ONLINE ISSN 2069-7430
ISSN-L 1841-4737

PRO LIGNO
www.proligno.ro

Vol. 15 N° 4 2019
pp. 3-12

# AVAILABILITY AND UTILIZATION OF LESSER USED WOOD SPECIES UNDER CLIMATE CHANGE. APPLICATIONS OF NATIVE AND IMPROVED MODIFIED WOOD

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***Abstract:***

*This paper presents the results of literature sources of the site conditions and availability of lesser used wood species (luWS) in various Central and Southeast European countries under climate change influences, partly flanked by own experiences and additional investigations. Compared to the fostered and omnipresent dominating spruce, pine beech and oak species in Europe these long time sylvicultural suppressed luWS are often better adapted to the expected future climate-change scenarios, characterized mainly by warmer and in the growing season drier weather conditions. For ten selected luWS wood property data from literature and own investigations were collected to show the additional property and application range, widening not only the biodiversity in the forest, but also the material diversity of renewable bio-based materials.*

*In case of obtaining wood assortments and qualities from these luWS, not obtaining the required wood performances, a set of wood modification processes, like densification or impregnation of wood with traditional and renewable components are shown, able to improve important properties like durability, dimensional stability, behaviour under humidity or mechanical strength.*

***Key words:*** *climate change; change in forest site conditions and tree composition; bio- and material-diversity; lesser used wood species (luWS); wood property improvement.*

## INTRODUCTION

Since several decades, regionally also centuries, European forests are influenced or changed by both, sylvicultural management activities of foresters as well as environmental, chemical and climate change processes of individual - or industry-processes.

These influences resulted in a change of forest site conditions and structures as well as tree species composition with strong impact on the grown wood assortments and produced materials. Due to intensive forest management activities the productivity of European forests is high and of economic importance, with a similar quantity of wood production like in Asia or North America, and higher than South America or Africa.

In Europe, this wood production is focused on few tree species only, often concentrated on spruce, pine, beech and oak. In many European countries the sum of only these 4 species covers 70-85% of the national wood production. This resulted in high productivity and optimization in the forest and wood industry, but the bio- and material- diversity in both sectors was dramatically decreasing during the last century/ies). For many wood applications, these main species are not or not sufficiently suitable for higher value or exterior use, resulting in an increasing amount of imported assortments from outside Europe or a treatment and improvement of lesser suitable species with oils, biocides or wood modification processes. Not all of them are suitable for high value materials or environmental friendly, sustainable processes, leading to an increasing critic and exclusion of wood products, including also the exchange of bio-based materials and products by competitive, non-renewable materials like plastic, aluminum, concrete etc. with a much lower sustainability index compared to bio-based materials.

Nevertheless a lot of additional tree species exist in European forests, often better adapted to changing climate conditions, like drought, higher temperature, or storm. A lot of industrially non-wished tree species had been depressed or eliminated by forest management and sylviculture, leading to low stable and less resilient forest structures. Especially the man-made monoculture forests are strongly suffering under the influences of these changing climate parameters, leading to a decreasing productivity and an increasing exposure to diseases, calamities or forest fires and endangering the sustainability of high-productive, stable forest systems in many regions. A lot of lesser used wood species (luWS) show an environmental optimum, which is, partly already now or in future, much better adapted to the expected climatic and site condition scenarios, possibly appearing subsequently under the climate change processes. Kölling (2014) and Thurm et al. (2018) showed for special model regions in Germany the potential correspondence of the ecological spread of selected tree species (Fig. 1, yellow area) and their possible overlap with the actual site conditions (red- and blue-rimmed areas) as well as their running or future change under climate change conditions (expected scenario +2.3°C, decreasing precipitation during growing season [red arrow]). Their investigations also include the search and determination of European regions with an actual climate, already reaching today the values of the climate scenarios in the German model regions after 50 years. The additional and

ONLINE ISSN 2069-7430
ISSN-L 1841-4737
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supported enclosure of these up to now lesser-used or too-less used wood species, better adapted to the future climate, for example alder, hornbeam, ash, poplar, mountain ash or other Sorbus-species, or also species with an origin outside the local distribution of our native forests, like robinia, Eur. chestnut, walnut, platanus, or further cherry or oak species, can help to stabilize the forest environment and the bio-based sector, enabling an ongoing $CO_2$-fixation, leading to a decrease of the global warming.

