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Determining the health status of natural monument trees using acoustic tomography method

Tabiat anıtı ağaçların akustik tomografi yöntemiyle sağlık durumlarının belirlenmesi

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Abstract
Areas with natural beauty and rich biodiversity have had a different significance for people since ancient times. With the latest developments in industry, technology, and urbanization, the demand for natural areas has increased considerably. Accordingly, the need to protect such private areas has become even more significant. In order to protect areas with such natural characteristics effectively, problems and threat factors must be correctly revealed. For this purpose; a study was conducted to determine the health status of some trees, which are natural monuments in the Eastern Black Sea Region of Türkiye, using the acoustic tomography method. The general appearance of six trees in the study area was examined, and measurements were made with the Arbor Sonic 3D Acoustic Tomography device. In the research, it was found that the trunk of one of the natural monument trees was hollow. The other five trees were found to be in good general condition. According to the results of the tomography, it was determined that one of the six trees measured was in good health, three of them had partial hollows and decay, and two of them were completely hollow. According to the data obtained, it has been revealed that the acoustic tomography method is an effective tool in determining the health status of nature monument trees.

Özet
Doğal güzelliklere ve zengin biyolojik çeşitliliğe sahip alanlar, eski çağlardan beri insanlar için farklı bir öneme sahip olmuştur. Sanayi, teknoloji ve şehirleşmedeki son gelişmelerle birlikte doğal alanlara olan talep de oldukça artmıştır. Buna bağlı olarak bu tür özel alanların korunması ihtiyacı daha da önem kazanmıştır. Bu tür doğal özelliklere sahip alanların etkin bir şekilde korunabilmesi için sorunların ve tehdit faktörlerinin doğru bir şekilde ortaya çıkarılması gerekmektedir. Bu amaç için; Türkiye'nin Doğu Karadeniz Bölgesi'nde tabiat anıtı olan bazı ağaçların sağlık durumlarının akustik tomografi yöntemi kullanılarak belirlenmesi amacıyla bu çalışma yapılmıştır. Çalışma alanındaki altı ağaçın genel görünüşü incelenmiş, hem de Arbor Sonic 3D Akustik Tomografi cihazı ile ölçümler gerçekleştirilmiştir. Araştırmada tabiat anıtı ağaçların birinde ağacın gövdesinin içinin boş olduğu, diğer beş ağacın ise genel durumlarının iyi olduğu belirlenmiştir. Tomografi sonuçlarına göre ise ölçümü yapılan altı ağaçtan birinin sağlık durumunun iyi olduğu, üçünde kısmi oyuk ve çürüklük olduğu, ikisinin gövdesinin ise tamamen oyuk olduğu belirlenmiştir. Elde edilen verilere göre akustik tomografi yönteminin tabiat anıtı ağaçların sağlık durumunun belirlenmesinde etkili bir araç olduğu söylenebilir.

INTRODUCTION

Efforts to conserve biodiversity and natural resources have led to the establishment of protected areas in many countries around the world. The establishment of protected areas has played an significant role in protecting biodiversity and ensuring its continuity (Putz et al. 2001). National parks, nature parks, nature conservation areas, nature monuments, registered wetlands, and protected areas with protection status such as these are defined as "protected areas". Protected areas" are defined as national parks, nature parks, nature conservation areas, nature monuments, registered wetlands, and protected areas with protection status (Sezen 2017).

Natural monument trees hold a protected status in Türkiye. Natural monument trees are natural living things that are larger than the normal dimensions of similar trees in terms of diameter, height, and age, harbor the history and cultural characteristics of the region, and form a link between the past and the present, and even the future (Asan 1987).

