Hungarian University of Agriculture and Life Sciences (MATE)

INSTRUMENTAL STUDY OF THE HEALTH STATUS OF NORWAY SPRUCE /*Picea abies* (L.) H. Karst/ AND DWARF MOUNTAIN PINE /*Pinus mugo* (Turra)/ IN THE EASTERN ALPS.

(L.) H. Karst.

Theses of doctoral (PhD) dissertation

Falvai Dominika

Gödöllő

2022

Name of Doctoral (PhD) School: PhD School of Enviromental Sciences

Discipline: Environmental Sciences

Head of School: Csákiné Dr. Michéli Erika
professor, DSc
Hungarian University of Agriculture and Life Sciences
Institute of Environmental Sciences
Department of Soil Science

Scientific Supervisor: Dr. Czóbel Szilárd
professor, PhD
University of Szeged
Institute of Plant Sciences and Environmental Protection
Fakulty of Agriculture

....
Csákiné Dr. Michéli Erika
Approval of Head of School

....
Prof. Dr. Czóbel Szilárd
Approval of Scientific Supervisor

1. Background and objectives

A global analysis of climate change shows that the Earth's temperature has warmed by 0.7 °C on average since the beginning of the last century, and that the ten warmest years occurred after 1990. In the last three decades, the Earth's surface has been warmer than in any previous decade since 1850 (NATéR 2018). Several climate models predict a significant increase in temperature in mountainous regions, which, together with other factors, may affect the distribution of montane and subalpine species and the composition of the communities here. The development of the global climate is influenced to the greatest extent by the atmospheric presence of greenhouse gases and pollutants. The current climate problem is caused by changes in atmospheric processes, which are mainly related to anthropogenic activities (IPCC 2007). The indirect effects of emissions have now caused changes in physical and biological processes on all continents and oceans. Based on the research so far, it can generally be said that the responses of the living world to climate change differ from region to region and species, so these researches play an important role in predicting temporal and spatial changes as accurately as possible (Walther et al. 2002, Root et al. 2003, Parmesan & Yohe 2003, Parmesan 2006). Because of the basically passive attitude of nature conservation, active nature conservation interventions are hindered in many cases, so climate change endangers protected areas even more. If the living conditions of a nature reserve become unsuitable for the wildlife, the species living there cannot be replaced, only their adaptation and migration can be taken into account. Until now, the areas surrounding natural ecosystems have played an important role, but their importance may increase further in the event of a temperature rise of several degrees, when the conditions currently prevailing in the associations may change significantly. Examining the near-natural forests in which extensive silviculture is taking place can help us to monitor the changes (Czúcz et al. 2007). According to several studies, climatically defined transition zones are expected to react most sensitively to climate change (e.g. Risser 1995). The ecosystems of mountain vegetation - including the vegetation of high mountains - are inherently more vulnerable, partly because of their simple structure, and partly because many plant species live close to their survival limits here. On the basis of these characteristics, as well as through recent comprehensive research (Elmendorf et al. 2012, Gottfried et al. 2012), it has been proven that the high mountain ecosystems and the species occurring here react more sensitively and faster to global climate change. However, the responses of ecosystems to these changes are not, or are barely, known (Czóbel et al. 2008). The predicted level of emissions is not very promising, according to the pessimistic scenarios, we can count on an increase of up to 4 °C compared to the average of the period between 1986-2005 by the end of the 21st century (IPCC 2014).

High-altitude plants have adapted to low temperatures (Körner & Larcher 1988), since these high-altitude areas have a smaller area, making the species living here more sensitive to a warming climate. Alpine plants are less responsive to short-term climate fluctuations, on the other hand, -plants wich are located in the mentioned area- are much more affected by longer-term climate change, as most species are persistent, slow-growing and long-lived (Billings & Mooney 1968, Körner 2003, de Witte & Stöcklin 2010). High mountain ecosystems are regulated by climatic factors. Therefore, changes in the occurrence and composition of alpine plant species are extremely relevant as an indicator of the ecological effects of climate change (Theurillat & Guisan 2001, Grabherr et al. 2010, Malanson et al. 2011).

Territory of Hungary does not have high mountains, that is why I chose the examination of selected woody species of the eastern Austrian mountains as the topic of my doctoral research. Until now, the impact of climate change on woody plants in the Alps has typically been investigated using dendrochronological methods (e.g. Cherubini et al. 1998, Nicolussi et al. 2005, Savva et al. 2006, Chauchard et al. 2010). Examination of the tree population of mountainous areas along a vertical transect is also not common (Ohsawa et al. 2007), even though this type of examination provides a clear overview of the health status of a given tree species.

Based on the review of the literature, my doctoral research can be considered filling a gap because the health status of the norway spruce and dwarf mountain pine stands of the Alps had not been investigated before, using non-destructive instruments, along a vertical transect, in the entire area of the vegetation belt dominated by the selected plant species.

Understanding and detecting processes that damage tree trunks is crucial for the long-term maintenance of forests (Shigo 1991, Matheny

& Clark 1994, Mattheck & Breloer 1994, Mattheck 2007, Schwarze 2008). Based on these, I planned field measurements with portable instruments capable of measuring wood rot and fungal infection.

