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Selected properties of kauri wood (*Agathis australis* (D. Don) Salisb.)

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Abstract: *Selected properties of kauri wood (Agathis australis (D.Don) Salisb.).* The article presents results of the study of kauri wood which it was underground for 45,000 years and excavated in the form of logs from peat bogs located in the northern parts of New Zealand. Kauri wood is a raw material highly valued by the manufacturers of stringed musical instruments, not only because of its acoustic properties, but also because of the unique pattern of wood. The following wood properties were determined: widths of annual rings, the share of late wood, lengths of early and late wood tracheids, dimensions of wood rays and the density of their occurrence on the tangent section, as well as wood density and sound propagation velocity. The studied wood was characterised by narrow annual rings and a very low share of late wood zones (less than 15%). The weighted mean lengths of the tracheids in individual annual rings fell within a narrow range from 3600 μm to 3900 μm. All wood rays were uniseriate, and there were 20 rays per 1 mm^2 of the tangent section. The wood density was 460 kg/m^3, the mean velocity of sound propagation in longitudinal direction was 3700 m/s.

Keywords: kauri wood, macrostructure, tracheids, wood rays, velocity of sound propagation

INTRODUCTION

Kauri wood (*Agathis australis* (D.Don) Salisb.) is one of tropical species used in construction of stringed musical instruments. Wood intended for such use (resonance wood) should be characterised by defined parameters (Spycher et al. 2008). First of all, it should be taken from the zone of mature wood and be characterised by low heterogeneity of the structure and properties. Its annual rings should have similar widths and a slight share of late wood zones, as well as a low gradient of density within individual annual rings. At the same time, the wood should have high modulus of elasticity (Bucur 2006). In the case of wood intended for fiddles and guitars, the width of annual rings should be 0.5-2 mm because such material best resonates high pitches. In the case of cellos and contrabasses, that parameter should be between 2 mm and 4 mm because wood with wide annual rings best resonates low pitches (Buksnowitzet al. 2007). The share of late wood in annual rings should not exceed 33%, and the difference between the widths of rings on two adjacent centimetres along the radius cannot exceed 30% (PN – 63/D-95071).

Therefore, good resonance wood should be characterised by highmodulus of elasticity and simultaneously low density. These features cannot exist at the same time because the value of modulus of elasticity is positively correlated with wood density (KollmannandCôté 1984). Hence, wood density cannot be the only good criterion of its assessment in terms of its suitability for the production of stringed musical instruments.

Considering the above-mentioned requirements toward wood used in construction of stringed musical instruments, the authors decided to determine chosen properties of kauri wood (*Agathis australis* (D. Don) Salisb.), which was underground for approximately 45,000 years (Boswijk 2006). Kauri is a wood species highly valuedby the manufacturers of stringed musical instruments, not only because of its acoustic properties, but also because of the unique pattern of wood. The age of the studied wood was determined by the C14 method (Certificate of Authenticity 1999&2004).

MATERIAL AND METHODS

The study was carried out on wood kauri (*Agathis australis* (D. Don) Salisb.), originating from logs excavated from the peat bogs located in the northern parts of New

Zealand. The wood for study was in the form of a plank of the dimensions of 550 mm x 220 mm x 25 mm (L x T x R). The plank was delivered by the company Turkowiak Guitars, which bought the wood from a US-based company trading in wood.

Within the scope of this study, the authors decided to determine macrostructural parameters, such as annual ring width and the share of late wood. Microstructural tests resulted in determination of tracheid lengths within individual annual rings and dimensions of the rays wood. Additionally, the authors determined density of the wood and the velocity of ultrasound wave propagation.

To this end, a strip of wood, 20 mm long in the longitudinal direction, was cut off of the plank. The strip was used to determine macro- and microstructural parameters. The rest of the wood was used to determine density and sound propagation velocity.

The width of the early and late wood zones was determined using a stereoscopic microscope equipped with a camera and connected to a computer. Measuring was doneusing Motic Mot 2.0. program. The accuracy of linear measuring was 0.01 mm. Tracheid lengths were measured on material macerated using a mixture of acetic acid and oxygenated water at the temperature of 60^{o}C for 24 hours.The dimensions of wood rays(their height and the number of cells constituting them) were determined using solid preparations of tangent sections. Microstructural measuring was carried out using a light microscope and an image analyser, as well as the above-mentioned program, which, apart from determination of linear dimensions, also allows measuring of surface area. Having determined the surface area and the number of wood rays on a given area, the authors could calculate the density of the rays occurrence.

