Health status analysis of Norway spruce and shrubby pine along an elevation gradient

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Abstract: The results of numerous climatic models predict a significant increase in temperature, which coupled with other factors could affect mountain species distribution and community composition. In addition, it can accelerate an upward shift of alpine treelines. However the number of field measurements focusing on the health status of dominant trees in temperate mountains are limited. Our measurements were carried out in the Stuhleck Mountains along an elevation gradient from 850 to 1750 metres. Health status analysis of *Picea abies* and *Pinus mugo* have been completed by using FAKOPP 3D acoustic tomography, which is able to detect the size and location of decayed regions in the trunk non-destructively. For modelling the relationship between the decay of tree and other factors simple linear regression models were used. The results showed that the individuals of *Picea abies* and *Pinus mugo* had the worst health status in the lowest and uppermost range of the taxa in the studied area. It could be a sign of the upward shift of their range. Positive significant correlation was found between the decay and the ratio of whole trunk/healthy wood both in case of *Picea abies* and *Pinus mugo*. It seems, that acoustic tomography measurements are adequate to indicate non-destructively the altitudinal optimum and upward shift of different taxa.

Keywords: altitude, transect, acoustic tomography, decay, *Picea abies, Pinus mugo*

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Introduction

The rate of increasing temperature in mountain systems is projected to be two to three times higher in this century than that recorded during the 20th century (Nogués-Bravo et al. 2007). In addition, there is growing evidence that the rate of warming is amplified with elevation, such that high-mountain environments experience more rapid changes in temperature than environments at lower elevations. Elevation-dependent warming can accelerate the rate of change in mountain ecosystems (Pepin et al. 2015).

In light of these projections, warming is considered likely to affect ecosystem services and biodiversity (Máliš et al. 2016). The latter can be expressed through species extinctions and changes in the composition of associations (Nogués-Bravo et al. 2007).

The growing season has lengthened an average of 2.7 days every decade since 1951 (Defila & Clot 2005; OcCC 2008), and longer growing seasons enable plants to grow at higher elevations (Lenoir et al. 2008). Climatic warming is expected to induce an upward shift in species and forest distribution in parallel with alpine tree line (Vittoz et al. 2013, Bussotti et al. 2015, Máliš et al. 2016). The latter is because regeneration and growth of trees there are limited by low temperature (Liang et al. 2016).

An instrumental analysis focusing on the health status of different-aged *Quercus petraea* stands in the Carpathian Basin showed, that sessile oak stands located in a subatlantic area were the healthiest (Trenyik et al. 2019). The most severely deteriorated

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stands occur in the continental region where the value in the 60 years old age group reached 4.24%.

The aim of the study was to determine the state of health of *Picea abies* in the mountain, and *Pinus mugo* in the subalpine belt in a typical Eastern Alps mountain. Another goal was the compare the health status of the measured layers in both species in the light of the possible elevation shift.

Materials and Methods

The examinations were carried out in the Stuhleck Mountain, in the Eastern Alps along a vertical transect from 850 m to 1750 m above sea level in 2019. Among the dominant species of the given vegetation belt 3-3 tree individuals were measured in every 5 (between 1705-1750 m), 10 (between 850-1000 m) or 50 (1000-1700 m) meters. The sampling design based on the evaluation of preliminary results, using a 50 m masl (meters above sea level) sampling frequency, and conducted in 2018. In the montane belt (850-1700 m) the Norway spruce (*Picea abies*), while in the narrow subalpine belt (1700-1750 m) the shrubby pine (*Pinus mugo*) were investigated with an acoustic tomography. The measurements were completed in different layers from the soil respecting the various physiognomy of the species (0.4, 0.8, 1.2 m for *P. abies* and 0.2, 0.4 m for *P. mugo* respectively).