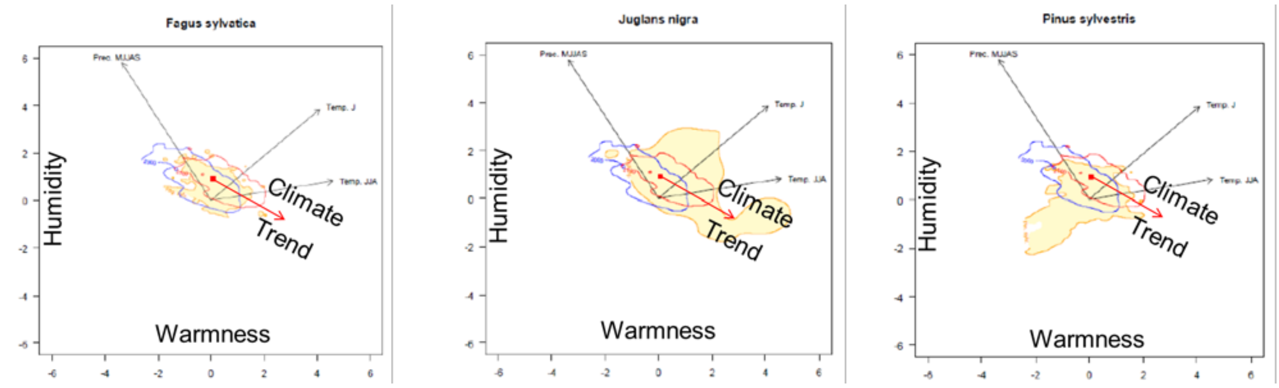


***Fig. 1.***
***Climate-Similarity of actual (blue and red circles) and future climate (+2.3°C, red arrow) and compare of their ecological optimum (yellow area) for a Test-Area in Germany for local and non-local tree species. Kölling 2014 (modified).***

In this paper examples of additional lesser-used tree and wood species, their ecological site optimum and their possible prosperity and availability are investigated, also including the widened property range and new applications on the bio-based market.

**MATERIAL, METHOD, EQUIPMENT**

Site conditions, ecological optimum, climate change scenarios: The presented examples and results base on the investigations of Kölling (2014) and Thurm et al. (2018).

Availability of wood and share of wood species in European Pilot-Studies: The presented data are published in several European and national Forest-Reports, commissioned or prepared e.g. by the European Commission (2018) or national institutions, dealing for example with State Forests in Poland (2018), BWI (2012) Dritte Bundeswaldinventur, Pro-Holz Webpages for Hungary or Croatia (2019) or Czech (Ministry of the Czech Republic [2018]) and Slovakian forests (Ministry of Agriculture of the Slovak Republic [1997]) or authors compiling data about Romanian (Ionascu 1999), Austrian (Teischinger 2019) or Slovenian forests (Poljanec 2019).

Properties of selected native wood species: Basic data for general wood properties delivered Wagenführ (2006) in his compendium. Own investigations about chemical, physical and mechanical wood properties were executed following the EN standards. Details are published in Pařil et al. (2014).

Property improvement by wood densification/ modification and their adaption for new applications: The wood plasticisation to enable the later densification without wood-damages was carried out by using steam or alternativ ammonia gas. For subsequent wood densification a press was used, partly followed by a temperature step of about 110°C, for heat treatment or curing processes the temperature was raised up to 160-230°C. Extraction and impregnation steps were carried out with hot water or a methanol-water 1:1 mix; extracts like Robinetin-derivates of different composition or DMDHEU-water-solutions were impregnated into the wood by using vacuum-pressure cycles; leaching tests were carried out by exposure of the impregnated samples to water. Chemical analysis were done by using HPLC, GC or Spectrophotometer. Details are described in Rademacher et al. (2007), Bollmus et al. (2010), Pařil et al. (2014), Horníček et al. (2015), Sablík et al. (2016) and Rademacher et al. (2017).

**RESULTS AND DISCUSSION**

**Availability of Wood in Europe**

The productivity of European forests is traditionally high compared with other worldwide important centers of wood production. Each with about 19-20% USA and EU28 are leading the ranking list of totally 1.8 Bio $m^3$ of actual (5-year average global production 2010-14) yearly produced industrial round wood (energy wood not included), followed by total South America, Russia, China and Canada with about 13% down to 8% of the worldwide production (Fig. 2, European Commission 2018).

Accordingly forests and wood play an important role in the European economy, but also in the landscape characteristic or the ecological, health and tourism sector, like cleaning and filtering functions of drinking water and air, or human welfare.

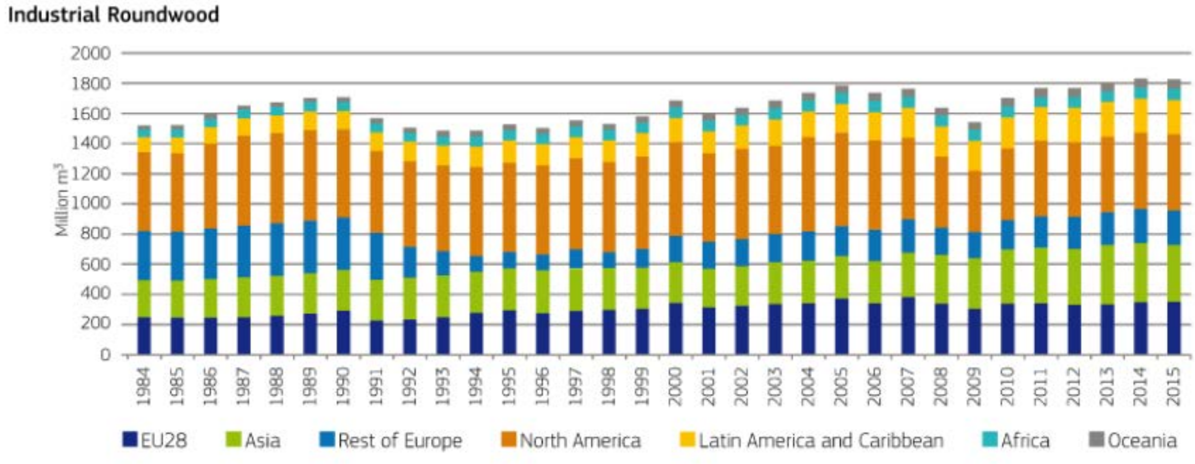


***Fig. 2.***
***Worldwide production of industrial round wood per year (European Commission 2018).***

**Share of Wood Species in European Pilot-Studies**

The share of tree species and the added up percentage of coniferous and broadleaf species in Europe are, partly due to their site conditions, but highly due to man-made forestry management interventions, extremely different. Following an overview of the ICP-Forest Report (2012), the broadleaf forest share is ranging from 98% in Moldavia down to less than 5% in Sweden, with a focus of South-East European countries with >>50% broadleaf species and of Scandinavien and Alpine countries with <<50% broadleaf species (Fig. 3).