Wood density was determined by the stereometrics method in air-dry conditions, and ultrasound propagation velocity using a material sampler, type 543E, equipped with a transmitting-receiving head of the frequency of 0.1 MHz.The time needed by the sound wave to penetrate across the sample was determined and the wave's velocity was calculated according to the following formula: C = l/t (m/s), where:l – trajectory of ultrasound wave within the studied sample(m), t – time needed by the ultrasound wave to penetrate across the studied sample(s).

RESULTS

Results of macrostructural measurements are presented in Table 1.The average width of annual rings was 2.07 mm, and the share of late wood ranged from 8% to 14%. Such a low share of late wood is an important parameter of wood used in construction of stringed musical instruments.

Table 1. Descriptive statistics of macrostructural parameters of kauri wood

Property of wood	Mean	Minimum	Maximum	Standard deviation	Coefficient of variation
	mm				%
Rings width	2.07	0.81	3.18	0,89	43
Width of late wood	0.20	0.10	0.31	0.08	40
Percentage of late wood (%)	10.03	7.75	13.95	1.90	19

The length of tracheids was determined for three chosen annual rings of the studied wood. Descriptive statistics of the length of tracheids in early wood and late wood are given in Table 2.

Table 2. Descriptive statistics of tracheid lengths in chosen annual rings of kauri wood

Number of ring	Zone	Mean	Minimum	Maximum	Standard deviation	Coefficient of variation
		μm				%
2	early	3510	1695	6011	1279	36
	late	5029	3591	7720	1121	22
4	early	3887	2689	5892	821	21
	late	4632	3052	6941	933	20
6	early	3795	2541	5492	767	20
	late	4777	3465	6589	904	10

Number of the annual ring given in the table does not mean the cambial age of the ring but it is a consecutive number of the ring in the studied sample.

In each studied annual ring the tracheids in early wood were approximately20% shorter compared to the tracheids in late wood. Histograms of the distribution of tracheid lengths in the studied annual rings are similar to normal distribution, which is illustrated in Fig. 1.

Wood used in construction of musical instruments should be characterised by homogenous structure. This feature of wood is described by, inter alia, weighted mean length of tracheids. This property was calculated based on the tracheid lengths measured in the early and late wood zones and the share of those zones in the annual rings. Calculations were carried out according to the following formula otherwise known as the rule of mixtures (Gibson and Ashby 1997):

weighted mean length of tracheids = early tracheid length x early wood share + late tracheid length x late wood share.

The calculated values of the weighted means were very similar and equalled 3672 μm (2^{nd} annual ring), 3930 μm (4^{th} annual ring), and 3888 μm (6^{th} annual ring). Such results prove high homogeneity of the cell lengths in the annual rings of the studied kauri wood.

The analysis of the wood rays dimensions suggests that in kauri wood one can find only narrow, and more precisely uniseriate rays but of various heights. This parameter varied from 1 (56.8 μm) to 20 cells (612 μm) in height. Frequency of the occurrence of wood rays with a defined number of cells is illustrated in Fig. 2. On the surface of the tangent section (67 mm^2) one could observe that the most rays (190 rays) was of the height of 4 cells (131 μm), and the least (10 rays) was highest rays composed of more than 14 cells (386 μm).

Histogram of the distribution of the heights of wood rays is illustrated in Fig. 3. Presented data indicate that the range of heights was large, for the height classes ranged from 50 um to 650 um. Nevertheless, the number of rays was similar in individual classes of height. In the six defined height classes the number of rays was the same (11%), and together those rays amounted to as much as 66% of all the rays. The four consecutive height classes encompassed another 20% of rays (5% of rays in each class). Such distribution of the analysed parameter suggests a very even distribution of the rays on the tangent section, despite their various heights. Altogether, measurements of 1310 were taken in the course of this study. The density of rays occurrence was calculated dividing the number of rays by area unit of the tangent section, and thus obtaining the result of 20 rays/1 $mm^2$of the section.

