acid hydrolysis with 72% sulphuric acid following TAPPI T 222 om-02. Klason lignin was determined as the mass of the solid residue after drying at 105ºC and the acid-soluble lignin was determined by the absorbance at 206 nm using a UV/VIS spectrophotometer (TAPPI Useful Method UM 250). The monosaccharides including neutral sugars and uronic acids as well as acetates were quantitatively determined in the hydrolysis liquor by High Performance Anion Exchange Chromatography. All determinations were made in duplicate samples.

Ethanol-water extracts

The ethanol-water extracts were prepared using 0.5 g of the sample and 20 ml ethanol/water (50/50, v/v), for 30 min at 40 ºC in an ultrasonic bath. After filtration, the supernatant extract was used to determine the contents in total phenolics, condensed and hydrolysable tannins and flavonoids.

The total phenolics content was estimated according to the Folin–Ciocalteu method using gallic acid as a standard (Singleton and Rossi 1965; Miranda et al. 2016). Total flavonoids were quantified by an aluminium chloride colorimetric assay, and the results were expressed as mg of (+)-catechin equivalents on a dry extract base (Jia et al. 1999; Miranda et al. 2016). Tannin content was determined by the vanillin-H2SO4 method, and the results were expressed as mg of (+)-catechin equivalents on a dry extract base (Abdalla et al. 2014; Miranda et al. 2016).

Brinell hardness

Brinell hardness perpendicular to the grain was evaluated according to EN 1534 (2010) with test specimens with the following dimensions: 40 x 40 x 10 mm. Seven replicates from the second log of each tree felled and seven extra replicates from the first and third log of one tree per site in a total of 49 replicates for each location.

The tests were conducted at 20 ºC ± 2 ºC and 65 % ± 5 % relative humidity, using a universal machine AG 250KNIS-MO from Shimadzu, capable of measuring the applied load with an accuracy of 1 %. The test specimens is set to the machine table and a 10 mm steel ball indented into the surface of the wood at a steady and constant force in order to achieve 1 kN in 15 ± 3 s. The load was maintained for 25 ± 5 s and, after removal, the indentation was measured on images acquired immediately after testing with an Olympus SZX-ZB12 stereoscopic microscope and Olympus DP-Soft software. Crossed diameters (d1 and d2) were measured to evaluate the size of the deformation inflicted by the ball. The Brinell hardness values (HB) were determined according to Eq. 1 in $N.mm^{-2}$,

$$HB = \frac{2F}{\pi D[D^2 - d^2)^{1/2}} \qquad (1)$$

where F is the force applied (N); d is the diameter of the indentation, in mm (average of two perpendicular diameters d1 and d2) and D is the diameter of the ball, in mm.

Determination of density

Density was calculated according to the Portuguese Standard NP616 (1973) on the same test specimens used for the determination of the Brinell hardness and termite resistance. All specimens were conditioned for one week at controlled temperature and humidity (20 ± 1°C; 65 ± 5%) and weighed. Dimensions of each specimen were then measured using a caliper and density calculated based on weight and volume and adjusted to 12% equivalent moisture content (EMC).

Termite resistance

The natural durability of the wood was evaluated according to the recommendations of EN350: 2016; therefore, the natural durability against the attack by subterranean termites was determined following the general procedure described in EN 117: 2012 with adaptations as described. Six replicates (50 mm x 25mm x15 mm) from the second log of each tree felled and six extra replicates from the first and third log of one tree per site in a total of 42 replicates for each location were tested.

The termites, *Reticulitermes grassei* (Clément), were collected from fallen logs from a forest area of *Pinus pinaster* Aiton, located 38º32.436' N 09º07.848' W, 18 m elevation. They were kept in Petri dishes with moistened filter paper inside a conditioned room (24 ± 2 ° C; 80 ± 5%) for a maximum of 10 days. Colonies of 250 workers (plus 1-3 soldiers and 3-5 nymphs) were established in 750 ml glass conical flasks with moisturized sand (Fontainebleau sand and water; 4:1 v/v) as substrate. The test specimens were placed over glass rings after installation of the termites in their respective containers, and the test run for eight weeks at 25 ± 2ºC and 80 ± 5 % relative humidity. Ten *P. pinaster* untreated test specimens with the same dimensions were also included as virulence controls. After the exposure period, the test specimens were removed and cleaned and the survival rate (expressed in %) was determined. A visual examination of the wood blocks was performed according to the criteria specified in the standard for the evaluation of the level of attack (0=no attack; 1=attempted attack; 2=slight attack; 3=moderate attack; 4=strong attack). The test is considered valid if all virulence control test specimens reach a final level of attack of "4" and have an average survival rate above 50%.