Despite abundant data on tree growth trends and climate-induced responses (e.g. Camarero et al. 2021), the often shrub-like ecosystems of forest border areas have hardly been researched so far. Because of the latter, we do not have enough knowledge about the growth characteristics of the trees found here, and we have limited data on the changes that occur as a result of climate change (Büntgen et al. 2007, Palombo et al. 2013, Carrer et al. 2019, Šenfeldr et al. 2021). Since my research affects the dominant woody plant species of these ecosystems, the dwarf mountain pine, my doctoral research work can be regarded as filling a gap in this field as well.

The main goals of this survey were the following:

1. To determine and compare the rot and degree of fungal infestation of Norway spruce in three different sample areas in the Eastern Alps along vertical transects.
2. To determine and compare the rot and the degree of fungal infestation of dwarf mountain pine in three different sample areas in the Eastern Alps along vertical transects.
3. Collection of the most important meteorological background data in the examined sample areas.
4. Examination of the main soil parameters in the examined sample areas along the selected vertical transect.
5. Evaluation of the health status of the studied tree species as a function of the altitude and the measured and modeled background variables.

2. Materials and methods

Examined plant species

- **Norway spruce – *Picea abies* (L.) H. Karst**

It is an important forest-forming tree species in the European mountains and northern plains from Lapland to the Balkans. Its European distribution area is divided into a northern, mostly plain-hilly region, and an Alpine-Carpathian belt. In the Carpathians, it occurs between 500 and 1,800 m in the north and between 800 and 1,950 m in the south and forms a continuous belt above the beech forests. (Polunyin 1981, Debreczy & Rácz 2000).

- **Dwarf mountain pine – *Pinus mugo* (Turra)**

It is a plant of the Alpine mountain range, with its relatives to the following areas: west of the Pyrenees, north of the czech Bohemian-Ore and Giant Mountains, south-east area of the Carpathians, Pirini in the Balkan Mountains, Abruzzi Alps of the Apennine Peninsula, Serrania de Cuenca of the Iberian Peninsula. It is a species characteristic of the European high mountains, but it also occurs on peat bogs in the lower zone (Polunyin 1981, Debreczy & Rácz 2000).

Characterization of the investigated area

I carried out my doctoral research in the Alps, whose ranges stretch from the Ligurian Sea to the Carpathian Basin for nearly 1,200 km in length and about 180 km in width in the E-W direction (Küpper 1964). In the young chain unit formed as a result of the collision of the former Laurasia and Gondwana, huge transposed mantle folds were formed. The characteristic structure of the Alps has developed, in which three characteristic blankets can be distinguished based on the type of rock and the geographical location. The Helvetic blanket, which also includes Variscan elements, was formed in the former Laurasian areas at the beginning of the geohistorical Middle Ages. The Pennine mantle consists of rocks belonging to the area of the ocean basins located between Gondwana and Laurasia, while the so-called Eastern Alpine blanket refers to the large mass of Triassic sediments (limestone, dolomite) formed on the northern coast of Gondwana.

The research areas wich I selected in the Eastern Alps, Austria were the following:

- Hochkar Mountains
- Stuhleck Mountains
- Wechsel Mountains

The selected sites were dominated by the Norway spruce (*Picea abies*) in the lower altitude montane zone and the dwarf mountain pine (*Pinus mugo*) in the subalpine zone, so I selected these tree species to examine the health status examination with the ArborSonic and ArborElectro measuring instruments.

During 2018, in the case of *Picea abies*, which prevails in the montane zone, 135 trees were measured in the area of the Hochkar Mountains (800-1500m), 162 in the area of the Stuhleck Mountains (850-1700m), while a total of 163 trees were measured in the Wechsel Mountains (800-1600m). Also in 2018, in the case of *Pinus mugo*, which is dominant in the subalpine zone, I examined 36 trees in the Hochkar Mountains (1550-1760m), 6 in the Stuhleck Mountains (1750m), and 14 in the Wechsel Mountains (1600-1700m). In 2018, I measured a total of 171 trees in the Hochkar Mountains, 168 in the Stuhleck Mountains, and 177 in the Wechsel Mountains.
During 2019, in case of *Picea abies*, 369 trees were measured in the Hochkar Mountains (800-1540m), 342 in the Stuhleck Mountains (850-1700m), and 369 in the Wechsel Mountains (800-1600m). During 2019, in case of *Pinus mugo*, 234 trees were measured in the Hochkar Mountains (1550-1750m), 60 in the Stuhleck Mountains (1705-1750m), and 114 in the Wechsel Mountains (1610-1700m). In 2019, I measured a total of 603 trees in the Hochkar Mountains, 402 in the Stuhleck Mountains, and 483 in the Weshsel Mountains.
The basic consideration in selecting the tree specimens was to be at least 10 meters away from the nearest road, and their trunk diameter and canopy should be as representative as possible of the tree specimens occurring at a given height.