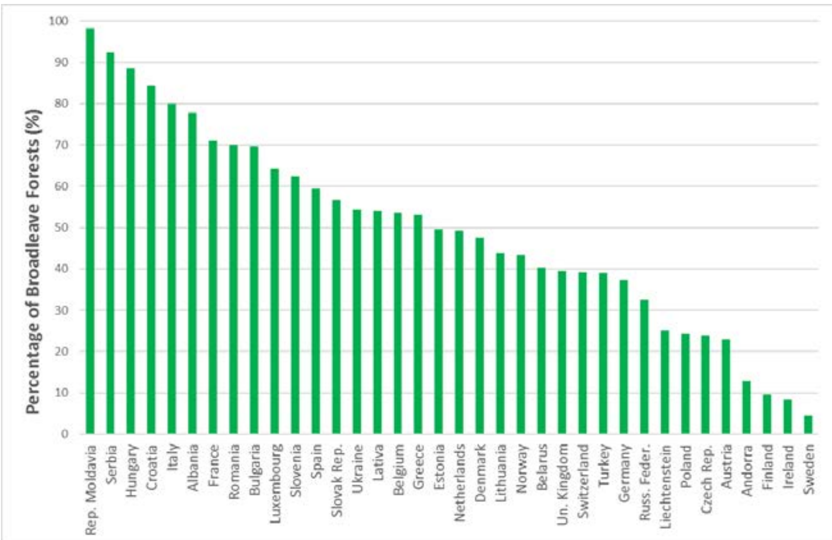


***Fig. 3.***
***Percentage of Broadleaved trees in European Forests (%). Data Source: ICP Forests (2012). Forest Condition in Europe. 2012 Technical Report of ICP Forests.***

In eight selected countries, focussing on E-, Central- and SE- Europe, the forest share of single tree species or spec. groups were chosen to show the range in different forest species compositions.

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ISSN-L 1841-4737

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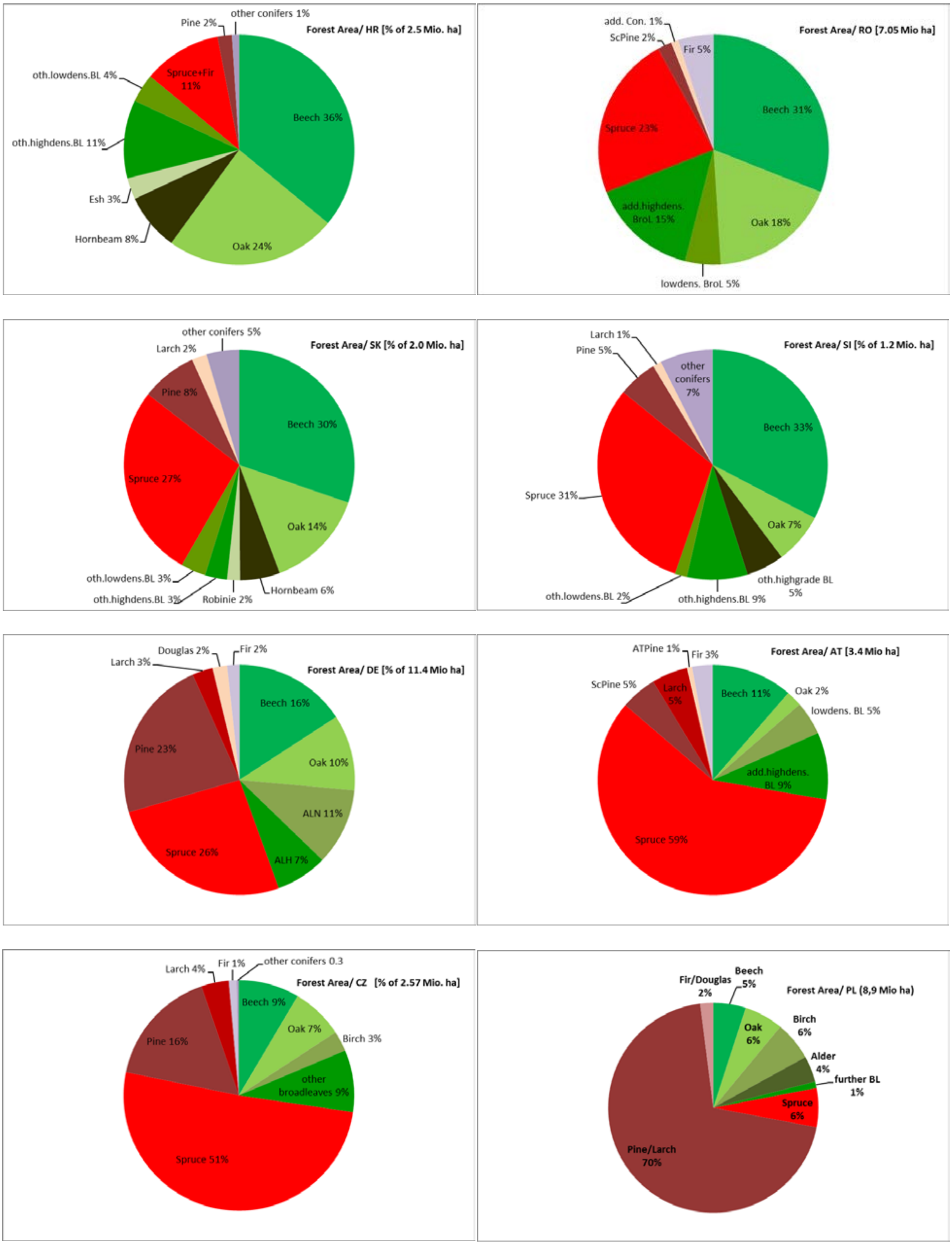


