Wave Propagation Technology in Non-destructive assays for Wood Qualifying in Tropical Amazon

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Abstract

Non-destructive tests use techniques which allow a body to be evaluated without changing its physical, mechanical and dimensional features and without compromising its future use. Impulse tomography analysis is a non-destructive method which allows a piece of wood to be analyzed by passing mechanical waves through it, allowing researchers to evaluate its qualities in advance and detect the presence of defects. This research reports the assessment of the efficiency of impulse tomography as a technique for identifying defects and the in situ evaluation of tree wood from Amazonian timber species. The data were collected at INPA's Tropical Forestry Experimental Station (ZF-2), located at BR 174, Manaus/AM, in a plot 1 (one) hectare in size, where 7 species were chosen at random. For evaluation, the ARBOTOM pulse tomograph at DAP (diameter at breast height) was used to rapidly capture cross sectional images of the wood. Next, the trees were cut to evaluate cross sections of the wood by eye and samples were taken to determine the density of the wood. The results enabled researchers to detect the presence of distinct zones in the wood by varying the mechanical wave speed indicated by various colour zones revealed in the X-ray. These colour differences are attributable to variations in density related to the different wood substances in the tree. It was found that the wood density and mechanical wave velocity correlated with R^2 0.647. The dynamic elastic modulus of the species studied was satisfactory, showing a good degree of resistance. Impulse tomography technique provides complete information and can assist forest managers to make a decision about tree felling that is guided by the assessment of the internal quality of the wood.

Keywords: *Non-destructive Testing. Pulse tomography. Tree tomography. Wood quality. Amazonian Wood varieties*

1. INTRODUCTION

Non-destructive tests were first devised in response to the need to evaluate material properties without affecting the object undergoing evaluation. They are performed on materials to check whether or not lesions or defects are present, and run on defined physical principles, without changing any physical, chemical, mechanical or dimensional characteristics of the materials being tested, thus leaving the ability in these materials to operate or perform their role uncompromised or altered for later use, as reported by Candian (2007).

In the forestry industry, the non-destructive (END) test has also been applied using various techniques. Impulse tomography in particular has emerged as an advantageous technique for evaluating the inside of trees. In medicine, tomographic tests are mostly used for medical diagnosis. Timber tomography works on identical principles. By means of mechanical wave emissions, internal images of the wood of any tree under scrutiny can be projected.

Wood tomography has two major objectives, namely the analysis of internal defects and dimensional characterization. From the images that it generates, information of various kinds can be obtained, such as the ratio of heartwood to sapwood, reaction wood and the presence of knots, internal defects and wood rot, among other things, according to Rinntech (2005). Amodei et al. (2010) also confirms the application of the technique in the logging industry, allowing the interior of the logs to be visualized and optimizing the location and orientation of the cutting of planks.

In this context, using techniques that preserve the integrity of the standing tree signals an evolution in research, which adds value to the evaluated product and reduces costs, making assay more economical. Barros (2016) commented on the assays that destructive methodology is more expensive due to the time consumed in the various stages of obtaining samples and resources; this methodology also prevents the subsequent use of so many samples, which are required for the mechanical and physical tests.

Because it is a new technique, few studies using pulse tomography have so far been described, especially on a living tree. Thus, the aim of this research is to attract subsidies for the development of new methodologies of non-destructive testing of live trees in the Amazon, using the impulse tomography technique; this would assist in the characterization of the internal quality of the wood and decision making about any arboreal individual in loco. If possible, it should provide mechanisms that aid forest management in the end, through a "quality inventory" using impulse tomography?

2. CONCEPTUAL-THEORETICAL REVIEW

In Brazil, the use of non-destructive tests on wood is still in its infancy. However, according to Oliveira (2005), it has been gaining ground in recent years, constituting a valuable tool for the forest sector, especially in the selection of individuals still in the field.

In the view of Ferreira (2009), non-destructive evaluation in the forestry area has been used for a number of purposes. In urban forests this kind of analysis makes it possible to detect internal defects in trees, and thus establish appropriate management measures for treating them, increasing their longevity and biological health. In forest plantations, Pereira (2009) maintains that such techniques allow us to evaluate the quality of timber and to characterize it as suitable for use in products made of solid wood and also in the management and selection of trees in sustainable forests, as aspects of forest improvement.