ArborSonic 3D Acustic Tomograph (FAKOPP)

The ArborSonic 3D Acoustic Tomograph instrument measures the speed of sound propagation within a tree trunk and is able to detect the size and exact location of rotten or hollow regions without destruction (Divós & Szalay 2002, Frankl et al. 2006, Falvai et al. 2021). By measuring the speed of sound, the Acoustic Tomograph provides an excellent opportunity to detect hidden defects (cavities, decay) in living trees (Kloiber et al. 2006), i.e. it is suitable for examining decay. It measures the speed of propagation perpendicular to the fibers, which can reach 1500-1800 m/s, which is 15 times faster than the speed of propagation in air. The FAKOPP instrument was developed taking advantage of this significant difference and based on the fact that the propagation speed of sound waves is closely related to the mechanical properties of wood (Divós & Divós 2005, Divós et al. 2005). Rotting and its extent are mostly not visible from the outside. Knowledge of the internal state of the tree trunk fundamentally affects the assessment of the tree. By measuring the speed of sound, the size and location of cavities and decay in the trunk of the tree can be determined. A decrease in speed between two sensors indicates the presence of decay.

Acoustic tomographic measurements were performed in several vertical trunk layers, taking into account the different physiognomy of the species studied. I made sure that the geometry of the trunk of the selected trees was circular rather than elliptical or irregular. This was important so that the basic conditions were similar for the examined trees.

In 2018, decay measurements were made along a vertical transect, at heights of 50 meters above sea level, in all three test areas, both for norway spruce and dwarf mountain pine. In 2018, I measured 460 trees for *Picea abies* and 56 trees for *Pinus mugo* in the area of the three mountain ranges.

Based on the evaluation of the acoustic tomograph data collected in 2018 - as preliminary tests - in 2019, I used a finer spatial scale and denser sampling at certain altitudes in order to more accurately evaluate the changes in the degree of decay. In 2019, I measured a total of 1,080 trees for *Picea abies* and 408 for *Pinus mugo* in the area of the three mountain ranges.

Acoustic tomography measurements were performed at three heights (0.4, 0.8, and 1.2 m) from the ground level for Norway spruce using the ArborSonic 3D acoustic tomograph, and at two heights (0.2 and 0.4 m) for dwarf mountain pine using the ArborSonic 3D acoustic tomograph.

ArborElectro impedance tomograph

I examined fungal infection or deterioration with the ArborElectro impedance tomograph (ArborElectro, Sopron), which can non-destructively detect the location and size of active fungal infection within the trunk to get a more accurate picture of the stand and on the health status of tree speciments. The instrument measures the electrical resistance between electrodes on a specific slice of the trunk (unit: Ohm * m). The electrical resistance depends on the ion concentration of the area between the two electrodes, which is determined by the presence or absence of the fungus. With this method, fungal infections can be determined and detected at a very early stage (Divós et al. 2007).

During the fall of 2019, I used the ArborElectro Impedance Tomograph in all three test areas to measure the fungal infection of the trees. The latter, if it could be measured, I called rot during the evaluation. The processes of the measurements made with the ArborElectro Impedance Tomograph measuring device are the same in the three selected areas. The examination of fungal infection was carried out along the transect already mentioned in the FAKOPP examination in the case of all three mountain ranges, on exactly the same trees that were examined for rot. In the case of the selected trees, I measured them with the impedance tomograph in one layer, at a height of 80 cm, counting from the ground level.

Soil tests

In 2018 and 2019, I collected the samples required for the geological measurements in the Hochkar, Stuhleck and Wechsel mountains. In each of the three mountain ranges, I collected one soil sample for each examined altitude, next to the examined trees at different heights. The evaluation of the samples was preceded by a mechanical preparation (sieving, shredding). After drying the samples, it was possible to start the evaluations, which included soil pH and total carbonate (cc) measurements. I measured the pH of the soil in a 1:2.5 (w/v) soil:water and 1 M KCl suspension using a digital pH meter (Buzás 1989). The carbonate content of the soil was determined using the Scheibler calculator method (Buzás 1989). In addition to the laboratory tests, in 2019 I measured the soil thickness (Finnern 1994) in all three sample areas along the vertical transect with the Pürckhauer stick soil sampling measuring device at the altitudes where instrumental measurements were made.

Angle of descent measurement

In the fall of 2019, in case of all three mountain ranges, I measured the slope angles along the examined transects in order to determine the steepness of the given slope section. I performed the measurements in all three mountain ranges at the altitude of the 2018 decay tests, i.e. at an altitude of 50 meters above sea level, from the lower limit of the norway spruce belt to the continuous upper limit of the dwarf mountain pine belt.

Meteorological data collection

I downloaded the air temperature and precipitation data from the internationally recognized database of www.ecad.eu in September 2021. E-OBS includes daily average, maximum and minimum temperature values, as well as daily total precipitation. In all three sample areas included in my research, I used interpolated GPS data, since there were no meteorological stations providing data for the database on the selected mountains.

