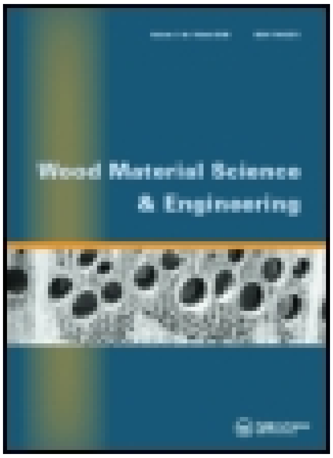

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ORIGINAL ARTICLE

Influence of biotic factors on the mechanical properties of wood, taking into account the time of harvesting

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Abstract
The aim of the present paper is to investigate the influence of biotic factors (fungi and insects) on the mechanical properties of wood through the effect of blue-stain, taking into account the time of harvesting and the time of stay of wood in the forest. Specifically, the resistance to axial compression and to bending (modulus of rupture (MOR)) was studied using infected specimens of Scots Pine (*Pinus sylvestris*) and Norway Spruce (*Picea abies*) (the usual types of wood used in woodwork). The specimens were obtained from logs of Scots Pine and Norway Spruce that were harvested in three different seasons of year, namely in July 2012, November 2012 and June 2013, respectively, in the forest of Elatia-Greece, and the attack pace by biotic factors with respect to the time of logging was studied. The placement of the experimental surfaces of each type of tree was made on skid road and in the stand. Totally, 120 laboratory measurements in axial compression and 120 measurements in bending (MOR) took place. The results proved that blue-stain hardly affect the mechanical properties of both wooden species and particularly the specimens that were derived during the winter logging.

Keywords: *Blue-stain, mechanical properties, axial compression, bending, modulus of rupture.*

Introduction

In Greece, the traditional logging, takes place in spring or in early summer, depending on weather conditions of the year, as, for example, logging can only occur after the snow melts and not in winter. As a result, logged wood remains in the forest ecosystem (along the forest roads) for quite a long time (usually for over four months up to a year and sometimes more) until taken to be sold and thus it is commonly infected by biotic factors such as insects and fungi that can cause blue-stain (Mantanis 2003). The direct consequence of this fact is that the wood is infected even before it is sold while it is difficult to find completely healthy wood. It is therefore easy to understand the economic consequences of the wood losing much of its value in a short time after logging, even though it took the trees several decades to reach a marketable size (Tsumis and Voulgaridis 1978).

Associations between fungi and bark beetles of coniferous trees are numerous, and mainly involve the beetle genera *Ips* and *Dendroctonus* and the fungal genera *Ceratocystis* and *Ophiostoma* (Webber and Gibbs 1989). Many of these fungal species are collectively known as blue-stain fungi (Whitney 1982). Some of these fungi are pathogenic and associated with aggressive bark beetles, thus causing severe damage to living trees (Bramble and Hoist 1940, Mathre 1964, Molnar 1965, Homtvedt *et al.* 1983, Redfern *et al.* 1987).

Blue-stain is the most common agent of wood discolouration and appears mainly in the sapwood of conifers, especially of *Pinus nigra* (Mantanis 2003). The colour of the sapwood changes between blue to grey or bluish black either in its totality or in spots. The fungi that cause blue-stain are mostly ascomycetes and deuteromycetes (Schmidt and Czeschlik 2006). Therefore, it is believed that bark-boring insects are actively involved in the propagation of blue-stain by transferring the spores, even though they do not affect the mechanical properties of the wood, as they feed in the layer between bark and

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wood. On the contrary, wood-boring insects affect heavily the mechanical properties of wood, as they bore long tunnels in the sapwood and heartwood. Some of the main species that attack Forest Pine and Norway Spruce in Greece are *Criocephalus rusticus* (L.), *Ergates faber* (L.), *Monochamus galloprovincialis* (Ol.), *Rhagium bifasciatum* (F.), *Urocerus gigas* (L.), *Xyloterus lineatus* (Oliv.) (Avtzis and Avtzis 2003, Avtzis *et al*. 2013).

