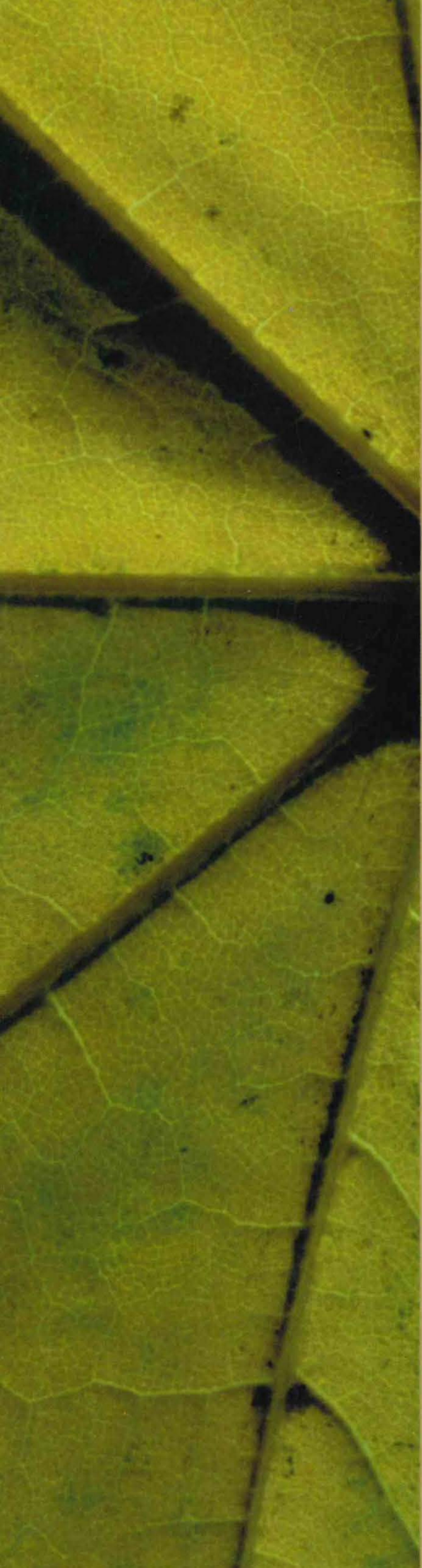


Acta Silvatica & Lignaria Hungarica

An international Journal
in Forest, Wood
and Environmental
Sciences

Volume 15, Nr. 1

2019

ACTA SILVATICA
&
LIGNARIA
HUNGARICA

ACTA SILVATICA & LIGNARIA HUNGARICA

AN INTERNATIONAL JOURNAL
IN FOREST, WOOD
AND ENVIRONMENTAL
SCIENCES

VOLUME 15, NR. 1
2019

UNIVERSITY OF SOPRON
PRESS

ACTA SILVATICA ET LIGNARIA HUNGARICA
An International Journal in Forest, Wood and Environmental Sciences
issued by the Forestry Commission of the Hungarian Academy of Sciences

The journal is financially supported by the
Hungarian Academy of Sciences (HAS),
Faculty of Forestry, University of Sopron (FF-US),
Simonyi Karoly Faculty of Engineering, Wood Sciences and Applied Arts, University of Sopron (SKF-US),
National Agricultural Research and Innovation Center, Forest Research Institute (NARIC-FRI),
Sopron Scientists' Society of the Hungarian Academy of Sciences (SSS).

HU ISSN 1786-691X (Print)
HU ISSN 1787-064X (Online)

Manuscripts and editorial correspondence should be addressed to
Tamás HOFMANN, ASLH Editorial Office
University of Sopron, Pf. 132, H-9401 Sopron, Hungary

Phone: +36 99 518 311
E-mail: aslh@uni-sopron.hu
Information and electronic edition: http://aslh.nyme.hu

The journal is indexed in the CAB ABSTRACTS database of CAB International; by SCOPUS, Elsevier's Bibliographic Database, by EBSCOhost database and by Sciendo (the brand of De Gruyter Open Sp. z. o. o. for publishing services)

Published by University of Sopron Press,
Bajcsy-Zs. u. 4., H-9400 Sopron, Hungary
Cover design by Andrea KLAUSZ
Printed by Lővér-Print Kft., Sopron

ACTA SILVATICA ET LIGNARIA HUNGARICA

Vol. 15, Nr. 1

Contents

ACTA SILVATICA ET LIGNARIA HUNGARICA

Vol. 15, Nr. 1

Tartalomjegyzék

10.2478/aslh-2019-0001 *Acta Silv. Lign. Hung., Vol. 15, Nr. 1 (2019) 9–21*

Forest Fire Risk Assessment Model Using Remote Sensing and GIS Techniques in Northwest Algeria

Abdelkader BENGUERAI* – Khéloufi BENABDELI – Abdelkader HARIZIA

Faculty of Nature Sciences and Life, Laboratories for Geo-Environment and Spatial Development (LGESD),
University of Mascara, Mascara, Algeria

Abstract – Algeria loses more than 20,000 hectares of forest to fire every year. The losses are costly both in terms of life and property damage, which weighs heavily on the environment and the local economy. Geomatics can complement the conventional methods used in fire hazard prevention and management. The objective of our study is to use the geographic information system (GIS) and the Remote Sensing (RS) technology to develop the fire risk assessment map of the forest massif of Zelamta located in Southeast Mascara province (Northwest Algeria). The methodology employed was an empirical model involving three parameters that can control fire behaviour: geomorphology, vegetal cover combustibility, and human activity. The obtained results can help in the decision-making process as well as provide cartographic support for forest fire prevention and management.

mapping / fire risk model / Zelamta forest / Algeria

Kivonat – Erdőtűz kockázat becslése távérzékelési és GIS technikák segítségével északnyugat Algériában. Minden évben több mint 20.000 hektár erdő pusztul el Algériában. A tüzek jelentős személyi-, környezeti-, anyagi- és gazdasági károkat okozhatnak. A geométerek kiegészítő eszközök lehetnek a tűzveszély megelőzésében és kezelésében alkalmazott hagyományos módszerekkel. Célunk, hogy a Földrajzi Információs Rendszert (GIS) és a távérzékelést használjuk egy Zelamta erdei tűzveszélytérkép kifejlesztésére, amely délkeleti Mascara tartományban található Algériában. Az alkalmazott módszertan egy empirikus modell, amely három paramétert tartalmaz, amelyek szabályozzák a tűz viselkedését: a talaj topo-morfológiáját, a növényvédő anyag éghetőségét és az emberi tevékenységet. A kapott eredmények értékes kartográfiai támogatást jelentenek az erdőtüzek kezelésében és megelőzésében, valamint a döntéshozatalban.

térképezés / tűzkockázati modell / Zelamta erdő / Algéria

1 INTRODUCTION

Forest fires have a strong impact in Mediterranean basin countries where the annual fire-affected area exceeds 700,000 hectares. On average, Mediterranean basin countries experience 60,000 forest fires annually, with some countries experiencing over 20,000 per year within their own borders. Though many forest fires can be attributed to the combination of dry weather conditions and other natural factors such as lightning. Humans remain the principal cause of most forest fires in the Mediterranean basin, be it unintentionally through

---

[*] Corresponding author: abdelkader.benguerai@univ-mascara.dz; DZA-29000 MASCARA, B.P 305, Algeria

negligence (cooking fires, campfires, cigarette butts) or intentionally through purposeful acts of arson. Regardless of cause, the forest fires destroyed annually up to 700,000 hectares of forests in Mediterranean countries (C.R.S.T.R.A 2009).

According to the Algerian Directorate General of Forests (DGF), in 2017, forest fires burnt 13,414 hectares, of which 37.24% are forests; 31.41%, are matorral shrub land; and 31.35% are brushwood. Between June 1 and October 5, 2017, 2803 fires were registered. This highlights the importance of forest fire mapping, which contributes to the development and updating of risk prevention plans and is also an essential link for post-crisis management. On the other hand, forest fire mapping allows for the spatial location of the disaster area. Forest fire mapping also facilitates the analysis of the various factors involved in the fire process, and contributing to understanding of the fire behaviour. Whatever means against forest fires are employed, there is no doubt that the damage these fires cause is usually quite significant by the time the fire is declared. This is why prevention remains the only effective way to fight this phenomenon. The variety of factors that control the risk of forest fires means that prevention by traditional means is still insufficient. This is concretized through interactive cartography and with modern and rapid means such as GIS and Remote Sensing.

The objective of this study is to evaluate the susceptibility of the areas exposed to fire risk through a model that spatially integrates multi-source data. Spatial variability mapping of the main factors in forest fire risk allows for a characterization based on a thematic analysis through the modelling of the physical and human parameters.

Forests fires are common in Algeria. During period spanning 50 years, from 1962 to 2012, an average of 1,415 fires were reported per year. These fires burned about 30,000 hectares annually (DGF 2012), leading to a total loss of around 1,693,443 hectares. This figure might not seem significant at first, but it is quite alarming when it is compared to the total forest area of Algeria, which is only four million hectares (Berrichi et al. 2013). The forest area destroyed annually by past fires is 35,000 ha (1961 to 2001). Financial losses related to the sole commercial value of wood (and cork), control operations, and vegetation restoration are estimated at 26–31 million dollars a year (DGF 2007).

2 MATERIALS AND METHODS

2.1 Location of study area

The study area is located in northwest Algeria, forty kilometres southeast of Mascara town (*Figure 1*); the state forest is about 2 km from the town of Zelamta. The exact coordinates of the study area are 0.532° east longitude and 35.278° north latitude.

The study area is in the plateau of Tagremaret on the northern slope of the Saida (province) mountains and extends over an area of 8,719 ha (*Table 1*).The dominant species here is *Tetraclinis articulata*, which dominates by more than an 8/10 ratio. In the 1960s, the good quality trees grown here provided up to 3,000 tons of firewood through receptacle operations. The soil is a browned rendzine type with a calcareous crust and a sandy silt texture. The study area is in a forestry formation belonging to the Barbary red cedar matorrals; its average floristic composition is as follows:

- Holm oak (*Quercus rotundifolia* Lam.) with a recovery rate of 30%
- Barbary thuja (*Tetraclinis articulata* (Vahl) Mast.) with a recovery rate of 25%
- Narrow-leaved mock privet *(Phillyrea angustifolia L.)* with a recovery rate of 15%
- Mastic pistachio (*Pistacia lentiscus L.*) with a recovery rate of 10%

The area exudes typical Mediterranean climatic factors; it is semi-arid with an average annual rainfall of 350 mm and a dry period spanning six months from May to October.

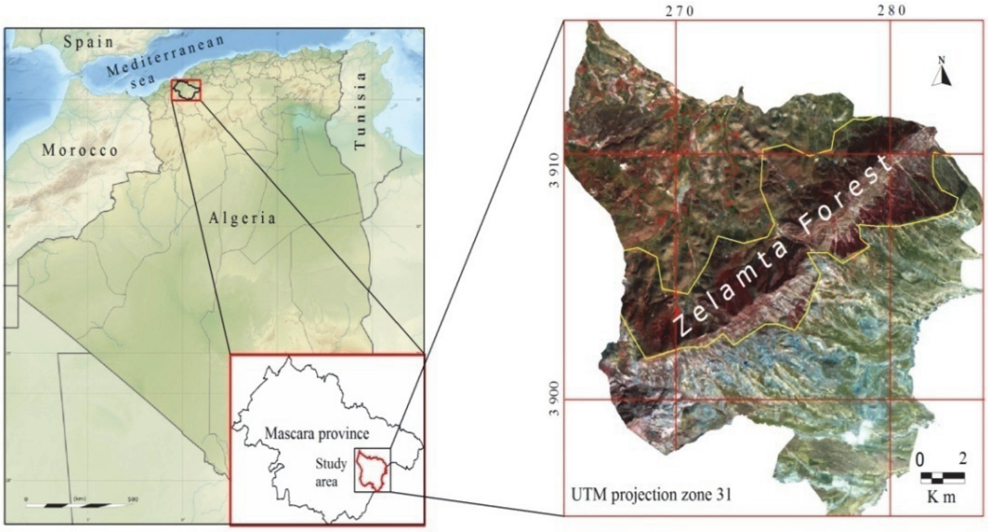


Figure 1. Localization of the study area

2.2 Land use in the study area

The land use/cover in the study area contains agriculture, forest, rangeland, and urban agglomerations (*Table 1*). The land use emphasizes the impact of highly flammable litter, which is the origin of many fires. When fire begins in the litter, it is often difficult to detect. Fire consumes the litter slowly before spreading to the herbaceous layer, which is of greater flammability. Wind can also spread fire over large areas, thereby increasing the overall fire risk.

Table 1. Land cover/land use areas in hectares

Land cover	Area (ha)	Percent
Agriculture	9930.07	41.49
Rangeland	5210.88	21.77
Agglomeration	71.45	0.30
Matorrals	5578	23.31
Forest	3141	13.13

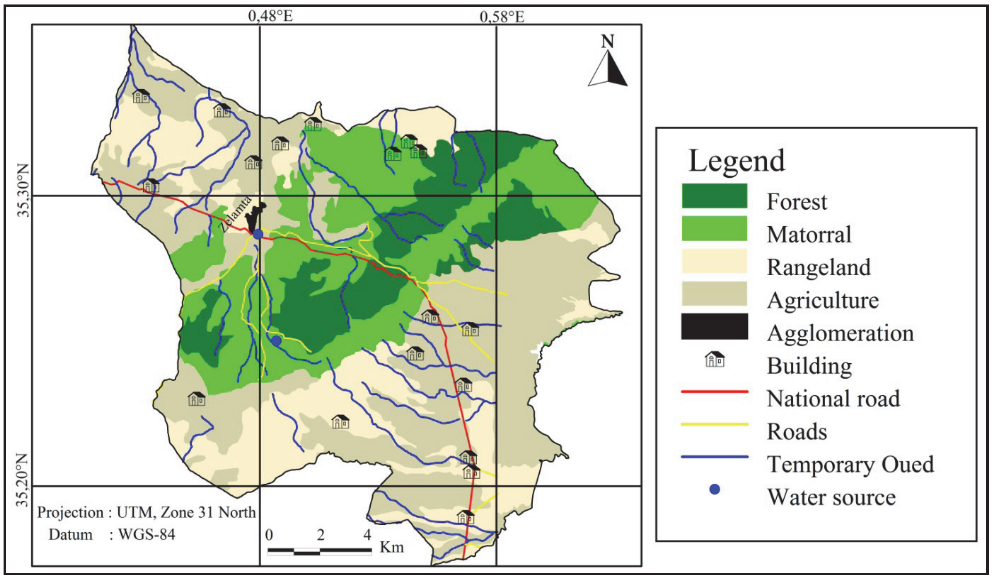


Figure 2. Occupation and land use mapping of the study area

The forest stand characteristics such as structure, existence of vertical or horizontal discontinuities, vegetation cover density, and species composition may have an effect on a forest stand's sensitivity to fire. The intensity, frequency, and size of forest fires are related to the physical (climatic factors) and vegetal environment. The creation and spread of fires are dependent on the combination of different natural conditions and human activity (Zaoui 2013).

The material used in the present work is composed of MapInfo 7.0 and ENVI 4.3 software, vector and Raster-based ASTER (Advanced Space-borne Thermal Emission)-GDEM (Global Digital Elevation Model); the data are posted on a 1 arc-second (approximately 30–m at the equator) grid and referenced to the 1984 World Geodetic System (WGS84)/ 1996 Earth Gravitational Model (EGM96). This paper analyses also the utility of the vegetation index (NDVI) for mapping the land cover characteristics over the study area.

The set of cards made were imported in "grid" format to be classified according to the codes assigned to each card by the MapInfo Vertical module equipped with a calculator allowing for the application of the model formulas used by crossing the obtained maps.

Forest fire risk assessment has been the subject of several research papers (Dagorne – Castex 1992, Mariel 1995) and several indices of fire risk have been established. The index that interests us in the present work is designed by (Dagorne et al. 1994) for Mediterranean forests. The choice of this model is justified by the significant combustibility of the vegetation found in the Mediterranean basin and the intersection of this vegetation with the topographical parameters. The possibility of accessing information, which enables it to be evaluated and taken into consideration, was another justification factor.

The index is given by the following formula:

$$RI = 5CI + 2MI + 3HI \tag{1}$$

Where:

RI: Risk index;
CI: Combustibility index;
MI: Topomorphological index;
HI: Land-use index.

Based on the principle of the weighted sum, this index is designed as a model assigning each parameter a weighting coefficient based on its influence on fire spread. Risk indices are calculated by mathematical models that set, as input data, the parameters influencing fires and different weights (Siachalou et al. 2009).

The parameters selected in this study were the moisture of the vegetation type, the slope, the aspect of the anaglyph, and the distance from roads and settlements (Chuvieco – Congalton 1989, Jaiswal et al. 2002, Erten et al. 2002).

2.3 The Combustibility Index (*CI*)

The combustibility index CI was calculated from the formula developed by (Alexandrian 1982). It is expressed in the following form:

$$CI = 39 + 0.23\,BV(E1 + E2 - 7.18) \tag{2}$$

BV represents the bio-volume of the plant formation obtained by adding the percentages of recovery of each biological strata; E1 and E2 are the caloric intensity scores (between 1 and 9) of the both dominant high (E1) and low (E2) ligneous plant species. The bio-volume intervenes differently according to the value of the sum (E1 + E2). If this sum is less than 7.18 (low fuel or low calorific species per unit of low bio-volume), the index remains below 40 (Missoumi et al. 2002). If this is not the case, it will be all the higher as bio-volume is important (Cemagref 1989). In order to have a flammability rating for each plant species, two elements are needed: the average time of ignition and the frequency of ignition; the notes of calorie intensity of the main dominant species of Mediterranean vegetation established by Cemagref from which (E1 and E2) were extracted with the exception of (*Tetraclinis articulata*), which has been likened to the (*Juniperus oxycedrus*), the closest species. (E1 = 5 for *Quercus rotundifolia*, E2 = 7 for *Tetraclinis articulata*, E2 = 5 for *Phillyrea angustifolia* and E2 = 4 for *Pistacia lentiscus*) of the Zelamta State Forest.

2.4 The Topomorphology Index (MI)

Three morphological parameters are involved in the topomorphological model: elevation, slope, and aspect data. These were extracted from SRTM DEM, which were determined by remote sensing satellites such as Shuttle Radar Topography Mission with Digital Elevation Models. At the end of the 2014 year, the United States government released the public availability of enhanced global SRTM topographic data will greatly benefit international. This 1-arc second global digital elevation model has a spatial resolution of about 30 meters. It covers most of the world with an absolute vertical height accuracy of less than 16 m.

