Cent. Eur. For. J. 64 (2018) 34–40 sciendo DOI: 10.2478/forj-2019-0001

CENTRAL EUROPEAN Forestry Journal

http://www.nlcsk.sk/fj/

ORIGINAL PAPER

Instrumental analysis of health status of *Quercus petraea* stands in the Carpathian Basin

Petra Trenyik[1]*, Julianna Skutai[1], Orsolya Szirmai[2], Szilárd Czóbel[1]

[1] *Szent István University, Department of Nature Conservation & Landscape Ecology, Pater Károly Street 1, H–2100 Gödöllő, Hungary*
[2] *Botanical Garden of Szent István University, Pater Károly Street 1, H–2100 Gödöllő, Hungary*

Abstract

Numerous prognoses indicate that climate change will manifest itself in extreme climatic conditions. Therefore, it will be of high importance to know in what extent can plant communities and certain species adapt to altering environmental conditions. Our examinations were implemented in stands of sessile oak common in the Carpathian Basin. The reason behind it has been that, according to climatic models, the realized niche of this species can be reduced by 80% in some regions by 2050. Examinations were made in 3 points of an approximately 400 km long (East-West) transsect crossing the Carpathian Basin: 3 submontane regions of a subatlantic, a continental and a subcarpathian mountain were involved with 5 age groups in each regions. Health status examinations of sessile oaks have been completed by using FAKOPP 3D acoustic tomograph. Among the three venues trees of the subatlantic area were the healthiest; here, the 100 years old age group showed the lowest deterioration, only 0.68%. The most severely deteriorated stands occur in the continental region where the value in the 60 years old age group reached 4.24%. It seems that, besides annual precipitation, the method of planting also influences the health status of stands, since considerable differences could be observed between coppice and seedling stands.

Key words: sessile oak; Central Europe; acoustic tomograph; age groups; layers

Editor: Jaroslav Holuša

1. Introduction

It can be generally stated that responses of life forms regarding climate change alter by regions and also by species. Researches fulfil important roles in the exact and reliable predictions about changes occurring in relation of time and space (e.g. Walther et al. 2002; Root et al. 2003; Parmesan & Yohe 2003; Parmesan 2006).

Based on the trend analyses related to the second half of the 20th century and involving the Carpathian Basin temperature rise, decrease of precipitation and more extreme precipitation conditions – regarding both frequency and quantity – can be clearly observed (Domokos 2003).

According to the result of modelling Bartholy & Schlanger (2004) states that (+0.8) – (+2.8) °C temperature change can be expected by 2050 while this value can be as high as (+1.3) – (+5.2) °C by 2100. As for modelling precipitation (−1) – (+7)% and (−3) – (+14)% can be foreseen by 2050 and 2100, respectively. Calculations made within the model indicate that winters and springs will be more humid while summers and autumns will be more arid compared to the present situation.

Several studies state that climate-determined transitional zones will react the most sensitive way on climate change (e.g. Risser 1995). Due to their geographical location ecosystems of the Carpathian Basin can be particularly vulnerable to the currently observed and predicted changes of precipitation (Czóbel et al. 2010). However, responses of these ecosystems to these changes are hardly or not known (Czóbel et al. 2008).

Continental xerophytic and mesophytic oaks usually encompass flatlands in the Carpathian Basin while following the lines of mid-mountains. Extremely arid areas of these mid-mountain ranges with their shallow topsoil are not favourable for the closed stands since water is the limiting factor for these communities (Borovics & Mátyás 2013; Trenyik et al. 2017). Numerous publications mention the fact that some severe drought periods affected the Carpathian Basin since the 1970s due to the extremities of the climate (Pieczka et al. 2011). Parallel to this aridification the decay of main tree species has been

*Corresponding author. Petra Trenyik, e-mail: trenyikpetra@gmail.com, phone: +36 30 5242 789

observed. Among them the deterioration of sessile oak (*Quercus petraea*) has been remarkable. The reason of this process was investigated by numerous researchers such as Jakucs et al. (1988) and Berki (1991). Eventually Vajna (1990) provided the answer for this rather complex issue. In his opinion arid years are responsible for the decay of oak trees. Parasite fungi and folivorous insects appear, in great numbers, on trees weakened by the lack of water. Later it has also been observed that in those stands where the climate is close to the tolerance limit of the stand the vitality of tree species is compromised (Szőllősi et al. 2008).