Blue-stain occurs mainly in wood of coniferous trees, usually pine (as well as in fir, spruce, fir, etc.), and rarely in wood of hardwoods (beech, poplar, oak, ash, tropical species, etc.). The blue-stain significantly reduces the commercial value of wood, because the appearance of wood products (sawn timber, etc.) is not attractive. Moreover, the discolouration causes mistrust in consumers as far as the quality and (mechanical) strength of wood is concerned (Tsoumis and Voulgaridis 1978, Abdullah and Ahmet 2006). The most common colour fungi belong to the species Alternaria, Cadophora, Diplodia, Discula, Graphium, Hormodendron and Hormonemia. These fungi use starch and simple sugars for their nourishment that can be found in the sap wood. They cannot develop exclusively in heartwood because it does not contain necessary substances for their nutrition (Knabe 2002). There is no cyan discharge from fungi that attack wood, and the cell walls still have their natural pale yellow colour. The cyan staining of wood is an optical phenomenon. The unripe fungal textures are colourless, but the matured are of darker colour, but when we notice them through the translucent cell walls, they appear to be cyan (Karanikola 2008). The cyan staining can affect upright, live or dead trees and it is transferred with the help of various bark-boring insects (Kailidis 1990).

Norway Spruce wood (*Picea abies*) and Scots Pine wood (*Pinus sylvestris*) were and still are the most important wood species for construction applications in Greece and most of Central Europe. Particularly sapwood of those two species is extremely susceptible to colonization by wood-inhabiting fungi (Higley 1999).

In the current investigation, this problem is approached from three different directions: (a) attack of round wood in the stand, (b) rate of attack of round wood in relation to season of logging and (c) influence of blue-stain on the mechanical properties of wood.

Methodology

The conduction of this research included the use of wooden specimens coming from the trees of Scots Pine (*P. sylvestris*) and Norway Spruce (*P. abies*) that were harvested in the forest “Elatia” of the Prefecture of Drama-Greece (in the location “Outpost 109” of the forestry section 140D) in two positions with the same orientation at an altitude of about 1500–1580 m.

The specimens used for the measurement of strength to axial compression and bending came from 12 healthy trees that were harvested in three different seasons of the year and they remained in the forest so that the infestation of blue-stain could be estimated. Two trees of Scots Pine and two trees of Norway Spruce were harvested in each cutting and totally eight logs had formed for each species of a length of 1.00 m. The approximate age of the trees was 80 years and the stem diameter ranges from 26 to 36 cm (Table I). The logs had relatively small differences of mean diameter and cortical thickness and they remained in the forest (the total of the three loggings were 24 logs of each species). In all cases, the lower part of the trunk of the tree of length about 1.00–1.50 m was not used in order to ensure more uniform material (this part has a larger diameter and greater cortical thickness). Twelve trees were harvested and formed 16 logs per cutting resulting in the formation of a total of 48 logs. The time of stay of logs in the forest was four months for the first logging, seven months for the second and four months for the third.

Remarks about the progress of blue-stain (Figure 1) were made each month from the date of each logging which is four months for first logging, seven months for the second, and four months for the third logging (data for 15 months were collected).

Forty specimens for each species of tree and for each cutting were used for the laboratory measurements of the strength to axial compression and bending. The moisture content of the specimens was 7–8%. The total number of specimens was 80 per each species of wood and per cutting. Table II lists the mechanical properties of wooden specimens

Table I. Stem diameter of trees.