The combined effect of these three parameters is expressed by the following equation:

$$MI = 3p + (m\ x\ e) \tag{3}$$

Where:

p is the slope (coded between 1 and 4) (*Table 3*);
m: represents the morphology of the area (coded 1 to 4) (*Table 5*) and
e: exposure (coded 0 to 3) (*Table 4*).

The results of combining and weighting of various topomorphological parameters are listed in *Table 6*.

2.4.1 Slope (p)

Slope is a parameter that influences the fire spread rate (Weise et al. 1997). Fire moves more quickly up aslope and less quickly down a slope (Kushla et al. 1997). Also, the fire spread rate may rise on steeper slopes due to flames being angled closer to the ground surface, and the process of heat convection can be enhanced by wind effects due to fire behaviour (Whelan 1995, Neary et al. 1999, Adab et al. 2012).

2.4.2 Morphological topography index (m)

Topography plays an important and leading role in the behaviour of forest fires by influencing the morphology and speed of fire spread. In general, topographic influences vary depending on slope inclination, exposure, and elevation of the soil. Unlike atmospheric agents, topography is a constant factor from which it is possible to determine and especially predict the influence of fire spread.

2.4.3 Aspect (e)

Aspect is correlated with the amount of solar energy and the surrounding area receives the radiations. Vegetation is typically drier and less dense on south-facing slopes than on north-facing ones (Anderson 1982, Prasad et al. 2008). Drier fuels are more exposed to ignition risk. In addition, easterly aspects get more ultraviolet and direct sunlight earlier in the day than westerly aspects do. Consequently, easterly aspects become drier faster (Anderson 1982, Prasad et al. 2008). In this study, elevation, slope, and aspect elements were obtained from ASTER-GDEM data, which were determined by remote sensing.

2.5 Distance from road and settlement networks

Anthropogenic factors are important variables that influence fire occurrences, as represented by some elements such as proximity to roads and settlements. It is recognized that human activities are a basic factor affecting fire occurrences (Adab et al. 2012). The more intense the human activities, the more fire risk increases. Distance to roads and road density are potentially important parameters because roads allow people to go into the forested and grassland areas and cause ignitions (Adab et al. 2012). Also, forested and grassland areas near settlements are more prone to fire ignition because accidental fires can be caused by residents inside the forest (Jaiswal et al. 2005).

3 RESULTS AND DISCUSSION

3.1 Map of the combustibility index (CI)

The combustibility index (CI) map was extracted from the vegetation map, the NDVI map, and the combustibility of each species. Vegetation density, or relative biomass, is considered a significant factor in the spread of forest fires.

On the other hand, calculating the Normalized Difference Vegetation Index (NDVI) determines that it was similar to that established by Cemagref (1989) with the exception of the Barbary thuja (*Tetraclinis articulata*), which has been assimilated into the *Juniperus oxycedrus*, which is the closest species (Missoumi et al. 2002).

The combustibility index values are coded in four classes reflecting, as best as possible, the fuel distribution in the Zelamta massif in relation to the combustibility of each species. The results of this treatment are illustrated by the combustibility index map (*Figure 3*) and summarized in *Table 2*.

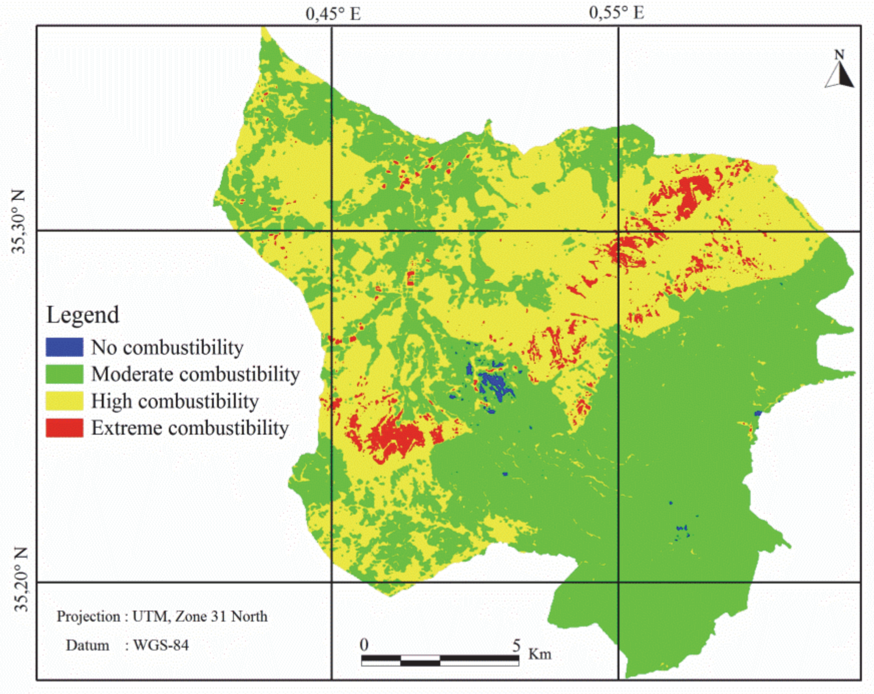


Figure 3. Map of combustibility index of Zelamta forest

Table 2. Combustibility classes of the study area (CI)

Combustibility classes	Risk zones	Note	Area	
			ha	%
CI< 40	No combustibility	1	77.8	0.33
40 ≤ CI< 50	Moderate combustibility	2	13060	54.57
50 ≤ CI< 60	High combustibility	3	10040	41.95
60 ≤ CI	Extreme combustibility	4	753.6	3.15

Vegetation is characterized by its combustibility, which represents its ability to spread fire by burning. It therefore reflects its way of burning, releasing more or less significant amounts of heat. Combustibility depends on the structure and dominant species of the forest. It is correlated with the amount of fuel biomass associated with the fuel structure and its composition. More than 41% of the study area present a high combustibility index and only 3.15% has a very high combustibility index (*Table 2*, *Figure 3*), while the high and very high combustibility index are concentrated in the forest. This can be explained by the dominance of thermophilic species such as *Pistacia lentiscus*, thermophilous conifers such as *Tetratclinis articulata*, and sclerophyllous species such as *Quercus rotundifolia*. These species are very susceptible to fire and can increase the spread risk.

3.2 Topomorphology index (MI)

3.2.1 Slope map

Slope modifies the relative flame inclination with respect to the ground during an upward propagation and the efficiency of heat transfers by radiation and convection; ascending fires burn more quickly on steep slopes.

On the other hand, a descending foresees its speed considerably slowed down. Four slope classes were selected based on their incidence, frequency of occurrence, and spatial distribution (*Figure 4, Table 3*).

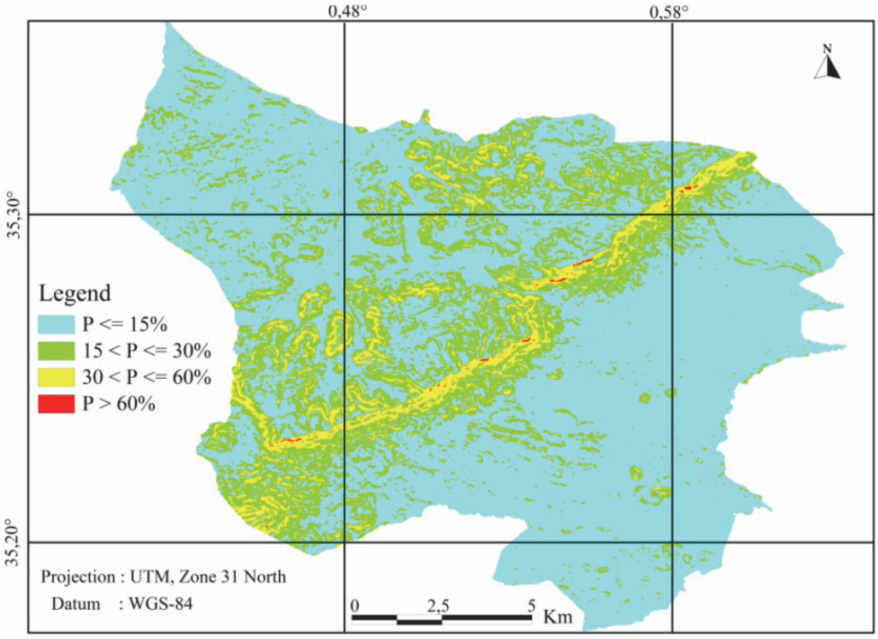


Figure 4. Slope map of the study area

Table 3. Grading of slope

Grade	Slope Classes	Area		Slope
		ha	%	
1	P ≤ 15%	17139.13	71.62	Low slope with no impact on the spread
2	15 < P ≤ 30%	5393	22.54	Moderate slope causing a moderate acceleration of the fire front
3	30 < P ≤ 60%	1378	5.76	High slope, significant acceleration of the fire front
4	P > 60%	21.27	0.09	Slope with very high risk of turbulence, jumping fire, conflagration

The slope map shows a strong to very steep slope within the forest, whereas the low to very low slope class is found in crops and rangelands.

3.2.2 Aspect map

The aspect reflects slope situation with respect to prevailing winds and sunshine. Indeed, it also plays an indirect role on fire progression. On slopes exposed to winds, spread differs from those in downwind exposures. In general, the southern and eastern slopes have the most favourable conditions for fire (*Table 4*).

Table 4. Exposure Classes

Orientation	Code	Area	
		ha	%
North	0	5245	21.91
West	1	4933.4	20.62
South	2	6475	27.06
East	3	7278	30.41

Four main classes of aspect were selected, with each exhibition corresponding to a quarter of 45° centred on the average value of this exhibition. These classes are determined with respect to the four cardinal points with values expressed in degrees with the north as their origin (*Table 4)*.

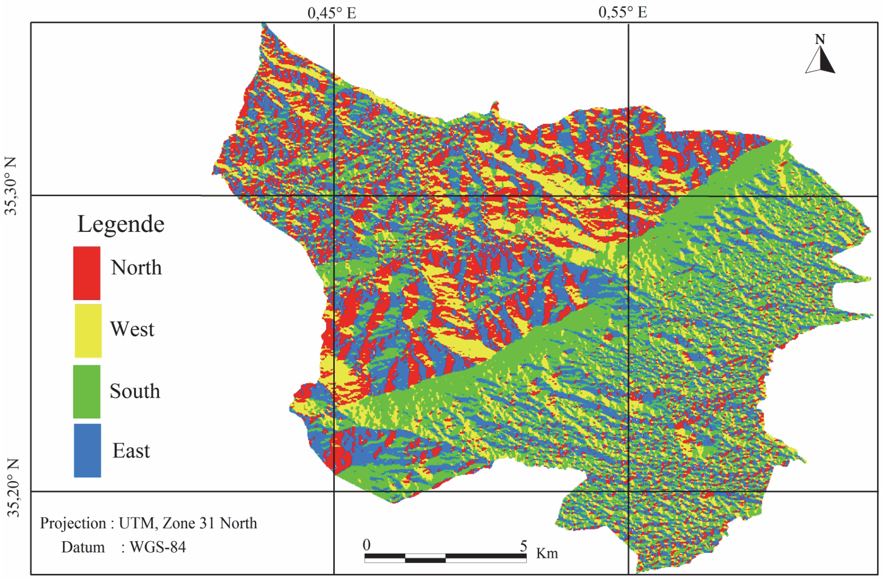


Figure 5. Aspect map of the study area

The aspect map shows only 30.41% of areas with easterly exposures and 27.06% with southerly exposures, but the adverse exposures are in the east. Sunshine and prevailing winds (west and north) account for less than 43% of the total area study.

3.2.3 Topomorphological map (m)

The position in the slope or the topomorphology “m” weights the intensity of the fire according to the position on the relief. The topomorphology was selected according to the classes of slopes derived from the Digital Elevation Model (DEM).

Table 5. Classes of the topomorphology "m"

Morphology classes	Grade	Morphology of study area	Area	
			ha	%
P ≤ 3%	1	Plain (No fire jumps)	1732.25	7.24
3 < P ≤ 12.5%	2	Lower piedmont (Less fire jumps)	13752	57.46
12.5 < P ≤ 25%	3	High Piedmont (more fire jump)	6076.5	25.39
P > 25%	4	Steep (Jumps fire accentuated)	2370.65	9.91

More than 92% of the studied area comprises mountains and high foothills, while less than 8% are constituted by plains and foothills.

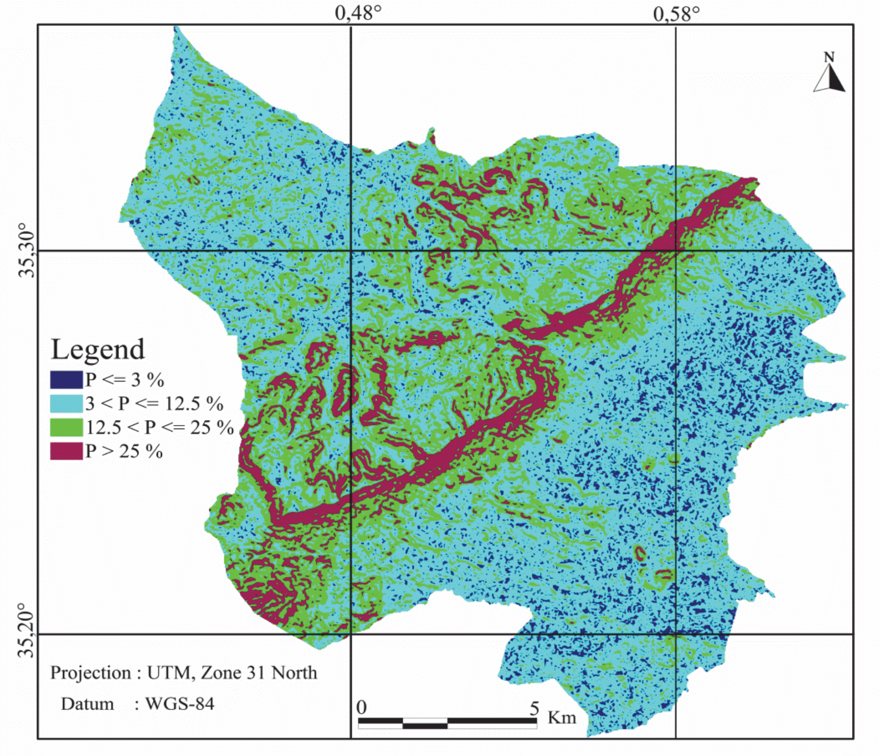


Figure 6. Topomorphological map of the study area

Topographic variables that affect fire behaviour include elevation and aspect, which affect moisture gradients, and topographic features like narrow valleys or steep slopes, which influence fire spread. Topography also affects vegetation distribution and productivity because it impacts energy and water balances and, therefore, precipitation, runoff, temperature, wind, and solar radiation (Alexandre et al. 2015). The forest is crossed by a continuous chain of mountains, which favours the spread of fires and hinders human intervention.

3.2.4 Map of the Topomorphological Index (MI)

The topomorphological index is obtained from the superposition of the slope map, the exposure map, and the topomorphology. All of these are integrated with the formula (3) of the topomorphological index in the GIS. The results obtained correspond to the four topomorphological classes, which are summarized in *Table 6* according to their importance.

Table 6. Classes of the topomorphological index

MI	Code	Signification	Area	
			ha	%
MI < 9	1	Unfavourable	18116	75.70
9 < MI < 14	2	Moderately favourable	3283	13.72
14 < MI < 19	3	Favourable	2249.15	9.40
MI > 19	4	Very favourable	283.25	1.18

75.70% of the study area is unfavourable to fire intensification and is far from the forest. The moderately favourable conditions for fire risk amount to 13.72%. On the other hand areas, constituted by forest formations, with high (9.40%) and very high values (1.18%) of MI (*Table 6, Figure 7*) are very susceptible to fires.

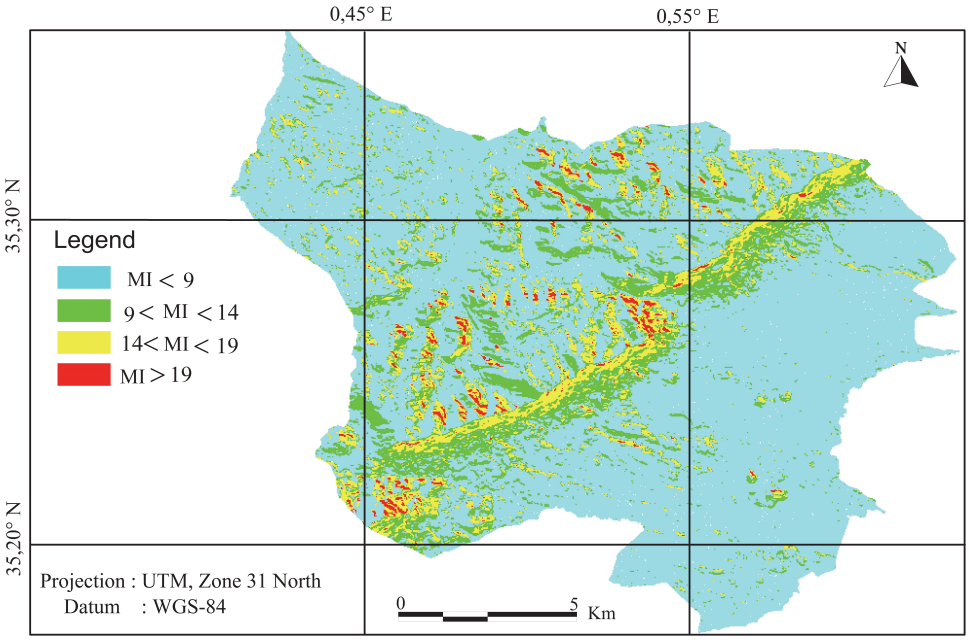


Figure 7. Map of the Topomorphological Index

3.3 Human Occupation Index (HI)

The HI is compiled according to the formula adopted in the two indices, neighbourhoods, and human occupations. It is assimilated by buffer surfaces of 100 m, and by other roads and roadways according to the degree of traffic, and around homes located within or on the edge of the forest. The human occupation index reflects small areas where the risk of forest fires begins; this situation is due to the low human densities and the low density of the road network implanted in the forest.