Statistical evaluation

In the case of all three mountain ranges, I used the PAST (PAleontological STatistics Version 3.21 and 4.05) statistical software package (Hammer 1999-2015, Hammer 1999-2021, Hammer 2001) to examine the correlations between the abiotic and the measured biotic parameters. For the basic statistics I used the sum- mary statistics, two sample t test and boxplot modules of the software.

I used version 3.6.1 of R for further detailed statistical calculations. (R core team 2020).

3. Results

In the case of both Norway spruce and Dwarf mountain pine, we found a significant, but partly different, correlation between the degree of decay and the altitude above sea level. Based on the acoustic tomographic data, the *Picea abies* population of the Wechel Mountains appears to be the healthiest, while that of the Hochkar

Mountains is the least healthy. In the Hochkar and Stuhleck mountains, the correlation between fungal infection and altitude was similar to the values measured by acoustic tomograph.

The decay results show that the health status of *Picea abies* individuals was the worst at the lower distribution limit of the species in all three investigated mountains. Based on the decay measurements, it seems that under the current climatic conditions, the spruce is in the best state of health at an altitude of between 1000 and 1500 meters above sea level, which altitude range can also be considered the optimum distribution of the species in the examined mountains. In this region, the values of *Picea abies* decay were similar to the data for Quercus petraea stands of different ages in the Carpathian Basin. The significant deviation of the significantly higher decay values observed at the lower distribution limit of the spruce indicates that the lower region of the distribution area of the species is less favorable for the species, so it can be assumed that the lower distribution limit of the tree species will move upwards by 50-100 meters, which is, for example, the Hochkar -mountain range, it is highly probable based on the decay data. Based on our results, it seems that although it would be more favorable for the spruce to move to higher areas in terms of the decreasing level of fungal infection, it rots more in several mountain ranges near the upper altitude limit of the distribution of the tree species - presumably due to the increasing level of stress. The latter can create a barrier to the upward movement of the spruce, so with the upward movement of the lower distribution limit, even a narrowing of the area may occur in case of *Picea abies*. The latter would be unfavorable from a nature conservation point of view, as it would be accompanied by a narrowing of the habitat it dominates. Presumably, only a part of the species associated with the sedges would be able to adapt to this narrowing of the area, which could lead to a decrease in the habitat's species diversity in the long term.

The significantly higher decay values of the dwarf mountain pine compared to the norway spruce can be explained by the greater abiotic stress characteristic of the higher region. In the case of *Pinus mugo*, no clear trend can be verified between the deterioration of the measured height levels. Based on the median values, the population of the Stuleck Mountains proved to be the healthiest, while the population of the Weschel Mountains had the worst health status due to the higher median and high interquartile range. In case of *Pinus mugo*, we observed a different trend in the relationship between the deterioration values and the altitude above sea level in the investigated mountains. However, when evaluating the results, it should be considered that the investigated *Pinus mugo* belt of the Hochkar Mountains was the widest (200 m), compared to the 100-meter belt of the Weschel Mountains and the 50-meter belt of the Stuleck. Thus, for drawing general conclusions, the changes measured in the Hochkar Mountains can be considered as guidelines. The changes observed in the Hochkar Mountains clearly show that the height of distribution of both investigated species, and thus the zone dominated by them, is expected to shift upwards. This expected trend may be different in several mountain ranges of the Alps in the future, which is depending on the environmental parameters.

The higher decay values observed in part at the upper limit of the distribution of *Picea abies* and *Pinus mugo* may also indicate that if the area of the tree species shifts upwards, it exposes them to increasing cold stress and more extreme weather events (e.g. stronger and more frequent wind storms, ice breaks), which may result in decreased fitness. The potential shift of mountainous vegetation belts and the transformation of habitats may not be favorable from a nature conservation point of view, because it is likely that not all species are able to migrate together with the tree species that make up the stands.

Based on the evaluation of the linear correlations, the *Picea abies* population of the Wechsel Mountains proved to be the most sensitive to environmental factors.

4. Summary of new scientific results

I summarize my new scientific results in the following points:

1. Based on the tests, it can be stated that in all three mountain ranges between 1,000 and 1,500 meters the rate of norway spruce rot is low, while the highest degree of rot of the species can be detected at and near the lower limit of its distribution at the stand level, and at the upper limit of the vertical distribution of spruce, fungal infection has decreased in all three mountain ranges extent.
2. At the lower limit of the distribution of norway spruce in the mountains of the Eastern Alps, a retreat of 50-100 m is expected in the near future, based on the high values of rot and fungal infection.
3. Based on the decay values, among the three investigated sample areas, the norway spruces of the Wechsel Mountains have the best health status.
4. In the case of *Picea abies*, I measured the highest average rot in all three examined areas at the height closest to the ground level (40 cm).
5. The dwarf mountain pine stands in all three test areas can be characterized by a significantly higher decay value compared to the norway spruce, regardless of the height above ground level.
6. Based on the decay data of the Hochkar Mountains, the study area with the largest vertical extent of norway pine belt, a further upward movement and expansion of *Pinus mugo* is expected.