Measurements were made using the FAKOPP 3D acoustic tomography, which is able to detect the size and location of decayed or hollow regions in the trunk non-destructively (Trenyik et al. 2017), and calculate the ratio of whole trunk and healthy wood. This non-destructive mobile instrument is suitable for determining the extent of rotting. 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 and Divós 2005). This advanced method of examination measures the propagation speed of sound within the tree. The basic measurement principle is that sound velocity drops if there is a hole between two sensors. The existence of deterioration and cavities are mapped by identifying the change of propagation speed (Divós et al. 2005, 2007). FAKOPP is generally used in case of park trees in order to examine the health status of one specimen (Trenyik et al. 2019).

Statisitical analysis

Data input and processing was carried out in Microsoft Excel 365 online version and for professional statistical computing it was used R programming language and environment version 3.6.1. (R Core Team 2019). For editing of the R scripts during the statistical analyses, it was used Tinn-R code editor (Faria et al. 2013) together with RStudio integrated development environment (R Studio Team 2015). For advanced statistical graphs, it was used the additional packages „ggplot2" (Wickham 2016).

For modelling the relationship between the decay of tree (*expressed by percentage*) and some other factors – wall thickness (ratio of whole trunk and healthy wood), high of measurement and metres above sea level – it was used simple linear regression models (Faraway 2005), where decay of tree was used as continuous dependent variable and the other factors as continuous explanatory variables. During the regression analysis the best-fitting curve was obtained by the method of ordinary last squares (OLS). Coefficient of determination (R2) was used for measurement of how close the data are to fitted regression line. However, in case of graphical representation of results we were using local regression models, the curve fitting was carried out with help of locally estimated scatterplot smoothing (LOESS)

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with 95% interval confidence (CI) of the regression line. Smoothing method was chosen based on the size of the largest group and smoothing parameter (α) was 0.8, which means the loess curve incorporate 80% of the total data points (Jacoby 2000).

One-way analysis of variance (ANOVA) type I (sequential) sum of squared was used (Zar 1984) in case of the modelling the relationship between decay of trees and the metres above sea level (MASL), where MASL was used as categorical explanatory variable. To detect the difference among factor level means after ANOVA, Fisher's least significant difference (LSD) test with Bonferroni correction (Mendiburu 2019) and Dunnett-Tukey-Kramer pair-wise multiple comparison test (Lau 2013) was used also at significance level 0.05. Calculating the factor level means (with 95% confidence intervals – CI) were carried out with help of „treatment contrasts" which was also used to determine the difference among factor level means (Pekár and Brabec 2016). In this case the lowest MASL factor level value was used as control group.

After analysis all statistical models were checked. For testing the normality of data, it was used Cramer-von Mises test and Anderson-Darling test at significance level 0.05 from the "nortest" package (Gross and Ligges 2015). For testing the heteroscedasticity (also at significance level 0.05) it was used Breusch-Pagan test from package "lmtest" (Zeileis and Hothorn 2002) and Fligner-Killeen Test of Homogeneity of Variance. D'Agostino's K-squared test was used for testing the skewness and Anscombe-Glynn test was used for testing the kurtosis from the "moments" package (Komsta and Novomestky 2015). To detect outliers in data it was used Grubb's test from "outliers" package (Komsta 2011) and Cook's distance. Durbin-Watson test from "lmtest" package (Zeileis and Horthorn 2002) was used for measuring of autocorrelation in the residuals from regression analysis. The assumption checking of all selected statistical models was also repeated with help of different diagnostic plots.