3.4 Fire Risk Index Map (RI)

The calculation of the fire risk index is the result applying the formula (1) cited above to the intersection between layers of the combustibility index, the layer of the topomorphological index, and the index of human activity:

Table 7. Classes of the Fire Risk Index (RI)

Fire risk classes	Signification	Area (ha)	Percent of area study
$RI < 6$	Low Risk	16718	69.86
$6 < RI < 9$	Moderate Risk	251.4	1.05
$9 < RI < 12$	High Risk	6391	26.71
$RI > 12$	Very High Risk	571	2.39

The forest cover spans 8,719 hectares (36.44%) of the study area (*Table 1*); the high and very high risk represents successively 26.71% and 2.39%, which generally characterizes the forest (*Table 7*, *Figure 8*).This is explained by the topomorphological conditions unfavourable to fire outbreaks (steep slopes, exposure to the south and east).In addition, the forest is dominated by a high combustibility index, which maximizes the risk of fires. This requires silvicultural work and the creation of an opening to pastures according to periods by respecting the standards of the pastoral charge per livestock unit.

This conclusion is confirmed by exploiting the statistical data of fires from 1985 to 2006; we recorded a total burned area of 779,872 ha from 32,354 fires. The average area per household is 24.10 ha (Arafa 2008).

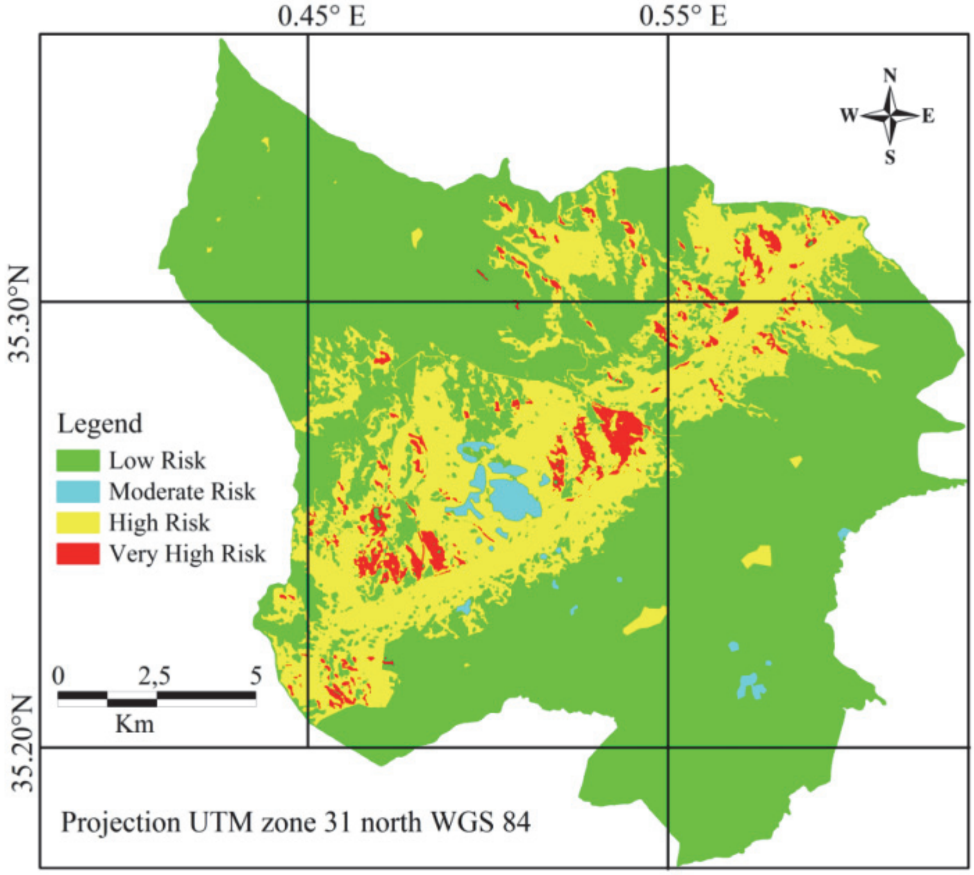


Figure 8. Map of the Fire Risk Index

3.5 Validation of forest fire risk model

Results validation was performed through field trips, Fire Service documents, and interviews with the forest conservation managers. In this context, it should be noted that no information card for past fires was available.

The main fires to which our study area has been submitted are presented in a form. These sheets provide information on the characteristics that make it possible to understand the natural conditions of combustion and fire propagation. They also provide information regarding damage, intensity, and fire surface.

4 CONCLUSION

Forest fires have been serious menace in Northern Algeria. During the period from 1985 to 2010, 42,555 fires affecting a forest area of 910,640 hectares were reported. The fires are concentrated mostly in August (Meddour et al. 2013). The results obtained in the present research are based on modelling using Geographic Information Systems in fire risk mapping, which is increasingly used for the study of natural and socio-economic phenomena. This tool is essential and complementary to decision making and is operational in fire risk management. The fire risk map made as part of this study can help forest managers and forest agencies easily locate high risk fire zones and can also help these authorities take preventive policies to limit the loss of human life, natural resources, and property. Forest fire risk prevention policies should be oriented toward land use planning and urban planning from a sustainable development perspective.

REFERENCES

Adab, H. – Kanniah, K. D. – Solaimani, K. (2012): Modelling forest fire risk in the Northeast of Iran using remote sensing and GIS techniques. Springer Science+Business Media. Nat Hasards 65: 1723–1743. https://doi.org/10.1007/s11069-012-0450-8

Alexandrian, D. (1982) : Estimation de l'inflammabilité et de la combustibilité de la végétation. [Estimation of flammability and combustibility vegetation.] Newsletter of Cemagref n 228. (in French)

Alexandre, P.M.– Stewart, S.I.– Mockrin, M.H.–Keuler, N.S. Syphard, A. D. –Bar-Massada, A. – Murray, K.C.– Radeloff, V. C. (2015): The relative impacts of vegetation, topography and spatial arrangement on building loss to wildfires in case studies of california and colorado. springer science, pp 415–430. https://doi.org/10.1007/s10980-015-0257-6

Anderson, H. (1982): Aids to determining fuel models for estimating fire behavior. Usda forest service, mt. baker–snoqualmie national forest, mount lake terrance, WA, USA.

Arafa, A.M.T.(2008) : Les incendies de forêt en Algérie : Stratégies de prévention et plans de gestion. [Forest fires in Algeria: Prevention strategies and management plans.] Memory of magister in ecology and environment, mentouri university of cosntantine (Algeria), 115 p. https://bu.umc.edu.dz/theses/biologie/ARF5120.pdf

Berrichi, M. – Benabdeli, K. – Letreuch, B.N. – Haddouche, M. (2013): Feux de forêts en Algérie : entre points de vue des écoliers et politique de la prévention. [Forest fires in Algeria: points of view of school children and political prevention], p. 32. (in French). Mediterránea. serie de estudios biológicos, 24: pp132–159. https://doi.org/10.14198/MDTRRA2013.24.05

CEMAGREF (1989). Guide technique du forestier méditerranéen français, chapitre IV : protection des forêts contre les incendies. [Technical Guide of the French Mediterranean Forester, Chapter IV: Protection of forests against fire.] Forestry Technical Division, Aix-en-Provence, France, 61 p. (in French)

C.R.S.T.R.A (2009): Center of scientific and technical research in arid regions, Algeria. Atelier international de formation sur les risques majeurs et les catastrophes naturelles. Stratégies de prévention et de protection [International training workshop on major hazards and natural disasters. strategy of prevention and protection], 310 p. (in French)

CHUVIECO, E. – CONGALTON, R.G. (1989): Application of remote sensing and geographic information systems to forest fire hazard mapping. Rem. Sens. Environ. 29: 147–159. https://doi.org/10.1007/s11069-012-0450-8

DAGORNE, A. – DUCHÉ, Y. – CASTEX, J.M. – OTTAVI, J.Y. – DALLIER, D. –DE COSTER, A. (1994): Protection des forêts contre les incendies et système d'information géographique: Application à la commune d'Auribeau sur Siagne (Alpes Maritimes). [Forest fire protection and geographic information system: application to the municipality of Auribeau Siagne.]Revue forêt méditerranéenne, XV, 2: 153–158. (in French)

DAGORNE, A. – CASTEX, J.M. (1992). Gestion des espaces forestiers et sub-forestiers en zones rouges. L'exemple de Saint-Césaire sur Siagne [Management of forest and sub-forest areas in red zones. The example of Saint-Césaire on Siagne.] (Alpes Maritimes, France), Finisterra, Vol. 27, (53–54): 141-166. (in French)

DGF (2007): Directorate General for Forests. Politique forestière nationale et stratégie d'aménagement et de développement durable des ressources forestières et alfatières. [National forest policy and management strategy and sustainable development of forest resources], p. 32. (in French).

ERTEN, E. – KURGUN, V. – MUSAOGLU, N. (2002): Forest fire risk zone mapping from satellite imagery and GIS case study. International J. Appl. Earth Obs. Geoinf., 4: 1–10.

JAISWAL, R.K. – MUKHERJEE, S. – RAJU, K.D. – SAXENA, R. (2002): Forest fire risk zone mapping from satellite imagery and GIS. J. Appl. Earth Obs. Geoinf. 4 (1): 1–10. https://doi.org/10.1016/S0303-2434(02)00006-5

JAISWAL, RK. – KRISHNAMURTHY, J. – MUKHERJEE, S. (2005): Regional study for mapping the natural resources prospect and problem zones using remote sensing and GIS. GeocartoInt 20 (3): 21–31.

KUSHLA, J.D. – RIPPLE, W.J. (1997): The role of terrain in a fire mosaic of a temperate coniferous forest. For. Ecol. Manag., 95 (2): 97–107. https://doi.org/10.1016/S0378-1127(97)82929-5

MARIELL, A. (1995) : Cartographie du niveau de risque d'incendie : exemple du massif des Maures [Mapping the level of fire risk: example of the Maures massif, Cemagref report.]. (in French)

MEDDOUR, O.S. – LOVREGLIO, R. – MEDDOUR, R.– LEONE, V.–DERRIDJ, A. (2013): Fire and people in three rural communities in kabylia (Algeria). Open J. For., 30–40, http://doi.org/10.4236/ojf.2013.31006

MISSOUMI, A. –MEDERBAL, K. – BENABDELI, K. (2002) : Apport des Systèmes d'informations géographiques dans la prévention et la lutte contre les incendies de forêts. Exemple de la forêt domaniale de Kounteidat, Algérie. [Contribution of geographic information systems in the prevention and fight against forest fires. example of the kounteidat state forest.] Revue forêt méditerranéenne t. XXIII, 1: 11–22. (in French)

NEARY, DG – KLOPATEK, C.C – DEBANO, L.F – FFOLLIOTT, P.F. (1999): Fire effects on belowground sustainability: a review and synthesis. For. Ecol. Manag. 122: 51–71. https://doi.org/10.1016/S0378-1127(99)00032-8

PRASAD, V.K. – BADARINATH, K.V.S. – EATURU, A. (2008): Biophysical and anthropogenic controls of forest fires in the Deccan plateau. Ind. J. Environ. Manag. 86 (1):1–13.

SIACHALOU, S. – DOXANI, G. – TSAKIRI-STRATI, M.(2009): Integrating remote sensing processing and gis to fire risk zone mapping: a case study for the seih-sou forest of Thessalonik. International Cartography Conference (ICC) 2009, Santiago, Chile, 11/2009. RefW-27-18481.

WEISE, D.R. – BIGING, G.S. (1997): A qualitative comparison of fire spread models incorporating wind and slope effects. For. Sci. 43 (2): 170–180.

WHELAN, R.J. (1995): The ecology of fire. Cambridge University Press, Cambridge

ZAOUI, M. (2013) : Gestion des risques de feu dans la forêt de M'sila Wilaya d'Oran. [Fire risk management in the M'sila forest of Oran city]. Master of science in forestry, ecosystem management and conservation option. Abou-bakrbelkaïd university of Tlemcen, 177 p. (in French)

10.2478/aslh-2019-0002 *Acta Silv. Lign. Hung., Vol. 15, Nr. 1 (2019) 23–34*

Insulation Panels Made from Thermally Modified Bark

Zoltán PÁSZTORY[a*] – Dimitrios TSALAGKAS[a] – Norbert HORVÁTH[b] –
Zoltán BÖRCSÖK[a]

[a] Innovation Center, University of Sopron, Sopron, Hungary
[b] Department of Wood Sciences, University of Sopron, Sopron, Hungary

Abstract – Thermally treated and ground poplar bark was used as the raw material for pressed bark insulation panels. Bark chips were treated for one, two, and three hours at 180 °C after a slow warming, drying process. The physical and mechanical properties of the pressed panels were investigated and compared to each other and to the control panel made of untreated bark chips. Thermal conductivity showed slight deviations and ranged from 0.064 – 0.067 $W \cdot m^{-1} \cdot K^{-1}$. The MOR and MOE showed a significant increase of 100%. The internal bond increased by 27% while the water absorption and thickness swelling decreased by 53.8% and 69.1% respectively. Panel density did not change significantly because the target density was the same for every panel type. The mechanical and physical properties of thermal insulation panels made of heat-treated chips increased significantly.

thermal insulation / thermal modification / bark panel

Kivonat – Őrölt és hőkezelt nyárfa kéregből készültek hőszigetelő panelek. A kéreg aprítékot szárítás céljából lassan melegítettük 180 °C-ra, majd ezen a hőmérsékleten 1, 2, illetve 3 órán át hőkezeltük. Az elkészült panelek egyes fizikai és mechanikai tulajdonságait a kontrol, kezeletlen anyagból készül panelek tulajdonságaival vetettük össze. A panelek hővezetése kis szórást mutatott: 0,064 – 0,067 $W \cdot m^{-1} \cdot K^{-1}$ értékek között. A hajlító szilárdság (MOR) és a rugalmassági modulusz (MOE) jelentősen (100%-kal) növekedett. A belső kötés (IB) 27%-kal növekedett, míg a vízfelvétel és a vastagsági dagadás 53,8, illetve 69,1%-kal csökkent. A panelek sűrűsége nem változott számottevően, mivel mindig ugyanaz volt a célsűrűség. Összességében a fizikai és mechanikai tulajdonságok kedvezően változtak a hőkezelés hatására.

hőszigetelés / hőkezelés / kéreg panel

1 INTRODUCTION

As most researchers have accepted climate change, reducing energy consumption has become increasingly important. One method for reducing energy demand for buildings is thermal insulation, and many regulations to improve the insulation of buildings have been passed. The EU has set a goal for all new building to be nearly-zero energy buildings the end of 2020. On the one hand, this has led to an increased variety of available building insulation materials. On the other hand, the importance of natural-based, recyclable materials and solutions is increasing and is expected to continue growing in the future as environmental aspects become

---

[*] Corresponding author: pasztory.zoltan@uni-sopron.hu; H-9400 SOPRON, Bajcsy-Zs. u. 4, Hungary

more pressing. Therefore, research focusing on natural-based insulation materials is expanding. Several studies on the insulation of natural materials have been completed including rice husk, sugar cane, coconut fiber, (Panyakaew – Fotios 2008), cotton stalk fibers (Zhou et al. 2010), various grasses (Vėjelienė et al. 2011), papyrus (Tangjuank – Kumfu 2011), pineapple (Tangjuank 2011), jute (Fadhel 2011), oil palm (Manohar 2012), wool (Zach et al. 2012), wood ashes, cotton, animal hair (Rébék-Nagy – Pásztory 2014), plant stalks, textile waste and stubble fibers (Binici et al. 2014) and straw (Volf et al. 2015). The thermal conductivity of insulation made of wood or other plant fibers ranged between 0.037 – 0.065 $W \cdot m^{-1} \cdot K^{-1}$ and similar thermal conductivity was measured by other researchers (Hurtado et al. 2016, Schiavoni et al. 2016, Veitmans – Grinfelds 2016). Bark was also among the investigated materials (Kain et al. 2013, Pásztory – Ronyecz 2013, Pásztory et al. 2017b).

The thermal modification of wood is well known. With heat treatment, dimensional stability and resistance against wood degrading organisms increases, while some strength properties decrease (Seborg et al. 1953, Rowel – Youngs 1981, Hill 2006). Many variables influence the results achieved during heat treatment including tree species, chamber design, treatment duration and temperature, closed or open system, medium, etc. (Rapp 2001, Militz 2002, Hill 2006, Esteves – Periera 2009, Navi – Sandberg 2012, Bak – Németh 2012, Horváth – Csupor 2012, Sandberg – Kutnar 2016).

Boards are heat treated mainly to reduce water uptake and thickness swelling. Lehmann (1964) treated the chips at 204 °C for 15, 30, and 45 minutes and found that particleboard dimensional stability increased slightly, but strength properties decreased. Tomek (1966) studied the heat treatment (1-8 minutes; 230 – 300 °C) of oak chips. The water absorption (WA) and thickness swelling (TS) of the particleboard made from the treated material was reduced; the modulus of rupture (MOR) increased. Lee et al. (2017) investigated the physical-mechanical properties of particleboard made from heat-treated rubber wood (*Hevea brasiliensis* (Willd. ex A. Juss.) Müll.Arg.). Four different temperatures (50, 100, 150 and 200 °C) and three different durations (one, two, three hours) in dry and wet conditions were investigated. The heat treatment of the particles improved the dimensional stability, but mechanical properties decreased with the duration of the heat treatment. Ohlmeyer – Lukowsky (2004) investigated single layer pine particleboard. The particles were treated at 240 °C. The modification decreased the EMC, the WA, and the TS. The internal bond (IB), the MOE, and the MOR of the particleboard decreased as well. Mendes et al. (2013) compared the effect of thermal pre-treatment of strand type particles on the physical-mechanical properties of OSB panels produced from *Pinus taeda* L. The particles were treated at 200 °C and 240 °C. In relation to control panels, thermal treatment of particles at 200 °C negatively affected their physical and mechanical properties, while thermal treatment at 240 °C significantly improved their physical properties and weakened their mechanical properties. Paul et al. (2006) examined the physical and mechanical properties of OSBs made from Scots pine (*Pinus sylvestris* L.) chips treated at 220 °C and 240 °C for 30 minutes, which resulted in decreased thickness swelling and increased dimensional stability. The pre-treatment left the internal bond strength unaffected and greatly reduced the bending properties (MOE, MOR). Boonstra et al. (2006) investigated a two-stage steam pre-treatment (with temperatures below 200 °C) of particleboard made of Norway spruce (*Picea abies* (L.) H. Karst.) and Scots pine (*Pinus sylvestris* L.) chips. The WA and TS decreased, as did the IB. Kwon – Ayrilmis (2016) investigated the physical and mechanical properties of flakeboard made of heat-treated flakes (at 150, 170 and 190 °C; 2 hours). The TS, WA, MOR, MOE decreased as temperature increased, while IB strength increased.