5. Publications related to the topic of the dissertation

MTMT ID: 10071405

1. ***Publications in international peer-reviewed journals with an impact factor***

1. **Falvai, D**.; Saláta, D.; Baltazár, T.; Czóbel, Sz. (2021): Instrumental Study of the Health Status of *Picea abies* and *Pinus mugo* (Turra) and Their Relation to Environmental Parameters in the Eastern Alps. Forests 12, 716. https://doi.org/10.3390/f12060716 IF: 2,221 (Q1 besorolású)
2. Járdi, I.; Saláta. D.; Falusi. E.; Stilling. F.; Pápay. G.; Zachar. Z.; **Falvai. D**.; Csontos. P.; Péter. Norbert.; Penszka. K.; (2021): Habitat Mosaics of Sand Steppes and Forest-Steppes in the Ipoly Valley in Hungary. Forests 13, 135. https://doi.org/10.3390/f12020135 IF: 2,221 (Q1 besorolású)
3. Rusvai K., Saláta D., **Falvai D**., Czóbel SZ. (2022): Assessment of weed invasion at bait sites in a Central European lower montane zone. Perspectives in Plant Ecology, Evolution and Systematics doi.org/10.1016/j.ppees.2022.125669 IF: 3.634 (Q1 besorolású)

2. A peer-reviewed, full-text scientific communication published in scientific journals (accepted for publication).

2.1. In a non-impact factor journal in a foreign language

1. **Falvai D.**, Baltazár T., Czóbel Sz. (2019): Health status analysis of Norway spruce and shrubby pine along an elevation gradient. Columella – Journal of Agricultural and Environmental Sciences. 6(2): 29-36. DOI: 10.18380/SZIE.COLUM.2019.6.2.29

2. Demeter A., **Falvai D.**, Trenyik P., Czóbel Sz. (2017): Ecological indicator based comparative study of tree of heaven (*Ailanthus altissima*) stands' herb layer. Columella: Journal of Agricultural and Environmental Sciences 4: 15-20.

3. Trenyik P., Ficsor Cs., Demeter A., **Falvai D.**, Czóbel Sz. (2017): Examination the health state with instrumental measurements and the diversity of sessile oak stands in Zemplén mountains. Columella: Journal of Agricultural and Environmental Sciences 4: 21-30.

2.1.1. Domestic edition

1. **Falvai D.**, Baltazár T., Szegleti Zs., Czóbel Sz. (2020): *Picea abies* és a *Pinus mugo* fafajok egészségi állapotának vizsgálata a Wechsel-hegység természetközeli erdőállományaiban. Természetvédelmi Közlemények 26: 16-27 DOI: 10.20332/tvk-jnatconserv.2020.26.16

3. Announcements published in congress publications

3.1. Conference publications

3.1..1. Abstract in Hungarian

1. **Falvai D.**, Baltazár T., Czóbel Sz. (2019): A lucfenyő (*Picea abies*) és a törpefenyő (*Pinus mugo*) egészségi állapotának elemzése magassági gradiens mentén. Health status analysis of norway spruce (*Picea abies*) and shrubby pine (*Pinus mugo*) along an elevation gradient. pp. 53-55. In: Pápay G. (szerk.) "IV. Fenntartható fejlődés a Kárpát-medencében" konferencia. "Gyepek biodiverzitása a Kárpát-medencében" Absztraktkötet. 87 p. Hódmezővásárhely, 2019. december 4. Szent István Egyetem, Egyetemi Nyomda. ISBN: 978-963-269-879-3
2. **Falvai D.**, Szirmai O., Czóbel Sz. (2018): A Gödöllői Botanikus Kert kiválasztott faállományának teljeskörű faérték és ökoszisztéma szolgáltatás számítása. Calculation of the complete tree value and ecosystem service of selected tree stock of the Gödöllő Botanical Garden. pp. 64. In: Molnár V.A., Sonkoly J., Takács A. (szerk.) XII. Aktuális Flóra- és Vegetációkutatás a Kárpát-medencében. Program és összefoglalók: 12th International Conference Advances in research on the flora and vegetation of the Carpato-Pannonian region. Programme and Abstracts, Debrecen, Magyarország: Debreceni Egyetem TTK Növénytani Tanszék.
3. **Falvai D.**, Baltazár T., Czobel Sz., (2021) : A *Pinus mugo* és a *Picea abies* egészségügyi állapotának vizsgálata egy vertikális transzekt mentén, a Keleti-Alpok egy kijelölt mintaterületén. pp.106. In: Cseresznyés D., Király Cs. XVI Kárpát – Medencei környezettudományi konferencia. Program és összefoglalók: 16th Carpatian Basin Conference for Envionmental Sciences. Programme and Abstracts, Budapest, Magyarország: Eötvös Lóránd Tudományegyetem Természettudományi Kar. ISBN: 978-963-8221-82-7
4. **Falvai D.**, Baltazár T., Czobel Sz., (2020) : *Pinus mugo* és a *Picea abies* egészségi állapotának egy magassági gradiens mentén való elemzése. p. 28. 1 p. In:
   Lukács Gábor, Kormos Éva. LXII Georgikon napok nemzetközi tudományos konferencia. Programme and Abstracts, Keszthely, Magyarország: Georgikon Kar. ISBN: 9789632699417
5. **Falvai D.**, Czobel Sz., (2020): Possibilities of instrumental measurement related to the tree health. pp.47 In: Hosam E.A.F. Bayoumi Hamuda.11th ICEEE – 2020 International annual conference on "Sustainable Envirnmental Protection & Waste Management Responsibility". Programme and Abstracts, Budapest, Magyarország: Óbuda University Institute of Environmental Engineering & Natural Sciences (KTI) Rejtő Sándor Faculty of Light Industry & Environmental Engineering (RKK). ISBN: 978-963-449-203-0
6. **Falvai D.**, Baltazár T., Czobel Sz., (2021) : Fakopp 3-Dimensional Acoustic Tomography measurements, in the Eastern Alps, along a designated vertical transect. pp.36 . In: Hosam B. H., Bodáné-Kendrovics