***Fig. 4.***
***Percentage of single broadleaved and coniferous trees in Polish (PL), Czech (CZ), Austrian (AT), German (DE), Slovenian (SI), Slovakian (SK), Romanian (RO) and Croatian (HR) forests (%). Data sources in text.***

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Selected countries with a higher share of coniferous trees (>70% Con.) were: Poland, dominated by Pine (State Forests in Poland 2018) as well as Czech Republic (Ministry of the Czech Republic 2018a) and Austria (Teischinger 2019), both dominated by >50% spruces with partly very low oak + beech share (sum ca. 10-15%) and a very low share of non-oak or -beech species (Fig. 4). In case of Slovenia (Poljanec 2019) and Germany (BMEL 2014) the share of both groups was quite balanced (DE [2012] 55% Con. and 45% Bl [broadleaved], SI [2018] 45% Con. and 55% Bl). In Slovakia [1997] with 42% con. and 58% Bl the Bl-share was already higher (Min. of Agriculture of the Slovak Republic 1997). In these last mentioned three Central-European countries the share of non-oak and non-beech broadleaved species reached already 13-18%. For Slovakian forests information about a higher share of individual luWS are available, showing already a much higher biodiversity in the SK-forests: Beside the omnipresent dominating spruce, pine, fir, beech and oak with a sum of approx. 83% 7 lesser used broadleaved species (hornbeam, maple, ash, robinia, birch, alder, poplar) showed a share between 1-5%, several spec. (elm, tilia, willow, other Bl) between 0.1-0.3% (Fig. 5).

In case of Romania (69% [1998]; Ionascu 1999) and Croatia (86%; Pro-Holz 2019) the broadleaved species were dominating the forests, the share of non-oak or -beech reaches 20-26%. Especially hornbeam or robinia showed appreciable amounts of each up to 6-8% in these selected South-East European forests. Locally, outside these selected countries, the share of single lesser used wood species was even higher (e.g. Hungary: 22% robinia, 10% poplar, 10% additional Bl, flanked by 32% oak and 12% beech [Pro-Holz 2019]).

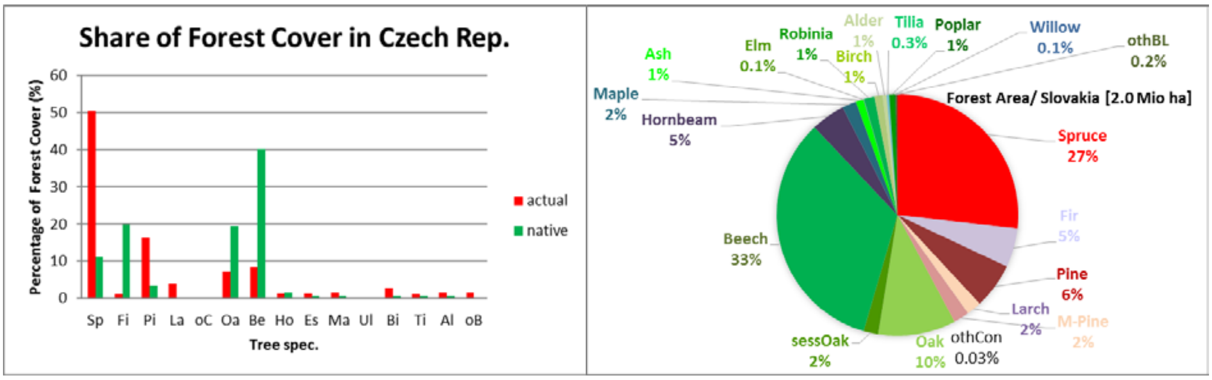
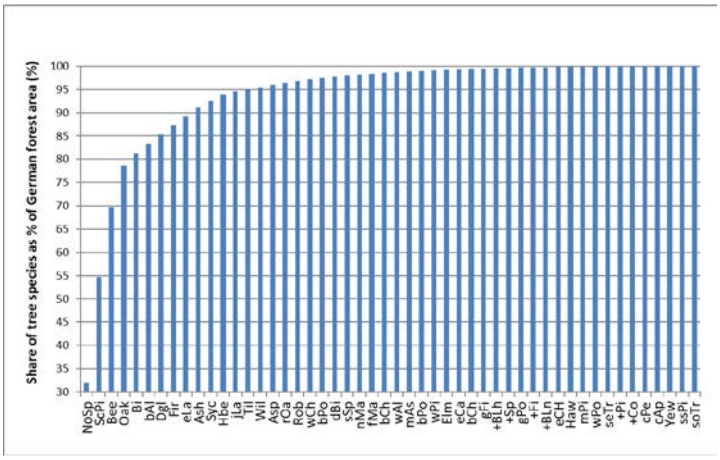