Non-destructive testing (NDT) with the application of wave propagation techniques for the evaluation of material properties became possible only with the development of elasticity theory and measuring equipment (Gonçalves & Trinca, 2011).

It was Jayne (1959) who initiated the fundamental hypothesis for the non-destructive assessment of wood. She proposed that energy storage and wood dissipation properties are controlled by the mechanisms that determine the static behavior of this material, and can be measured non-destructively.

In the case of wood, Gonçalves & Trinca (2011) claimed that applications previously devoted to determining the longitudinal modulus of elasticity, would also allow the global elastic constants to be determined and would allow characteristics to be evaluated directly in/on the tree. This tree assessment may focus on determining properties and/or the assessment of integrity.

The first research with mechanical waves to evaluate the interior of timber trees according to Bucur (1983) was done in in the 1980s, in order to verify the elastic constant in wood increments and compare it with X-ray densitometry.

Cardian (2011) reports several non-destructive ways of classifying wood, including visual classification, ultrasound, *stress wave timers*, transverse vibration and the use of resistographs and structural lumber sorting machines (MSR).

Impulse tomography, used to evaluate tree trunk injuries, is characterized as a less invasive technique, capable of providing evaluations of whole cross-sections of individuals in a single measurement (Nicolotti et al., 2003), through information provided by passing mechanical waves through the wood. Pereira (2007) confirms this observation, noting that until then no instruments had so quickly and conveniently revealed whole sections of trees; this suggests how revolutionary tomography was for this task. An added advantage was that very few signs of its use were left behind.

For Rinntech (2005), impulse tomography is based on the principle of mechanical wave timing, where the impulse velocity inside the tree is closely correlated with tissue density, the modulus of elasticity and moisture; the purpose is to reconstruct cross sections of trees, generating a mechanical wave velocity graph, also called a tomographic image.

Studies of impulse tomography by Nicolotti et al. (2003) join those of Martinis et al. (2004), Gilbert and Smiley (2004), Pereira (2009), Rollo (2009), Amodei et al. (2010) and Uliana (2010) in registering good results in comparison with other techniques. It has proved to be an important way of advancing the characterization of wood quality.

According to Bucur (2006), the propagation velocity of mechanical waves tends to increase with as humidity declines, occurring more intensely below the Fibre Saturation Point, precisely because of the greater intensity caused by the modulus of elasticity than is apparent. Thus, the highest wave propagation velocities are generally achieved in wood species of higher density and lower water content.

Of the physical properties, Panshin & De Zeeuw (1980) affirm that the density is the attribute most often used in characterizing wood. It is defined as the ratio between dry mass and saturated volume (g/cm^3 or kg/m^3), which gradually decreases in the medulla direction. Specific density or mass is one of the main indicators of wood quality, because it relates to the physical and mechanical properties of this material in industrial use and is easily determined. Generally, the density increases as the mechanical strength and natural durability of the wood increases.

Cardian (2011) notes that the determination of the mechanical properties of wood using wave propagation is based on the relationship between the speed of sound, the modulus of elasticity and the density, allowing aspects of wood quality to be verified, such as knots, and marrow, among other things.

3. MATERIAL AND METHODS

3.1 Characterization of the study area

The study area is located in the municipality of Manaus, in the state of Amazonast, the Experimental Station of Tropical Forestry of the National Institute of Amazonian Research (EEST //INPA), km 50 of Highway BR-174, Manaus/AM, with the geographical coordinates of latitude 2º38'14.60" S and longitude 60º9'22.37" W (Figure 1). This area is covered by humid tropical forest on firm ground in the Amazon, or Dense Tropical Forest, according to the classification of RADAMBRASIL (PELD, 2015).