There are a total of 113 natural monuments in Türkiye. Of these Natural Monuments, 90 are registered as trees and 23 are registered as areas. There are threatening factors such as illegal felling, natural disasters, insect damage, various diseases, and partly wildlife. In order to ensure that these trees, which are of high importance and have been granted status and protection, are truly protected and passed on to future generations, their health status should be determined and monitored regularly. While external observation techniques play a crucial role in assessing the health status of natural monument trees, internal decay or deterioration may not manifest externally

Existing damage to the tree can manifest itself as exposed roots, decaying stems, and broken branches. Tree defects can cause trees to fall, which is very dangerous for the people around them (Hanum et al. 2020). Detecting internal defects lurking in tree trunks is a challenge for arborists and managers. Foresters, arborists, physiologists, plant pathologists, and ecologists have long sought reliable, portable, and non-destructive methods to detect, quantify, and visualize internal decay in living trees (Johnstone et al. 2010a).

The importance of non-destructive assessment techniques is indisputable when it comes to live trees. Forest management and the wood industry place special emphasis on assessing the condition of living trees for both technical and biological reasons (Nicolotti et al. 2003). One of the latest technologies used for this purpose is the application of three-dimensional computed tomography (Gergel et al. 2019). The most common devices used to measure wood decay in trees are those that record the transmission time of multiple acoustic stress waves (Johnstone et al. 2010b). Given that the density of the wood influences the sound wave velocity, a decrease in this velocity can serve as an indicator of wood deterioration (Socco et al. 2004).

Recent technological advancements have led to the development and application of a wide range of tomographic methods for determining of wood properties. Among these methods, X-ray computed tomography has been very useful in testing tree trunks and wood structures for internal structure assessment (Okochi et al. 2007, Pereira et al. 2017). However, the use of X-rays or gamma-rays for wood measurements is not practical as they are not portable for field evaluation. More importantly, the method poses a radiation hazard to users (Wang et al. 2004, Yu et al. 2013). Among these methods, sonic tomography has been recognized as one of the most effective methods for detecting internal cavities and decay of trees or logs and has been widely adopted in field measurements (Brazee et al. 2011, Pereira-Rollo et al. 2014, Espinosa et al. 2017, Liao et al. 2017).

Acoustic tomography is a technique that records differences in sound wave transmission speed to produce an internal cross-sectional image of a tree. It produces color images of the internal structure of tree trunks in 2D and 3D tomography images by recording the sound wave transmission speed difference along the trunk. Urban forestry and arboriculture applications have studied and applied this technology, demonstrating its effectiveness in identifying internal tree decay and damage (Gao et al. 2014, Merlo et al. 2014).

Since 1999, sonic tomography has become a standard tool for advanced technical tree safety auditing and is now practiced by more than a thousand arborists worldwide (Rinn 2015). The goal of acoustic tomography is to map the tree trunk in as much detail as possible and as conditions allow, without penetrating into the structure, i.e., damaging it (Vizvari et al. 2019). According to Qiu et al. (2019), acoustic tomography seems to be a good, cheap, and non-destructive way to find problems inside structures and check the stability of tree systems. In another study, Qi et al. (2013) obtained tomography images on ten oak trees using acoustic tomography and found it to be a useful tool for visualizing and detecting internal decay in tree trunks, which will help urban forestry tree care professionals make the right decisions about tree health, maintenance, and hazardous tree assessment. In a study published in 2020, Alani et al. looked at how acoustic tomography could be used to look at the inside structure of living trees, specifically to find places inside the trees that were dying.

In another study that employed acoustic tomography to assess tree health, researchers measured century-old red oak trees to identify structural defects, pinpoint their general location, and estimate their size (Wang and Allison 2008). In addition, some studies on *Prunus serotina* Ehrh. have proven acoustic tomography to be an effective tool for detecting internal rot. The tomogram was able to show the location, size, and shape of internal rot (Li et al. 2014).

The aim of this study was to determine the health status of natural monument trees in the eastern Black Sea region using acoustic tomography. For this purpose, measurements were made on six natural monument trees, two in Artvin and four in Gümüşhane, and their health status was tried to be determined.

MATERIAL AND METHOD

Case Study Area

This study was carried out on the natural monument trees in Gümüşhane and Artvin provinces of the 12th Regional Directorate. The study was carried out on six natural monument trees, four in Gümüşhane (*Populus nigra* L. Gümüşhane-Şiran, *Juniperus communis* L.Gümüşhane-Şiran, 2-*Abies nordmanniana* Link. Gümüşhane-Kürtün) and two in Artvin (*Picea orientalis* (L.) Link. Artvin-Taşlıca, *Fagus orientalis* Lipsky Artvin-Murgul).