***Fig. 5.***
***Percentage of single tree species in Czech Republic for the actual and potential situation in forests (%; Forest Inventory 2017, Czech Republic [left]) and of single tree species in Slovakia (Ministry of Agriculture of the Slovak Republic, Forestry Section, 1997 [right]).***

In case of Czech Republic the national Inventory (Ministry of the Czech Republic 2018b) delivers a compare between the actual share of single tree species and the former potential native share, showing in case of spruce, pine and larch an extreme 5 to 7-fold surplus in the actual forests, whereas in case of fir, oak and beech the actual forest composition is 3 to 15-fold lower than in the potential forest community (Fig. 5). For further, also lesser used wood species, the share between actual and native situation is approximately balanced, sometimes little bit lower, sometimes higher.

For Germany the third national forest inventory (BWI 2012) separated about 50 different tree species in the German forests (Fig. 6). Here only spruce and pine already showed a share of more than 50% of the forest area, including beech and oak this share was already >80%. Additional 6 tree species, already much lower in the share (birch, black alder, Douglas and white fir, Eur. larch and ash) already exceeded the 90% area line. Additional 20 species, reaching from sycamore to elm, already covered 99.5%, and additional further 20 species, reaching from Eur. chestnut to sorb tree are sharing the remaining 0.5% of the forest area in Germany.

From the viewpoint of their potential existence these additional, lesser used tree species could enrich the biodiversity in forests and stabilize impacted forests due to the wide range of their environmental optimum or amplitude, in many cases better adapted to warmer and during the growing season drier climate periods. Also their contribution to additional material properties, urgently required for new innovative applications and products, could help to improve the market position of locally produced, renewable bio-based goods. However, due to decades or centuries of depressing luWS and preferring faster growing, easily processable species, often from the coniferous sector, the actual potential of luWS in many European regions is low and needs rethinking and technical diversion of all stakeholders, foresters, wood industry, landscape architects and end consumers.



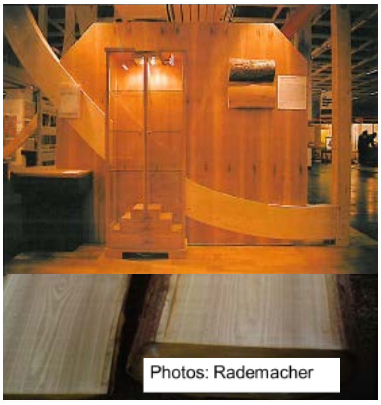




***Fig. 6.***
***Percentage of single tree species in German forests ([%] Source: BWI 2012, Germany. Data compilation Dr. T. Mette, LWF Freising) and applications with Mt. Ash furniture and Castanea.***

**Properties of selected native Wood Species**

Like already mentioned, broadleaved or hardwood species can play an important role in the future forest biodiversity and the applied wood material diversity. Whereas broadleaf species in general cover a wide range of the potential wood species properties (for example: density, mechanical strength, dimensional stability, thermal or acoustic insulation, durability), the dominating broadleaved species oak and beech are located in the median-high to higher density range, connected with higher strength, but also lower dimensional stability or thermal insulation potential (Fig. 7; all values from Wagenführ 2006). Oak and beech show a density average of about 650-680 kg $m^{-3}$ and a strength of approx. 90-120 N $mm^{-2}$ in case of bending strength and 60 N $mm^{-2}$ in case of compression strength. Their related relatively low dimensional stability is shown for example in a volume swelling percentage of 14% in oak and even 18% in beech (Fig. 8; all values from Wagenführ 2006).

In order to widen this narrow field of wood properties of oak and beech, a selected set of additional 10, mainly central European tree species with up to now only minor (value) utilization was chosen to examine their potential applications. On the lower density range willow or poplar are delivering density values of about 330-420 kg $m^{-3}$, related with a bending strength of only 40-60 N $mm^{-2}$ and a better volume swelling of about 10-12%. The median to median-high range is covering the 500-650 kg $m^{-3}$ density range, with black alder and castanea in the median and birch, ash and oak in the median-high range, connected with a bending strength of already about 80-120 N $mm^{-2}$ and a volume swelling of approx. 13-14%. In the highest density range the selected species beech, sorb tree, mountain ash, robinia and hornbeam cover a density range of about 680 till more than 800 kg $m^{-3}$, related with a bending strength of 110-160 N $mm^{-2}$ and a volume swelling of up to 19%.

Concerning any divergences of the normally quite narrow density <-> swelling relationship we can differ 3 groups along the XY-diagram distribution in the graph (Fig. 8): one group of mainly lighter and uniform-structured wood species, like willow, poplar, black alder or birch, more or less directly located on the regression line (blue) and two groups with more heavy and heterogeneous structured wood: the first group contains mainly heartwood-components free wood species like beech, sorb tree, mountain ash and hornbeam in a higher swelling range (red), the second group exist of more heavy species, but mainly containing heartwood components in a higher amount in the wood, like castanea, oak or robinia, all in a lower swelling range (green), reduced due to this structure-stabilizing effect.