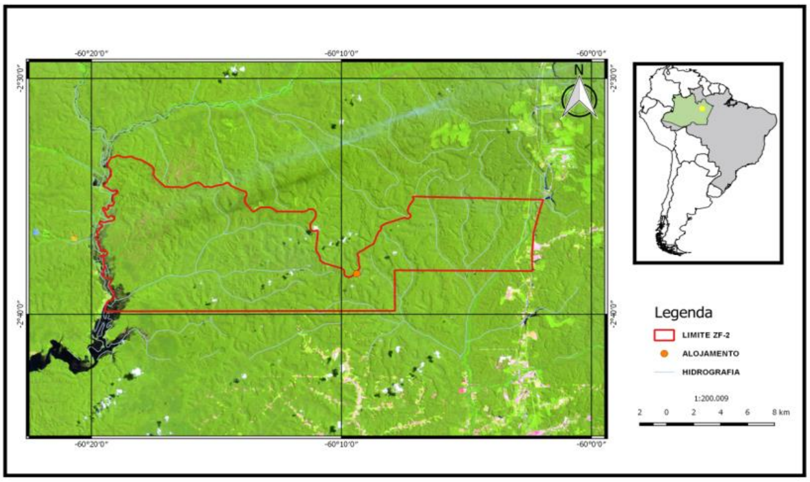

Figure 1: Location map of the study area: Tropical Forestry Experimental Station - ZF2 /INPA, Manaus/AM.

In a plot of 01 (one) hectare, of secondary forest the visual analysis of each selected tree was performed, recording information about the presence or absence of visible hollows, attacks by insects such as beetles, termites or the presence of fungi.

Seven species of wood from the Amazon were studied: Ingazeira or Ingá xixi (*Ingá alba*), Ingarana (*Inga paraensis*), Ingá-red (*Inga sp.*), Red-pitched (*Protium puncticulatum*), Maparajuba (*Manilkara amazônica*), Abiurana (*Pouteria guynensis*) and Muiragiboya (*Swartzia recurva*). The selection of these species was based on their frequent occurrence in the study plot. The species were identified at INPA's Wood Anatomy Laboratory. The species are native to the Amazon region and have differentiated wood material (heterogeneous), with heartwood and well-defined sapwood.

Regarding the experimental design, each tree analyzed was considered as a single sampling unit in a total of 7 individual trees.

3.2 Internal Analysis

A non-destructive test by the impulse tomography technique was made for the internal evaluation of the tree wood with a RINNTECH model pulse tomograph device (from a German company). The handset consists of 24 sensors, a special hammer, battery, charger, connecting cables, Panasonic brand CF-52 notebook and *software* installed from ARBOTOM.

To obtain the X-ray images of the species, the DAP height of each tree was fixed to be equidistant and sensors (numbered and arranged clockwise) were connected to each other by cable, with the battery connected to a laptop. Each sensor received 5 hammer blows that produced mechanical waves in the stem wood of the trees; the number increased until the percentage of error reached the range of 0-10% that was acceptable, following the Arbotom Software Delta % Table. This signal was transmitted and received by sensors installed around the circumference of the trunk and varied according to the density of the wood. The waves took some time, called the wave propagation time, to run through the wood of each tree and reach the sensors. The time that this took was automatically measured by the equipment *software* and its speed was calculated. In this way a colour-coded X-ray image of a cross-section of the tree trunk was formatted (Figure 02).

Figure 2: Application of the pulse tomograph to the tree stem.

The X-ray image is always accompanied by a colour palette, which represents the variation in the impulse velocities that traverse the cross-section. Rinntech (2005) observes that the higher the speed of the wave travelling through the wood, that is, the shorter the propagation time between two points of the tree, the greater its resistance. In other words, if the wood is in good condition the wave can travel at high speed, but if it encounters rotten wood, a hollow or a crack, it will have to slow down.

Having obtained the velocity values, it was possible to calculate the dynamic elasticity modulus (MOE_d), by applying Equation (1).

(1) $MOEd = V^2 \times \delta \times \left(\frac{1}{g}\right)$ where MOE_d = dynamic elasticity modulus (MPa)

δ = specific material mass (g/cm^3)

V = wave propagation speed (m/s)

g = acceleration of gravity (9,804 m/s^2)

To evaluate the data obtained in this non-destructive technique of wave emission, the trees to which it had been applied were felled and cut into logs so that the visual evaluation of the wood could be compared with the X-ray images.

3.3 Wood Density

The density was determined from specimens (samples) of 5 cm-thick discs cut from each tree. The samples were cut and properly oriented, with dimensions of 2 cm x 2 cm x 3 cm. The samples were saturated in water for 20 days to obtain a saturated mass and volume. The bulk density was determined by the stereometric method, with the aid of a digital caliper, measuring the width, thickness and length of the sample; for the saturated mass, a digital scale with 0.01g precision was used. The density was calculation by means of Equation 2.

(2) $\rho_b = \frac{P}{V}$ where ρ_b = Density (g/cm^3 ou kg/m^3)

P = wood mass (g)

V = wood volume (cm^3)

Statistical analyses of the technological characteristics of the species were performed according to a single factor design (treatment = individuals), with unbalanced data. The data were analyzed to yield descriptive statistics, observing the variation of wave velocity between the trees.