Sometimes thermal post-treatment was used, but steam injection and post-treatment only work with isocyanate, PMUF, MUF, and phenol-formaldehyde adhesives (Boonstra et al. 2006). The swelling of the heat-treated particleboard decreased in tests by Ernst (1967).

Suchsland – Enlow (1968) reduced the swelling with one to two hours of heat treatment at 218 °C, and the mechanical properties of phenolic bonded particleboard were not adversely affected. Menezzi – Tomaselli (2006) examined the effect of thermal post-treatment on OSB dimensional stability. The thermal treatment was effective and reduced the TS, EMC, but did not affect WA. The longer the treatment, the better the dimensional stability became. Oliveira et al. (2017) evaluated the effect of post-heat treatment on the physical and mechanical properties of MDF panels. The dimensional stability of the MDF increased, but all the thermally treated panels revealed a significant decrease in their MOR and MOE. Ayrilmis et al. (2009) also examined the thermal post-treatment of MDF. The heat treatment improved the TS, but WA and linear expansion properties were adversely affected. The MOR and MOE values decreased with increasing temperature. H'ng et al. (2012) post-heat treated particleboard made of rubber wood (*Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg.) in a laboratory press at 100, 150, and 180 °C for 90, 180, and 270 seconds. The thermal treatment reduced the TS, but the WA was not affected.

Thermal conductivity also decreases with thermal treatment (Kol – Sefil 2011, Korkut et al. 2013, Pásztory et al. 2017a). Sekino – Yamaguchi (2010) reduced the thermal conductivity of their insulation panel made of wood shavings by carbonizing the wood material. Similar processes can occur during heat treatment as the structure and the composition of the wood and bark are similar, but not the same.

The main goal of this investigation was to improve the mechanical properties and examine the thermal insulation property changes of insulation panels made of poplar bark. The secondary goal was to investigate the effect of thermal treatment duration on thermal conductivity and other parameters.

1.1 Abbreviations and symbols

TS	Thickness swelling (%)
WA	Water uptake (wt%)
EMC	Equilibrium moisture content (%)
ρ	Density ($\mathrm{kg \cdot m^{-3}}$)
λ	Thermal conductivity ($\mathrm{W \cdot m^{-1} \cdot K^{-1}}$)
MOE	Modulus of elasticity (MPa)
MOR	Modulus of rupture (MPa)
IB	Internal bond (MPa)

2 MATERIALS AND METHODS

2.1 Raw material

In Hungary, 88% of harvested timber are broadleaved species, primarily black locust (*Robinia pseudoacacia* L.) and poplar (*Populus* sp.) (NÉBIH 2016). We studied the 'Pannónia' poplar clone (*Populus* × *euramericana* (Dode) Guinier cv. *Pannónia*), which is widespread in Hungarian plantations and favored by the wood industry because of its advantageous mechanical properties. Bark was collected from a nearby sawmill (TAEG PLC Wood Processing Plant); the bark originated from the base to the first branches of the harvested stems. Inner and outer bark was not separated. The collected bark was hammer ground and dried to 8% moisture content. Particles smaller than 0.5 mm were fractionated from the chips.

2.2 Pre-heat treatment

A custom-made labor chamber was used for the treatment. Since the chamber interior is not airtight from the outside, steam escapes from the system during the treatment and oxygen is present. The system is an open and dry system. The bark chips were heated from room temperature to 95 °C in one hour, from 95 °C to 130 °C in another two hours, and then to the peak temperature of 180 °C top in another 30 minutes. Three different treatment durations (constant temperature) were used which lasted one (T1), two (T2) and three (T3) hours *(Figure 1)*. During cooling, the thermal inertia of the chamber was exploited; hence, the specimens were cooled to 25 °C in about 15 hours. Three panels were produced from each type.

Figure 1. Treated raw materials
(C – control; T1 – one hour treatment; T2 – two hours treatment; T3 – three hours treatment)

2.3 Pressing conditions

A laboratory hot press (Siempelkamp) produced panels of 500 mm × 500 mm × 20 mm with the targeted density of 340 $kg \cdot m^{-3}$. The pressing time was 18 seconds per thickness millimeter, at 180 °C, with a pressure of 2.86 MPa, which was reduced after 120 seconds to 2.00 MPa and after an additional 120 seconds to 1.15 MPa to release steam pressure inside the panel.

2.4 Measurements

The physical and mechanical properties of the panels were examined. The thermal conductivity (λ) of all the panels was measured by a hot plate method. The temperature of the cold side was 5 °C and the hot side was 15 °C, with a mean temperature of 10 °C according to the standard (MSZ ISO 8301). To ensure parallel heat flow perpendicular to the surface of the panel, 15 cm of side insulation was used around the specimens. Before the thermal conductivity measurement, the panel had to reach a steady state, which was determined when the fluctuation of the last per minute measurement was under 0.002 $W \cdot m^{-1} \cdot K^{-1}$. The measuring equipment made one measurement every minute, and the average of the last 100 measurements was accepted as the measured result of the panel. The averages of the three data points collected were taken as the results.

Board moisture content and bulk density (ρ) were calculated from ten samples taken from the panels. The thickness swelling (TS) and water absorption (WA) after immersion in water for 2 and 24 hours were calculated according to European standard EN 317 (1993). Ten 50 mm × 50 mm specimens were weighed and their thicknesses measured with an accuracy of 0.01 g and 0.1 mm, respectively. The samples were stored at 20 °C and 65% relative humidity for seven days before measuring.

Bending strength, modulus of elasticity (MOR, MOE) (EN 310), and internal bond (IB) (EN 319) were tested using Instron 5506, a universal testing machine. The specimens were prepared from different areas of the board and cut according to the EN 326-1 (1994) European standard.

For color measuring a Konica-Minolta CM-2600d spectrophotometer with an 8 mm aperture was used SpectraMagic NX software was used to determine the color coordinates (L*; a*; b*) in the CIELab-system. The positive value range of the a* axis is blue; the negative range is green; the positive value range of the b* axis is yellow; and the negative values are blue. The third axis, L*, is perpendicular to the other two, and the lightness values there were between 0 and 100. Due to the mixed structure of the samples, the measurements were taken at five points on a mat of 2 cm-thick conditioned chips.

The differences between the panels were evaluated with "Statistica 13" software. To find means of different treatment that significantly varied from each other, the Tukey-test was run on the raw data. In this test, the means of every treatment were compared to the means of every other treatment and the difference between the two means was identified if this difference was greater than the expected standard error. On the basis of the differences and the identities of the different variables (MOR, MOE, TS, WA, EMC), the treatments were grouped to identify the similarities and differences between treatments.

3 RESULTS AND DISCUSSION

The density of the bark panels treated for one, two, and three hours and the control were 336, 349, 352, and 336 $kg\cdot m^{-3}$ respectively. The density of the panels treated for three hours (T3) is a little higher, which may be caused by the inhomogeneity of the laboratory scale experiment *(Table 1)*.

The thermal conductivity of the panels was 0.064, 0.065, and 0.067 $W\cdot m^{-1}\cdot K^{-1}$ respectively, and the control panels had 0.067 $W\cdot m^{-1}\cdot K^{-1}$. Although the thermal conductivity of artificial insulating materials is lower (0.015 – 0.045 $W\cdot m^{-1}\cdot K^{-1}$), the environmental impact of naturally-based insulation is lower. Solid wood's thermal conductivity is also relatively low (0.08 – 0.2 $W\cdot m^{-1}\cdot K^{-1}$) (Touloukian et al. 1971, Glass – Zelinka 2010), but different wood-based panels can achieve even better values (0.05 – 0.08 $W\cdot m^{-1}\cdot K^{-1}$) (TenWolde et al. 1988, Kamke 1989). The thermal conductivity of the panels studied here is located in the middle of that said range.

The thermal conductivity of wood and wood products is influenced by many factors: density, moisture content, chemical composition, porosity, grain direction, etc. (MacLean 1941, TenWolde et al. 1988, Ragland et al. 1991, Suleiman et al. 1999). Heat can be transferred in such panels by heat bridges between the particles and air convection in large gaps. Because the same weight of treated bark was used to press the panels, there is a similar amount of air gaps in the panels; only density affects this. Conductivity increases with density because the amount of solid content increases with density. Parallel to the increasing density of the studied panels, the thermal conductivity of the panels made of treated bark particles increased. The T1 panels (one hour treatment) had the lowest thermal conductivity and density. The control and the T1 panels had a similar density, but the treated panels had lower thermal conductivity.

Thermal treatment affected the cell walls by changing the molecular structure and relationships of the wall. During the heat treatment, mass loss is detectable in the wood; first the transformation and decomposition of the hemicelluloses takes place. The amount of hydroxyl and carbonyl groups decreases in the cell wall, which allows it to absorb less water. Due to weight loss, small cavities and voids form in the cell wall (Stone – Scallan 1965, Tjeerdsma et al. 1998, Tjeerdsma – Militz 2005, Windeisen et al. 2007, Kocaefe et al. 2008, Mitsui et al. 2008, Yin et al. 2011, Kekkonen et al. 2014, Gao et al. 2019). These processes cause a decrease in thermal conductivity. On the other hand, we produced panels of almost the same density from heat-treated materials. Panels made of heat-treated raw material have lower thermal conductivity at the same density (T1), and reach the value of control panels at about 5% higher density (T3). This shows the heat treatment had an effect on the microstructural and chemical levels, but panel density had a greater impact on the thermal conductivity of the panel than the heat treatment. By using other heat-resistant adhesives and post-manufacture heat treatments of the finished panels, panel density and thermal conductivity could be drastically reduced.

Table 1. The physical and mechanical properties of panels, pre-treated with different durations (T1-T2-T3=one hour – two hour – three hour) and the control (C)

	C	**T1**	**T2**	**T3**
Physical properties				
ρ (kg·m^{-3})	336.80 (± 22.95)	336.40 (± 13.53)	349.78 (±20.73)	352.29 (±12.74)
EMC (%)	8.88 (±0.22)	8.33 (±0.22)	8.44 (±0.21)	7.66 (±0.17)
WA (wt%)	217.89 (±48.0)	185.57 (± 23.58)	123.19 (±25.93)	100.61 (±34.82)
TS (%)	17.67 (±2.84)	10.68 (±2.49)	7.65 (±1.49)	5.45 (±0.72)
Thermal properties				
λ (W·m^{-1}·K^{-1})	0.067 (± 0.004)	0.064 (±0.003)	0.065 (±0.005)	0.067 (± 0.001)
Mechanical properties				
MOR (MPa)	0.54 (±0.17)	0.45 (±0.09)	0.89 (± 0.21)	1.08 (± 0.22)
MOE (GPa)	0.28 (±0.08)	0.22 (±0.03)	0.41 (±0.13)	0.56 (± 0.06)
IB (MPa)	0.037 (±0.014)	0.032 (±0.018)	0.039 (±0.009)	0.047 (±0.014)

The **equilibrium moisture content** (EMC) of the control panel was higher (8.88%) than all of the treated bark panels. The T3 (7.66%) has the lowest EMC. A Tukey-test was completed on the data. The T1 and T2 created a group, and the control and the T3 were in individual groups. As a result of heat treatment, the EMC decreased. With increasing temperature and/or time, EMC decreased (Akyildiz – Ateş 2008, Esteves – Pereira 2009). Heat reduces equilibrium moisture content by degrading the hemicellulos, which is one of the major hygroscopic components of wood, and by degrading and volatilizing extractives or further breaking down other low-molecular weight polymers, and increasing cellulose crystallinity.

The control panels had higher **water uptake** (WA) (217.89%) and **thickness swelling** (TS) (17.67%), than any treated panels. Both the WA and TS decreased parallel with the duration of the treatment. The one-hour treatment caused the smallest decrease (WA: 185.57%; TS: 10.68%), and the three-hour treatment caused the highest (WA: 100.61%; TS: 5.45%). The control and T1 form a group based on the WA, the T2 and T3 form another group based on both the WA and the TS. Wood swelling decreased with increasing treatment times and temperature (Boonstra et al. 2006, Winandy – Smith 2006, Kocaefe et al. 2015). The study of Xiangquan et al. (1997) illustrated that post-treatment of the particleboard manufactured from fast growing poplars is effective to improve dimensional stability. Thickness swelling decreased with increasing time and temperature of the post-heat treatment.

As mentioned above, the chemical structure of the cell walls is modified during the heat treatment, and equilibrium moisture content (EMC), water uptake (WA), and thickness swelling (TS) decreased (Tjeerdsma – Militz 2005; Boonstra, 2006, Akyildiz – Ateş 2008, Esteves – Pereira, 2009, Kol – Sefil 2011, Kocaefe et al. 2015, Pelit et al. 2017). As bio-based (lignocellulose) materials are hygroscopic, they absorb water from the surrounding air. As the thermal conductivity is higher in water than in wood, there are strong correlations between the moisture content and thermal conductivity as well as the moisture content and air humidity of the wood and wood products. Since EMC decreases, the panel will contain less water under the same conditions; consequently, its thermal conductivity will be lower (Kol – Sefil 2011, Palumbo et al. 2016, Pelit et al. 2016, Brischke 2017).

The T1 panels had the lowest **MOR** and **MOE**, (0.45 MPa; 0.22 GPa respectively), but these values are similar to the control panel (0.54 MPa; 0.28 GPa respectively). Parallel to the increasing treatment duration, both MOR and MOE increased. Based on the Tukey-test, C and T1 formed one group, and the T2 and T3 formed two other individual groups. In most cases, panels made of pre-heat treated particles or chips, or panels treated after the manufacturing have lower mechanical properties (MOE, MOR) than the untreated particles, chips, or panels (Seborg et al. 1953, Lehmann 1964, Rowel – Youngs 1981, Ohlmeyer – Lukowsky 2004, Lee et al. 2017, etc.). Tomek (1966) found results similar to ours, but this contradicts the results of the majority of researchers.

If all the properties are examined together (with a Tukey test), the control panel and T1 are often in the same group. T2 and T3 are similar in many aspects and form a group, but in other cases they are significantly different. That is, one-hour treatment (T1) caused a relatively small change in the base material, so it is slightly different from the control, while the ever-increasing treatments (T2 and T3) show increasing changes *(Figure 2)*.

Figure 2. Grouping the treated and control panels based on the Tukey test

The L*, a* and b* **color coordinates** of the untreated chips were 42.46, 13.37 and 36.18 respectively. Parallel with the increasing treatment duration, the lightness obviously decreased, and the red color showed an increasing tendency. The yellow color first increased, but after two and three hours of treatment, it dramatically decreased *(Table 2)*.

Wood color change during heating is mainly due to the chemical transformation of the extracts in the temperature range of 100 – 200 °C. The degree of color change, both in an inert and oxidative atmosphere, increases dramatically between 160 – 180 °C. The lightness of the wood decreases considerably, and its color shifts towards the less saturated, reddish ranges (Németh 1998). As treatment time increases, the rate of change significantly decreases and the color approaches the limit value for each tree species and treatment time. However, a very long treatment time yields the color characteristics obtained at higher temperatures (Németh 1998).

Table 2. CIELab color coordinates of the control and the treated chips

	a*	**b***	**L***
C	13.37	36.12	42.46
T1	16.57	45.26	30.59
T2	20.93	37.30	22.15
T3	23.61	22.33	13.07

In general, insulation boards are not visible in wall construction and there was no purpose for producing visible insulation in this study. However, the degree of treatment is clearly visible and predictable from the measured colors; the small particle pieces are heated faster and more evenly than solid wood.

4 CONCLUSIONS

Heat-treated poplar bark particles are suitable for insulation panels. As described above, it is possible to produce a panel of heat-treated bark particles as the UF adhesive is able to form a bond between the heat treated particles. The effect of heat treatment is hardly perceptible on the mechanical properties of the panels, and the effect of density is stronger: the MOR and MOE of the panels with higher density, even treated for longer periods, are higher.

The thermal conductivity (0.067 $W \cdot m^{-1} \cdot K^{-1}$) of our poplar bark panels lies in the middle of the heat conducting range of other wood-based panels (0.05 – 0.08 $W \cdot m^{-1} \cdot K^{-1}$). The thermal conductivity of these insulation panels made of bark can be reduced by heat treatment. By treating the particles with one hour of heat before the panels are manufactured, the thermal conductivity of a panel – at the same density – decreased to 0.064 $W \cdot m^{-1} \cdot K^{-1}$. In fact, after three hours of treatment, the thermal conductivity of a panel with a density of about 5% is the same as that of the control panel (0.067 $W \cdot m^{-1} \cdot K^{-1}$). That is, by heat treating the particles prior to panel production, the thermal insulation properties of the panels can be improved. A big problem with natural thermal insulation materials is that their moisture content changes in parallel with atmospheric humidity, which strongly influences heat conduction. Pre-manufacturing heat treatment of the raw material bark changes its chemical structure, thus decreasing the water absorption and swelling of the manufactured panels. A three-hour treatment reduced the water uptake to half, decreased the thickness swelling to one-third, and pushed the EMC down 10%. The significantly lower moisture sensitivity is an advantages for practical usage such a treated insulation panel.

The study found that treatment duration affects the changes; the longer treatment at the same temperature causes greater changes in physical and mechanical properties. Color coordinates can help separate the differences caused within the heat-treated bark chips.

5 ACKNOWLEDGMENTS

The work was conducted as part of the ”Sustainable Raw Material Management Thematic Network – RING 2017”, EFOP-3.6.2-16-2017-00010 project in the framework of the Széchenyi 2020 Program. This project is supported by the European Union, co-financed by the European Social Fund.

REFERENCES

ABDULLAH, F.A. (2011): Theoretical and experimental investigation of natural composite materials as thermal insulation. Al-Qadisiya Journal For Engineering Sciences 4 (2): 26–36.

AKYILDIZ, H.M. – ATEȘ, S. (2008): Effect of heat treatment on equilibrium moisture content (EMC) of some wood species in Turkey. Research Journal of Agriculture and Biological Sciences 4 (6): 660–665

AYRILMIS, N. – LAUFENBERG, T.L. – WINANDY, J.E. (2009): Dimensional stability and creep behavior of heat-treated exterior medium density fiberboard. European Journal of Wood and Wood Products 67: 287–295. https:/doi.org/10.1007/s00107-009-0311-7

BAK, M. – NÉMETH, R. (2012): Changes in swelling properties and moisture uptake rate of Oil-Heat-Treated poplar (*Populus* × *euramericana* cv. Pannónia) wood. BioResources 7: 5128–5137.