The additional inclusion of tree species outside Europe from tropical or sub-tropical locations is strongly widening this observed density <-> strength and <-> swelling relationship, showing the potential range of natural solid wood: very low dense species like balsa show very low strength and swelling properties, extreme high dense species (here: Azobé, Greenheart, Guaiac, African Ebony and Macassar Ebony) with densities of 1000 kg $m^{-3}$ and more (max ca. 1150 kg $m^{-3}$) reach bending strength properties of 250 N $mm^{-2}$, but also show a volume swelling behavior of 20% and more. The lower density <-> strength relationship of some very heavy tropical heartwood species (esp. Ebony and Guaiac), shown by much lower strength properties related to their density, can be attributed to the high amount of heartwood components, which contribute to the mass or density with partly 20% or more; these components are well suitable to improve the dimensional stability and deliver mainly the durability of these wood species by bonded phenolic compounds, but due to their missing fibril-structure they are not able to improve the strength, especially not the bending or tensile strength.

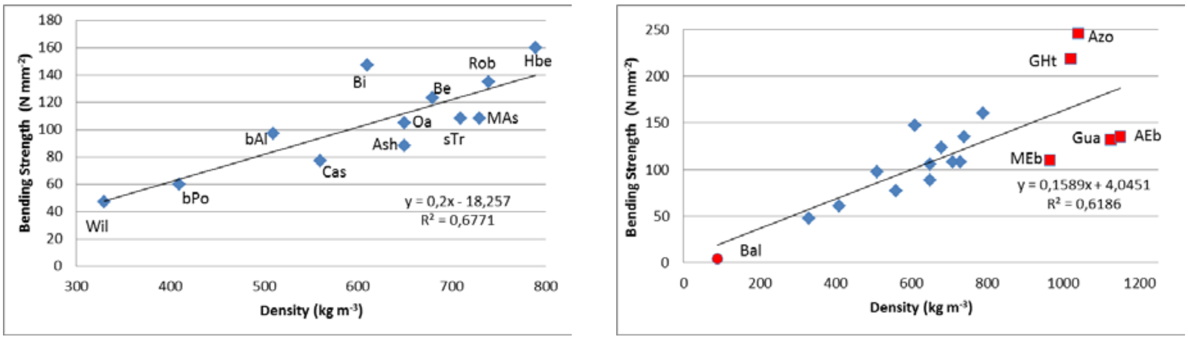



*Fig. 7.*
***Bending strength <-> Density relationship of 12 Central European species (Willow [Wil], black Poplar [bPo], black Alder [bAl], Castanea [Cas], Birch [Bi], Ash, Oak [Oa], Beech [Be], sorb Tree [sTr], Robinia [Rob], Mountain Ash [MAs], and Hornbeam [Hbe; blue rhombs]) as well as (right) Balsa (red circle) and 5 tropical heartwood species (Azobé [Azo], Greenheart [GHt], Guaiac [Gua], African Ebony [AEb]) and Macassar Ebony [MEb; red squares]). Wagenführ 2006.***

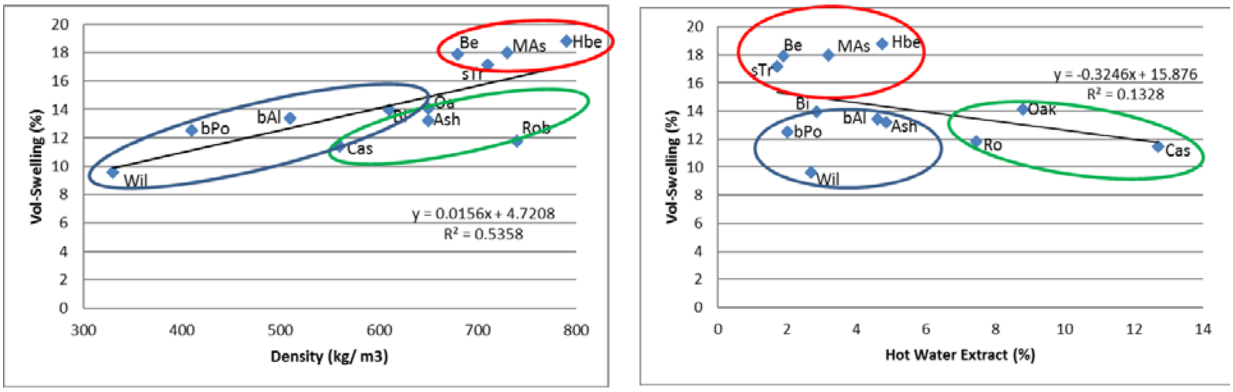



*Fig. 8.*
***Volume-Swelling <-> Density relationship of 12 Central European species (Willow [Wil], black Poplar [bPo], black Alder [bAl], Castanea [Cas], Birch [Bi], Ash, Oak [Oa], Beech [Be], sorb Tree [sTr], Robinia [Rob], Mountain Ash [MAs], and Hornbeam [Hbe; blue rhombs]).***

**Properties distribution within the same native wood species**

Property variations among the same wood species, depending on site conditions, climate, sylviculture management, age, and location in trees, are well known. This delivers, like shown in Fig. 9 for robinia and hornbeam, selected applications of single wood assortments, e.g. the use of robinia wood material from the stem basis for median density and strength requirements, via the median and higher stem till the tops and branches of the tree with highest density and strength values (Fig. 9). The opposite trend happens in hornbeam: lowest density in branches, but equal MOR (Fig. 9.).