4. RESULTS AND DISCUSSION

4.1 X-ray Imagery

The application of the impulse tomograph to the wood of the trees produced the tomographic images presented in Figure 3, which show the alterations in the properties of the wood that could be observed from the patterns of coloration which are shown in the varying propagation velocities of the mechanical waves. This may be observed in the colour scale next to the X-ray images, which indicates the speed of the mechanical wave propagation (meters //second) as it passed through the wood.

According to Rinntech (2005), the red, orange and yellow tones indicate a slower speed of mechanical wave propagation, while the blue and green tones indicate higher velocity zones.

The colour scale reveals, then, that the blue portions present higher wave velocity values and the reddish portions present lower wave velocity values. In addition, it was possible to identify that each image displayed a specific pattern in the varying colours related to the velocities, which made it difficult to compare the images.

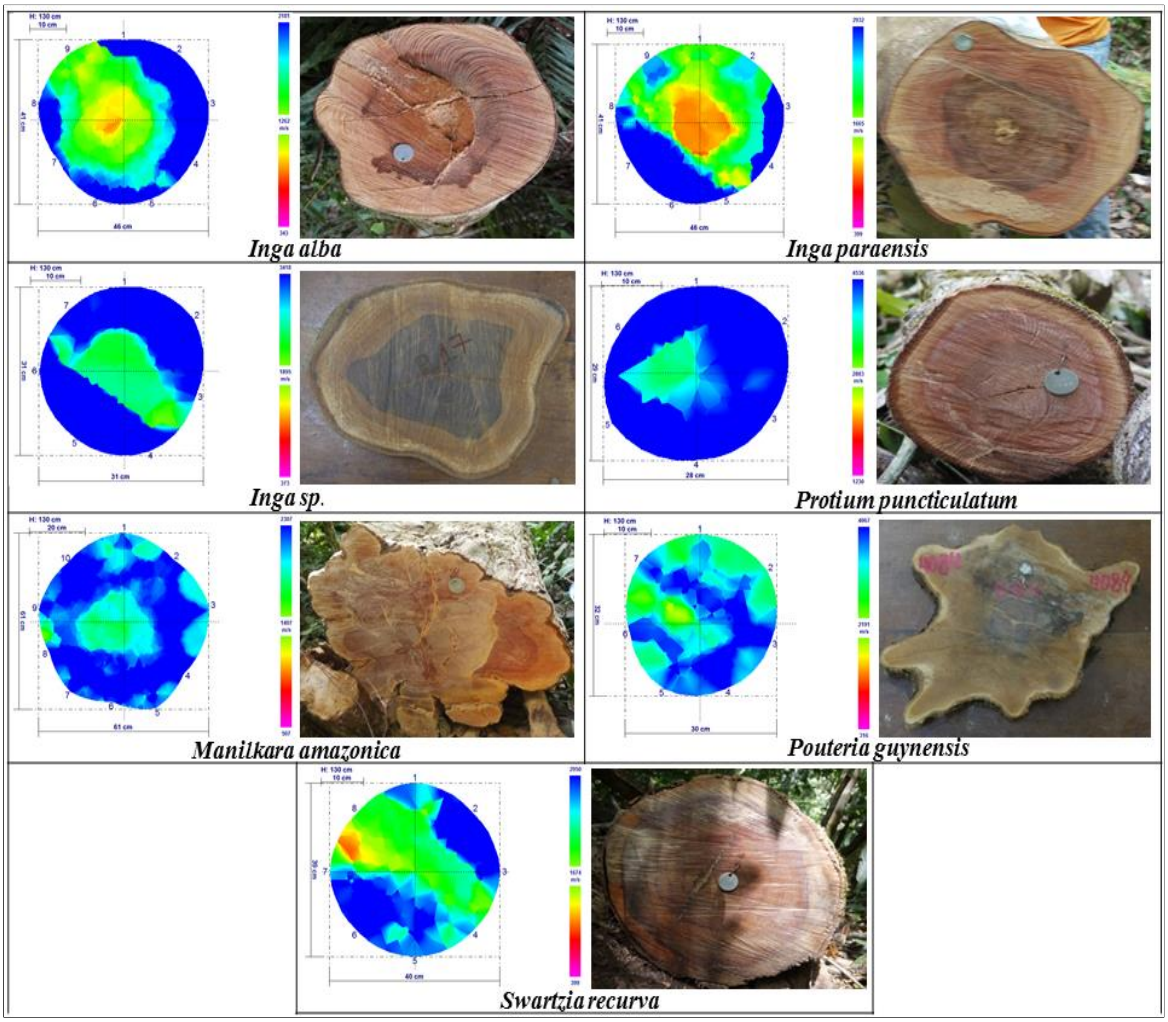

Figure 3: (A) X-ray images in a cross section of the trunk; and (B) cross-sectional views of each tree.