R., Demény K., Kaszás J., Szeder A., Sósné – Berecz M., Várkövi j., Tamássy Zs. V th International Symposium – 2021 "Environmental Quality and Public Health. Programme and Abstracts, Budapest, Magyarország: Óbuda University Institute of Environmental (RKK). " ISBN: 978-963-449-238-2

3.1.2. Foreign abstract

1. **Falvai D.**, Czóbel Sz., Baltazár T. (2020): Instrumental health condition examination of coniferous trees along a vertical transect. p. 10. In: Ozaslan M. et al. (eds.): International Conference on Veterinary, Agriculture and Life Sciences (ICVALS) October 29-November 1, 2020 – Antalya, TURKEY. Abstract Book. 27 p.
2. Czóbel Sz., **Falvai D.**, Ficsor Cs. (2019): Health condition studies of dominant coniferous trees along an elavation transect in the eastern Alps. In: 2nd International Conference ADAPTtoCLIMATE, 2 p. Paper: ADAPTtoCLIMATE2019_Falvai_etal , 2 p.
3. **Falvai D.**, Baltazár. T., Czobel. Sz., (2019): Observing the health status of coniferous trees in the eastern Alps. In: Rosario G. Gavilán ; Alba Guitérrez-Girón. 28th EVS Meeting: Abstracts & Programme : Vegetation Diversity and Global Change. 131-131 pp. Madrid, Spanyolország. ISBN: 9788409137381
4. **Falvai D.**, Czóbel Sz. (2019): Tűlevelű fák egészségi állapotának vizsgálata egy magassági transzszekt mentén. 40-41 pp. In: Szigyártó, I-L; Szikszai, A (szerk.) XV. Kárpát-medencei Környezettudományi Konferencia Kolozsvár, Románia: Ábel Kiadó, (2019) 303 p. ISSN: 1842-9815.
5. Czóbel, Sz ; Németh, Z ; Ficsor, Cs ; **Falvai, D** ; Szegleti, Zs ; Szirmai, O (2018): Ecological features of three forest spring geophytes. p. 38. In: University, of Wroclaw (szerk.) 27th Congress of the European Vegetation Survey. 23-26 May, 2018 Wrocław, Poland. Book of Abstracts, Oral presentations. Wrocław, Lengyelország : University of Wroclaw.

6. References

BILLINGS W.D., MOONEY H.A. (1968): The ecology of arctic and alpine plants. Biological Reviews of the Cambridge Philosophical Society 43: 481–529.

BUZÁS I. (1989): Soil and agrochemical test method book 2. Physico-chemical and chemical test methods for soils. Agrokémia Talajt. (38) 504–505.p.

BÜNTGEN U., FRANK D.C. , KACZKA R.J. , VERSTEGE A., ZWIJACZ-KOZICA T., ESPER J. (2007): Growth responses to climate in a multi-species tree-ring network in the Western Carpathian Tatra Mountains, Poland and Slovakia. Tree Physiol, (27) 689-702.p. doi:10.1093/treephys/27.5.689.

CAMARERO J.J., GAZOL A., SÁNCHEZ R., SALGUERO., FAJARDO A., MCINTIRE E.J., GUTIÉRREZ E., WILMKING M. (2021): Global fading of the temperature–growth coupling at alpine and polar treelines. Glob. Change Biol, 27 (9), 1879-1889.p. doi:10.1111/gcb.15530

CARRER M., PELLIZZARI E., PRENDIN A.L., PIVIDORI M., BRUNETTI M. (2019): Winter precipitation-not summer temperature-is still the main driver for Alpine shrub growth. Sci. Total. Environ., (682) 171-179.p. doi: 10.1016/j.scitotenv.2019.05.152.

CHAUCHARD S., BEILHE F., DENIS N., CARCAILLET C. (2010): An increase in the upper tree-limit of silver fir (Abies alba Mill.) in the Alps since the mid-20th century: A land-use change phenomenon. 259, 8, 31, 1406-1415.p. doi.org/10.1016/j.foreco.2010.01.009.

CHERUBINI P., DOBBERTIN M., L.INNES J. (1998): Potential sampling bias in long-term forest growth trends reconstructed from tree rings: A case study from the Italian Alps. doi.org/10.1016/S0378-1127(98)00242-4.