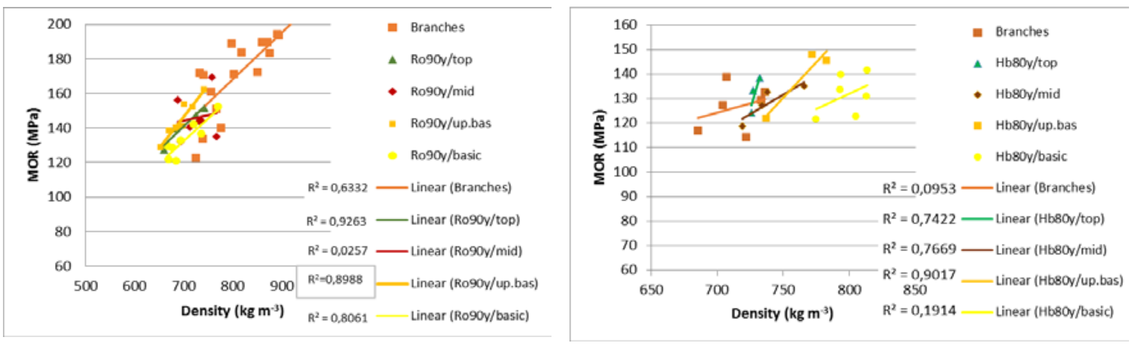



*Fig. 9.*
***Property relationship Density <-> MOR in different stem-heights of 90 yrs. Robinia (Ro) and 80 yrs. Hornbeam ([Hb] yellow, brown, green, red markers) and branches (brown squares).***

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**Property Improvement by Wood Densification and their Adaption for new Applications**

Light-weight wood materials can play an important role in applications of bio-based materials: compared to iron, steel, aluminum or concrete wood has an excellent weight – strength relationship, delivering materials with low weight for special demands, like flexible building constructions or automotive and other kinds of traffic, for example in case of e-mobility with heavy batteries.

But also the opposite can be of interest, resulting in a demand to use more heavy natural wood assortments for higher strength requirements or to densify lighter wood with several technics.

Lighter wood species often grow much faster than heavy ones due to savings of carbohydrates for thinner cell wall materials, often combined with a wider tolerance for poorer or dryer sites. Thus wood densification, even in case of volume loss, can play an interesting role in wood utilization, especially in case of additional combined upgrading processes, like thermal or chemical treatments.

The following example show the density and MOE values after the densification of fast growing poplar (clone F4) from plantations of short rotation coppice (SRC) management systems in the Czech Rep. Using humidity, temperature and pressure, this VTC process (Viscoelastic Thermal Compression) delivers engineered wood assortments of different density and strength classes (Fig.10).

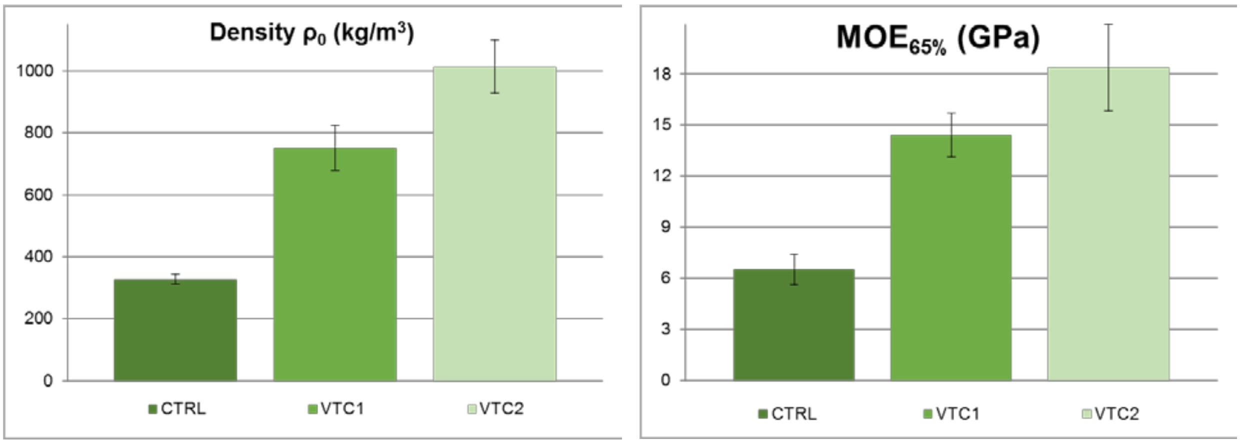


***Fig. 10.***
***Density and MOE properties of native SRC-Poplar (CTRL) and after VTC-plasticization and densification treatment (VTC1: densification factor ca. 2, VTC2 ca. 3 [Horníček et al. 2015]).***

**Property Improvement by chemical Wood Modification and their Adaption for new Applications**

LIGNAMON: Another wood modification technic, the Czech patent ‚LIGNAMON', is using physical, thermal and chemical modification technics by combining steaming, ammonification and heating steps with the wood densification treatment, delivering a material which has compared to the former raw material (native beech) a 1.6-fold higher density (1075 kg m$^{-3}$), a 2-fold higher hardness (35 MPa), and a 30% reduced equilibrium moisture content (21% emc). Compared to only densified beech after $H_2O$-steaming (50% Volume Swelling VSw), the VSw of LIGNAMON was 2-fold reduced and showed additionally a better durability during outdoor exposure (Pařil et al. 2014).