In general, the surface images of the cross sections of the seven individual trees do not present an image pattern that allows us to differentiate the woody material (heartwood vs. sapwood), but it is clear that the image composition is formatted according to the passage of the mechanical wave inside the wood, responding in line with the woody material found. Therefore, the image compositions do not follow a standard. In this study, it can be inferred that wood is a material that varies according to species and also within a single tree.

The X-ray images of the species *Inga alba* and *Inga paraensis* showed red//orange coloration, more evident in the latter, the internal defect in the *heartwood* area being confirmed only in its specimens. However, the percentage of hollow areas detected by visual analysis (1.25%) was smaller than that found by X-ray imaging (13.87%). A comparison between the data obtained by the visual analysis of the wood and the X-ray images shows that the X-ray reading overestimated the affected area by about 12%. This may be related to the diameter of the stem, its shape, or small differences of density between healthy and injured wood and even between heartwood and sapwood.

X-ray imaging and visual analysis both showed the better quality of *Inga sp.* with an absence of internal defects, indicating that the wave propagation did not suffer interference or discontinuity during its course; only some differentiation between the mechanical wave velocities could be observed. Another factor that could have been responsible was wood density, which ranged from 0.90 to 0.97 g/cm^3.

Protium puncticulatum recorded the image in blue and green with soft yellow shading. No deteriorated areas were found by visual analysis, a fact which is confirmed by the X-ray image and the values of the wave velocities that formed it, confirming the absence of deteriorated tissue in this individual tree. The speed ranged from 329 to 3,814 m/s, for a density of 0.84 to 0.88 g/cm^3, showing good quality wood.

Manilkara amazonica and *Pouteria guynensis* presented similar images regarding colour arrangement, where blue and green predominated in the image. This formatting may have been related to the geometric shape of the wood, causing spaces between the sensors, and reducing the speed of the mechanical wave that passed through. Neither species presented any internal defects, leaving only the differentiation between the mechanical wave velocities to be observed.

Swartzia recurve in its composition presented greater variation of green and blue, with a small red area between sensors 7 and 8. In the visual analysis, no internal wood defects were found to justify the presence of red, but it may have been related to some intrinsic characteristic of the wood.

Analyzing the formation of the X-ray images suggests that they may be related to the constitution of the wood, or to the pattern of hits executed on each sensor, since it was clear from the wood images that these specimens were free of internal defects. Since the tomograph works on various parts of the wood, producing images in response to the various sensors attached to the tree, it eventually recognizes several levels of density along the section.

Observations regarding the variation of the images corroborate the findings of Rollo (2009), who analyzed tomographic images of the Tipuana species; he maintains that blue and green are the colours that indicate higher velocity mechanical wave propagation, while those in the yellow and red part of the spectrum indicate lower velocity.

The images thus generated revealed the varied state of the wood, through the construction of the cross sections, demonstrating the practicality of handling the equipment. This procedure was recommended by Rinntech (2005), who advised that X-ray images should not be the sole basis for deciding to evaluate a cross section; they should be used in combination with other data collected from the tree.

The results achieved are in agreement with those found by Medeiros et al. (2017) using the impulse tomograph in Amazonian forests, implying that this technique is demonstrably efficient, since there were no major divergences between the tomographic image obtained and the visible state of the wood after logging. These were confirmed, both by the chainsaw operator's cut-off evaluation and by that of the impulse tomography.

Likewise, the impulse tomograph was used to evaluate the trunks of *Quercus alba* and *Carya spp.* trees, showing correlation between the reading and the visual evaluation, with an error of 3% to 8% in the image produced, besides being effective in locating and identifying deteriorated areas of the wood. Close correlation was found between the tomographic readings and the visual evaluation of the sections after tree felling (GILBERT & SMILEY, 2004), as in Amodei et al. (2010), who analyzed the wood of the *Tectona grandis* tree and recorded that impulse tomography helped to diagnose regions where the wood had suffered degradation.