An Arborsonic 3D acoustic tomography device (Fakopp Arborsonic 3D Tomograph 10 channel, Hungary), computer, GPS device (Garmin Etrex 32x, Switzerland), tape measure, tree diameter, and height meters were used in the study. The Arborsonic 3D acoustic tomography device consists of twelve sensors, twelve sensor connection devices, a bluetooth connection device, and a sensor removal apparatus (Figure 1). After establishing the necessary connections, a computer processed the received values and made measurements to generate a tomography image.

Figure 1. Acoustic tomography equipment

In the measurements made in the field, the circumference, diameter, and height of the trees were measured and recorded. After completing these measurements, we began measurements with the acoustic tomography device. In the acoustic tomography device, the sensors were first connected to each other and to the tree.

In the second stage, the sensors were connected to the computer via a bluetooth connection device. When the connection with the computer was established, general information about the measured tree was entered in the first tab in the Arborsonic 3D acoustic tomography program. The program entered the tree's height measurement, its geometric shape, the number of installed sensors, its circumference length at the measured height, the number of centimeters the sensor nailed into the tree, and the bark thickness in the second tab. Next, we obtained the device's connection confirmation with the computer by pressing the start button. When the connection was established, the third tab in the program was started, and the sensors were hit five times with a metal hammer (according to the confirmation sound from the computer program). The confirmation sound, which followed the hammer strike, illuminated the number of the hit sensor in green on the computer screen. In this way, after receiving the confirmation sound from each sensor, the measurement was completed, and the measurement results were obtained in the fourth tab of the program. Due to the large size of the tree trunks and the lack of sufficient sensors, 2D measurement images were analysed instead of 3D measurements. In the 2D image, green colour means healthy, yellow colour means that the wood has started to deteriorate, red colour means that the wood has deteriorated and purple colour means that the wood is hollow. In this way, without cutting a standing tree, cavities and decay in the trunk were determined based on the difference in the propagation speed of sound waves in the intact and decayed parts of the tree trunk. In the tomography image obtained as a result of the measurement, the green colored parts represent the intact tissue of the tree, the red colored parts represent the rotten tissue of the tree, and the blue colored areas represent the hollow and hollow parts of the tree. Following the field measurements, the measurements, Latin name, diameter, height, age, health status, coordinates, location, and terrain conditions of each natural monument were entered into the inventory report. Tomography images of each tree were entered into the "Acoustic Tomography Measurement Results" table. In tree measurements, the device also shows the damage rate of the tree. This was also determined in the measurements.

RESULTS AND DISCUSSION

A total of six natural monuments located within the borders of Artvin and Gümüşhane provinces were evaluated and measured.

Melodere Oriental Spruce Natural Monument Measurement Results

When Melodere oriental spruce Natural Monument was observed from the outside, no signs of drying or decay were observed. The decay area was measured at 51% in the measurement (Figure 2).