Statistical analysis

The descriptive statistic, correlation and regression analysis and analysis of variance (ANOVA or Student's t-test), where relevant, were performed using Microsoft Excel® (2010) and SigmaStat version 2.0 (Jandel Corporation).

RESULTS AND DISCUSSION

Chemical analysis

Table 2 displays the results regarding the chemical analysis of *Q. cerris* heartwood. The analysis of variance showed no significant difference (P>0,05) between the two sampling sites for the mean values of total extractive content (P=0.415) and total lignin content (P=0.820).

Table 2. Chemical composition (% of the total dry mass) and monosaccharide composition (% of total monosaccharides) of the heartwood of *Q. cerris* from KB and KD. Mean and standard deviation of 6 trees per site and 2 replicates per tree.

	KB	**KD**
Ash	0.88 (0.21)	0.97 (0.26)
Extractives		
Dichloromethane	1.02 (0.21)	1.01 (0.17)
Ethanol	2.12 (0.41)	2.65 (0.86)
Water	3.29 (1.06)	3.33 (0.86)
Total	6.43 (1.33)	6.99 (0.94)
Lignin		
Klason lignin	23.23 (1.36)	24.00 (1.41)
Soluble lignin	3.05 (0.30)	2.45 (0.24)
Total	26.27 (1.32)	26.45 (1.28)
Monosaccharides		
Ramnose	0.74 (0.08)	0.88 (0.12)
Arabinose	1.41 (0.12)	1.69 (0.08)
Galactose	1.98 (0.63)	2.18 (1.13)
Glucose	62.23 (2.41)	58.49 (2.46)
Xilose	30.41 (1.71)	33.06 (2.92)
Manose	2.07 (1.55)	3.04 (1.83)
Galacturonic acid	1.93 (0.14)	1.87 (0.13)
Acetic acid	0.23 (0.01)	0.21 (0.01)

The heartwood of *Q. cerris* presented the following average composition: ash 0.93%, total extractable substances 6.7% and total lignin 26.4%. The extractives consisted mainly of polar compounds extracted by ethanol and water (5.7% of heartwood), corresponding to 85% of the total extractives.

The striking chemical feature of *Q. cerris* heartwood is the low content in extractives (6.43% for KB and 6.99% for KD). In fact, oaks have in general a large amount of extractives. For instance, Sousa et al. (2009) reported values of total extractives between 18.8-19.3%, and total lignin 22.6-23.7% for the heartwood of *Q. faginea*. Carmona (2009) refers to total extractive contents between 14.8% and 15.7% (where the extractives in ethanol and water represent about 93% of the total extractives) in *Q. robur*.

The chemical composition of the polysaccharides shows that glucose is the major sugar, corresponding to about 60.4% of the total monosaccharides present. The second most important sugar observed was xylose with a value of 31.7%, which means that hemicelluloses in *Q. cerris* heartwood are predominantly xylans with low contents of arabinose and acetyl groups.

The monomeric composition of polysaccharides is similar to that found for other oak woods in terms of predominance of glucose followed by xylose. Regarding *Q. faginea*, Sousa et al. (2009) reported glucose and xylose values of 59.9% and 30.3% of the total monomers, respectively. A similar composition was reported for *Q. laurina* and *Q. crassifolia* woods with dominance of glucose (52.3–56.7%) and xylose as the second most abundant sugar (28.5–35.1%) (Ruiz-Aquino et al. 2015).

Composition of ethanol-water extracts

The results obtained for the ethanol-water extracts of *Q. cerris* heartwood are presented in Table 3.