According to Candian and Sales (2009), sound and more rigid wood generally has a faster tension wave propagation velocity, with an inner modulus of elasticity than deteriorated wood has. The presence of line degradation between the two transducers results in a decrease in the velocity of the voltage wave propagation in comparison with a reference velocity.

The image of the internal structure of the wood generated by the impulse tomograph, in response to the different transmission speeds of the sound waves, can be correlated with the physicochemical properties (density, modulus of elasticity, humidity, etc.) and makes it possible to determine the percentage of heartwood//sapwood, reaction wood, knots, wood rot, marrow eccentricity, etc., as observed by Rinntech (2005) and Picus (2015).

4.2 Frequency of tree wood velocity

The wave velocity inside the trunk of the trees in question had a positive asymmetric distribution (Figure 4), and it can be concluded that the mode is higher than the median and the mean.

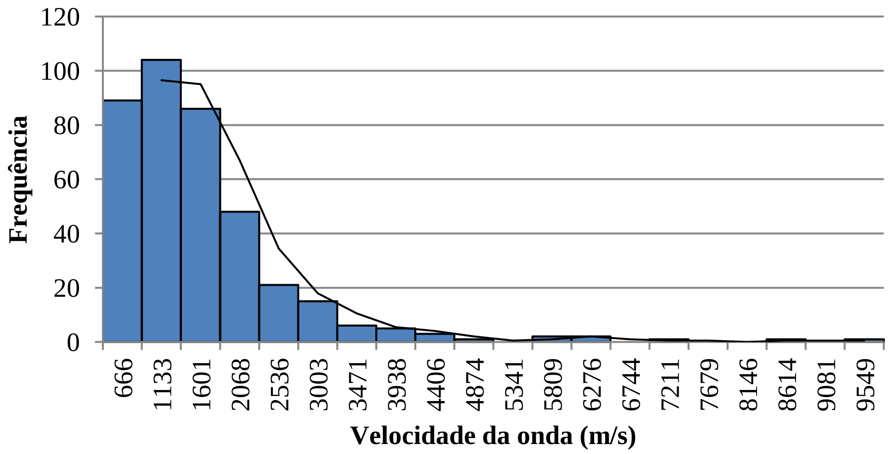

Figure 4: Frequency histogram of the mechanical wave velocity in the wood of the sample trees.

In 100% of the trees, the wave velocity through the wood recorded readings in the ranges of 666-1,133, 1,133-1,601 and 1,601-2,068 m //s. For 90% of trees the mechanical wave velocity values in the wood ranged from 2,068-4,874. However, in 28.5% of the trees a frequency of 4.874-9.549 m //s was observed from data evidenced in the histogram of the wave speed frequency through the wood.

The wide variation in velocity recorded for trees of the same age on the same site (plot) can be attributed to the physicochemical differences found between species and even within the same tree, since tree trunks exhibit different types of wood, related to the stages of their formation.

These differences confirm what Rinntech (2005) concluded about the particularities that need to be taken into account between species. In addition, they can be attributed to external influences (wind, rain, loud noises) and the inherent influence of the equipment, such as stroke quality (the different intensity of the strikes on the sensors) and the ways in which the metal connectors were fastened.

Similar studies confirming this result of the use of pulse tomography were observed by Amodei et al., (2010) who evaluated 8 *Tectona grandis* LFA trees and found great variation of velocities (500 - 3,091 m

//s) among the trees studied, though they were the same age and from the same stand. This can be attributed to the anatomical, physical and chemical variations found between the trees and even within the same tree.

With regard to variations in velocity, Dijk (2014) states that the cross-sectional dimension has also been held responsible for velocity variations because it affects the freedom of wave propagation.

In the cross sections analyzed, the zones showing an estimated velocity of between 600 and 1,600 m/s correspond to the areas with signs of deterioration, while zones with higher speeds, between 1,200 and over 2,000 m/s, indicate healthy wood. In this study, it was observed that, although the trees presented these two speed scales, one for healthy wood and the other for possible deterioration, only one tree presented an internal defect that was worse than the one registered in the X-ray image. Thus, it appears that not all speeds below 1,600 m/s mean defective wood; they may be related to the characteristics of the wood within the wood or even to the species itself.