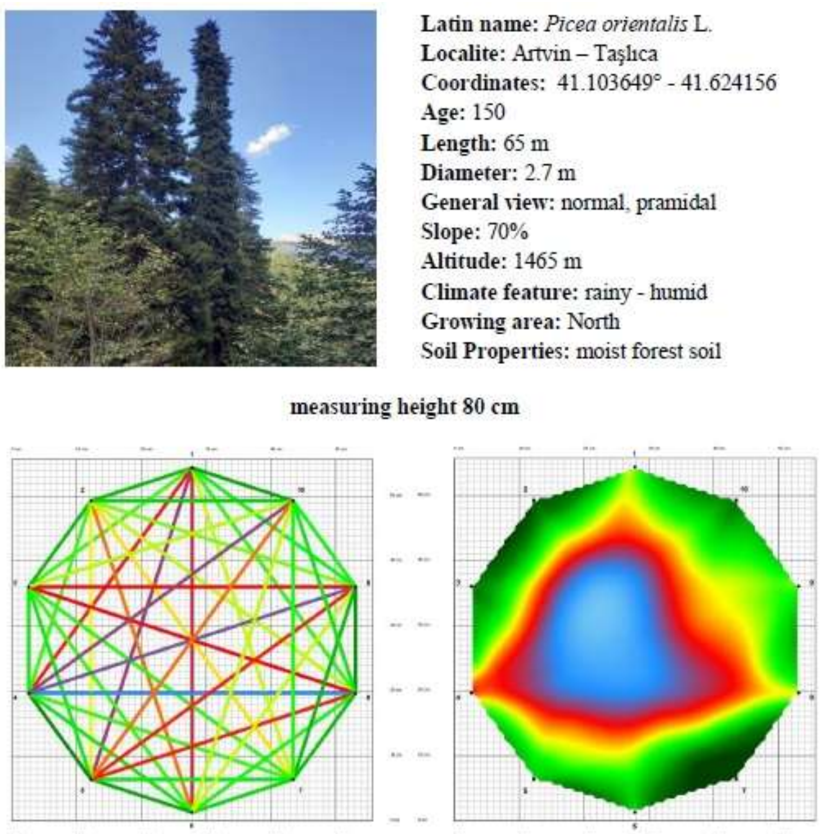

Figure 2. Melodere oriental spruce natural monument inventory scorecard and images

Kamilet Oriental Beech Nature Monument Measurement Results

When the Kamilet oriental beech Natural Monument was observed from the outside, no decay, drying, damage, or defects were observed. The tree's large circumference at breast height and gnarled structure allowed for measurements at 3 meters. No defects were observed inside the tree in the Acoustic Tomography images. The decay area was measured at 27% (Figure 3).

Latin name: *Fagus orientalis* Lipsky
Localite: Artvin – Murgul
Coordinates: 41.326923° - 41.595619°
Age: 300
Length: 54 m
Diameter: 3.4 m
General view: un formal
Slope: 70%
Altitude: 1225 m
Climate feature: rainy - humid
Growing area: North
Soil Properties: moist forest soil

measuring height 300 cm

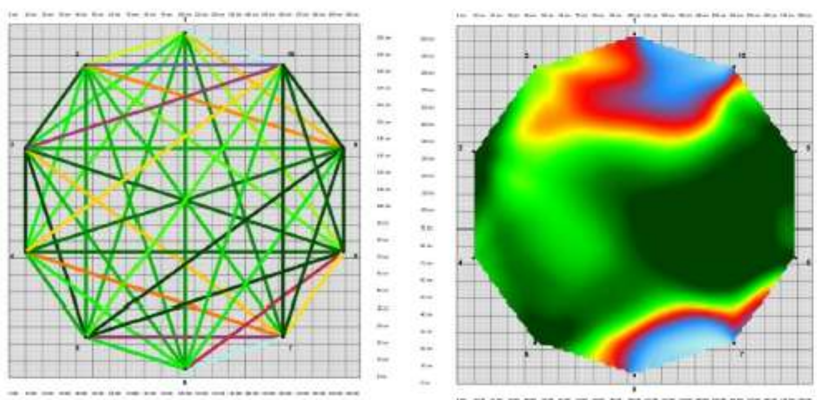

Figure 3. Kamilet oriental beech nature monument inventory report card and images

Ali Aga's Poplar Nature Monument Measurement Results

Examining the Ali Aga's poplar Nature Monument from the outside revealed a large cavity in the body structure, despite its seemingly healthy appearance. Even though it wasn't necessary, we made acoustic tomography measurements to re-test the device's reliability. Acoustic tomography images confirmed the cavity inside the tree. The decay area was measured at 73% (Figure 4).

Kirani Evliya Juniper Nature Monument Measurement Results

When the Kirani Evliya Juniper Nature Monument was observed from the outside, no decay, drying, damage, or defects were observed. Acoustic Tomography images revealed a large cavity inside the tree. In the measurement made, the decay area was measured at 64% (Figure 5).