CZÓBEL SZ., SZIRMAI O., NAGY J., BALOGH J., ÜRMÖS ZS., PÉLI E.R. & TUBA Z. (2008): Effects of irrigation on the community composition, and carbon uptake in Pannonian loess grassland monoliths. Community Ecology 9: 91-96.

CZÚCZ B., KRÖEL-DULAY GY., RÉDEI T., BOTTA-DUKÁT Z., MOLNÁR ZS. (2007): Éghajlatváltozás és biológiai sokféleség – elemzések az adaptációs stratégia tudományos megalapozásához. MTA ÖBKI 280. p.

DEBRECZY ZS., RÁCZ I., (2000): Fenyők a Föld körül. Dendrológiai Alapítvány, Budapest, pp. 552, ISBN: 963-00-5898-7

DIVÓS F., DENES L., INIGUEZ G. (2005): Effect of crosssectional change of a board specimen on stress wave velocity determination. Holzforschung, 59:230–231.

DIVÓS F., DIVOS P. (2005): Resolution of Stress Wave Based Acoustic Tomography. In: 14th International Symposium on Nondestructive Testing of Wood. University of Applied Sciences, Germany, Eberswalde. ISBN 3-8322-3949-9

DIVÓS F., DIVÓS P. DIVÓS GY. (2007): Acoustic Technique use from seedling to wooden structures. In: Brashaw B. (Eds): Proceedings of the 15th International Symposium on Nondestructive Testing of Wood. Duluth, 230–231.p.

DIVÓS F., SZALAY L. (2002): “Tree evaluation by acoustic tomography,” in: Proceedings of the 13th International Symposium on Nondestructive

Testing of Wood, F.C. Beall (ed.), Forest Products Research Society, Madison, WI, 251-256.p.

ELMENDORF S. C., HENRY G. H. R., HOLLISTER R. D., BJÖRK R. G., BJORKMAN A. D., CALLAGHAN T. V., COLLIER L. S., COOPER E. J., CORNELISSEN J. H. C., DAY T. A., FOSAA A. M., GOULD W. A., GRÉTARSDÓTTIR J., HARTE J., HERMANUTZ L., HIK D. S., HOFGAARD A., JARRAD F. †, JÓNSDÓTTIR I. S., KEUPER F., KLANDERUD K., KLEIN J. A., KOH S., KUDO G., LANG S. I., LOEWEN V., MAY J. L., MERCADO J., MICHELSEN A., MOLAU U., MYERS-SMITH I. H., OBERBAUER S. F., PIEPER S., POST E., RIXEN C., ROBINSON C. H., SCHMIDT N. M., SHAVER G. R., STENSTRÖM A., TOLVANEN A., TOTLAND Ø., TROXLER T., WAHREN C-H., WEBBER P. J., WELKER J. M. AND WOOKEY P.A. (2012): Global assessment of experimental climate warming on tundra vegetation: heterogeneity over space and time. Ecology Letters. 15: 164–175.

FALVAI D., SALÁTA D., BALTAZÁR T., CZÓBEL SZ. (2021): Instrumental Study of the Health Status of *Picea abies [L.] Karst* and *Pinus mugo (Turra*) and Their Relation to Environmental Parameters in the Eastern Alps. Forests, (12) 716.p. doi:10.3390/f12060716.

FINNERN H. (1994): Pedological mapping manual. Verbesserte und erweiterte Auflage. Hannover. *Bodenkundliche Kartieranleitung. 4*.

FRANKL J., KLOIBER M., BRYSCEJN J. (2006): “Non-destructive inspection of a historic wooden structure damaged by fire,” in: Engineering Mechanics 2006 Svratka, Institute of Thermomechanics Acadamy of Sciences Czech Republic, Prague, 62-63.p.

GOTTFRIED M., PAULI H., FUTSCHIK A., AKHALKATSI M., BARANČOK P., ALONSO J. L. B., COLDEA G., DICK J., ERSCHBAMER B., CALZADO M. R. F., KAZAKIS G., KRAJČI J., LARSSON P., MALLAUN M., MICHELSEN O., MOISEEV D., MOISEEV P., MOLAU U., MERZOUKI A., NAGY L., NAKHUTSRISHVILI G., PEDERSEN B., PELINO G., PUSCAS M., ROSSI G., STANISCI A., THEURILLAT J-P., TOMASELLI M., VILLAR L., VITTOZ P., VOGIATZAKIS I., GRABHERR G.,(2012): Continent-wide response of mountain vegetation to climate change. Nature Climate Change. 2: 111–115.

GRABHERR G., GOTTFRIED M., PAULI H. (2010): Climate change impacts in alpine environments. Geography Compass 4: 1133–1153.

HAMMER Ø. (1999–2015): PAST–PAleontological STatictics Version 3.06 Reference Manual; Natural History Museum–University of Oslo, Norway, 225p.

HAMMER Ø.(1999–2021): PAST–PAleontological STatictics Version 4.05 Reference Manual; Natural History Museum–University of Oslo: Oslo, Norway, 284p.