Tree	Logging	Stem diameter (cm)
Scots Pine	1st	26
Scots Pine	1st	30
Scots Pine	2nd	36
Scots Pine	2nd	34
Scots Pine	3rd	30
Scots Pine	3rd	36
Norway Spruce	1st	32
Norway Spruce	1st	36
Norway Spruce	2nd	26
Norway Spruce	2nd	28
Norway Spruce	3rd	28
Norway Spruce	3rd	32

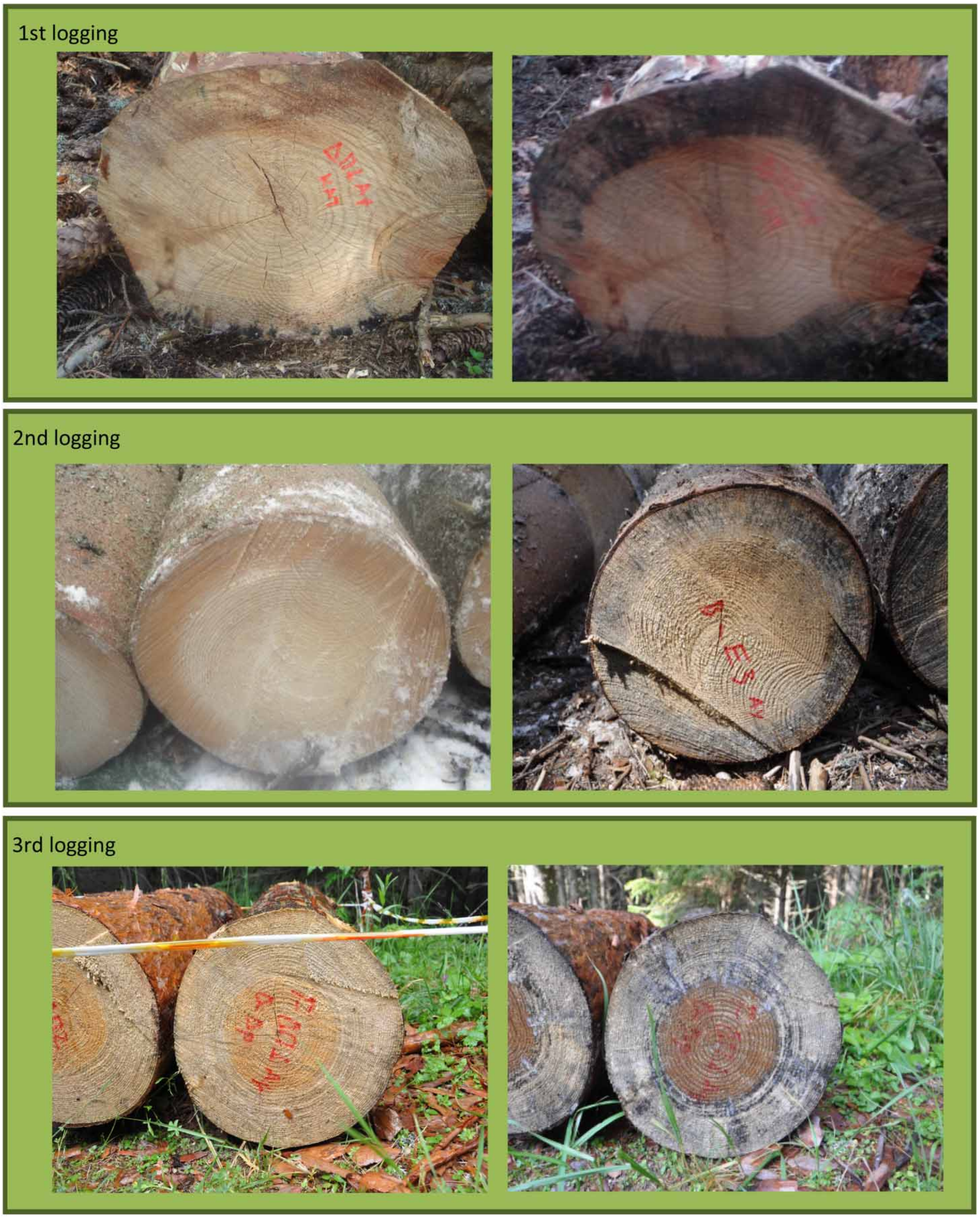

Figure 1. Spread of blue-stain for each logging.

that were measured as well as the dimensions of the specimens according to DIN EN 52185 (1976), DIN EN 52186 (1978), while the laboratory set-up of the measurements is depicted in Figures 2 and 3.