Some prognoses indicate the narrowing of the realized niche optimal for sessile oak; according to Czúcz et al. (2011) this narrowing process can reach 80 to 100% by 2050.

The FAKOPP 3D Acoustic Tomograph is a mobile instrument suitable for field research. It is suitable for determining the extent of rotting by using a method not destroying tree tissue. Parallel to the fibers the propagation speed of sound can reach 4000 to 5000 m/s; it is 15 times faster than in the air. FAKOPP has been developed based on this considerable difference as well as on the fact that propagation speed of sound waves is in strong correlation with the mechanical characteristics of wood substance (Divós & Divós 2005). This advanced method of examination measures the propagation speed of sound within the tree. The existence of deterioration and cavities are mapped by identifying the change of propagation speed(Divós et al. 2005, 2008).

FAKOPP is generally used in case of park trees in order to examine the health status of one specimen. There was no previous example of using it on sessile oak (*Quercus petraea*) in systematically selected places and age groups, thus our examination can be considered as novum.

Limited amount of international literature can be found about acoustic tomograph examinations. Among them FAKOPP has mainly be used with the goal of examining the accuracy of the instrument. Liang (2008) compared in several cases the extent of deterioration indicated by the instrument and the heartwood formation that could be seen after felling. The result of this examination was that in case of trees where internal check had been found in the trunk the instrument typically slightly overestimates the extent of deterioration. Wang et al. (2007, 2008) drew the same conclusion when examining the health status of *Prunus serotina* trees.

Similar examination were carried out by Wang et al. (2007, 2008) involving 200-year-old red oak (*Quercus rubra*) trees, although they implemented, beside using FAKOPP, visual inspections regarding the health status of trees. After cutting the examined specimens it was experienced that problems could generally be identified by both methods, however the instrument was able to determine the extent and place of deterioration, too.

The objective of our examinations was to reveal, by instrumental measurements, the health status of sessile oaks in 5 different age groups in 3 mid-mountain regions alongside the West-East transsect. Our presupposition was that the health status of oaks is related to the precipitation conditions; as a result of it the changes influence younger age groups as well. The three selected mountain ranges have different climatic features: travelling from West toward East the first, second and third mountain has subatlantic, continental and subcarpathian climate, respectively.

2. Materials and methods

Our examinations have been implemented in three different mountain ranges within the Carpathian Basin. These ranges are situated at the ends and the middle of a 400 km long East-West orientation transsect in the Carpathian Basin. The westernmost among them is the Kőszeg Mountains having subatlantic climate; the middle one is Börzsöny with continental climate and at the eastern end Zemplén Mountains have subcarpathian climate.

Five forest age classes were selected in each mountains; they represented five age groups from 20 to 100 years in 20 years intervals (Table 1). The following standard parameters were taken into account during selection so that data could be comparable: similar altitude above sea level (approx. 400 m), slope angle (<15º) and southern exposure. Furthermore, sessile oak (*Quercus petraea*) shall have be the main species of the stands (at least 70% of the canopy). Local forest management units helped in finding and selecting the suitable stands.

Table 1. The forest management units of the studied forest.

Age group	Kőszeg Mountains	Börzsöny Mountains	Kőszeg Mountains
20 years	Kőszeg 22 C	Diósjenő 27 A	Nagyhuta 109 A
40 years	Bozsok 10 A	Diósjenő 34 C	Nagyhuta 109 B
60 years	Bozsok 16 C	Diósjenő 31 B	Komlóska 53 D
80 years	Bozsok 17 E	Diósjenő 34 B	Makkoshotyka 15 A
100 years	Bozsok 15 C	Börzsöny 43 C	Háromhuta 101 D

Two 20 by 20 metre quadrats were delineated in each subcompartment. Sessile oak trees nearest to the corners of the quadrat as well as the one nearest to the middle of it were appointed as sample trees. Thus five sample trees were selected in each quadrat and 10 in each age group. Trunks of the sample trees were measured in five different heights (40 cm, 80 cm, 120 cm, 160 cm and 200 cm) by horizontally inserting the sensors. Due to the smaller diameter 6 sensors were installed in the two youngest (20 and 40 years) stands while 8 sensors were used in all the other ones. By completing the measures the extent of deterioration was revealed in percentage. Existence, size and location of frost ribs was also documented.