Latin name: *Populus nigra* L.
Localite: Gümüşhane - Şiran
Coordinates: 40.283713° - 38.997945°
Age: 500
Length: 30 m
Diameter: 1.57 m
General view: the body is hollow
Slope: 5%
Altitude: 1730 m
Climate feature: terrestrial
Growing area: West
Soil properties: red forest soil

measuring height 300 cm

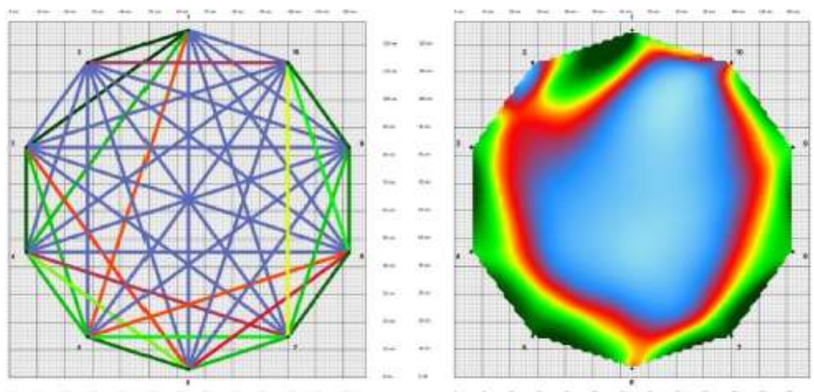

Figure 4. Ali Agha's poplar nature monument inventory report card and images

Latin name: *Juniperus communis* L.
Localite: Gümüşhane - Şiran
Coordinates: 40.294782° - 38.987252°
Age: 717
Length: 4.53 m
Diameter: 4.4 m
General view: the body is hollow
Slope: 5%
Altitude: 270m
Climate feature: terrestrial
Growing area: southeast
Soil properties: red forest soil

measuring height 90 cm

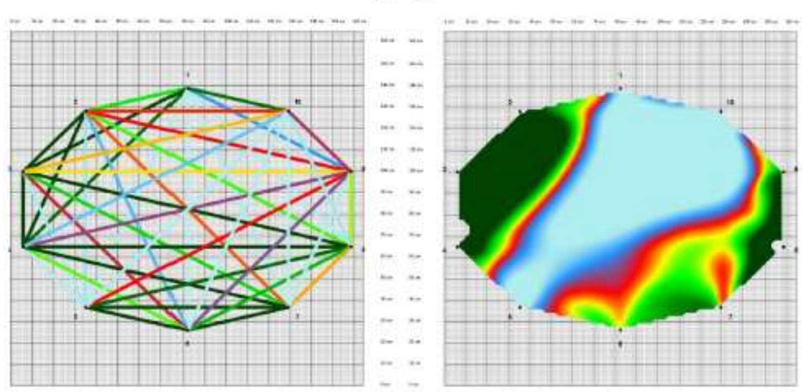

Figure 5. Kirani Evliya Juniper nature monument inventory report card and images

Spider Forest Fir[1] Natural Monument Measurement Results

When the Spider Forest Fir[1] Natural Monument was observed from the outside, no decay, drying, damage, or defects were observed. In the Acoustic Tomography images, it was determined that cavities started to form inside the tree. In the measurement, the decay area was measured at 51% (Figure 6).

Spider Forest Fir[2] Nature Monument Measurement Results

When the Spider Forest Fir[2] Natural Monument was observed from the outside, it was seen that the tree was standing a little sideways, but no decay, drying, damage, or defects were observed. Acoustic Tomography images showed that there were large gaps in the tree. In the first measurement, the decay area was measured at 60% (Figure 7).