BINICI, H. – EKEN, M. – DOLAZ, M. – AKSOGAN, O. – KARA, M. (2014): An environmentally friendly thermal insulation material from sunflower stalk, textile waste and stubble fibres. Construction and Building Materials 51**:** 24–33. https:/doi.org/10.1016/j.conbuildmat.2013.10.038

BOONSTRA, M.J. – PIZZI, A. – ZOMERS, F. – OHLMEYER, M. – PAUL, W. (2006): The effects of a two stage heat treatment process on the properties of particleboard. Holz als Roh- und Werkstoff 64: 157–164. https:/doi.org/10.1007/s00107-005-0055-y

BRISCHKE, C. (2017): Performance of the bio-based materials: Moisture performance (Chapter 5.4) In: JONES D. – BRISCHKE C. (eds.) Performance of Bio-based Building Materials. Woodhead Publishing Series in Civil and Structural Engineering. ISBN: 978-0-08-100982-6

DEL MENEZZI, C.H.S. – TOMASELLI, I. (2006): Contact thermal post-treatment of oriented strandboard to improve dimensional stability: A preliminary study. Holz als Roh- und Werkstoff 64: 212–217. https:/doi.org/10.1007/s00107-005-0052-1

ERNST, K. (1967): Möglichkeit zur Verminderung der Quellung bei Spanplatten. Holztechnologie 8: 41–47.

ESTEVES, B.M. – PEREIRA H.M. (2009): Wood modification by heat treatment: a review. BioResources 4 (1): 370–404.

FAO (2015): Forest products 2009-2013. FAO Forestry Series No. 48 FAO Statistics Series No. 204. ISBN 978-92-5-008811-2. http://www.fao.org/3/a-i4746m.pdf

GAO, Y. – XU, K. – PENG, H. – JIANG, J. – ZHAO, R. – LU, J. (2019): Effect of heat treatment on water absorption of chinese fir using TD-NMR. Applied Sciences 9: 78. https://doi.org/10.3390/app9010078

GLASS, S.V. – ZELINKA, S.L. (2010): Moisture relations and physical properties of wood. Wood handbook : wood as an engineering material: Chapter 4. Centennial ed. General technical report FPL; GTR-190. Madison, WI: U.S. Dept. of Agriculture, Forest Service, Forest Products Laboratory. pp. 4.1–4.19.

H'NG, P.S. – LEE, S.H. – LUM, W.C. (2012): Effect of post heat treatment on dimensional stability of UF bonded particleboard. Asian Journal of Applied Sciences 5 (5): 299–306. https:/doi.org/10.3923/ajaps.2012.299.306

HILL, C. [2006]: Thermal Modification of Wood. In: Hill [2006]: Wood Modification. Chemical, Thermal and Other Processes. John Wiley & Sons, Ltd. ISBN-13 978-0-470-02172-9. pp:99-128.

HORVÁTH, N. – CSUPOR, K. (2012): The protective effectiveness of dry heat treatment on Turkey oak against fugal decay. In: Németh R; Teischinger A. (eds.) (2012): Proceedings of the 5th Conference on Hardwood Research and Utilisation in Europe 2012: „Hardwood Science and Technology". University of West-Hungary, Sopron, Hungary. pp. 362–369

HURTADO, P.L. – ROUILLY, A. – VANDENBOSSCHE V. – RAYNAUD C. (2016): A review on the properties of cellulose fibre insulation. Building and Environment 96: 170–177. https:/doi.org/10.1016/j.buildenv.2015.09.031

KAIN, G. – BARBU, M.C. – HINTERREITER, S. – RICHTER, K. – PETUSCHNIGG, A. (2013): Using bark as a heat insulation material. BioResources 8 (3): 3718–3731.

KAMKE, F.A. (1989): Thermal conductivity of wood-based panels. In: Hasselman, D.P.H. – Thomas, J.R. (eds.): Thermal conductivity 20. Proceedings of the Twentieth International Thermal Conductivity Conference, held October 19–21, 1987, in Blacksburg, Virginia. pp. 249-260. ISBN 978-1-4613-0761-7

KEKKONEN, P.M. – YLISASSI, A. – TELKKI, V.V. (2014): Absorption of water in thermally modified pine wood as studied by Nuclear Magnetic Resonance. Journal of Physical Chemistry C 118: 2146–2153. https://doi.org/10.1021/jp411199r

KOCAEFE, D. – PONCSAK, S. – DORÉ, G. – YOUNSI, R. (2008): Effect of heat treatment on the wettability of white ash and soft maple by water. Holz Roh Werkstoff 66: 355–361. https://doi.org/10.1007/s00107-008-0233-9

KOCAEFE, D. – HUANG, X. – KOCAEFE, Y. (2015): Dimensional stabilization of wood. Current Forestry Reports 1(3): 151–161. https:/doi.org/10.1007/s40725-015-0017-5

KOL, Ş.H. – SEFIL, Y. (2011): The thermal conductivity of fir and beech wood heat treated at 170, 180, 190, 200, and 212°C, Journal of Applied Polymer Science 121 (4): 2473–2480. https://doi.org/10.1002/app.33885

KORKUT, S. – AYTIN, A. – TAŞDEMÍR, Ç. – GURĂU, L. (2013): The transverse thermal conductivity coefficients of Wild cherry wood heat-treated using the ThermoWood method. ProLigno 9 (4): 649–683. Online ISSN 2069-7430.

KWON, J.H. – AYRILMIS, N. (2016): Effect of heat-treatment of flakes on physical and mechanical properties of flakeboard. European Journal of Wood and Wood Products 74: 135−136. https:/doi.org/10.1007/s00107-015-0961-6

LEE, S.H. – ASHAARI, Z. – JAMALUDIN, F.R. – YEE, C.N. – AHAMAD, W.N. (2017): Physico-mechanical properties of particleboard made from heat-treated rubberwood particles. European Journal of Wood and Wood Products 75: 655−658. https://doi.org/10.1007/s00107-016-1145-8

LEHMANN, W.F. (1964): Retarding dimensional changes of particle boards. Information Circular 20, Forest Products Research, Forestry Laboratory, Oregon State University.

MACLEAN, J.D. (1941): Thermal conductivity of wood. Heating, piping & air conditioning 13 (6): 380−391.

MANOHAR, K. (2012): Renewable building thermal insulation – Oil Palm fibre. International Journal of Engineering and Technology 2 (3): 475–479.

MENDES, R.F. – JÚNIOR, G.B. – DE ALMEIDA, N.F. – SURDI, P.G. – BARBERIO, I.N. (2013): Effects of thermal pre-treatment and variables of production on properties of OSB panels of *Pinus taeda*. Maderas. Ciencia y Tecnología 15 (2): 141−152. https:/doi.org/10.4067/S0718-221X2013005000012

MITSUI, K. – INAGAKI, T. – TSUCHIKAWA, S. (2008): Monitoring of hydroxyl groups in wood during heat treatment using NIR spectroscopy. Biomacromolecules 9: 286−288. https://doi.org/10.1021/bm7008069

NAVI, P. – SANDBERG, D. (2012): Thermo-hydromechanical processing of wood. Chapter 9: Heat Treatment. pp. 249−286. EPFL Press. ISBN 978-2-940222-41-1

NÉBIH (2016): Erdővagyon és erdőgazdálkodás Magyarországon 2015. [Forest values and forest management in Hungary in 2015.] https://portal.nebih.gov.hu/documents/10182/206281/2015_leporello_magyar_web_300dpi.pdf/672fd0f8-3a59-4dc7-a51a-13fd0daa7c2f . (in Hungarian)

NÉMETH, K. (1998): A faanyag degradációja. [The degradation of wood.] Mezőgazdasági Szaktudás Kiadó, Budapest. (in Hungarian)

OHLMEYER, M. – LUKOWSKY, D. (2004): Wood-based panels produced from thermal treated wood – Properties and Perspectives. Wood-Frame Housing Durability and Disaster Issues Conference. October 4–6 2004, Las Vegas, USA pp. 127−132.

OLIVEIRA, S.L. – FREIRE, T.P. – MENDES, L.M. – MENDES, R.F. (2017): The effect of post-heat treatment in MDF panels. Materials Research 20 (1): 183−190. https:/doi.org/10.1590/1980-5373-MR-2016-0259

PALUMBO, M. – LACASTA, A.M. – HOLCROFT, N. – SHEA, A. – WALKER, P. (2016): Determination of hygrothermal parameters of experimental and commercial bio-based insulation materials. Construction and Building Materials 124: 269−275. http://dx.doi.org/10.1016/j.conbuildmat.2016.07.106

PANYAKAEW, S. – FOTIOS, S. (2008): Agricultural Waste Materials as Thermal Insulation for Dwellings in Thailand: Preliminary Results. 25th Conference on Passive and Low Energy Architecture, Dublin, 22nd to 24th October:1-6

PÁSZTORY, Z. – HORVÁTH, N. – BÖRCSÖK, Z. (2017a): Effect of heat treatment duration on the thermal conductivity of spruce and poplar wood. European Journal of Wood and Wood Products 75: 843–845. https:/doi.org/10.1007/s00107-017-1170-2

PÁSZTORY, Z. – MOHÁCSINÉ, R.I. – BÖRCSÖK, Z. (2017b): Investigation of thermal insulation panels made of black locust tree bark. Construction and Building Materials 147: 733−735. https:/doi.org/10.1016/j.conbuildmat.2017.04.204

PÁSZTORY, Z. – RONYECZ, I. (2013): The Thermal Insulation Capacity of Tree Bark, Acta Silvatica et Lignaria Hungarica 9: 111–117. https:/doi.org/10.2478/aslh-2013-0009

PAUL, W. – OHLMEYER, M. – LEITHOFF, H. – BOONSTRA, M.J. – PIZZI, A. (2006): Optimising the properties of OSB by a one-step heat pre-treatment process. Holz als Roh- und Werkstoff 64: 227−234. https:/doi.org/10.1007/s00107-005-0073-9

PELIT, H. – KORKMAZ, M. – BUDAKÇI, M. – ESEN, R. (2017): The effects of densification and heat treatment on thermal conductivity of fir wood. The Online Journal of Science and Technology 7(3): 117-122. International Science and Technology Conference, Vienna-Austria, July 13−15, 2016.

RAGLAND, K.W. – AERTS, D.J. – BAKER, A.J (1991): Properties of wood for combustion analysis. Bioresource Technology 37: 161−168.

RAPP, A.O. (ed.) (2001): Review on heat treatments of wood. COST Action E22: Environmental optimisation of wood protection. Proceedings of Special Seminar Antibes, France, 9th February 2001. ISBN: 3 926 301 02 3

RÉBÉK-NAGY, P. – PÁSZTORY, Z. (2014): Természetes anyagok szigetelőképessége. [Thermal performance of natural materials.] Faipar 62: 31−36. https:/doi.org/10.14602/WoodScience-HUN_2014_6 (in Hungarian)

ROWEL, R.M. – YOUNGS, R.L. (1981): Dimensional stabilization of wood in use. Research Note FPL-0243, Forest Products Laboratory, Forest Service, USDA

SANDBERG, D. – KUTNAR, A. (2016): Thermally modified timber: Recent developments in Europe and North America. Wood and Fiber Science 48: 28−39.

SCHIAVONI, S. – D'ALESSANDRO, F. – BIANCHI, F. – ASDRUBALI, F. (2016): Insulation materials for the building sector: A review and comparative analysis. Renewable and Sustainable Energy Reviews 62: 988−1011. https://doi.org/10.1016/j.rser.2016.05.045

SEBORG, R.M. – TARKOW, H. – STAMM, A.J. (1953): Effect of heat upon the dimensional stabilization of wood. Journal of Forest Product Research Society 3 (3): 59−67.

SEKINO, N. – YAMAGUCHI, K. (2010): Carbonizing binderless wood shaving insulation panels for better insulation and durability Part 1: Relationship between thermal conductivity and carbonizing temperature. Proceedings of the International Convention of Society of Wood Science and Technology and United Nations Economic Commission for Europe – Timber Committee October 11−14, 2010, Geneva, Switzerland. Paper IW-3 pp. 8.

STONE, J.E. – SCALLAN, A.M. (1965): Effect of component removal upon the porous structure of the cell wall of wood. Journal of Polymer Science: Part C 11: 13−25.

SUCHSLAND, O. – ENLOW, R.C. (1968): Heat treatment of exterior particleboard. Forest Products Journal 18 (8): 24−28.

SULEIMAN, B.M. – LARFELDT, J. – LECKNER, B. – GUSTAVSON, M. (1999): Thermal conductivity and diffusivity of wood. Wood Science and Technology 33: 465−473.

TANGJUANK, S. – KUMFU, S. (2011): Particle board from papyrus fibres as thermal insulation. Journal of Applied Sciences 11 (14): 2640−2645. https://doi.org/10.3923/jas.2011.2640.2645

TANGJUANK, S. (2011): Thermal insulation and physical properties of particleboards from pineapple leaves. International Journal of Physical Sciences 6 (19): 4528−4532. https:/doi.org/10.5897/IJPS11.1057

TENWOLDE, A. – MCNATT, J.D. – KRAHN, L. (1988): Thermal properties of wood and wood panel products for use in buildings. USDA Forest Sevice DOE/USDA-21697/1

TJEERDSMA, B.F. – BOONSTRA, M. – PIZZI, A. – TEKELY, P. – MILITZ, H. (1998): Characterisation of thermally modified wood: Molecular reasons for wood performance improvement. Holz Als Roh- und Werkstoff 56: 149–153. https://doi.org/10.1007/s001070050

TJEERDSMA, B.F. – MILITZ, H. (2005): Chemical changes in hydrothermal treated wood: FTIR analysis of combined hydrothermal and dry heat-treated wood. Holz Als Roh-Und Werkstoff 63: 102–111. https://doi.org/10.1007/s00107-004-0532-8

TOMEK, A. (1966): Die Heißvergütung von Holzspänen, ein neues Verfahren zum Hydrophobieren von Spanplatten. Holztechnologie 7: 157−160.

TOULOUKIAN, Y.S. – POWELL, R.W. – HO, C.Y. – KLEMENS, P.G. (1971): Thermophysical and Electronic Properties Information and Analysis Center Lafayette In, TPRC Data Series Volume 2, https://apps.dtic.mil/dtic/tr/fulltext/u2/a951936.pdf retrieved on March 13, 2019

VEITMANS, K. – GRINFELDS, U. (2016): Wood fiber insulation material. Proceedings 22nd Annual International Scientific Conference "Research for Rural Development 2016" 18-20 May, 2016 Vol. 2: 91−98. ISSN 2255-923X

VĖJELIENĖ, J. – GAILIUS, A. – VĖJELIS, S. – VAITKUS, S. – BALČIŪNAS, G. (2011): Evaluation of structure influence on thermal conductivity of thermal insulating materials from renewable resources. Materials Science 17 (2): 208−212. http://dx.doi.org/10.5755/j01.ms.17.2.494

VOLF, M. – DIVIŠ, J. – HAVLÍKA, F. (2015): Thermal, moisture and biological behavior of natural insulating materials. Energy Procedia 78: 1599−1604. https:/doi.org/10.1016/j.egypro.2015.11.219

WINANDY, J.E. – SMITH, W.R. (2006): Enhancing composite durability: using thermal treatments. In: Barnes HM (ed.): Proceed Wood Protection, March 21–23, Forest Prod Society, New Orleans, Louisiana, pp 195−199

WINDEISEN, E. – STROBEL, C. – WEGENER, G. (2007): Chemical changes during the production of thermo-treated beech wood. Wood Science and Technology 41: 523–536. https://doi.org/10.1007/s00226-007-0146-5

XIANGQUAN, Z. – RENSHU, L. – WEIHONG, W. – ANBIN, P. (1997): Heat post-treatment to reduce thickness swelling of particleboard from fast-growing poplars. Journal of Forestry Research 8(3): 188−190. https://doi.org/10.1007/BF02855417

YIN, Y. – BERGLUND, L. – SALMÉN, L. (2011): Effect of steam treatment on the properties of wood cell walls. Biomacromolecules 12: 194–202. https://doi.org/10.1021/bm101144m

ZACH, J. – KORJENIC, A. – PETRÁNEK, V. – HROUDOVÁ, J. – BEDNAR, T. (2012): Performance evaluation and research of alternative thermal insulations based on sheep wool. Energy and Buildings 49: 246–253. https://doi.org/10.1016/j.enbuild.2012.02.014

ZHOU, X. – ZHENG, F. – LI, H. – LU, C. (2010): An environment-friendly thermal insulation material from cotton stalk fibers. Energy and Buildings 42**:** 1070−1074. https:/doi.org/10.1016/j.enbuild.2010.01.020

10.2478/aslh-2019-0003 *Acta Silv. Lign. Hung., Vol. 15, Nr. 1 (2019) 35–45*

Funding Modalities for Timber Housing in Brazil

Victor DE ARAUJO[a*] – Francisco DE ARAUJO[b] – Maristela GAVA[c] –
José GARCIA[d]

[a] Research Group on Development of Lignocellulosic Products (LIGNO Research Group), Itapeva, Brazil
[b] Edification course, Demétrio Azevedo Junior Technical School, Paula Souza Center (CPS), Itapeva, Brazil
[c] Timber Industrial Engineering Course, São Paulo State University (UNESP), Itapeva, Brazil
[d] Department of Forest Sciences, University of São Paulo (USP), Piracicaba, Brazil

Abstract – This paper investigated the existence and participation of public and private real estate credit lines for timber house funding in Brazil. The analysis was completed through face-to-face interviews with Brazilian timber housing producers. Semi-structured questionnaires were applied in this survey method to obtain a sectorial approach of the industry. Accesses to full financing for timber housing and credit for the acquisition of construction materials were the main two issues studied. About 107 producers were fully evaluated from all sectors. Half of the studied companies offer full housing finance and, simultaneously, most loans still come from private banks. Credit directed to raw materials emerges as the most common method of accessing funding for timber-based construction despite the lower economic value of this form of credit compared to other, more complete financial options. Public banks disseminate partial credit more frequently because of lower rates and lower restrictions, such as the absence of insurance requirements against risks from these construction ventures. Full funding proliferation will stimulate this market.

timber house / construction / real estate funding / incentives / interviewing / sectoral research

Kivonat – A faházak finanszírozási módszerei Brazíliában. A tanulmány a faházak finanszírozására szolgáló állami és magán ingatlanhitelek meglétét és részesedését vizsgálja Braziliában. Az elemzés a brazíliai faház-gyártókkal folytatott személyes interjúk alapján készült. A felmérési módszerben félig strukturált kérdőíveket alkalmaztunk az ágazat szektorális megközelítése érdekében. A vizsgálat két fő kérdését a faházak teljes finanszírozásához való hozzáférés és az építőanyagok megszerzéséhez nyújtott hitelek képezték. Körülbelül 107 gyártót értékeltünk ki minden ágazatból. A vizsgált vállalatok fele teljes lakásfinanszírozást kínál, és egyidejűleg a legtöbb hitel még mindig magánbankokból származik. A faanyagú építmények finanszírozásának leggyakoribb módját a nyersanyagokra vonatkozó hitelek jelentik, annak ellenére, hogy ennek a hitelformának alacsonyabb a gazdasági értéke más, teljesebb pénzügyi lehetőségekhez képest. Az állami bankok gyakrabban nyújtanak részleges hitelt az alacsonyabb kamatlábak és a kevesebb megszorító tényező miatt, mint amilyen például az építési vállalkozások kockázataira vonatkozó biztosítási követelmények mellőzése. A teljes finanszírozás elősegítésével a piac stimulálható.

faház / építkezés / ingatlanfinanszírozás / ösztönzők / személyes interjú / ágazati kutatás

---

[*] Corr. a: victor@usp.br / engim.victor@yahoo.de; BR-18409-010 ITAPEVA (SP), 519 Geraldo Alckmin, Brazil

1 INTRODUCTION

Among its main evaluation components, the Brazilian housing shortage includes improvised homes, rustic houses, and dwellings with excessive densification, cohabitation, and excessive rent burdens. These dwellings may be singular or combined. (IBGE 2013, FIESP 2016, IBGE 2017). The housing shortage also correlates to dwellings that must be built to replace those homes lacking safe conditions or to ensure adequate housing for families without residences (Genevois – Costa 2001).