Annual average precipitation data provided by the Hungarian Meteorological Service were also used during the assessment. These data were recorded between

1961 and 2015 at certified weather stations nearest to the selected stands.

For normally distributed data the t-test was applied to identify significant differences between datasets. Statistical analyses were calculated using SigmaPlot2000 (SPSS Inc., Chicago, USA). Regressions and correlations were fitted and computed using SigmaPlot2000.

3. Results

3.1. Twenty years old stands

The stand in continental mountain was the healthiest: the extent of deterioration was only 1.5% within the youngest age group (Fig. 1). The 20-year-old stand of the subatlantic mountain was in slightly worse condition: the measured decay was 1.88% considering all values recorded in the five layers. It can clearly be seen by the figure that the highest rate of decay was measured in the subcarpathian region: the value was 3.46%. Similar trend can be observed as regards of standard deviation calculated within the layers: its range was between 0.29 and 1.77 in the subatlantic mountain; between 0.99 and 3.00 in the continental mountain, while it shows the highest values between 0.65 and 3.52 in the subcarpathian mountain.

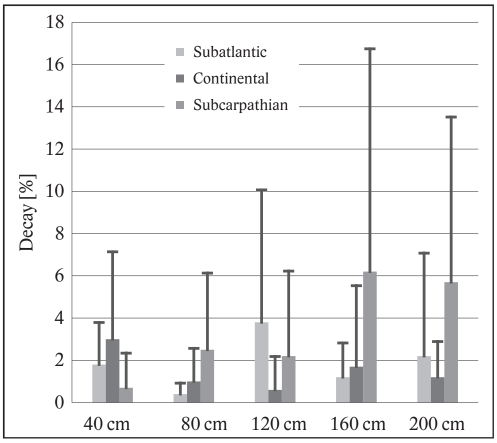

Fig. 1. Average decay and standard deviation of 20 years old *Quercus petraea* trees grown under three different climatic regions of the Carpathian Basin. Acoustic tomographic measurements were made at 5 height layers of tree trunks.

3.2. Forty years old stands

In case of this age group different data of average deterioration were compared to the younger trees. The healthiest stand was found in the subatlantic mountain, where the extent of decay was only 0.9%, followed by 1.54% measured in the subcarpathian mountain and 2.14% decay in the continental mountain (Fig. 2). Deterioration rate was dispersed between 0.1 and 2 in the subatlantic mountain, since the standard deviation reached only 0.77. As for the continental mountain the extent of decay was between 0.7 and 3.7 in the different layers, thus the standard deviation was 1.33. The highest deterioration and standard deviation was recorded in the lowest layer of tree trunks in the continental mountains: the decay reached 3.7% with a standard deviation of 5.85. At the opposite end the smallest deviation and deterioration were observed in the 4th layer of the subatlantic mountain: the decay was only 0.2% with a standard deviation of 0.42.

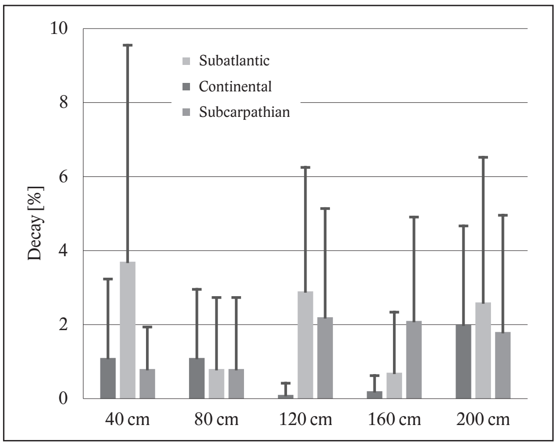

Fig. 2. Average decay and standard deviation of 40 years old *Quercus petraea* trees grown under three different climatic regions of the Carpathian Basin. Acoustic tomographic measurements were made at 5 height layers of tree trunks.