Results

The results of the laboratory measurements are included in Figures 4 and 5. The results of the mean values of measurements of the resistance to axial compression and bending for the specimens of Scots Pine and Norway Spruce and for each logging are presented in Table III.

It was observed that the spread of blue-stain was larger at 90 days after logging and especially in Scots Pine, as far as the first cutting is concerned. The spread of blue-stain during the same period for the Norway Spruce was significantly lower but later

Table II. Mechanical properties, number and dimension of specimens according to standards DIN EN 52185 (1976), DIN EN 52186 (1978).

Mechanical properties	Number of specimens	Dimensions of specimens (mm)	Standards
Axial compression strength (N/mm^2)	40	40 × 20 × 20	DIN EN 52185
Bending strength (N/mm^2)	40	300 × 20 × 20	DIN EN 52186

Figure 2. Laboratory set-up for the measurement of the resistance in axial compression.

Figure 3. Laboratory set-up for the measurement of the resistance in bending.

it does not seem to affect the compressive and bending strength. The mean compressive strengths for Scots Pine and Norway Spruce are 53.35 and 53.31 N/mm^2 while the mean bending strength are 89.77 and 83.80 N/mm^2, respectively. It is also clear that the bending strength is not decreased because of the inflection of the specimens to blue-stain.

The second logging of the trees took place in November that is considered to be the best logging period in terms of blue-stain attack to logs in the forest, because the inflection is the smallest. It was not observed any spread of cyanosis during the period between November and April for both species. On the contrary, it was found the spread of blue-stain mainly in logs of Scots Pine and less in these of Norway Spruce during May and July. We can notice (Table III) that the mechanical properties of resistance to axial compression and bending are affected very little due to blue-stain. The mean values of compressive strength for Scots Pine and Norway Spruce are 55.65 and 56.28 N/mm^2, respectively, while the corresponding values for bending strength are 91.87 and 86.56 N/mm^2. Comparison of the values of the mechanical properties of defected woods with not defected as the reference (Tsoumis 1991) is not feasible, because the mechanical properties depend on, among other, the moisture content (Tjeerdsma 2006), the dimensions of the trunk and the conditions of the microenvironment (Brüchert *et al.* 2000) and the annual rings width (Aleinikovas and Grigaliunas 2006).

The remaining 80 specimens emanated from the logs of the third harvesting were more affected by blue-stain because the last logging was realized in the worst terms of favourable attack conditions of blue-stain (June of next year). The greater spread of blue-stain had mainly arisen in August (two months after the logging) and continued until October. The spread was more pronounced in the logs of Scots Pine and less in Norway Spruce. However, it appears that the mechanical strengths were not affected very significantly. But in comparison with the laboratory measurements of specimens from the