Housing was a private sector industry in Brazil until the 1930s. No policies to solve housing deficits existed before then, and initial measures to address the issue of housing for low-income people only arose later (Pinto 2015). The number of families residing in precarious housing decreased by about 740,000 (-2.8%) between 2010 and 2014, but 6.2 million families still reside in poor housing conditions, which is a significant number (FIESP 2016, IBGE 2017). The most effective way to reduce this number is to expand low interest credit lines to fund both social housing and larger homes for those from more advantaged social classes.

Federal government programs played a key role in the expansion of housing funding in Brazil in the past decade (Pinto 2015). As a result, brick masonry has been the most popular construction method in this Latin American country.

Masonry houses – which have deep roots in Brazilian culture – will prevail in the popular “My Home, My Life” (Minha Casa, Minha Vida) housing program over the next few years. This will narrow the field of prefabricated housing systems significantly (Santos 2009).

Despite a restrained beginning, this Brazilian program for social housing development has provided the insertion of industrialized techniques such as light-woodframe and steelframe its criteria for acceptable forms of construction. Nevertheless, many restrictions for other and frequently less popular construction methods exists.

The main Brazilian organization for public funding – Caixa Econômica Federal – estimated a 30% increase in popular funding, amounting to R$ 225,000 for the Brazilian housing program “My Home, My Life” from 2015 to 2016. Local governments continue to bet on growth and job creation on this program, and has adopted important measures such as readjustments in the income profile of beneficiary families to increase all people served; increases in the maximum property value; and reorganization of obstacles present in this program for the public bidding and hiring of construction companies (Brazil 2017). Due to these limitations, this paper aimed to study the funding solutions for timber houses in Brazil. Thereby, this approach justification is also supported by Zani (2013), who demonstrated the timber housing market has persisted in Brazil since the end of the nineteenth century.

1.1 Theoretical Background

In the early 2010s, *Banco do Brasil* bank regulations for the “My Home, My Life” social housing program did not permit funding for wood-based residences (Banco do Brasil 2012). From 2012, rare initiatives were established in the terms of light-woodframe building utilization for popular housing. Ferreira (2013) and Brasil (2015) declared that the target public for such initiatives exclusively includes those families with a monthly income of R$ 1,600.00. Ferreira (2013) referred the “Residencial Haragano” as the first light-woodframe enterprise for the Brazilian “My Home, My Life” housing program, which is situated in Pelotas, Rio Grande do Sul state, and has 280 units based on 45m^2-houses. Platform light-woodframe technique was also applied to other house allotments as mentioned by Brazil (2015), who drew attention to “Moradias Nilo” project that included the construction of 66 light-woodframe houses in Curitiba, Paraná state. However, other timber houses based on similar prefabrication were not applied further in this program.

No timber-based construction systems could attain housing funding for programs that allow its large-scale application (Kiss 2009). A lack of technical references and standard documents has persisted over the last decade. Thereby, Brazil (1998) created the Brazilian Housing Construction Quality and Productivity Program (PBQP-H), whose objective is to support local efforts to modernize and promote basic attributes from the housing sector, and to increase service and goods competitiveness. Brazil (2007) created the Technical Evaluation of Modern Products and Conventional Systems (SiNAT) to prescribe and harmonize requirements, criteria, and methods for the technical evaluation of traditional or modern products, processes, and systems in the National System. In addition, Kiss (2009) cited accredited institutions such as the Technological Research Institute (IPT) and Falcão Bauer Institute as being responsible for granting the Technical Evaluation Document (DATec) for housing building system testing, while SiNAT rules on evaluation guidelines to stimulate the modernization in civil construction.

Platform light-woodframe insertion as a new housing technique was allowed in the Brazilian program "My Home, My Life" and occurred by its accreditation and approval. Thus, the SiNAT 005 guideline to allow light-woodframe technical evaluation as regulated by PBQP-H (2017) was established for construction systems made with light parts based on lumber or panel finishing. According to Falcão Bauer (2015), the DATec 020-A typified the first official two-year-valid document whose focus approves light-woodframe as a construction technique based on timber for the production of low cost housing.

Although timely, this strategy still restricts wooden house production for the "My Home, My Life" social program in that only larger companies can present real conditions to charge high investments to perform all the stages from this evaluation.

Against this direction, whose focus was based on modern application, the Brazilian Government also authorized wood for housing on simplified construction techniques such as stilt houses (*palafitas*) for people living in northern regions in the same "My Home, My Life" social program (Alves 2014). No SiNAT guideline was openly shared to regulate these stilt houses, and no DATec was issued to any local company, thereby permitting the production of this specific low quality wooden construction. This drastic situation sets the precedent for the production of stilt houses without the support of any technical studies, which proves the real disadvantages of this example of precarious housing. This situation is really unclear. Over the years, Blanco Junior (2006), Sá (2009) and Menegassi – Silveira (2015) have detailed that the Brazilian government had formerly performed a key role in the eradication of stilt houses as they were considered substandard solutions.

Due to stilt houses utilization in the northern regions, this public strategy can unfortunately cause the dissemination of an erroneous culture of wooden residences with low technological and production qualities, prejudicing the market of other timber houses based on modern techniques. The stimulus towards the use of advanced timber-based house techniques could eradicate this governmental problem and reduce the housing shortage with those higher added-value examples.

Some credit lines for wood-based houses in Brazil are available with interest rates comparable to funding for masonry. This, despite limitations on the number of financial organizations suitable for this purpose, as well as many restrictions on the type of material used for houses (Santiago 2012). This convenience has been offered by private banks with strategic purposes to provide housing finance for medium to high income people. Evidence that public banking institutions have also provided such funding for timber housing exists, but this information has not been officially disclosed and is not available to everyone. Thus, if public housing policies allow timber house producers greater access to the "My Home, My Life" social program, different timber building techniques could improve their market share, including those populations with better social conditions.

This paper aimed to verify the conditions of public and private funding for timber housing in Brazil through an interview survey conducted with timber house producers. Two hypotheses were emphasized: few producers offer public timber housing finances to their clients; and, credit lines for raw material acquisition have been the main financial solutions for wooden houses.

2 MATERIALS AND METHODS

2.1 Survey method and materials

Earlier, De Araujo (2017) completed extensive research into the Brazilian timber housing sector to check and characterize its current condition, aspects, and other unprecedented views related to producers, manufacturers, and products. The goal was to assist sector development. As suggested by De Araujo et al. (2018 a, b, c, 2019), this present study utilized timber housing producers, standard questionnaires, and bibliographic documents to share data and support the process.

This study was formulated to verify funding for timber houses in Brazil. For this purpose, the methodology was supported with a survey based on personal interviews and a structured questionnaire given to wood-based housing developers in Brazil. This method was fully detailed by De Araujo et al. (2018 a, b, c, 2019). The face-to-face interviewing process was supported by two qualitative queries, with response details for affirmative replies.

The first question was: "Does your company have full wooden house funding for your clients?". Trichotomous responses "yes", "no" or "not informed" were indicated; then, in an affirmative statement, multiple open answers were asked to detail such options between private and/or public financial institutions and banks available to fully fund wooden housing produced in each evaluated producer.

The second question was: "Does your company have a credit agreement for raw material acquisition for wooden housing?" As in first question, trichotomous responses "yes", "no" or "not informed" were indicated; but in the case of an affirmative statement, two multiple answers were declared, that is, *Construcard* and/or *BB Construção*. This open-hybrid step allowed for the insertion by interviewees of other unlisted responses.

With respect to declarations to add detail the answers, multiple answers were allowed; that is, for both queries, an evaluated company could present two or more answering possibilities to detail each response. Thus, qualitative answers were converted into a percentage and, according to the "Raosoft Sample Size Calculator" (Raosoft, 2004), a margin of error was identified for this surveying, similar to the approaches contained in De Araujo et al. (2018 a, b, c, 2019).

3 RESULTS AND DISCUSSION

3.1 Sectoral estimation and survey

Population estimates from a search of producer websites as well as prescribed and performed sampling amounts are listed in *Table 1* The margin of error was ±3.325%, which is acceptably within 10% standard and close to 5% ideal level as prescribed by Pinheiro et al. (2011). Thus, the survey can be classified as reliable. More than half of the entire sector was evaluated (n = 107 producers). The overall listing contains 210 producers as suggested by the extensive research by De Araujo (2017) and its related approaches were referenced as "*" while statistical sampling values prescribed by the literature were referenced as "**" in *Table 1.*

Table 1. Analysis of sectoral population and survey sampling results.

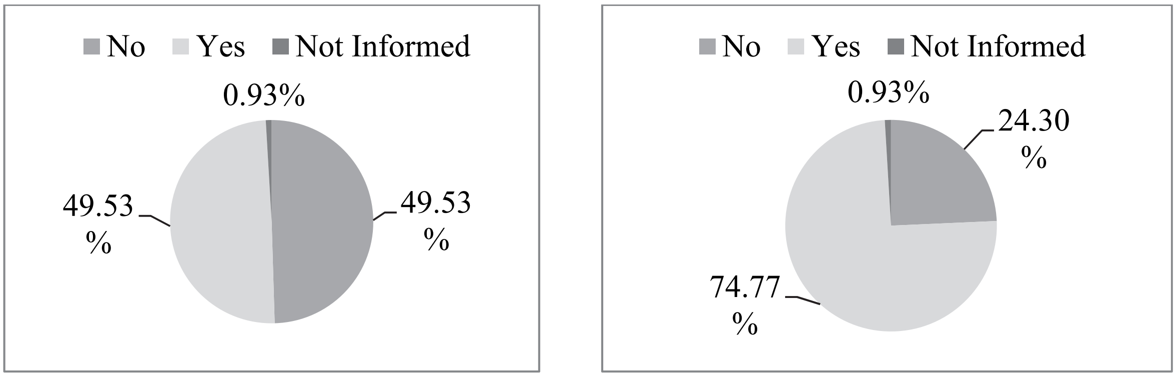
Result	Company (Unit)	Margin of Error (%)
Overall Sectoral Population*	210	–
Prescribed Acceptable Sampling**	66	10.00
Prescribed Ideal Sampling**	136	5.00
Interviewees' Sampling*	107	6.65

* Values from this study and De Araujo et al. (2018 a, b, c, 2019); ** Values according to Pinheiro et al. (2011)

3.2 Housing Funding Modalities for Timber Houses in Brazil

Two housing credit categories were considered: full real estate finance for properties (*Figure 1a*), and partial funding as exclusive credit for the acquisition of raw materials (*Figure 1b*).

With full funding for timber housing in Brazil, half of sampled entrepreneurs declared the offering of such financial options in their product lines, that is, timber-based houses (*Figure 1a*).



(a) (b)

Figure 1. Available funding options to clients of timber housing: (a) full funding, and (b) credit to material purchase (n = 107 interviewees)

Few producers provided this full funding through public organizations (*Figure 2*), because around 13% of producers shared this financial operation through federal banks (*Caixa Econômica Federal* and *Banco do Brasil*) and about 7% in state institutions (*Banrisul*). *Caixa Econômica Federal* emerges as a rare public bank offering credit lines for timber houses. The mutual interests for these credit lines are applied without tax incentives or reduced interest rates such as those present in popular funding. This situation is the opposite of the European scenario as revealed by Kuzman – Sandberg (2017) who noted that several nations from this continent have encouraged the use of timber in construction through low-interest loans or subsidies.

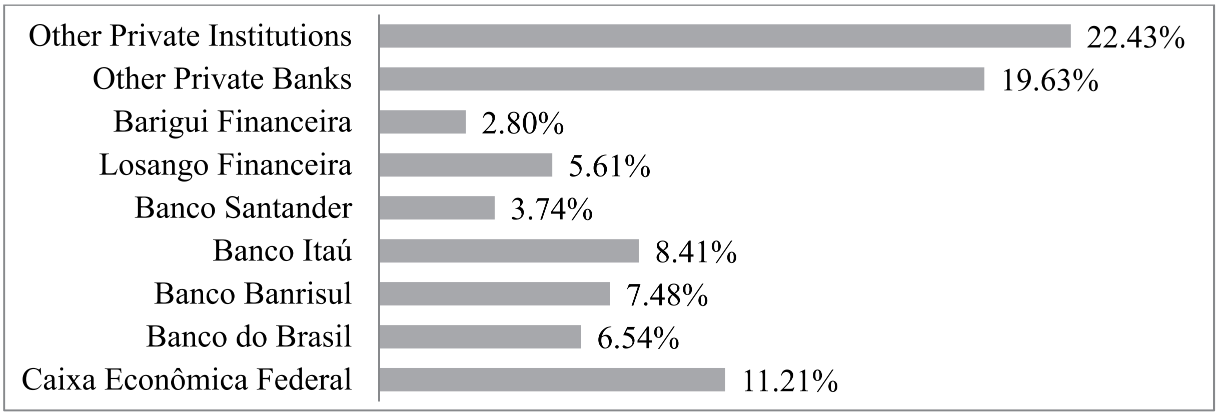


Figure 2. Available organizations: full timber housing funding (n = 107 interviewees).

Full loans are the main preferred public strategy for social housing because they satisfy a broader economic profile of residents, rather than the affluent exclusively (Makachia 2015). However, this strategy could be extended to other social levels and other construction projects such as those built from timber.

In contrast to the public banking approach (*Figure 2*), several sampled producers offer full financing for timber housing through private organizations, whereas around 31% is from banks (*Itaú*, *Santander*, *BM Sua Casa*, *Pan*, etc.) and almost 30% is from financial institutions (*Barigui*, *Losango*, *Sicredi*, *Credipar*, *Cresol*, *Visa*, etc.), which do not have a main banking function.

Punhagui (2014) indicated that only two organizations supplied funding for full timber housing. In contrast, this present research verified that – despite the low offering in the producers studied here (*Figure 2*) – at least 13 institutions and banks share this financial payment modality for local clients.

However, the low offering of public funding is related to a current Brazilian government restriction in the expansion of this financial operation for wood-based residences, despite the local presence of these types of housing, which, according to Zani (2013) and De Araujo (2016 a), originated in the nineteenth century. Santiago (2012) suggested that few insurers are able to secure timber houses in Brazil, which limits the market for these housing solutions because funded houses demand insurance against physical damages and against the consumer losses and deaths. In her approach, Punhagui (2014) verified that three insurers offer this insurance service; however, two of these carry some restrictions.

The scenario was quite different regarding the specific credits to acquire raw materials for construction (*Figure 1b*) whereby only about a quarter of studied companies still had not offered this possibility. The results demonstrated an inverse situation to full funding because public credits for material purchases exhibited greater offering to the producers at the detriment of private credits for the same objective (*Figure 3*). Both main public banks *Banco do Brasil* and *Caixa Econômica Federal* enable *BB Construção* and *Construcard* as small public credit lines, respectively; these are exclusive cards for the acquisition of raw materials for construction. The funded amounts are limited because the narrow focus prevents them from being utilized for labor payment and/or other construction objectives.

This situation has demonstrated that these special credits for raw materials have emerged as more convenient options to supply the full funding shortage for timber housing, especially since such modalities do not require insurance and are unhindered by restrictions concerning timber application. This limitation of full real estate funding for wooden houses in Brazil (*Figure 1a*) resulted in the creation and proliferation of exclusive partial credits for raw materials, which have lower restrictions and lower values shared by the financial organizations.

This alternative became popular in the studied companies due to the free acquisition of raw materials, allowing for the use of timber and its engineered composites (beams and panels). This directed credit, which has a low economic value, has been widely used as an efficient alternative to credit access by the clients of wooden houses (*Figures 1b* and *3*). The greater popularity these credits from public banks is justified by the generally lower interest rates. This chronic situation is similar to Punhagui (2014), whose credit for material acquisition has become the main way to commercialize houses from this sector, whereas companies sampled in her study declared the inexistence of funding for prefabricated wooden houses.

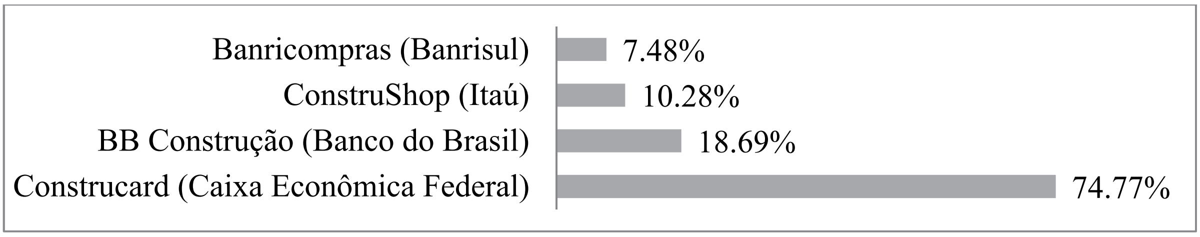


Figure 3. Available organizations: credit to raw material purchase (n = 107 interviewees).