3.3. Sixty years old stands

In case of 60-year-old trees deterioration was clearly the lowest in subatlantic and subcarpathian mountains; on the contrary, remarkably high values were measured regarding oaks of the continental mountain (Fig. 3). Average rate of decay was only 0.8% in the subatlantic mountain with the fluctuation between 0.5 and 1.2% in the different layers. Standard deviation was also low: 0.29. Average level of deterioration was 4.24% accompanied by a high rate of standard deviation (3.00) since the amount of decay was distributed between 1.6 and 9% in the continental mountain. Average deterioration in the subcarpathian mountain was 1.44%; the values were dispersed between 0.5 and 2.2% within the layers and, as a result, lower standard deviation (0.65) was calculated. Both the decay and the standard deviation reached outstanding values (3.7% and 5.85, respectively) in the lowest layer of tree trunks in the continental mountain. It can be stated that in this age group the highest (i.e. 5th) layers show the least amount of deterioration: this value was 1.2%, 1.6% and 1.7% in the subatlantic, continental and subcarpathian mountains, respectively. Low standard deviation were associated to these small deterioration rates: 2.39 in subatlantic, 0.96 in continental and 2.98 in subcarpathian mountain.

As a result of the statistical analysis significant difference has been identified in the 60-year-old age group among the three mountains /continental-subatlantic ($p<0.05$); continental-subcarpathian ($p<0.05$); subatlantic-subcarpathian ($p<0.05$)/.

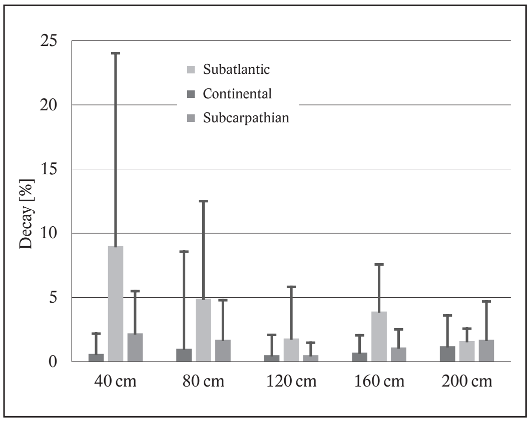

Fig. 3. Average decay and standard deviation of 60 years old *Quercus petraea* trees grown under three different climatic regions of the Carpathian Basin. Acoustic tomographic measurements were made at 5 height layers of tree trunks

3.4. Eighty years old stands

In each of the three regions greater extent of deterioration was observed regarding this age group and standard deviation values were also higher. Average decay was 3.34% in the subatlantic mountain with the fluctuation between 1 and 5.3% among the layers. Remarkably high decay (between 2.8 and 5.3%) and deviation (between 8.02 and 10.53) was measured in the lower three layers. As regards of the continental mountain average decay level was 1.94% with a standard deviation of 1.29. In this case the lower two layers had the greatest deterioration: 3.4% and 3.1%. Their respective standard deviation values were 4.55 and 4.20. In the subcarpathian mountain the average decay level reached only 1.26% accompanied by 1.61 standard deviation; the rate of deterioration was between 0.2 and 4.1%. The first layer had 4.1% decay and a considerably high standard deviation of 10.92.

We found significant differences between subatlantic and subcarpathian stands ($p<0.05$).

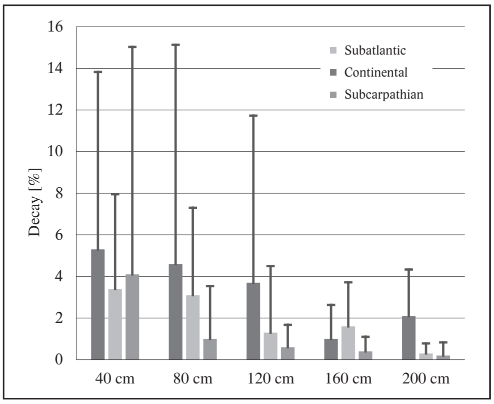

Fig. 4. Average decay and standard deviation of 80 years old Quercus petraea trees grown under three different climatic regions of the Carpathian Basin. Acoustic tomographic measurements were made at 5 height layers of tree trunks.

3.5. Hundred years old stands

As for the oldest examined trees the highest extent of decay was measured in the subcarpathian mountain (Fig. 5). The subatlantic stand was the healthiest: its average decay was only 0.68% dispersed between 0.3 and 1.2% among the layers. The average standard deviation was also low: 0.34. Deterioration of sessile oaks in the continental mountain was measured 2.78% with a low deviation of 1.15. It is due to the fact that decay values fluctuated between 1.8 and 4.6%. Average deterioration in the subcarpathian mountain was 3.42% while the standard deviation was higher: 3.52. The lowest two layers had both the highest decay and deviation. The former was 7.9% and 6.4%; the latter 11.23 and 9.58, respectively.