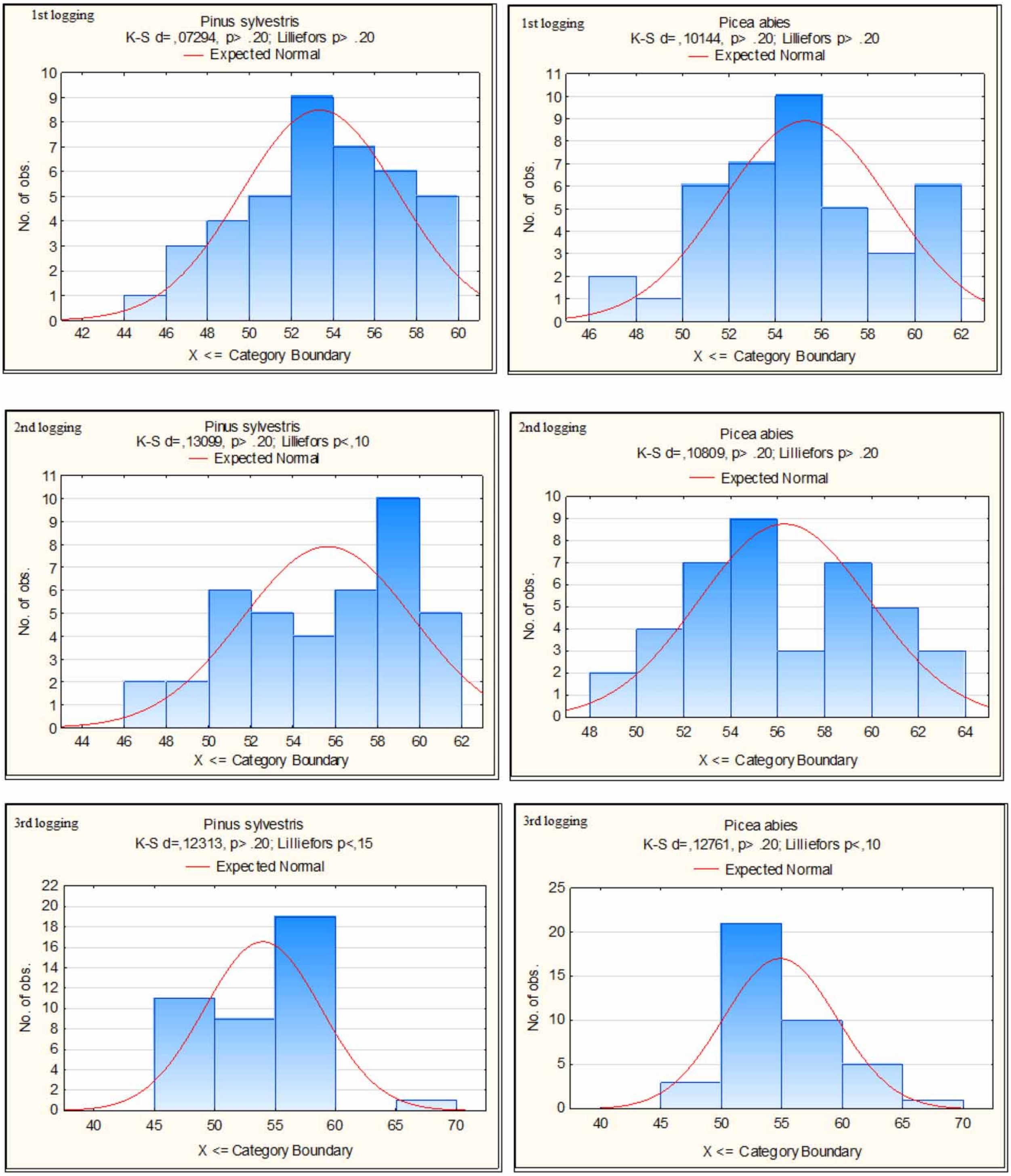

Figure 4. Maximum axial compression strength (*N/mm*^{2}) for the specimens of Scots Pine (*P. sylvestris*) and Norway Spruce (*P. abies*) for each logging.

first logging, the mechanical strengths were more affected. Nevertheless, it is generally considered, that the influence of blue-stain to the mechanical strengths for both Scots Pine and Norway Spruce was not very remarkable. Specifically, the mean values of resistance to axial compression for Scots Pine and Norway Spruce are 53.99 and 54.86 N/mm^2, respectively, while the corresponding values for bending strength are 83.17 and 81.28 N/mm^2.