Similarly, Dackermann et al. (2014) have also found that voids, cracks, and degradations generally cause the wave to slow down in order to find a different path around the defects; these deviations extend the travel time of the wave. Moreover, the speed of propagation of mechanical waves tends to be higher in species with denser wood.

In general, Wang (2013) states, mechanical waves propagate faster in healthy, high-quality woods than in poor-quality decayed woods, as Rayner & Boddy (1988) also observe; this is because rot changes the physical and mechanical properties of wood, degrading cell wall components, reducing the mass, the elastic properties and the internal strength of the material.

4.3 Relationship between pulse tomography speed and wood density

A dispersion diagram was constructed for the species using the collected data. The correlation of wood density with wave propagation velocity through pulse tomography has as its principle the emission time of the wave and the waiting time for the response. By graphically presenting this correlation of the 7 species analyzed, the value of R^2 was found to be 0.647 (Figure 5).

The value of the coefficient of determination (R2) was significant in the 1% Tukey test, suggesting that the mean pulse tomography velocities and wood density averages obtained over a cross-section are similar for all samples.

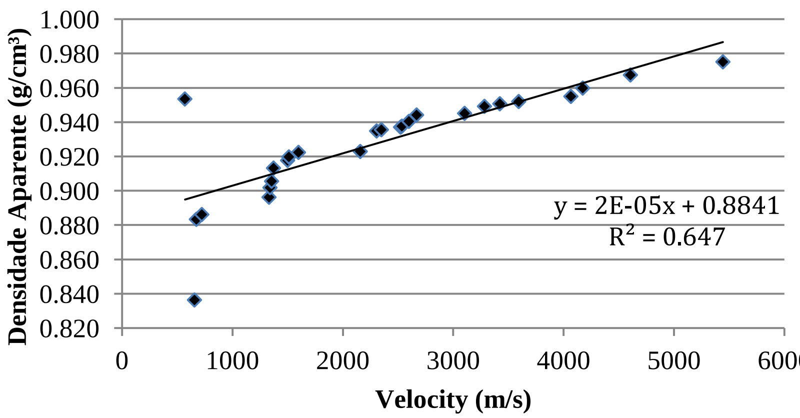

Figure 5: Dispersion diagram of the mean mechanical wave velocity (x axis) vs. mean apparent density (y axis), with significant R^2 at 1% by the t test.

R^2 is understood as the coefficient of determination, ranging from 0 to 1. It represents a measure of adjustment of the statistical model, that is to say, how well the model can explain the observed values. Thus, it is observed that R^2 0.647 demonstrates that the velocity and density values are correlated, since the impulse wave velocity tends to increase directly with the increase in density. This recalls the theory of acoustic physics, in which sound propagates faster in a solid medium, corroborating the view that the wood is of good quality and composed of healthy material.

This result confirms the theory of Rinntech (2005), according to which the impulse velocities within wood are closely correlated with the density of the material, and therefore can be used to gather information about its quality.

Uliana (2010), using pulse tomography to detect lesions and hollows in the Manilkara huberi (*maçaranduba*) species, found that the tomographic image was correlated with the quality of the stem after cutting, confirming the relationship between speed and wood quality.

Other studies also confirm the close correlation between the mechanical wave velocity generated by pulse tomography and wood density: see Rinntech (2005); Oliveira & Sales (2005); Pereira et al. (2007) and Lin et al. (2011).

Evaluating standing trees, Stević et al. (2013) used the sound tomograph and resistograph and obtained results showing that the wood structure was not damaged, but contained local cracks that reached its core. Rollo et al. (2013), using pulse tomograph and resistograph on two healthy torques of *Eucalyptus saligna* Sm, claims that by generating an image of the entire cross-section, pulse tomography presents more complete data than those generated by the resistograph. However, studies of live trees, with internal lesions and of different species and densities should be performed to better understand this technology.

The information provided by the use of pulse tomography allowed us to evaluate the wood a preliminary, non-destructive, qualitative way. Impulse tomography proved to be an effective and practical method, which provided more information about the internal state of the trees than other methods did, besides enabling affected areas to be found. It is an innovative and easy-to-use technique for characterizing the wood of any tree.

However, Stangerlin et al. (2008) states that mechanical wave velocity in living trees should take into account not only wood density, but such other factors as modulus of elasticity, moisture content, anatomical characteristics, grain type and sample size, which also influence the form of wave propagation.