We found significant differences between continental and subcarpathian stands ($p<0.01$). The assessment of average decay divided by layers of the different mountains provided only one significant difference, namely between the 4th layers of continental and subatlantic stands ($p<0.05$). Statistical analyses were implemented among the different age groups within each of the three mountain types, but no significant differences were found among the stands selected in continental, subatlantic and subcarpathian mountains.

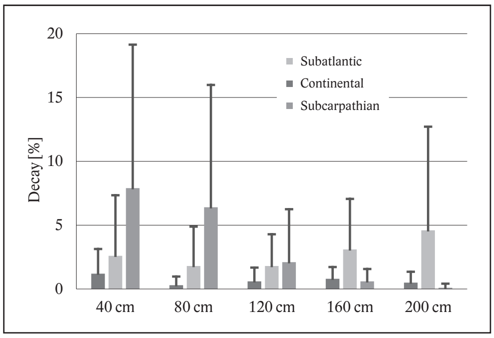

Fig. 5. Average decay and standard deviation of 100 years old *Quercus petraea* trees grown under three different climatic regions of the Carpathian Basin. Acoustic tomographic measurements were made at 5 height layers of tree trunks.

3.6. Assessment of precipitation data

After processing the precipitation data the results were indicated together with the rate of decay (Fig. 6). Based on the average precipitation recorded in the last 50 years the continental mountain proved to be the wettest (686 mm), followed by the slightly drier subatlantic mountain with 632 mm, while the subcarpathian mountain received the least precipitation (590 mm). As far as the health status is concerned the continental mountain provided the highest value of deterioration: 2.52%. The subcarpathian mountain came second with 2.24% and the subatlantic region had the lowest value: 1.52%.

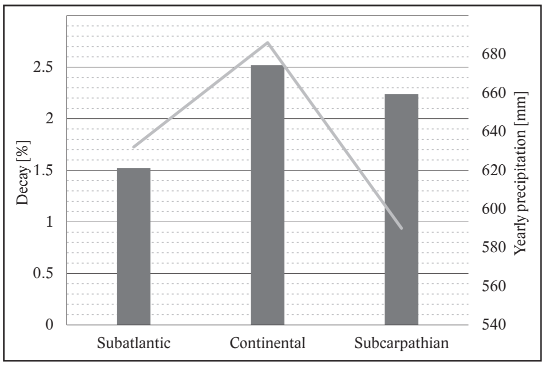

Fig. 6. Average decay (%) of *Quercus petraea* trees and average yearly precipitation (mm) in the examined mountains of the Carpathian Basin.

4. Discussion

Mátyás et al. (2010) and Czúcz et al. (2011) examine the climatic tolerance of tree species in Europe with particular attention to drought-tolerance of species. They concluded that in case of both beech and oak temperature and precipitation are two factors determining the distribution of species and the creation/vanishing of places macroclimatically suitable for these species. Although only precipitation conditions were involved in our examination, higher average decay was observed in the subcarpathian region where the annual amount of precipitation is lower as opposed by the subatlantic mountain where precipitation level is higher and the extent of deterioration is lower.

Berki et al. (2016) examined, via a survey implemented in 30 years, the vitality-decrease of oak trees occurring in arid periods. They found that the health status is around 70 to 90% in wetter areas (100% – completely healthy; 0% – dead) and approximately 50% in zones close to the aridity limit.

Results, released by the Forestry Protection Network of Hungary, based on leaf fall examination showed that beech and hornbeam trees are the healthiest among the stand-forming tree species of the region. Softwoods, poplars and other hardwoods are in moderate health condition while the health status of oak and coniferous forests is the worst.

Researches deal with the health of oak forests not only at stand level but also regarding specimens. Szőlősi et al. (2008) and Mészáros et al. (2007) examined the ecophysiology features that influence the climatic sensitivity of sessile oak (*Quercus petraea*) and Turkey oak (*Quercus cerris*). What kind of physiological reactions do they provide against the climatic fluctuations in their vegetation periods? What are their mechanisms protecting them during potential water utilisation disorders occurring in drought periods? In case of sample trees of both oak species they found that temperature and precipitation conditions during the leaf forming period have considerable influence on the size and mass of assimilating foliage developed in the vegetation period. Drought occurring in the leafing period can have serious effects on not only the rate of leaf forming but also on the annual production of the trees. On the one hand, production of organic matter and its storage determining the physiology for the next year is decreased. On the other hand, trees reaching a weakened health would be exposed to pests and other harmful organisms. In case of the examined oak species the photosynthetic apparatus shows great vulnerability and sensitivity for abiotic stress factors during spring.