Table 3. Ethanol-water extracts of the heartwood of *Q. cerris* from KB and KD: yield and content of total phenolics, condensed tannins and flavonoids. Mean and standard deviation of 6 trees per site.

	Blinaja	**Duboçak**
Extraction yield (%)	2.2 (1.3)	2.1 (1.0)
Total phenolics (mg GAE / g extract)	338.8 (152.8)	284.2 (97.9)
Condensed tannins (mg CE / g extract)	38.9 (26.1)	12.3 (6.0)
Flavonoids (mg CE / g extract)	67.4 (45.3)	61.2 (24.0)

There were no significant differences between the two locations, except for the condensed tannins that were higher in KB.

The total polyphenol content was on average 310.5 mg GA/g of extract, the average tannins and flavonoids 25.6 mg CE / g extract and 64.3 mg CE / g extract. No hydrolysable tannins were found. Lavisci and Scalbert (1991) have reported levels of polyphenols of 3-4 mg / g of *Q. cerris* wood. *Q. cerris* heartwood shows comparatively low amount of phenolics and tannins in comparison with other oaks, normally used in cooperage, and where high values of hydrolysable tannins and the non-existence of condensed tannins are reported.

Brinell hardness and Density

The results obtained for the Brinell hardness are presented in Table 4 as well as the average density of each group of test specimens. Significant differences were found between sites for density ($p<0.001$) and Brinell hardness ($p<0.001$) that were lower in the KD samples.

Table 4. Brinell hardness and density of the heartwood of *Q. cerris* from Blinaja and Duboçak. Mean and standard deviation of 7 replicates, maximum and minimum values measured.

		Blinaja	**Duboçak**
Brinell hardness ($N.mm^{-2}$)	Average (std dev)	38.48 (3.88)	33.90 (5.25)
	Minimum - Maximum	29.99 – 48.45	23.45 – 47.60
Density	Average (std dev)	0.83 (0.02)	0.78 (0.05)
	Minimum - Maximum	0.79 - 0.88	0.71 - 0.88

A positive correlation was found between density and Brinell hardness (Fig. 1).

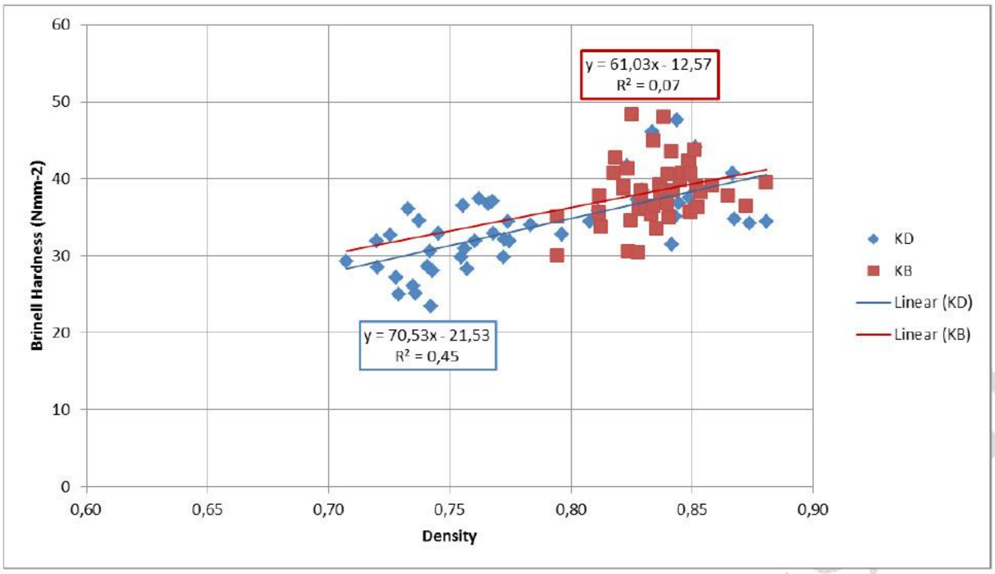

Figure 1. Relation between Brinell hardness and density of *Q. cerris* heartwood.