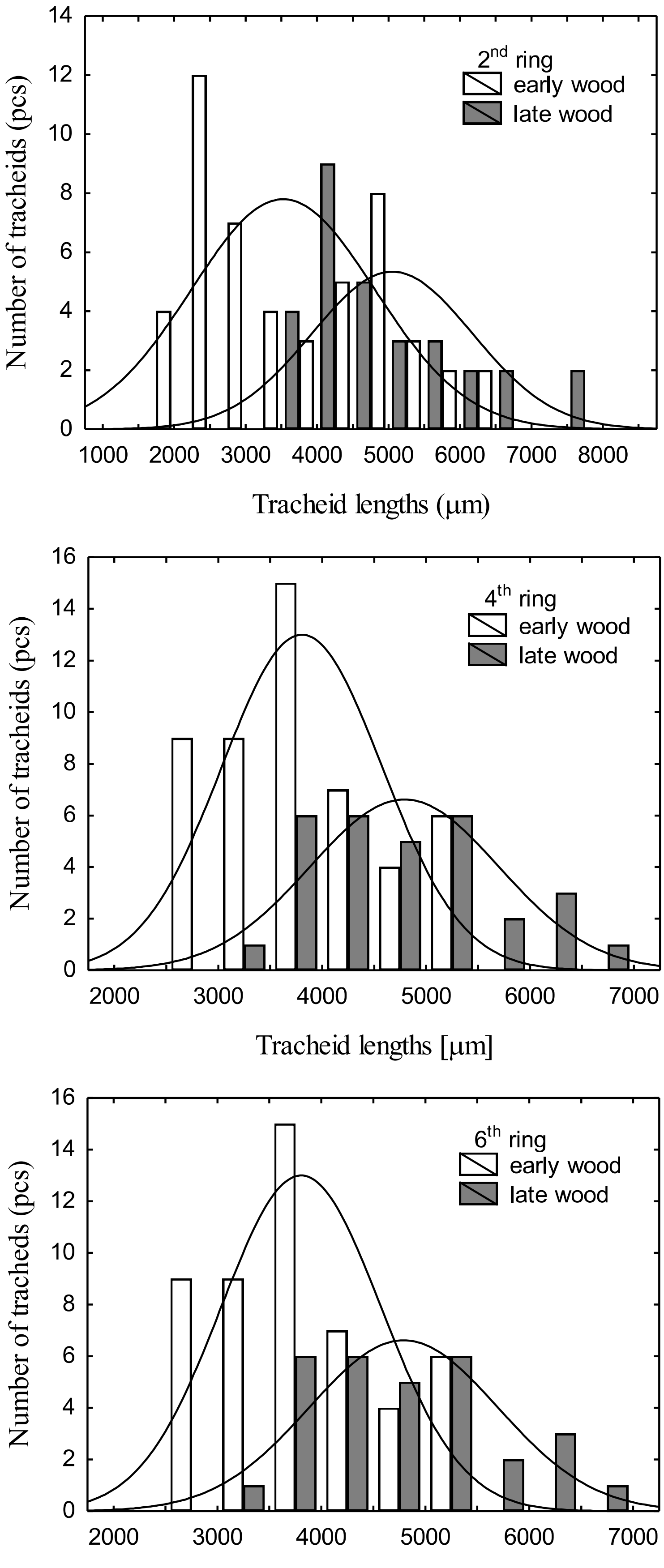

Figure 1. Histogram of the distribution of the tracheidlengths in kauri wood

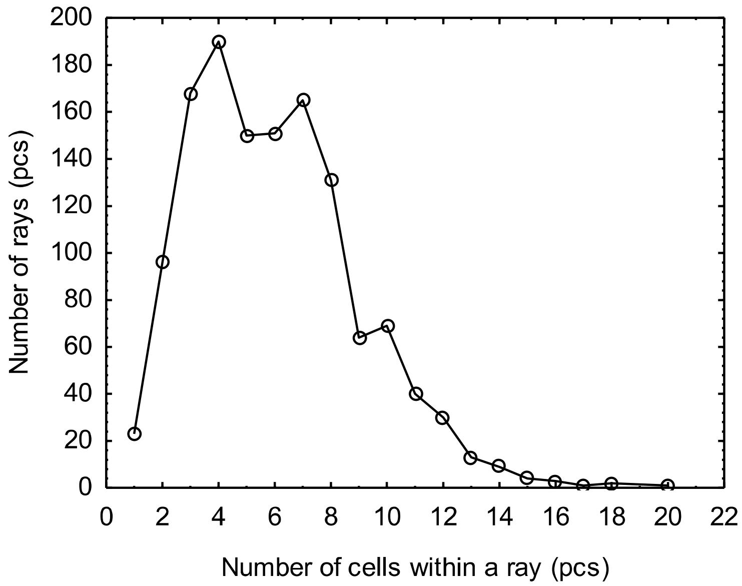

Figure 2. Frequency of the occurrence of wood rays of different heights expressed by the number of cells