Several instrumental examination involved the health status check of sessile oak stands. Trenyik et al. (2016) experienced deterioration patterns similar to our results in case of protected stands older than 100 years. This kind of decay is the most severe around the old root collar. During a FAKOPP examination implemented in different areas on old tree stands, beside the decaying trend characteristic of coppice stands, patterns of deterioration caused by frost ribs could also be identified (Trenyik et al. 2017a). In case of an other instrumental health survey check involving more stands of sessile oak it was concluded that lower average annual precipitation is paired with higher level of decay (Trenyik et al. 2017b).

In our examinations two trends were observed within each mountain regarding the distribution of deterioration among age groups. While generally lower rate of decay was measured in more layers in case of seedling stands, the highest level of deterioration was identified in the lowest layers (with a decrease in higher layers) in case of coppice stands. Following the assessment of our measurements in 3D and that of the notes made during field examinations the first of these trends was attributed to frost ribs and the decay initiated by them. As for the second trend the decay starting from root stock and typical of coppice trees was made responsible (Blake 1983).

5. Conclusions

Monitoring of the health status of forests has a long history, although its importance has increased due to climate change. More and more scientific researches aim to determine the climatic tolerance of certain species. Our examinations corroborate the results of health status checks implemented on oak trees in the Carpathian Basin. We were able to create a more exact and more delicate picture due to the instrumental measurement. Our examinations provided a clear view of the health of different age groups via the extent of decay in the tree trunks.

Our research has not justified the fact that precipitation conditions have strong impact on the health status of sessile oaks (Szőllősi et al. 2008). The reason behind it could be that differences among the average precipitation were small as regards of the involved mountains. That is why it is so important to acquire information on the climatic tolerance of main stand-forming tree species as well as to forecast, as accurately as possible, the impacts of climate change. The role of forest management will be even more significant so that stands with appropriate climate tolerance would be planted to the appropriate places.

References

Bartholy, J., Pongrácz, R., Matyasovszky, I., Schlanger, V., 2004: Climate tendencies occurred in the 20th century and projected for the 21st century in Hungary. AGRO-21 füzetek, p. 6–12.

Berki, I., 1991: Research into the cause of oak decay decline in Hungary. Proceedings of International Symposium on Ecological Approaches of Environmental Chemicals, Debrecen, p. 8–14.

Berki, I., Rasztovits, E., Móricz, N., Kolozs, L., 2016: The Role of Tree Mortality in Vitality Assessment of Sessile Oak Forests. South-East European forestry 7:91–97.

Blake, T. J., 1984: Coppice systems for short-rotation intensive forestry: the influence of cultural, seasonal and plant factors. Australian Forest Research, 13: 279–291.

Borovic, A., Matyas, Cs., 2013: Decline of genetic diversity of sessile oak at the retracting (xeric) limits. Annals of Forest Science, 70:835–844.

Czóbel, Sz., Horváth, L., Szirmai, O., Balogh, J., Pintér, K., Németh, Z. et al., 2010: Comparison of N_2O and CH_4 fluxes from Pannonian natural ecosystems. European Journal of Soil Science, 61:671–682.

Czóbel, Sz., Szirmai, O., Nagy, J., Balogh, J., Ürmös, Zs., Péli, E. R. et al., 2008: Effects of irrigation on the community composition, and carbon uptake in Pannonian loess grassland monoliths. Community Ecology, 9:91–96.

Czúcz, B., Gálhidy, L., Mátyás, Cs., 2011: Present and forecasted xeric climatic limits of beech and sessile oak distribution at low altitudes in Central Europe. Annals of Forest Science, 68:99–108.

Divos, F., Divos, P., 2005: Resolution of Stress Wave Based Acoustic Tomography. In: 14th International Symposium on Nondestructive Testing of Wood 2005, University of Applied Sciences, Eberswalde, Germany 2005.

Divos, F., Denes, L., Iniguez, G., 2005: Effect of cross-sectional change of a board specimen on stress wave velocity determination. Holzforschung, 59:230–231.

Divos, F., Divos, P., Divos, Gy., 2008: Acoustic Technique use from Seedling to Wooden Structures. Proceedings of the 15th International Symposium on Nondestructive Testing of Wood Duluth, Minnesota.