The importance of this present evaluation goes in favor to the current global trend regarding sustainable construction projects as well as those based on materials from renewable sources. Timber application and its better utilization for construction has been a persistent topic in several studies including Kniffen – Glassie (1966), Charles (1984), Gold – Rubik (2009), Roos et al. (2010), Kuzman – Grošelj (2012), Zani (2013), Punhagui (2014), Wang et al. (2014), Hurmekoski et al. (2015), Leite – Lahr (2015), De Araujo et al. (2016 a, b, 2018 c, 2019), Koppelhuber et al. (2017), Kuzman – Sandberg (2017), Ramage et al. (2017), Viluma (2017), Franzini et al. (2018), and Sotsek – Santos (2018), etc.

A significant and visible example was identified by De Araujo et al. (2016 a, b), which claimed that timber houses could reach all economic and social classes due to their interesting attributes of innovation, lightness, competitive costs, as well as efficient levels of sustainability, site cleaning, assembly time, low water usage, and material rationalization. Several features are within the main pillars for housing sustainability as defined by Makachia (2015), under which the houses are developed with consideration for the physical, social and economic environment. In this case, timber-based construction emerges as an efficient and healthy housing solution for nearly everyone.

Furthermore, strong industrialization of wooden housing prefabrication could be a focal point in the near future, consonant to housing shortages in underdeveloped and developing countries (De Araujo et al. 2016 b). Financial organizations must note and consider the agility resulting from this industrialization in construction. According to Punhagui (2014), funding for construction payment must be made available within shorter application and granting periods because prefabricated house construction is a rapid and efficient construction method in terms of assembly and production. The faster the work can be completed, the smaller the weekly site overhead cost for producers is (Powell 2012). This would also lead to lower interest payments (Renner-Smith 1981). Bureaucracy in the housing funding processes, be it public or private in nature, must be in accordance with efficient assembly times of timber housing techniques, which De Araujo (2017) assessed in his research. In this case, slowness in loan payments could generate financial problems for timber housing producers and respective suppliers because the sector has more compact economic, production, and machinery dimensions than the traditional masonry construction sector in Brazil does, as suggested in De Araujo et al. (2018 a, b, c, 2019).

These facts should be considered and serve as basis for diffusion of modern funding lines for wood-based housing, especially by public feature. This proposal must diffuse these examples in all of Brazil, as well as expand it to other Latin American countries through networks to mitigate local housing shortages, which could be supplied through modern and accessible houses.

4 CONCLUSIONS

Despite the low diffusion and popularity of housing funding for timber housing in Brazil, two modalities are readily available: full funding with an integral cost, and partial credit lines for raw material acquisition. This analysis also proved there are financial operations for these buildings in this South American nation despite some restrictions and obstacles.

Full funding is restricted and still depends on other financial institutions like insurers to ensure fluid operation. This has limited the program and directed most clients to private banks. Despite the advances in credit access to clients considering wooden housing, Brazil's housing funding system for timber solutions are not as accessible, consolidated, and plural as funding systems in developed countries. In addition, full resources also do not serve all social classes. As a result of these obstacles, credits for raw materials acquisition emerged as the main source of subsidized financial resources for housing in Brazil, by means of public and private institutions.

In Brazil, few wood-based housing producers have full funding for public class programs. The public only has access to timber houses through line credits to raw material purchase. Private banks still dominate this financial market under full funding for timber houses despite their unsubsidized rates. This essentially impedes those from the lower social classes from accessing such loans. These predictions were supported by a wide sampling process including more than half of whole timber construction sector. In addition, this discovery was statistically validated by the almost ideal margin of error, which ensured greater reliability of the survey.

Nevertheless, Brazil still requires greater local and governmental efforts to expand full funding for timber-based housing in order to increase the accessibility of sustainable and rapid residences for all families. A proliferation of these integral funding schemes for populations from lower and middle classes could stimulate Brazilian wood chains – which are dependent on public policies for their expansion – due to market limitation, which is restricted to few people.

Acknowledgments: This study was supported by the first author's own resources and his PhD. scholarship at the University of São Paulo (USP) under the supervision of the last author.

REFERENCES

ALVES, M.R. (2014): Governo autoriza uso de madeira no minha casa minha vida [Government authorizes the use of wood in my house, my life] (in Portuguese), http://exame.abril.com.br/brasil/governoautorizausodemadeiranominhacasaminhavida/

BANCO DO BRASIL. (2012): Programa minha casa minha vida [My house, my life program]. Brasília, DF, Brazil: Banco do Brasil.

BLANCO JUNIOR, C. (2006): As transformações nas políticas habitacionais brasileiras nos anos 1990: o caso do programa integrado de inclusão social da prefeitura de Santo André [The transformations in brazilian housing politics in years 1990: the case of the integrated program aimed at social inclusion of the Municipality of Santo André]. MSc thesis. University of São Paulo, São Carlos. (in Portuguese)

BRAZIL. (1998). Portaria n. 134, de 18 de Dezembro de 1998 [Ordinance number 134 of December 18, 1998]. Diário Oficial da União. Brasília, DF, Brazil: Casa Civil. (in Portuguese)

BRAZIL. (2007). Portaria n. 345, de 3 de Agosto de 2007 [Ordinance number 345 of August 3, 2007]. Diário Oficial da União. Brasília, DF, Brazil: Casa Civil. (in Portuguese)

BRAZIL. (2015). Minha casa minha vida entrega primeiro residencial com imóveis de madeira [My house my life delivers first residential building with timber houses]. (in Portuguese). http://www.brasil.gov.br/infraestrutura/2015/03/minhacasaminhavidaentregaprimeiroresidencialcomimoveisdemadeira

BRAZIL. (2016). Caixa aposta no mercado de habitação popular em 2016 [Caixa bets on the popular housing market in 2016]. http://www.brasil.gov.br/economia-e-emprego/2016/01/caixa-aposta-no-mercado-de-habitacao-popular-em-2016 (in Portuguese)

BRAZIL. (2017). Setor da construção civil aposta em crescimento e geração de empregos com mudanças no MCMV. 2017 [Construction sector bets in its increasing and in the job generation with changes in the MCMV]. www2.planalto.gov.br/acompanhe-planalto/noticias/2017/02/setor-da-construcao-civil-aposta-em-crescimento-e-geracao-de-empregos-com-mudancas-no-mcmv (in Portuguese)

CHARLES, F.W.B. (1984). Conservation of timber buildings. London, UK: Hutchinson & Co. pp. 1–256.

DE ARAUJO, V. – NOGUEIRA, C. – SAVI, A. – SORRENTINO, M. – MORALES, E. – CORTEZ-BARBOSA, J. – GAVA, M. – GARCIA, J. (2018a): Economic and labor sizes from the Brazilian timber housing production sector. Acta Silvatica et Lignaria Hungarica 14 (2): 95–106. https://doi.org/10.2478/aslh-2018-0006

DE ARAUJO, V.A. (2017): Casas de madeira e o potencial de produção no Brasil [Wooden houses and the potential of production in Brazil]. Ph.D. thesis. University of São Paulo, Piracicaba. (in Portuguese)

DE ARAUJO, V. A., CORTEZ-BARBOSA, J., GARCIA, J. N., GAVA, M., LAROCA, C., & CÉSAR, S. F. (2016a). Woodframe: light framing houses for developing countries. Revista de la Construcción 15 (2): 78−87. https://doi.org/10.4067/S0718-915X2016000200008

DE ARAUJO, V.A. – GUTIÉRREZ-AGUILAR, C.M. – CORTEZ-BARBOSA, J. – GAVA, M. – GARCIA, J.N. (2019): Disponibilidad de las técnicas constructivas de habitación en madera, en Brasil [Availability of timber housing construction techniques in Brazil]. Revista de Arquitectura 21 (1): 68−75. https://doi.org/10.14718/RevArq.2019.21.1.2014

DE ARAUJO, V.A. – LIMA JR., M.P. – BIAZZON, J.C.– VASCONCELOS, J.S. – MUNIS, R.A. – MORALES, E.A.M. – CORTEZ-BARBOSA, J. – NOGUEIRA, C.L. – SAVI, A.F. – SEVERO, E.T.D. – CHRISTOFORO, A.L. – SORRENTINO, M. – LAHR, F.A.R. – GAVA, M. – GARCIA, J.N. (2018b): Machinery from Brazilian wooden housing production: size and overall obsolescence. BioResources 13 (4): 8775–8786. https://doi.org/10.15376/biores.13.4.8775-8786

DE ARAUJO, V.A. – VASCONCELOS, J.S. – CORTEZ-BARBOSA, J. – MORALES, E.A.M. – GAVA, M. – SAVI, A.F. – GARCIA, J.N. (2016b). Wooden residential buildings – a sustainable approach. Bulletin of the Transilvania University of Brasov Series II: Forestry • Wood Industry • Agricultural Food Engineering, 9 (2): 53−62.

DE ARAUJO, V.A. – VASCONCELOS, J.S. – MORALES, E.A.M. – SAVI, A.F. – HINDMAN, D.P. – O'BRIEN, M.J. – NEGRÃO, J.H.J.O. – CHRISTOFORO, A.L. – LAHR., F.A.R. – GARCIA, J.N. (2018c): Difficulties of wooden housing production sector in Brazil. Wood Material Science & Engineering 1–10. https://doi.org/10.1080/17480272.2018.1484513

FERREIRA, R. (2013). MCMV da madeira: conheça a tecnologia e os custos de construção do primeiro empreendimento em wood frame do programa minha casa minha vida [MCMV of timber: know the technology and construction costs of first enterprise in wood frame from my house my life program]. Guia da Construção, 66 (146), 16−25. (in Portuguese)

FIESP. (2016). Levantamento inédito mostra déficit de 6,2 milhões de moradias no Brasil [Unprecedented survey indicates a 6.2 million housing shortage in Brazil]. (in Portuguese) www.fiesp.com.br/noticias/levantamento-inedito-mostra-deficit-de-62-milhoes-de-moradias-no-brasil/

FRANZINI, F. – TOIVONEN, R. – TOPPINEN, A. (2018). Why Not wood? Benefits and barriers of wood as a multistory construction material: perceptions of municipal civil servants from Finland. Buildings 8 (159): 1−15. https://doi.org/10.3390/buildings8110159

GENEVOIS, M.L.B P. – COSTA, O.V. (2001). Carência habitacional e déficit de moradias: questões metodológicas [Housing lacking and dwelling shortage]. São Paulo em Perspectiva 15 (1): 73−84. https://doi.org/10.1590/S0102-88392001000100009 (in Portuguese)

IBGE. (2013). Atlas do censo demográfico 2010 [Atlas of Demographic Census 2010]. Rio de Janeiro, RJ, Brazil: IBGE. (in Portuguese)

IBGE. (2017). Pesquisa nacional por amostra de domicílios – PNAD [National survey by dwelling sample]. (in Portuguese) http://www.ibge.gov.br/home/estatistica/pesquisas/pesquisa_resultados.php?id_pesquisa=40

FALCÃO BAUER. (2015). DATec n. 020-A: sistema de vedação vertical leve em madeira [DATec number 020-A: light system of vertical finishing based on timber]. São Paulo: Falcão Bauer. (in Portuguese)

GOLD, S. – RUBIK, F. (2009). Consumer attitudes towards timber as a construction material and towards timber frame houses: selected findings of a representative survey among the German population. Journal of Cleaner Production, 17 (2): 303–309. https://doi.org/10.1016/j.jclepro.2008.07.001

HURMEKOSKI, E. – JONSSON, R. – NORD, T. (2015). Context, drivers, and future potential for wood-frame multi-story construction in Europe. Technological Forecasting and Social Change, 99: 181–196. https://doi.org/10.1016/j.techfore.2015.07.002

KISS, P. (2009). Você sabe o que é SiNAT? [Do you know what SiNAT is?]. (in Portuguese) http://techne.pini.com.br/engenharia-civil/150/artigo287681-1.aspx

KNIFFEN, F. – GLASSIE, H. (1966). Building in wood in the Eastern United States. Geographical Review 56 (1): 40−66. https://doi.org/10.2307/212734

KOPPELHUBER, J. – BAUER, B. – WALL, J. – HECK, D. (2017). Industrialized timber building systems for an increased market share – a holistic approach targeting construction management and building economics. Procedia Engineering 171: 333−340. https://doi.org/10.1016/j.proeng.2017.01.341

KUZMAN, M.K. – GROŠELJ, P. (2012). Wood as a construction material: comparison of different construction types for residential building using the analytic hierarchy process. Wood Research 57 (4): 591−600.

KUZMAN, M.K. – SANDBERG, D. (2017). Comparison of timber-house technologies and initiatives supporting use of timber in Slovenia and in Sweden - the state of the art. iForest 10: 930−938. https://doi.org/10.3832/ifor2397-010

LEITE, J.C.P.S. – LAHR, F.A.R. (2015). Diretrizes básicas para projeto em wood frame [Basic guidelines for design in wood frame]. Construindo 7 (2): 1−16. (in Portuguese)

MAKACHIA, P.A. (2015). Innovative housing financing for sustainable growth. Working Paper Series. Nairobi, Kenya: Kenya Bankers Association. pp. 1−32

MENEGASSI, J. – SILVEIRA, T. (Orgs.) (2015). Estratégias de ação plano local de habitação de interesse social: município de Vila Velha / Espírito Santo [Action strategies of local plan of social housing: Vila Velha / Espírito Santo]. Vila Velha, ES, Brazil: Latus. (in Portuguese)

PBQP-H. (2017). Diretriz SiNAT: n. 005 – revisão 02 [SiNAT guideline: number 004 – revision 02]. Brasília, DF, Brazil: SNH. (in Portuguese).

PINHEIRO, R.M. – CASTRO, G.C. – SILVA, H.H. – NUNES, J.M.G. (2011): Pesquisa de mercado [Market research]. Editora FGV, Rio de Janeiro. (in Portuguese)

PINTO, E. G. F. (2015). Financiamento imobiliário no Brasil: uma análise histórica compreendendo o período de 1964 a 2013, norteada pelo arcabouço teórico pós-keynesiano e evolucionário [Real state financing in Brazil: a historic analysis comprehending 1964 to 2013, guided by the post-Keynesian and evolutionary theoretical framework]. Economia & Desenvolvimento, 27 (2): 276–296.

POWELL, G. (2012). Construction contract preparation and management: from concept to completion. New York, USA: Palgrave Macmillan.

PUNHAGUI, K.R.G. (2014): Potencial de reducción de las emisiones de CO_2 y de la energía incorporada en la construcción de viviendas en Brasil mediante el incremento del uso de la madera [Potential of reducion of CO_2 emissions and embodied energy in the housing construction in Brazil through the increasing of wood utilization]. PhD thesis. Universitat Politecnica de Catalunya / University of São Paulo, Barcelona / São Paulo. (in Spanish)

RAOSOFT. (2004): Raosoft sample size calculator, http://www.raosoft.com/samplesize.html.

RAMAGE, M.H. – BURRIDGE, H. – BUSSE-WICHER, M. – FEREDAY, G. – REYNOLDS, T. – SHAH, D.U. – WU, G. – YU, L. – FLEMING, P. – DENSLEY-TINGLEY, D. – ALLWOOD, J.; DUPREE, P. – LINDEN, P.F. – SCHERMAN, O. (2017). The wood from the trees: the use of timber in construction. Renewable and Sustainable Energy Reviews 68 (1): 333−359.

REINER-SMITH, S. (1981). Sprayed-concrete sandwich. Popular Science, 218 (5): 97−97.

ROOS, A. – WOXBLOM, L. – MCCLUSKEY, D. (2010). The influence of architects and structural engineers on timber construction – perceptions and roles. Silva Fennica 44 (5): 871–884. https://doi.org/10.14214/sf.126

SÁ, W.L.F. (2009). Autoconstrução na cidade informal: relações com a política habitacional e formas de financiamento [Self-construction in the informal city: relations with housing policy and financing forms]. MSc thesis. Federal University of Pernambuco, Recife. (in Portuguese)

SANTIAGO, F. (2012). Financiamento de casas que fogem da alvenaria convencional [Financing of those houses that are different from the conventional masonry]. http://casa.abril.com.br/materiaisconstrucao/financiamentodecasasquefogemdaalvenariaconvencional/ (in Portuguese)

SANTOS, A. (2009). Alvenaria vai predominar no minha casa, minha vida [Masonry will dominate My House My Life]. 2009. (in Portuguese) www.cimentoitambe.com.br/alvenariavaipredominarnominhacasaminhavida/

SOTSEK, N.C. – SANTOS, A.P.L. (2018). Panorama do sistema construtivo light wood frame no Brasil [Brazilian light wood frame system overview]. Ambiente Construído, 18 (3): 309–326. https://doi.org/10.1590/s1678-86212018000300283 (in Portuguese)

VILUMA, A. (2017). The situation with use of wood constructions in contemporary Latvian architecture. Mokslas – Lietuvos Ateitis 9 (1): 9–15. https://doi.org/10.3846/mla.2017.1007

WANG, L. – TOPPINEN, A. – JUSLIN, H. (2014). Use of wood in green building: a study of expert perspectives from the UK. Journal of Cleaner Production 65: 350–361. https://doi.org/10.1016/j.jclepro.2013.08.023

ZANI, A.C. (2013): Arquitetura em madeira [Wooden architecture]. Eduel / Imprensa Oficial do Estado de São Paulo, Londrina / São Paulo. pp. 1–396. (in Portuguese)

10.2478/aslh-2019-0004 *Acta Silv. Lign. Hung., Vol. 15, Nr. 1 (2019) 47–52*

The Effects of Thinnings on Yield and Value Changes in Black Locust (*Robinia pseudoacacia* L.) Stands: A case study

Károly RÉDEI[a] – Zsolt KESERŰ[b*] – János RÁSÓ[b] – János GÁL[c]

[a] Faculty of Agricultural and Food Sciences and Environmental Management, University of Debrecen, Debrecen, Hungary
[b] Forest Research Institute, National Agricultural Research and Innovation Centre, Püspökladány, Hungary
[c] Faculty of Forestry, University of Sopron, Sopron, Hungary

Abstract – Thinning experiments in black locust (*Robinia pseudoacacia* L.) stands have been conducted in Hungary for many years. Black locust is an economically important tree species supplying the domestic timber industry. This paper evaluates two effects of thinnings: the effect on yield and the effect on stand value. The case study has proved thinnings in black locust stands do not increase periodic total production, but do increase the stem-quality index by 11–24%.