DMDHEU: This wood modification technic, using 1,3-dimethylol-4,5-dihydroxyethylenurea as a non-biocide agent for cross-linking of the hydroxyl groups inside the cell walls, delivered a lot of exterior applications for treated beech wood, normally not suitable for outdoor use (Rademacher et al. 2007). DMDHEU is an example of several modification technics, like Furfurylation, Esterification or Silicium treatment, which interact chemically with the wooden cell wall. Other technics, like oil or wax treatments only fill the cell lumen, or heat treatment, using temperatures between 160-240°C, changes the cell wall structure and their binding sites.

The process was developed at the Göttingen University together with industry partners (BASF AG, Heinrich Fahlenkamp GmbH & Co KG, Becker KG, Variotec GmbH & Co KG) to enhance the utilization for beech wood, which was in the last decades more and more occurring on the Central European wood market, but not or not sufficiently used for higher value applications.

DMDHEU can improve the durability class of beech wood from 5 to 2 (partly 1-2) and the volume swelling, depending on the process (Fig. 11: treatment beech medium or high), from 17% to 6-12%, making outdoor applications possible (Bollmus et al. 2010).

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***Fig. 11.***
***Examples of exterior use of DMDHEU-treated beech wood products and improvement of the dimensional stability by reducing the volume swelling of beech & pine by medium or high treatment.***

Wood-impregnation with native agents: The utilization and application of bio-based materials from renewable origin is a plausible indication of sustainability and in case of wood an important advantage compared to non-renewable materials. But this principle should include also the entire process chain from forest to end consumer, requiring also in the wood modification and treatment steps solutions and agents from renewable, native origin (Rademacher et al. 2017).

The following example (Fig. 12) shows an impregnation process of poplar wood with extracts gained from residues of heartwood species, for example robinia wood. The methanol-water extract of sawmill or forest harvest residues was impregnated with vacuum-pressure cycles in an autoclave into poplar wood samples in order to increase their durability and dimensional stability, demonstrated to be improved by several investigations (Sablík et al. 2016; Rademacher et al. 2017).

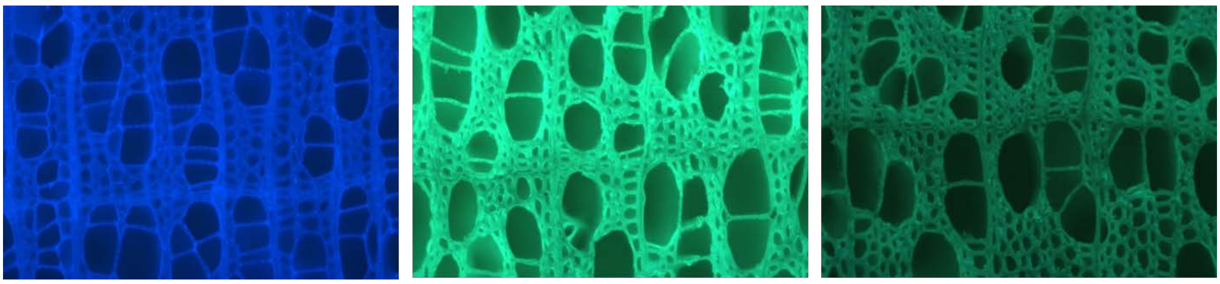

***Fig. 12.***
***UV-light induced shining in poplar wood: left: Reference, no impregnation (→ no green, but blue shining); mid: after robinia extract impregnation (intensive green shining); right: after leaching (lower, but still green coloured shining, indicating remaining amounts of robinetin-derivates in poplar wood).***

## CONCLUSIONS

The results demonstrated that the increase of the forestry cultivation and the wood-industry application of lesser used wood species (luWS) can improve the bio- and material diversity to a great extent. In frame of the climate change influences on forests and the produced wood locally dramatically damages of the forest health and the wood growth occurred, visible in bark beetle calamities, reduced growth conditions, or forest fires after drought or forest dieback. Additional luWS can help to reduce or replace the dominant species and diminishing the observed negative influences.

## ACKNOWLEDGEMENT

Support from the European Social Fund and the state budget of the Czech Republic, project "The Establishment of an International Research Team for the Development of New Wood-based Materials" reg. no. CZ.1.07/2.3.00/20.0269, the Czech Republic International Development Program “MOBILITY” (CZ.02.2.69/0.0/0.0/16_027/0007953), the German Federal Ministry for Education and Research (“Danube Network”, Grand-No. 01DS17011) and the BMBF Project “Improving forestry Biodiversity and material Diversity by adapted Forest-Management and Industry-Application Strategies for Wood from lesser used

Species under Climate Change Conditions", Grand-No. 01DS19043), and the Hungarian-Danube-Region-Co-financing (EU_KP_16-1-2017-0009) are gratefully acknowledged.

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