Domokos, P., 2003: Recent precipitation trends in Hungary in the context of larger Scale climatic changes. Natural Hazardous, 29:255–271.

Fischer, R., 2010: Forest condition in Europe: 2010 technical report of ICP Forests. Work Report of the Institute for World Forestry No. 2010/1, p. 108–109.

Jakucs, P., 1988: Ecological approach to forest decay in Hungary. Ambio, 17:267–274.

Liang, S., Wang, X., Wiedenback, J., Cai, Z., Fu, F., 2007: Evaluation of acoustic tomography for tree decay detection. In: Ross, R. J., Wang, X., Brashaw, B. K. (eds.): Proceeding of the 15th international symposium on nondestructive testing of wood, University of Minnesota Duluth and USDA Forest Products Laboratory Madison, p. 48–54.

Mátyás, Cs., Berki, I., Czúcz, B., Gálos, B., Móricz, N., Rasztovits, E., 2010: Future of Beech in Southeast Europe from the Prespective of Evolutionary Ecology. Acta Silatica & Lignaria Hungarica, 6:91–110.

Mészáros, I., Veres, Sz., Kanalas, P., Oláh, V., Szőllősi, E., Sárvári, É. et al., 2007: Leaf growth and photosynthetic performance of two co-existing oak species in contrasting growing seasons. Acta Silvatica & Lignaria Hungarica, 3:7–20.

Parmesan, C., 2006: Ecological and Evolutionary responses to recent climate change. Annual Review of Ecology Evolution and Systematics, 37:637–669.

Parmesan, C., Yohe, G., 2003: A globally coherent fingerprint of climate change impacts across natural systems. Nature, 421:37–42.

Pieczka, I., Pongrácz, R., Bartoly, J., 2011: Comparison of simulated trends of regional climate change in the Carpathian basin for the 21st century using three different emission scenarios. Acta Silvatica & Lignaria Hungarica, 7:9–22.

Risser, P. G., 1995: The status of the science examining ecotones. BioScience, 45:318–325.

Root, T. L., Price, J. T., Hall, K. R., Schneider, S. H., Rosenzweig, C., Pounds, J. A., 2003: Fingerprints of global warming on wild animals and plants. Nature, 421:57–60.

Solomon, S., Qin, D., Manning, M., 2007: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the 4th Assessment Report of the IPCC, Cambridge University Press.

Szőllősi, E., Koncz, P., Kanalas, P., Veres, Sz., Mészáros, I., 2008: Effects of drought on some ecophysiological traits of sessile oak (*Quercus petraea* L.). In: Proceedings of the VII. Alps-Adria Scientific Workshop Stara Lesna, p. 295–298.

Trenyik, P., Ficsor, Cs., Demeter, A., Falvai, D., Czóbel, Sz., 2017 b: Examination the health state with instrumental measurements and the diversity of sessile oak stands in Zemplén mountains. Columella, 4:21–30.

Trenyik, P., Szirmai, O., Barczi, A., Skutai, J., Czóbel, Sz., 2016: Examination on the state of health regarding a protected sessile oak stock. Analecta Technica Szegedinensia, 10:23–28.

Trenyik, P., Szirmai, O., Magyar, V., Demeter, A., Skutai, J., Czóbel, Sz., 2017 a: Instrumental measurement of health status of old natural sessile oak stands. Studia botanica Hungarica, 48:125–132.

Vajna, L., 1990: Fungi associated with oak-decline. EPPO Bulletin, 20:3.

Walther, G. R., Post, E., Convey, P., Menzel, A., Parmesan, C., Beebee, T. J. C. et al., 2002: Ecological responses to recent climate change. Nature, 416:389–395.

Wang, X., Allison, R. B., 2008: Decay detection in red oak trees using a combination of visual inspection, acoustic testing and resistance microdrilling. Journal of Arboriculture and Urban Forest, 34:104.

Wang, X., Allison, R. B., Wang, L., Ross R. J., 2007: Acoustic tomography for decay detection in red oak trees. Research paper FPL-RP-642; United States Department of Agriculture, Forest Service, Forest Product Laboratory: Madison, Wisconsin, U.S.A., p. 1–7.

Wang, X., Wiedenbeck, J., Liang, S., 2009: Acoustic tomography for decay detection in black cherry trees. Wood Fiber Science, 41:127–137.