HAMMER Ø., HARPER D.A.T., RYAN P.D. (2001): PAST–Paleontological Statistics Software Package for Education and Data Analysis. Palaeontol. Electron., 4, 1–9.p.

IPCC (2007): Fourth Assessment Report of Intergovernmental Panel on Climate Change. 24.p.

IPCC (2014): Impacts, adaptation, and vulnearibility. 987.p.
KLOIBER M., KOTLÍNOVÁ M. (2006): "Comparison of dynamic and static moduli of elasticity in damaged wood," in: Applied mechanics 2006, University of West Bohemia, 197-209.p.
KÖRNER C., (2003): Alpine plant life: functional plant ecology of high mountain ecosystems. Berlin, Germany: Springer. 349.p.
KÖRNER C., LARCHER W. (1988): Plant life in cold climates. In: Long SF, WoodwardFI, eds. Plant and temperature. Symp. Soc. Exp. Biol., 42. Cambridge, UK: TheCompany of Biologists, 25–57.p.
KÜPPER H. (1964) Ausztria földtani kutatásának ujabb eredményei és jelentőségük magyarország földtana szempontjából. Földtani közlöny dec.17. 115.p.
MALANSON G.P., ROSE J.P., SCHROEDER P.J., FAGRE D.B. (2011) Contexts for change in alpine tundra. Physical Geography 32: 97–113.
MATHENY N.P., CLARK J.R. (1994): A Photographic Guide to the Evaluation of Risk Trees in Urban Areas, International Society of Arboriculture, Champaign, IL, U.S.A. 85.p.
MATTHECK C. (2007): Updated Field Guide for Visual Tree Assessment. Karlsruhe, Karlsruhe Research Center, 170.p.
MATTHECK C., BRELOER H. (1994): Field guide for visual tree assessment (VTA). Arboricultural Journal 18:1–23.
NATéR (Nemzeti Alkalmazkodási Térinformatikai Rendszer) Agrárgazdasági Kutató Intézet a Magyar Bányászati és Földtani Szolgálat (2018) Éghajlatváltozási alkalmazkodáskutatás a hazai mezőgazdaságban.
NICOLUSSI K., KAUFMANN M., PATZELT G., PLICHT VAN DER J., THURNER A.(2005): Holocene tree-line variability in the Kauner Valley, Central Eastern Alps, indicated by dendrochronological analysis of living trees and subfossil logs. 14, 221–234.p. doi.org/10.1007/s00334-005-0013-y.
OHSAWA T., IDE Y. (2007): Global patterns of genetic variation in plant species along vertical and horizontal gradients on mountains. https://doi.org/10.1111/j.1466-8238.2007.00357.x
PALOMBO C. , CHIRICI G., MARCHETTI M., TOGNETTI R. (2013): Is land abandonment affecting forest dynamics at high elevation in Mediterranean mountains more than climate change? Pl. Biosystems., (147) 1-11.p. doi:10.1080/11263504.2013.772081
PARMESAN C. (2006): Ecological and Evolutionary responses to recent climate change. Annu. Rev. Ecol. Evol. Syst. 37: 637-669.
PARMESAN C., YOHE G. (2003): A globally coherent fingerprint of climate change impacts across natural systems. Nature 421: 37–42.
POLUNYIN O. (1981):Európa fái és bokrai. Gondolat Kiadó, Budapest, pp. 212., ISBN: 963-280-947-5
R CORE TEAM. (2020): R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL: http://www.R-project.org/.
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.

SAVVA Y., OLEKSYN J., REICH P. B., TJOELKER M. G., VAGANOV E. A., MODRZYNSKI J. (2006): Interannual growth response of Norway spruce to climate along an altitudinal gradient in the Tatra Mountains, Poland. – Trees – Struct. Funct. 20: 735–746. doi:10.1007/s00468-006-0088-9.

SCHWARZE F.W.M.R., (2008): Diagnosis and Prognosis of the Development of Wood Decay in Urban Trees. Rowville, Enspec 336.p.

ŠENFELDRA M., KACZKABE R., BURASC A., SAMUSEVICHB A., HERRMANNC C., SPYTE B., MENZELD A., TREMLB V. (2021): Diverging growth performance of co-occurring trees (*Picea abies*) and shrubs (*Pinus mugo*) at the treeline ecotone of Central European mountain ranges. 308–309.p. doi:10.1016/j.agrformet.2021.108608

SHIGO A.L. (1991): Modern Arboriculture, Shigo & Trees, New Hampshire. 421.p.

THEURILLAT J.P., GUISAN A. (2001): Potential impact of climate change on vegetation in the European Alps: a review. Climatic Change 50: 77–109.

WALTHER G.R., POST E., CONVEY P., MENZEL A., PARMESAN C., BEEBEE T.J.C., FROMENTIN J.M., HOEGH-GULDBERG O.H., BAIRLEIN F. (2002): Ecological responses to recent climate change. Nature 416: 389–395.

WITTE L.C., STÖCKLIN J. (2010): Longevity of clonal plants: why it matters and how to measure it. Annals of Botany 106: 859–870.