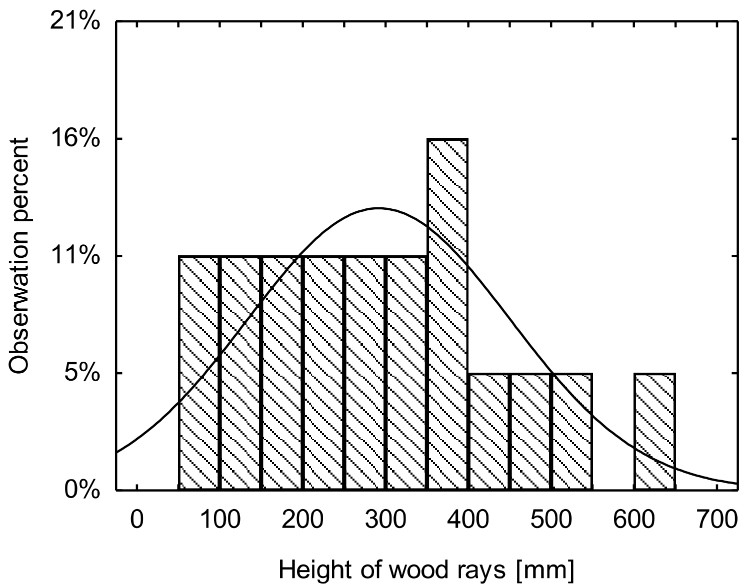

Figure 3. Histogram of the distribution of the rays height in kauri wood

The mean velocity of sound propagation in longitudinal direction was 3700 m/s (Table 3). The determined values of the studied velocity are much lower compared to the species of our climatic zone. For pinewood the sound propagation velocity in longitudinal direction is approximately 5500 m/s (while mean tracheid length is 3500 μm and density 520 kg/m^3) (Moliński et al. 2007), and for high-class fiddle spruce wood it exceeds 6000 m/s (while mean tracheid length is approximately 4000 μm and wood density approximately 370 kg/m^3) (Fabisiak et al. 2012).

Table 3. Descriptive statistics of the sound propagation velocity in kauri wood

Direction	Mean	Minimum	Maximum	Standard deviation	Coefficient of variation
	m/s				%
Longitudinal	3700	3600	3830	89	2.4
Radial	2140	2090	2190	41	1,9

Although, the mean tracheid length in kauri wood, determined in this study, was longer compared to the cited data for pine and shorter compared to resonance of spruce wood, the velocity of sound propagation in longitudinal direction was the lowest. The reason for such characteristic of kauri wood may be the anatomical structure. Preparations of the radial section of kauri wood indicate the structure and distribution of pits different from that observed in softwood species from our climatic zone.The kauri wood have large bordered pits, which resembling hexagons. Additionally, they are very densely located in two, and often three, rows across the tracheid's width (Wagenführ 2007). Due to the fact that cellulose microfibrils near the pits run at the angle of almost 90^{o}, such high density of those pits may have a bearing on the velocity of sound propagation (Hori et al. 2002, Fabisiak et al. 2010, Fabisiak and Mania 2016). The structure and density of the occurrence of wood rays (Patel 1968) can also have a large influence on the speed of propagation of the sound, especially in the radial direction.

CONCLUSIONS

Kauri wood was characterised by high homogeneity of both macro- and microstructure. It has narrow annual rings, very even widths of the rings, and a low share of late wood (8% to 14%). The weighted mean lengths of tracheids, in individual annual rings, range from 3600 μm to 3800 μm. The high homogeneity of the structure is also confirmed by the even distribution of the uniseriate wood rays (approximately 20 rays/1mm^2 of the tangent section). The anatomy of kauri wood directly influences its acoustic properties.

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Streszczenie: *Wybrane właściwości drewna soplicy (Agathis australis (D.Don) Salisb.).* Badania przeprowadzono na drewnie soplicy australijskiej, które znajdowało się w torfowych mokradłach w północnych rejonach Nowej Zelandii przez 45000 lat. Drewno to jest bardzo cennym surowcem dla producentów strunowych instrumentów muzycznych, nie tylko ze względu na jego właściwości akustyczne, ale także niepowtarzalny rysunek. W pracy oznaczono podstawowe parametry makrostrukturalne oraz cechy budowy anatomicznej takie jak długości cewek drewna wczesnego i późnego oraz wymiary i gęstość występowania promieni drzewnych. Oznaczono także gęstość drewna i prędkość propagacji dźwięku. Wykazano, że drewno to odznaczało się wąskimi przyrostami rocznymi i bardzo małym udziałem drewna późnego, nieprzekraczającym 15%. Obliczone średnie ważone długości cewek zawierały się w wąskim przedziale od 3600 μm do 3900 μm. Gatunek ten posiada tylko jednorzędowe promienie drzewne, a na 1 mm^2 przekroju stycznego jest ich 20. Średnia prędkość propagacji dźwięku w kierunku podłużnym kształtowała się na poziomie 3700 m/s, a w promieniowym 2140 m/s.

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