The regression between density and hardness was significant for KD samples (R^2=0.45; P<0.0001), while it was not significant for KB samples (R^2=0.07; P=0.06).

The average density and Brinell hardness values from KB were close to the ones obtained on a previous study of wood from the same region (Standfest et al. 2012): 0.86 for density and 39.92 N mm^{-2} for hardness. The average hardness values obtained for *Q. cerris* wood are lower than values reported for *Q. faginea* (50 N mm^{-2}) or *Q. suber* (56 Nmm^{-2}) but are nevertheless well within the required values for domestic flooring applications or commercial uses with moderate traffic (EN14354, 2004).

Termite resistance

The results obtained for the rate of termite survival at the end of the test and grade of attack are presented in Table 5. The control test specimens of maritime pine (n=10) had an average density of 0.66±0.07 and at the end of the test showed an average level of attack of 4 and an average survival rate of 66.20% ± 15.37%.

Table 5. Wood density, survival and level of attack after 8 weeks of exposure to R, grassei of *Q. cerris* heartwood from KB and KD. Mean and standard deviation of 6 replicates.

		KB			KD		
Tree	**Log**	**Density**	**Survival (%)**	**Level of attack**	**Density**	**Survival (%)**	**Level of attack**
I	2	0.81 (0.02)	54.40 (27.93)	3.33 (0.82)	0.82 (0.02)	58.20 (20.53)	3.33 (0.52)
II	2	0.79 (0.02)	67.27 (14.59)	3.67 (0.52)	0.79 (0.01)	33.53 (26.74)	3.33 (0.82)
III	1	0.80 (0.02)	59.27 (19.34)	3.50 (0.55)	0.79 (0.06)	45.53 (12.61)	3.33 (0.52)
III	2	0.77 (0.01)	53.47 (21.56)	3.67 (0.52)	0.87 (0.02)	45.93 (14.32)	3.17 (0.75)
III	3	0.83 (0.02)	55.93 (20.07)	3.83 (0.41)	0.76 (0.02)	29.40 (19.82)	3.67 (0.52)
IV	2	0.84 (0.06)	47.20 (27.00)	3.50 (0.55)	0.80 (0.03)	68.33 (8.23)	3.83 (0.41)
V	2	0.81 (0.01)	33.00 (12.54)	3.00 (0.55)	0.79 (0.02)	16.93 (16.67)	2.83 (0.75)
MEAN (n=42)		0.81 (0.03)	52.93 (21.94)	3.50 (0.55)	0.80 (0.04)	42.27 (23.26)	3.36 (0.66)

No significant differences were found between the *Q. cerris* heartwood samples from both sites. On average, the survival rate was 47.60 % and the level of attack 3.43. No significant correlation was found between wood density and rate of survival. The percentage of test specimens graded "3 and 4" was determined and found to be 90.5% for KD and 97.8% for KB. Taking into account the criteria defined by EN350 (2016) to assign a subterranean termite durability class (Table 1) to a certain species of wood, the heartwood from *Q. cerris* is classified as DC S (Not durable).

The fact that the species is susceptible to subterranean termites and has a heartwood classified only as "moderately durable" towards fungal decay (EN350, 2016) leads to a recommendation of use preferably "out of ground contact" unless it is conveniently treated or otherwise protected, particularly in locations where termites are a risk.

Although other factors may influence the natural durability against termites, the susceptibility of *Q. cerris* heartwood to termite attack is on line with the low extractives content found on the paired specimens (Table 2) and on the low content of tannins in the polar extracts (Table 3).

CONCLUSIONS

1. The heartwood of *Q. cerris* has a low content of extractives namely of polar compounds of phenolic nature, namely of tannins.

2. The *Q. cerris* wood is described as “not durable” against subterranean termites and its use in outdoor environments in ground contact should be avoided unless adequate protection is made.

3. *Q. cerris* wood shows adequate hardness and density for interior uses like flooring for domestic and commercial applications, with moderate use.