4.4 Dynamic elasticity modulus

Studies show that the relationship between ways of estimating wood strength can be accepted, whether mechanical or dynamic categories. Standard NBR 7190/1997 establishes four categories of hardness for hardwoods, with values ranging from 9,500 to 24,500 MPa of stiffness for timber structures. Figure 6 shows the dynamic modulus of elasticity (MOEd) values obtained by pulse tomography for the above sample of species.

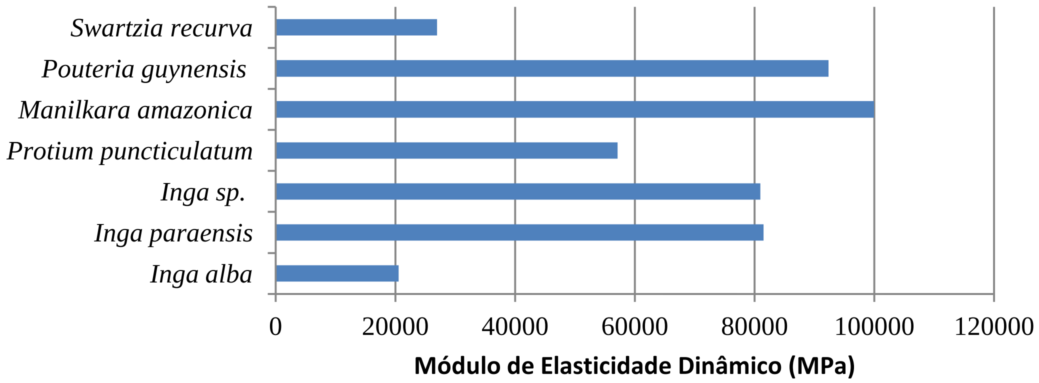

Figure 6. Dynamic modulus of elasticity via pulse tomography.

Teófilo (2016) reports that the modulus of elasticity is used to estimate the stiffness of a material. Stiffness is the ability of wood to resist bending (bending/deformation), while strength is the ability of a material to resist or oppose stress. Thus, the modulus of elasticity points to an evaluation of the quality of a material, measured by its stiffness, suggesting that the product presents resistance when subjected to stress. The greater the modulus of elasticity, the lower the elastic deformation resulting from the application of a particular stress (hence, greater stiffness).

The information from Teófilo (2016) corroborates this result that *Manilkara Amazonica* presented the highest value of the MOEd (99,963 Mpa), followed by *Pouteria guinensis* (92,364 Mpa), registering that these species present high resistance value when subjected to loads. In contrast, *Inga alba* (20,533 Mpa), which obtained the lowest MOEd value, should not is not discarded for use, since the value it possessed is within the classifications of NBR 7190/1997. Thus, it was found possible to determine the dynamic modulus of elasticity of wood by pulse tomography.

Few studies have been performed to determine the MOEd of a specimen by pulse tomography; most researchers use voltage wave emission or transverse vibration. However, Carrasco et al. (2017), who used the acoustic tomograph, concluded that it could be helpful for determining the modulus of elasticity in the fibres by only one experimental test.

This work confirms the need to agree on a standard classification for the dynamic method; it is needed because too little is known about these tests of live trees in the Amazon and the values obtained. The higher the MOE, however, the better the wood resistance.

5. CONCLUSION

The use of non-destructive tests to evaluate wood quality is an important tool to use since the tests do not change the characteristics of their sample.

The impulse tomography technique, by means of tomographic images that are associated with photographs of tree cross-sections, speed variations and species characteristics, allowed a preliminary evaluation of the internal quality of the wood in seven trees. The reconstruction of the cross sections indicated the possible defects present in the trees analyzed, showing that the impulse tomograph is an effective tool.

It was possible to associate the wood density with the mechanical wave propagation velocity generated by the pulse tomograph, confirming its influence on the formation of the image. The quality of the wood was also confirmed by the high values obtained with the dynamic elasticity modulus, via the velocity of the impulse tomography. This result confirms that through a "quality inventory" it becomes possible to predict the quality of wood *in situ* using impulse tomography techniques. These techniques help in decision-making in the pre-exploratory stage of forest management. It has been found that this information has helped to build an efficient methodology for assessing the quality of a tree's wood while it is still standing. The technique can be applied to other species, advancing the progress of the species or individual towards better use.

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