In this study, natural monument trees of historical, cultural, and ecological importance were selected, and the most significant factor in the use of the acoustic tomography method is to determine the health status of natural monument trees that are historically, culturally, and ecologically significant. In this study, in which visual assessment and acoustic tomography methods were used together on natural monument trees, visual assessment alone is not sufficient in determining the health status of trees, and the use of different assessment methods together gives more accurate results. In this study, five of the six natural monument trees measured appeared healthy according to the visual assessment. However, according to the tomography results, it was determined that one of them was healthy and the other five had health problems. The juniper tree in Kırıntı village of Şiran district of Gümüşhane looks healthy when the trunk, branches, and leaves are observed from the outside. According to the tomography results, a large hollow was detected inside the tree. In the tomography results of the Spider Forest Fir trees in Gümüşhane and the spruce tree in Artvin, large hollows were detected in the trunk. Considering the possibility of measurement error, measurements were repeated at different times, and a similar image was obtained from the previous tomography. The gnarled trunk structure of the eastern beech in Artvin, with a circumference of 10 meters, prevented the device from connecting at chest height. For this reason, necessary safety precautions were taken, and measurements were made at a height of 3 meters, where the circumference was slightly reduced. The tomography results of fir[1] and fir[2] trees, which are located about 50 meters away from each other in Spider Forest in Gümüşhane, are similar to each other. Large hollows were detected in both trees. However, the hollow detected in fir[2] is larger than the one detected in fir[1].

In a study that combined visual assessment and acoustic tomography to assess the health status of trees, the visual assessment method yielded an average tree damage level index of 4.3%, whereas the acoustic tomography method revealed an average wood damage value of 19.1%. This shows the acceptability of acoustic tomography for assessing tree conditions in addition to the visual assessment method (Karlinasari 2018). Recently, Tarmu et al. (2022) conducted a assessment on sample trees, followed by measurements with an acoustic tomography device, and then a log assessment by cutting the sample trees. It was revealed that tomography images are more accurate than visual assessment when assessing heavily decayed trees and can be used as a reliable method to assess decay.

Latin name: *Abies nordmanniana* Link.
Localite: Gümüşhane - Kürtün
Coordinates: 40.663684° - 39.033243°
Age: 425
Length: 55 m
Diameter: 3.9 m
General view: natural
Slope: 5%
Altitude: 2700 m
Climate feature: rainy
Growing area: northeast
Soil properties: moist forest soil

measuring height 100 cm

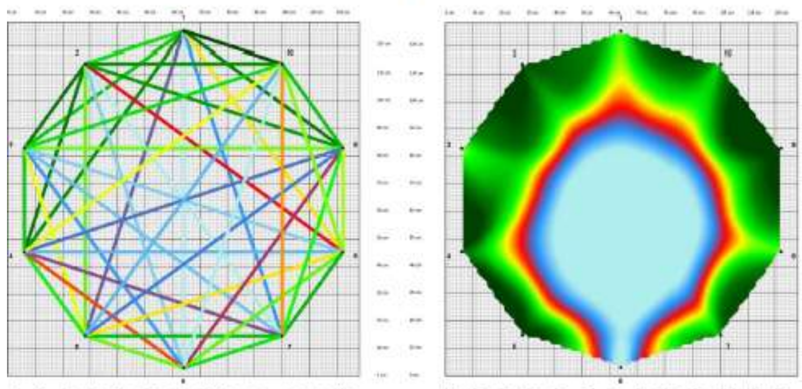

Figure 6. Inventory scorecard of Spider Forest fir[1] natural monument and images

Latin name: *Abies nordmanniana* Link.
Localite: Gümüşhane - Kürtün
Coordinates: 40.663668 °- 39.032689
Age: 425
Length: 55 m
Diameter: 4.9 m
General view: natural
Slope: 5%
Altitude: 1300 m
Climate feature: rainy
Growing area: northeast
Soil properties: moist forest soil