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Chapter 4
Conclusions and Recommendations

CONCLUSIONS AND RECOMMENDATIONS

The aim of this thesis was to contribute to the sustainable use of wood in the Balkan region, particularly in Kosovo. In order to achieve this aim, the following objectives were defined and accomplished throughout this research:

The first objective was to evaluate the forest resources available in Kosovo's forest that could be exploited and used as raw-material by the wood processing industry. For that the annual volumes of round wood felled were determined in relation to the amounts of timber available in the forest. The forest resources in Kosovo are managed by the Kosovo Forest Agency, which is part of the Ministry of Agriculture, Forestry and Rural Development and the reports conducted or existing in this organism have formed the basis of this study together with local surveys conducted in the country. The evidence provided in this study suggests that the annual volume as well as annual felling allowance of Turkey oak located in Kosovo forests, is sufficient enough to fulfill the needs of wood processing industry in Kosovo. This study shows that sawmills processing beech and oaks are located over the country and that there is a potential supply surplus allowing the increase of production of sawn products from beech and oaks. However, it has to be pointed out that such a production increase only makes sense if two factors converge: i) a market need for the sawn wood; and ii) an effective supply of quality logs.

The second objective was to describe the sawmill structure in Kosovo in view of a potential increase in oak supply and the production of added-value wood products. The results of the present study show that 74% of sawmills in Kosovo work with a frame-saw and are concentrated in the western districts, while 26% sawmills work with a band-saw and are concentrated in the eastern districts. This indicates that this frame saw mills have specialized in cutting softwoods and hardwoods and can cut timbers in thickness of 15 – 100 mm according to the dimensions and shapes required by customers.

The third objective of this thesis was to study *Quercus cerris* as a model timber species with high technological potential. For that mature trees at harvest age in two locations were felled and samples taken for stem and wood analysis. This objective was further divided into the following goals:

a) Evaluation of stem quality of *Quercus cerris* for the sawmilling industry regarding heartwood, sapwood and bark development along the tree as well as ring analysis and taper. The results show that *Quercus cerris* trees grown in Kosovo provided good potential as a timber species for the supply of stem wood to the saw-milling industry mainly because

- the growth rates were similar to those of other oaks
- the stems showed an overall low radial heterogeneity of ring width as well as a very low taper
- the trees contained a substantial proportion of heartwood, therefore allowing potential good yields of heartwood-only sawn wood components.

The bark content was high especially in the lower part of the stem where it included a high proportion of rhytidome, and should therefore be considered for complementary valorization.

b) Evaluation of insect natural durability of *Quercus cerris* heartwood and its relation to chemical composition and some mechanical parameters. The chemical composition of *Quercus cerris* heartwood is characterized by a low content of extractives namely of tannins and flavonoids. and showed no influence from the sites. *Quercus cerris* heartwood from both locations can be described as "not durable" against subterranean termites. The *Quercus cerris* heartwood from both locations tested showed adequate density and hardness values for in interior uses like flooring for both domestic and commercial applications, with moderate use. Exterior applications with adequate protection can also be relevant.

Overall the present results show the potential of Turkey oak trees to be used by the existing sawmills in Kosovo to produce timber and wood products for construction and carpentry both from a technological stem quality point of view as well as from the available resources in the forests.

Additional research should be carried out to better understand and evaluate the quality of the potential available *Quercus cerris* logs. The following future research lines are proposed:

- the sampling done in the present study was limited in terms of trees sampled and on the number of sites; therefore, a more intensive sampling should be done in more sites and trees, also collecting information on the forest characteristics at the sampling site e.g. structure, stand density and biometry.

- the present study did not investigate the quality of the potential available logs and further research is needed to study bucking and sawing yields; further the knottiness of the stem was not addressed in the present study and should be considered in further research
- the wood drying process of *Quercus cerris* wood should also be addressed since this is a key quality parameter for the wood planks
- the structural cellular features of the wood should also be studied, namely in association with protection treatments to improve the wood durability
- a further study of *Quercus cerris* bark regarding its cork content and chemical composition should also be made in order to assess its valorization potential
- finally, an evaluation of the impact that environmental factors, namely of climate factor have on tree and wood growth should be considered in view of the future scenarios of climate change.