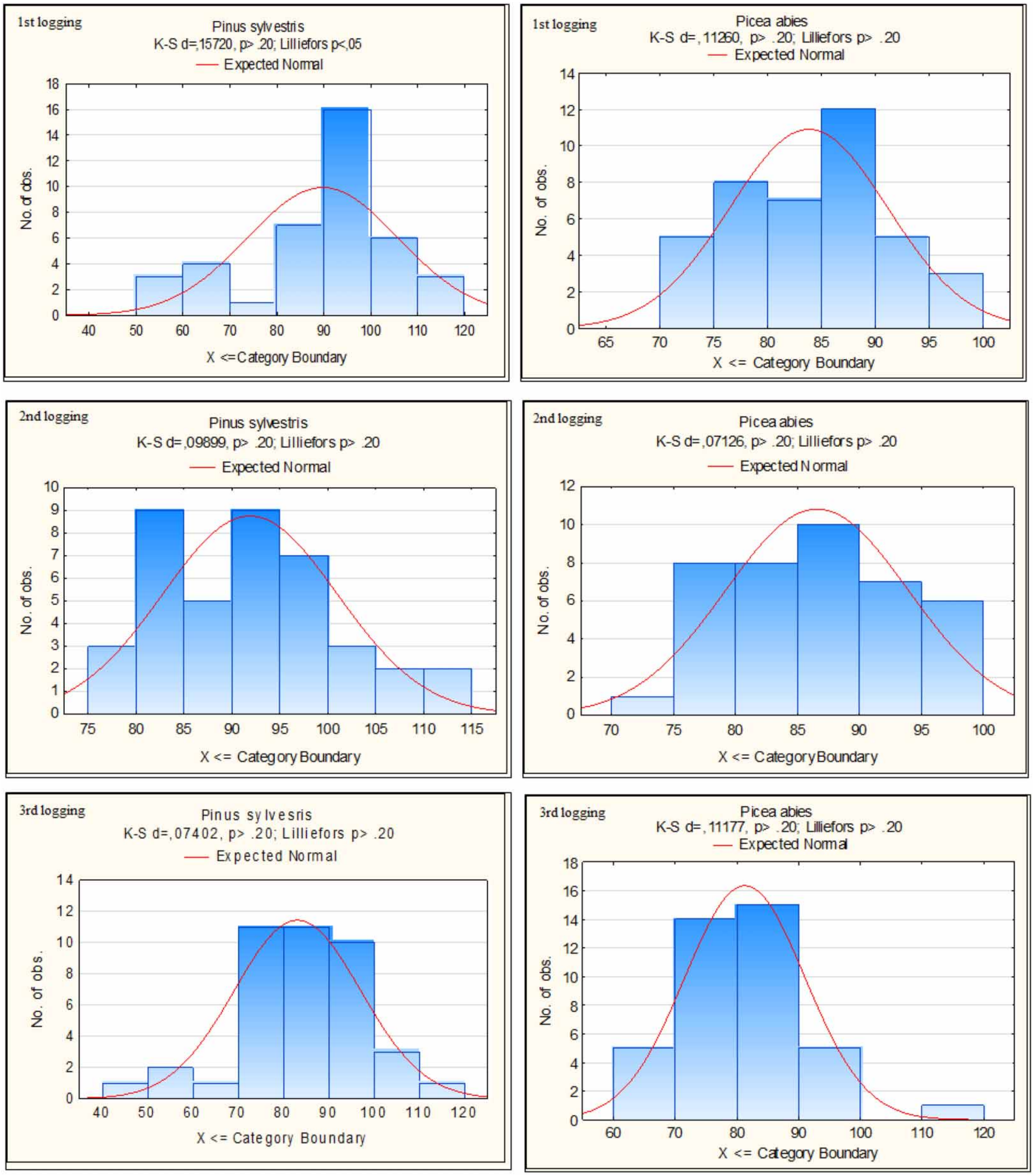

Figure 5. Maximum bending strength *(N/mm²)* for the specimens of Scots Pine (*P. sylvestris*) and Norway Spruce (*P. abies*) for each logging.