Robinia pseudoacacia / tending cuts / periodical total production / stand value

Kivonat – A gyérítések hatása az akácállományok (*Robinia pseudoacacia* L.) fatermés- és értékváltozására: esettanulmány. Az akácállományok (*Robinia pseudoacacia* L.) gyérítésével kapcsolatos magyarországi kísérletek hosszú időszakra nyúlnak vissza. Ezen állományalkotó fafajnak meghatározó gazdasági jelentősége van az ország faanyag ellátásában. Jelen dolgozat a gyérítések hatását két aspektusból, a fatermés és a minőség vonatkozásában elemzi. Az esettanulmány azt igazolja, hogy akácállományokban gyérítésekkel a korszaki összes fatermés nem, a törzsminőséget kifejező jelzőszám viszont 11–24%-al is növelhető.

Robinia pseudoacacia / nevelővágások / korszaki összes fatermés / faállomány érték

1 INTRODUCTION

Thinning is the removal of a proportion of the trees in a stand. It is usually implemented to provide more growing space for the remaining trees, to increase the total yield of usable timber over the life of the stand, and to provide wood from thinnings. Thinning affects stand growth and yield, diameter distribution, quality, and stability. In forestry practice, the effect of thinning on the average tree size or future crop trees is more important than its effect on stand growth and yield, particularly for species like black locust. Obviously, total production is only one factor influencing stand value. Volume distribution in different size classes is often of much greater importance because stem size and number influences harvesting costs and the markets to which the timber assortments can be sold.

---

[*] Corresponding author: keseru.zsolt@erti.naik.hu; H-4150 PÜSPÖKLADÁNY, Farkassziget 3, Hungary

Thinning should be a central part of any mitigation strategy implemented to reduce the impact of future climate change. There are three main reasons for this. First, wood products from stands that are thinned and pruned are more likely to be used in long-term end uses. Second, thinning helps maintain healthy, resilient forests able to sequestrate carbon from the atmosphere and store it as woody biomass. Finally, material produced in thinning can be used as fuelwood, which is a source of renewable energy, to help reduce fossil emissions.

Over the years, many studies have addressed the question of whether forest growth or yield can be increased or decreased through thinnings. Testing Wiedemann's hypothesis helps provide an answer to this question. The hypothesis states that volume growth is constant among a wide range of stand densities (Wiedemann 1943). This relationship varies among species, but also depends on stand age and site conditions (Pardé 1965, Assmann 1970, Persson, 1986, Kuiper – Schoenmarkers 1990, Pretzsch, 2009), so quantifying it for each forest species is necessary.

Most of the relevant publications in Hungary declare that thinnings cannot increase total stand production with various tree species; however, in many cases, thinnings can increase stand value (Majer 1969, Béky 1983, Halupa 1987, Béky – Solymos 1991, Rédei – Meilby 2009).

The following will present a thinning experiment, namely the effects of thinnings on black locust stand yield and value. The paper also verifies and confirms the above-mentioned statements in the case of black locust.

2 MATERIALS AND METHODS

The experiment was established at NEFAG Nagykunság State Forest Company (Szolnok), Pusztavacs forest estate, in the forest subcompartment Pusztavacs 201 E (*N 471017; E 193004*) (*Figure 1*). The site type was a free-draining humus sand soil in the forest-steppe climate zone (annual precipitation is normally less than 550 mm). The yield class of the particular black locust stand was III (Rédei 1984). Three thinning treatments were executed when the stand age was 22 years. We used a one-factor experimental design with two thinning grades without replicates. Each plot area was 2500 m^2. Treatment 1 is the control plot ($N = 770$ stems·ha^{-1}) with no thinning. In treatment 2, the usual density in the Hungarian black locust management ($N = 550$ stems·ha^{-1}) was applied (EMI 1984). In treatment 3, it is supposed that the growing space is more favorably used by an individual tree at a lower density ($N = 400$ stems·ha^{-1}).

The following parameters were measured at the ages of 22, 27, 32 and 36: stem number, diameter at breast height, and tree height. The calculated parameters were the following: basal area, stem volume, volume of dead trees, stand volume (living stock), total production, mean annual increment, and stem-quality index (SQI). Stem volume was calculated using the volume function based on the volume table for black locust (Sopp - Kolozs 2000):

$$\mathrm{v} = \frac{d^2 \cdot h^{po+1}}{(h-1{,}3)^{po} \cdot 10^8} \cdot (p_1 \cdot d \cdot h + p_2 \cdot d + p_3 \cdot h + p_4)$$

where

d is the diameter at breast height (cm),

h is tree height (m),

$p_o = 4$, $p_l = -0.6326$,

$p_2 = 20.23$, $p_3 = 0.00$ and

$p_4 = 3034$.

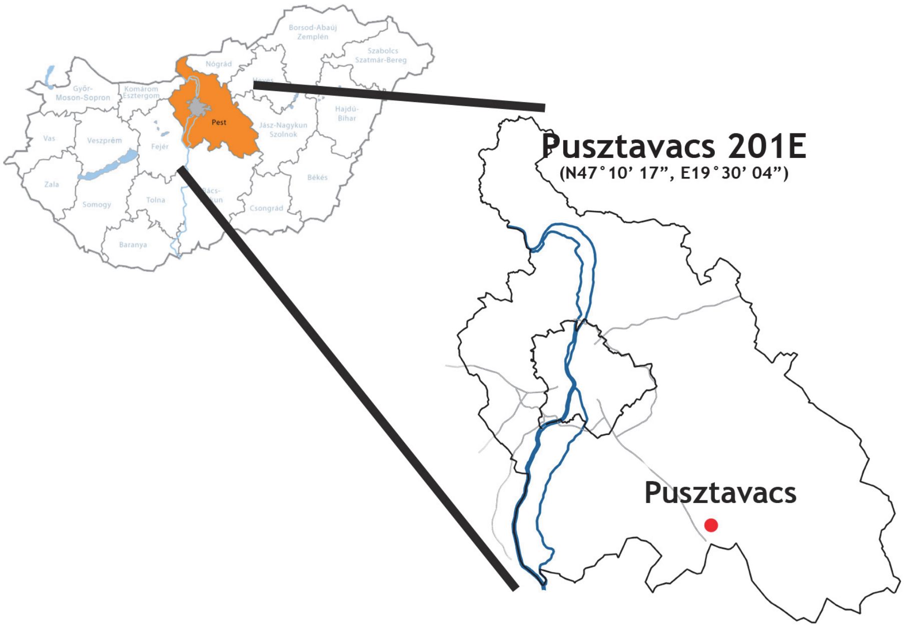


Figure 1. Location of the trial

Living stock (V) has been determined by means of a computer program developed by the Hungarian Forest Research Institute (HFRI) for calculating wood volume; the volume of the average tree (v_m) is computed according to the relation:

$$v_m = V \cdot N^{-1}$$

where N = number of stems per hectare.

The stem quality classes at the age of 36 are as follows (for calculating the stem-quality index):

- (x_1) Straight, cylindrical, healthy stems. Crooks are tolerated in one dimension only.
- (x_2) The stem is straight, forks are tolerated. Crooks are tolerated in one dimension only.
- (x_3) The stem is crooked and leaning. Minor crookedness in a second dimension is tolerated.
- (x_4) Very crooked in more than one dimension. Forked trees with stem defects.

The stem-quality index (SQI) was determined based on the following formula:

$$SQI = \frac{x_1 n_1 + x_2 n_2 + x_3 n_3 + x_4 n_4}{n_1 + n_2 + n_3 + n_4}$$

where

x_1, x_2, x_3, x_4 = tree quality classes,
n_1, n_2, n_3, n_4 = tree numbers belonging to the single tree quality classes.

3 RESULTS AND DISCUSSION

Table 1 contains the most important yield and stem-quality data. The table was compiled using data obtained from the stand surveys conducted between 22 and 36 years.

Table 1. Yield and stem-quality data at the age of 22–36 years (subcompartment Pusztavacs 201 E) Yield Class: III. (Based on Rédei, 1984)

Factors	Number of treatment		
	I. (control)	II.	III.
1. Initial wood stock before carrying the thinning (m^3ha^{-1})	182.1	244.3	219.4
– in percentage of the control (%)	**100.0**	**134.2**	**120.5**
2. Volume removed during the thinning (m^3ha^{-1})	0.0	64.0	77.6
3. Wood or living stock after thinning (m^3ha^{-1})	177.9	180.3	141.8
4. 14 years later:			
– living stock (m^3ha^{-1})	276.4	260.2	226.9
– in percentage of the control (%)	100.0	94.1	82.1
– mortality (m^3ha^{-1})	11.1	12.3	6.3
– wood stock (living stock + mortality) (m^3ha^{-1})	287.5	272.5	233.2
– in percentage of the control (%)	100.0	94.8	81.1
5. Change in living stock 14 years later (m^3ha^{-1})	98.5	79.9	85.1
– in percentage of the control (%)	100.0	81.1	86.4
6. Periodic total volume (m^3ha^{-1})	287.5	336.5	310.8
– in percentage of the control (%)	100.0	117.0	108.1
7. Mean ann. incr. of the periodic total vol. ($m^3 \cdot ha^{-1} \cdot yr^{-1}$)	7.5	6.6	6.5
– in percentage of the control (%)	100.0	88.0	86.7
8. Stem-quality index (SQI) at the age of 36 years	2.15	1.92	1.63
– in ratio of the control	1.00	0.89	0.76

The following conclusions may be drawn from the data in the *Table 1*:

- Based on the black locust thinning experiment presented above, *no increase of the periodic total production increment due to the thinnings could be observed*. The thinnings with different intensities did not increase the amount of total production in absolute terms as compared to the control plot. The percentage relations of the initial volumes to the control plot before thinning (row 1 in *Table 1*) are always higher than those after thinning (row 3 in *Table 1*).
- According to the experiment, thinnings had no effect on the periodic volume change. The periodic volume change ratio related to the control was dependent on the factors mentioned in the previous paragraph. More investigations are needed to give a more precise description of the changes.
- The periodic total production increment values also clearly indicate the thinnings do not have an increasing effect on the periodic increment of the total production. It is unlikely total production can be increased significantly (exceeding 5%) with thinnings in any regime; intensity and frequency in the case of black locust managed with relatively low average rotation ages. This does not exclude different results with different species and circumstances.
- In black locust stands, the *stand quality can be improved with thinnings* based on careful individual selection. In the present study, the related stand quality indicator exceeded the indicator of the control stand by 11–24%. Thus, the effect of the thinnings manifests primarily in improving stand quality and increasing stand value.

Two figures are presented to show the effects mentioned above. *Figure 2* presents the volume change 14 years after the thinning as a percentage of the control plot (100%), and *Figure 3* shows the increase in stand quality indicator as a percentage of the control plot value.

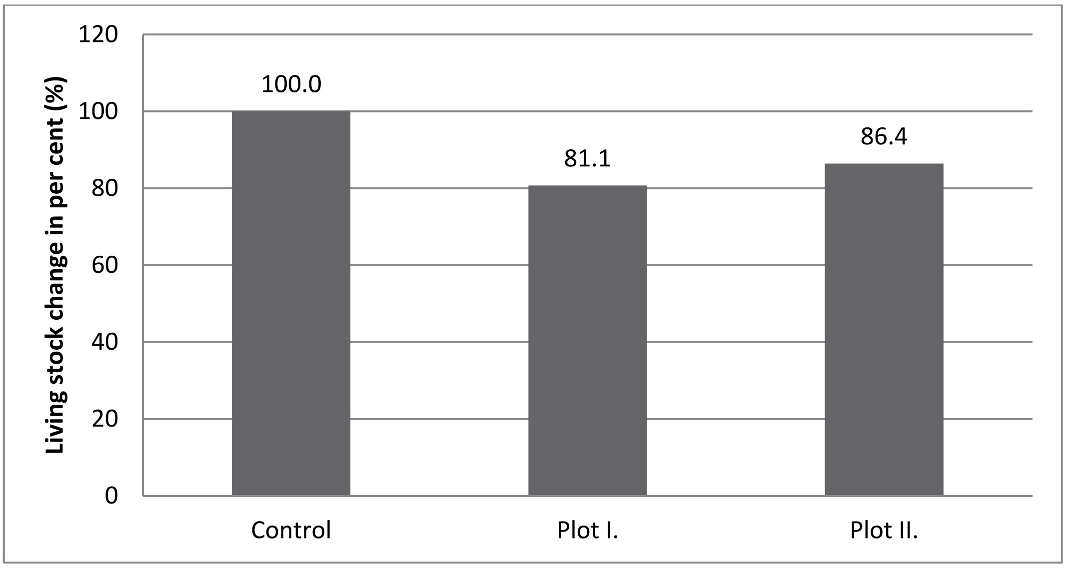


Figure 2. Living stock change 14 years after thinnings were completed in percent (subcompartment Pusztavacs 201 E)

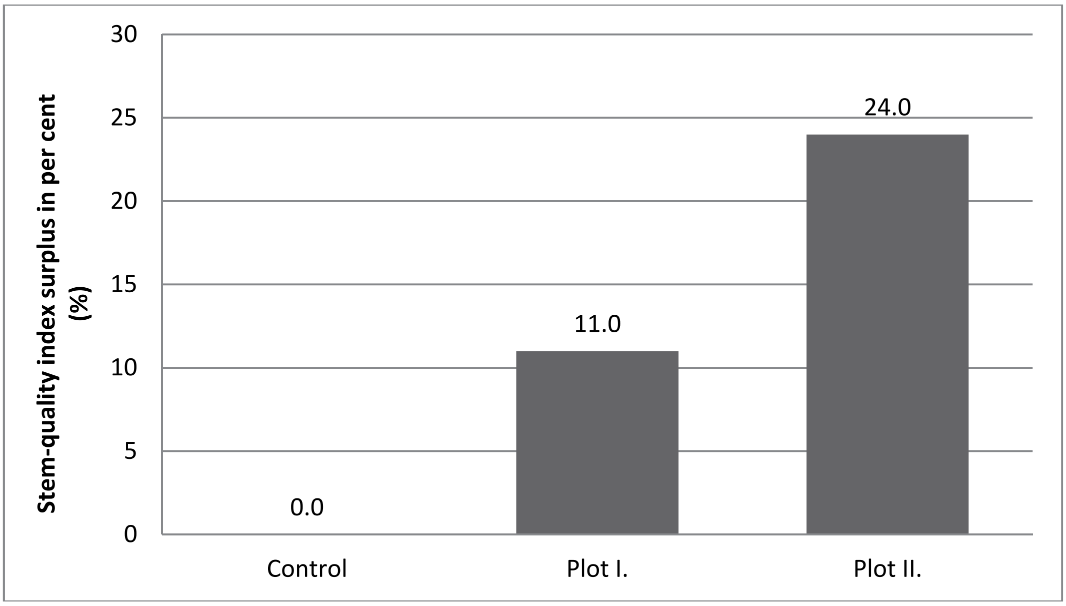


Figure 3. The percentage of stem-quality index change in comparison to the control (subcompartment Pusztavacs 201 E)

4 CONCLUSIONS

Thinning is a silvicultural operation where the main objective is to reduce tree density in a stand, improve the quality and growth of the remaining trees, and produce a marketable product. Thinning can also achieve other objectives such as changing stand species composition, improving the health of the remaining trees, or disturbing an established ground vegetation to enhance opportunities for natural regeneration.

The tree growth rate in a stand depends on the species cultivated, the environmental circumstances of the site on which a stand is established, and the applied silvicultural practices. Provided the site is fully occupied, with a reasonably intact canopy, where by trees can fully utilize the available resources, a stand will produce approximately the same amount of wood/yield at various stocking densities.

According to the investigations presented in this paper, stand volume growth varied slightly among the treatments. It was also verified that thinnings do not increase total production in black locust stands, but can improve stand value.

REFERENCES

ASSMANN, E. (1961): Waldertragskunde. BLV Verlagsgesellschaft, München-Bonn-Wien.

BÉKY, A. (1983): A nevelővágás hatása a faegyedek vastagsági növekedésére kocsánytalan tölgyesekben. (The effect of tending cuts on the diameter increment in *Quercus petraea* stands). Erdészeti Kutatások 75:173−177. (in Hungarian).

BÉKY, A. – SOLYMOS, R. (1991): Egy kocsánytalan tölgy erdőnevelési kísérleti sor tanulságai. (Conclusions from a thinning experiment in *Quercus petraea* stand). Erdészeti Kutatások 82: 227−235. (in Hungarian).

ERDŐMŰVELÉSI MŰSZAKI IRÁNYELVEK 1984. (Tending Cut Guidelines). Agroinform Kiadó. (in Hungarian).

HALUPA, L. (1987): A nyárnevelési kísérletek újabb eredményei. Erdészeti Kutatások 79: 79−84. (Further results obtained from poplar tending cut experiments. (in Hungarian).

KUIPER, C. – SCHOENMAKERS, L. (1990): Evaluation of a ten years thinning experiment in Douglas fir. Forest components. Wageningen Agricultural University papers 6: 48−56.

MAJER, A. (1969): A gyérítések racionalizálása. Rationalisation of thinnings. Az Erdő, XVIII. 9: 385−389. (in Hungarian).

PARDÉ, J. (1965): Intensité des éclaircies et production ligneuse. Revue Forestiéra Francaise 936−945.

PERSSON, O. (1986): Thinning in Norway spruce in Sweden. Swedish University of Agricultural Sciences. Report 18: 3−24.

PRETZSCH, H. (2009): Forest Dynamics, Growth and Yield. Springer, Berlin.

RÉDEI, K. (1984): Akácosok fatermése. (Yield of black locust stands). FRI Report. (in Hungarian).

RÉDEI, K. – MEILBY, H. (2009): Effect of Thinning on the Diameter Increment in Black Locust (*Robinia pseudoacacia* L.) Stands. Acta Silvatica et Lignaria Hungarica 5: 63−74.

SOPP, L. – KOLOZS, L. (2000): Fatömegszámítási táblázatok. (Volume tables). Mezőgazda Kiadó, Budapest. (in Hungarian).

WIEDEMANN, E. (1943): Der Vergleich der Massenleistung des Mischbestandes mit der Reinbestand. Allgemeine Forst- und Jagd- Zeitung 119: 123−132.

Guide for Authors

Acta Silvatica et Lignaria Hungarica publishes original reports and reviews in the field of forest, wood and environmental sciences. ASLH is published twice a year (Nr. 1 and 2) in serial volumes. It is online accessible under: http://aslh.nyme.hu

Submission of an article implies that the work has not been published previously (except in the form of an abstract or as part of a published lecture or academic thesis), that it is not under consideration for publication elsewhere. Articles should be written in English. All papers will be reviewed by two independent experts.

Authors of papers accepted for publication should sign the Publishing Agreement that can be downloaded from the homepage (http://aslh.nyme.hu).

All instructions for preparation of manuscripts can be downloaded from the homepage.