measuring height 110 cm

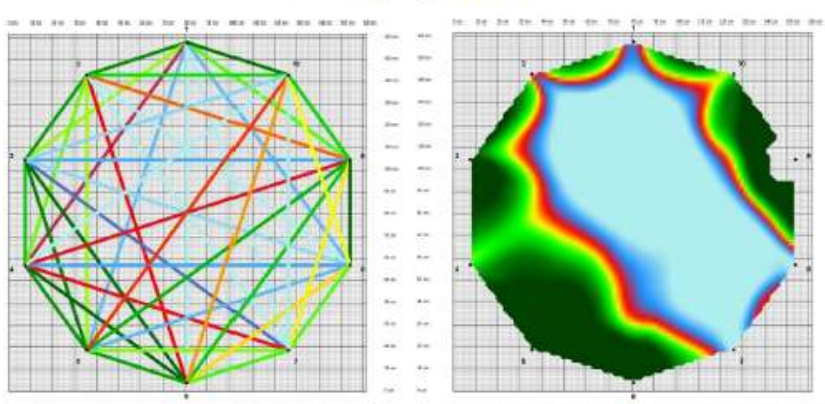

Figure 7. Inventory scorecard of Spider Forest fir[2] natural monument and image

In the acoustic tomography method, problems such as taking a long time to connect the device, problems in computer connection, problems such as lack of battery and charging, difficult measurements due to the thick diameter of some trees, and extremely difficult terrain conditions may cause disruption and prolongation of the measurements. In the acoustic tomography method applied in this study, each tree measurement took 30-45 minutes. Since this method takes a long time, it is thought that its use in forestry applications will not be efficient. In the study conducted by Gergel et al. in 2019, they support this view with the statement that these methods are not efficient in forestry because the measurements of devices such as Arbotom 3D and ArboSonic 3D take a long time. In a study using acoustic tomography and electrical resistance tomography methods to evaluate the time required for measurement in determining the health status of urban and park trees, it was shown that it takes about 52 minutes to measure a tree with one person and about 37 minutes with two people, and that working in a team of two people is moderately more efficient (Balas et al. 2020).

Cracks and knots in the tree can affect sound speed. Sending a sound wave into the wood affects all its characteristics, including growth rings, cracks, decay cavities, knots, and moisture. The characteristics mentioned affect both the rate and speed of these waves and also reveal the wave shape in the wood. Large cavities, cracks, ring cracks, and internal cracking increase the time it takes for the sound wave to travel from side to side in the cross-section of the poles. To detect cavities, acoustic inspection devices use the time it takes for sound to travel from side to side. Therefore, the presence of natural defects limits the effectiveness of the devices. Visual inspection alone, one of the traditional methods, can produce misleading results, especially in extremely rotten standing trees. However, non-destructive testing methods can be more useful if used in combination with traditional methods (visual inspection, excavation, making noise by hammering and drilling holes, etc.)

CONCLUSIONS

As a result, this study was conducted on six trees with natural monument status in the Eastern Black Sea region, and according to the results obtained, it was determined that one of the natural monument trees was healthy and the other five were in poor health. In this study, in which visual assessment and the acoustic tomography method were used together, it was concluded that visual assessment alone is not sufficient in determining the health status of the vehicles, and it would be more effective to apply different assessment methods together. Since acoustic tomography measurement with the Arborsonic 3D Acoustic Tomography Device takes 30-45 minutes for each tree, using this method in forestry applications will not be efficient. However, it is thought to be more suitable for determining the health status of trees in parks and gardens or trees with special status.

Despite the small gap in the fir[1] tree in Gümüşhane, the overall health status appears to be good. It would be appropriate to determine how far the cavity continues by performing 3D tomography scans in the fir[1] tree. The fir[2] tree, in which a large cavity was detected in acoustic tomography images, poses a danger with its sloping stance and proximity to the vehicle road.

The difficulty of the terrain conditions during field studies, connecting the device to the tree, setting up the computer, ensuring the connection between the device and the computer, and obtaining tomographic images by making measurements is a difficult and time-consuming method for each tree. For this reason, it is recommended that field measurements be carried out with at least two people, not one person. Furthermore, in order to increase the reliability and accuracy of the data obtained, it is also recommended to perform measurements and determinations with more than one non-destructive test device (resistograph, microhammer, x-ray tomography, shigometer, etc.).

In this study, significant results were obtained in determining the health status of natural monument trees and will shed light on such scientific studies to be carried out later.

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