The mean laboratory value (MLV) of strengths cannot be used in practice, due to the variability of wood as a material, to the effect of duration of loading, to the possibility of accidental overloading and to the experience from practice (Voulgarides 1988). Therefore, it is necessary to reduce the MLV of strengths. It is achieved through the calculation of typical strength (TS) by applying the following equation (Voulgarides 1988):

$$\text{Typical Strength (TS)} = \frac{\text{MLV} - 2.33 \times \text{standard deviation}}{2.5} (\text{N/mm}^2).$$

Table III. MLVs of mechanical properties of 40 specimens/tree/logging (total specimens 480).

	Axial compression strength (N/mm^2)		Bending strength (N/mm^2)	
	Scots Pine	Norway Spruce	Scots Pine	Norway Spruce
1st logging	53.35	55.31	89.77	83.8
	(3.80)	(3.60)	(16.05)	(7.30)
2nd logging	55.65	56.28	91.87	86.56
	(6.20)	(3.64)	(9.10)	(7.40)
3rd logging	53.99	54.86	83.17	81.28
	(4.80)	(4.70)	(13.90)	(9.70)

Standard deviation in parentheses.

Table IV. TS per forest species and logging.

	Typical axial compression strength (N/mm^2)		Typical bending strength (N/mm^2)	
	Scots Pine	Norway Spruce	Scots Pine	Norway Spruce
1η logging	17.83	18.78	20.94	26.70
2η logging	18.49	19.12	28.26	27.75
3η logging	17.10	17.58	20.26	23.42

The calculation of the value of TS according to the above equation gives values that are approximately equal to 1/3 of the MLVs (Table IV).Taking into account the TSs, the classification of woods of Scots Pine and Norway Spruce for each logging is presented in Table VI, according to the Hellenic Body for Standardisation (ELOT) and Eurocode 5 (prEN 338) (Table V).We can observe that the Scots Pine is classified as class C16, C18 and C16 for the first, second and third logging, respectively. The corresponding classification for the Spurce is C18, C20 and C16, respectively. The more adverse value of strengths is used for the classification and in the present case it happens for the axial compression strength. These results are in full correspondence with the pace of attack of blue-stain for the species, namely when the cyanosis appears to be the minimum then the values of mechanical properties are increasing. Blue-stain is minimum when the logging takes place in winter (second logging) (Dimou 2012).

Figures 6 and 7 depict in a graph the typical axial compression strength and the typical bending strength of the examined specimens of woods for each logging, respectively. It is obvious that both species of Scots Pine and Norway Spruce derived from the second logging appear to have the largest values of axial compression strength and bending strength, when the pace of attack of cyanosis is minimum.

Conclusions

This research work involves the study of influence of biotic factors (fungi and insects) on the mechanical properties of wood. It is achieved through the measurement of the strength in axial compression and bending (modulus of rupture (MOR)) of Scots Pine and Norway Spruce specimens taken from logs which resulted from three different periods of logging.

The thorough study of wooden specimens proved that their mechanical properties (e.g. strength to

Table V. Mechanical properties of bending and compression parallel to grain of solid timber grades (prEN 338).

ELOT EN 338 and EC5 Poplar and softwood species											
Classification		C14	C16	C18	C20	C22	C24	C27	C30	C35	C40
Strength properties (N/mm^2)											
Bending	$f_{m,k}$	14	16	18	20	22	24	27	30	35	40
Compression parallel to grain (axial compression)	$f_{c,0,k}$	16	17	18	19	20	21	22	23	25	26

Table VI. Classification per forest species and logging applying the mores adverse TS calculation and according to ELOT EN338 and EC5.

ELOT EN 338 and EC5 Poplar and softwood species									
Classification	C14	C16	C18	C20	C22	C24	C27	C30	C35
Scots Pine		1st + 3rd logging	2nd logging						
Norway Spruce		3rd logging	1st logging	2nd logging					

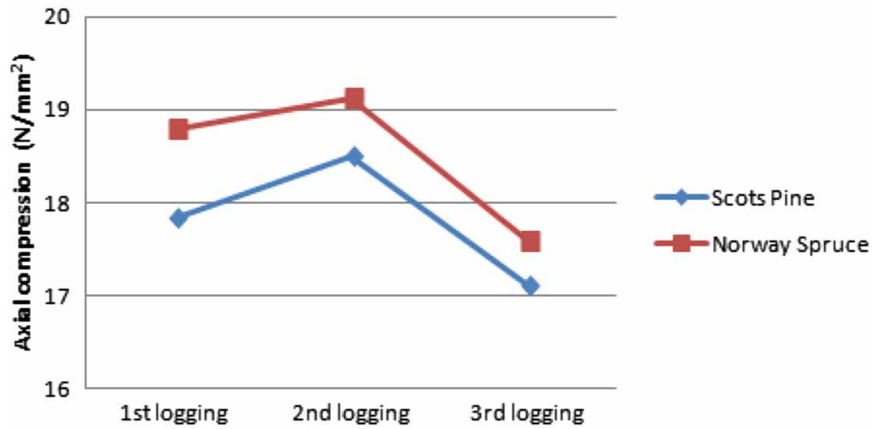

Figure 6. Mean typical values of axial compression strength of Scots Pine and Norway Spruce for each logging.

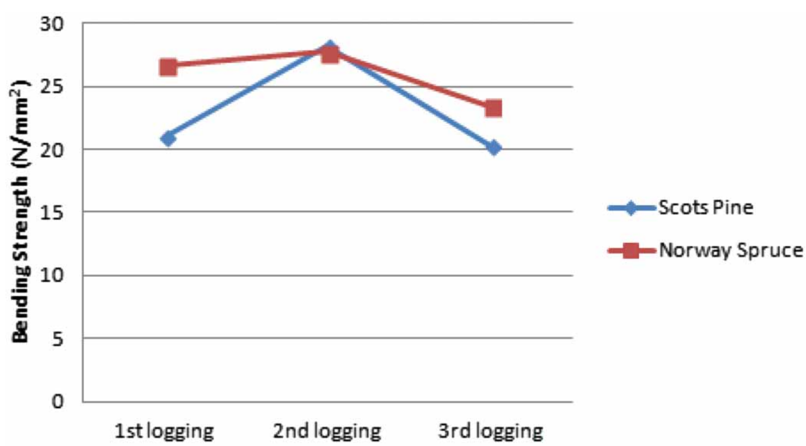

Figure 7. Mean typical values of bending strength of Scots Pine and Norway Spruce for each logging.

axial compression and bending) are not affected by wood-boring insects, since they do not attack them. On the contrary, even though bark-boring insects and fungi that cause the effect of blue-stain are commonly found to attack logged wood, their occurrence seems not to affect significantly the mechanical properties of wood. Specifically, the rate of attack of blue-stain to Scots Pine and Norway Spruce was much smaller to the specimens resulted from logging in November; consequently, higher values of strength in axial compression and bending in comparison with the specimens that came from other periods of logging (June and July). Other researchers (Tsoumis 1991) state that the consequences of blue-stain are not clear, but its influence is small in practice, excluding the resistance to impact while, Lum *et al.* (2006) proved that the values of bending MOR of woods that are affected by blue-stain are similar to those for that are unaffected. Moreover, Humar *et al.* (2008) mentioned that the results of the experiments to specimens of blue-stained wood of Scots Pine and Norway Spruce showed that this change is only aesthetic and does not influence either weight or mechanical properties. The classification of wooden species according to the requirements of Eurocode 5 (prEN 338) is within the limits of strength classes. The samples from the winter logging occupy higher classification for both wooden species in comparison with the other loggings.

Finally, we can conclude that changing the logging period from spring and summer – that is applicable in Greece – to autumn and winter, is generally acceptable, because it clearly reduces the rate of attack of blue-stain with result of the wood not losing its value in a short time after logging. However, it seems that the logging period does not influence in a remarkable way the strength in axial compression and bending of wood.

Disclosure statement

No potential conflict of interest was reported by the authors.

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