Results

There is no significant linear relationship between the decay and elevation of Norway spruce individuals ($F1{,}250 = 0.005$, $r2 < 0.001$, $p = 0.94$), however, a clear trend appears (*Figure 1.*). Nevertheless, due to the LOESS curve it can be concluded that the decay showed a continuous decrease from 850 to 1350 m, then the rate of deterioration increased significantly from 1350 to 1750 m. At higher elevations a statistically significant increase of the decay occurred of *Picea abies* stand from 1650 to 1700 m. The Anova also showed statistically significant difference between the decay of tree and metres above sea level ($F_{27,224} = 6.18$, $p < 0.001$). The largest difference of was found between elevation of the 850 m and 1700 m (Fisher's LSD-test: $p < 0.001$, Tukey's HSD test: $p < 0.001$). The highest average deterioration considering all examined layers were detected at the uppermost occurrence (1700 m) of *Picea abies* stand (averagely extent of deterioration is almost 39% (95% CI [31.8, 46.0])). On the other hand, the lowest average deterioration was recorded at 1200 m (0.7% (95% CI [0, 7.73]), 1350 m (0.44% (95% CI [0, 7.50]) and 1400 m (0% (95% CI [0, 7.05]) altitudes dominated by Norway spruce (Fig1).

In the case of *Pinus mugo* a significant correlation was found between the decay and elevation based on linear regression model ($F_{1,46} = 24.56$, $r^2 = 0.35$, $p < 0.001$) and Anova ($F_{7,40} = 6.51$, $p < 0.001$) analyses (Fig2). The decay slightly decreased from 1700 to 1715 m masl, then continuously increased up to the timberline. The differences were most pronounced between 1705 and 1710 m (Fisher's LSD-test: $p < 0.001$, Tukey's HSD test: $p < 0.001$) and 1705 m and 1745/1750 m (Fisher's LSD-test: $p < 0.001$, Tukey's HSD test: $p <$

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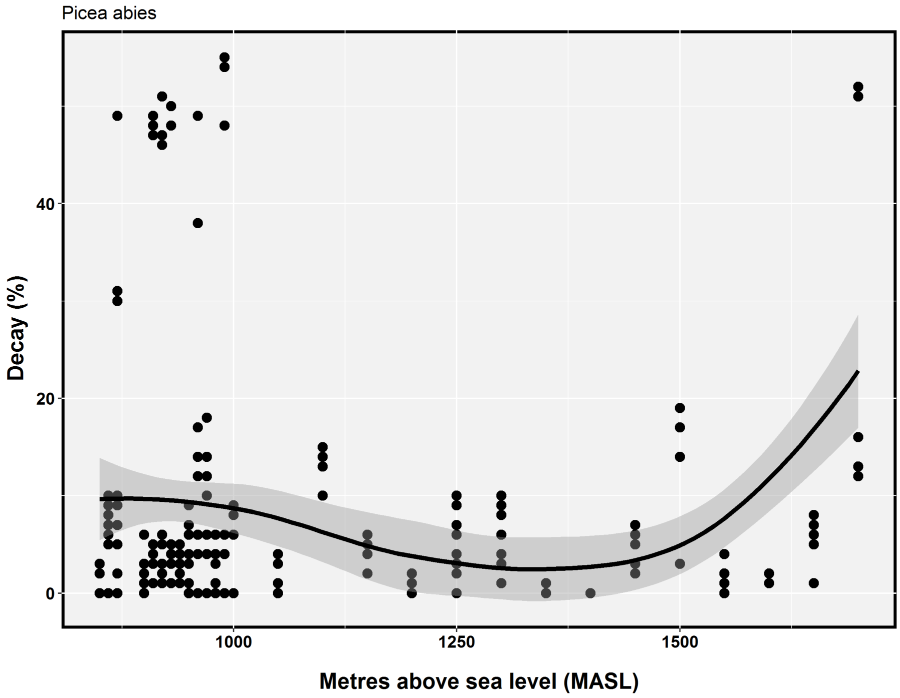

Figure 1. Spatial changes of the decay of *Picea abies* along an elevation gradient.

0.001). The highest deterioration (averagely 79% (95% CI [67.8, 90.9])) was found in case of 1745/1750 m of altitude, and the lowest deterioration (averagely 79% (95% CI [67.8, 90.9])) in case of 1710 m of altitude. The highest rate of deterioration and the highest average deterioration considering the two sampled layers were detected at the upper limit of the tree line (1745/1750 m), which is overlap with the uppermost

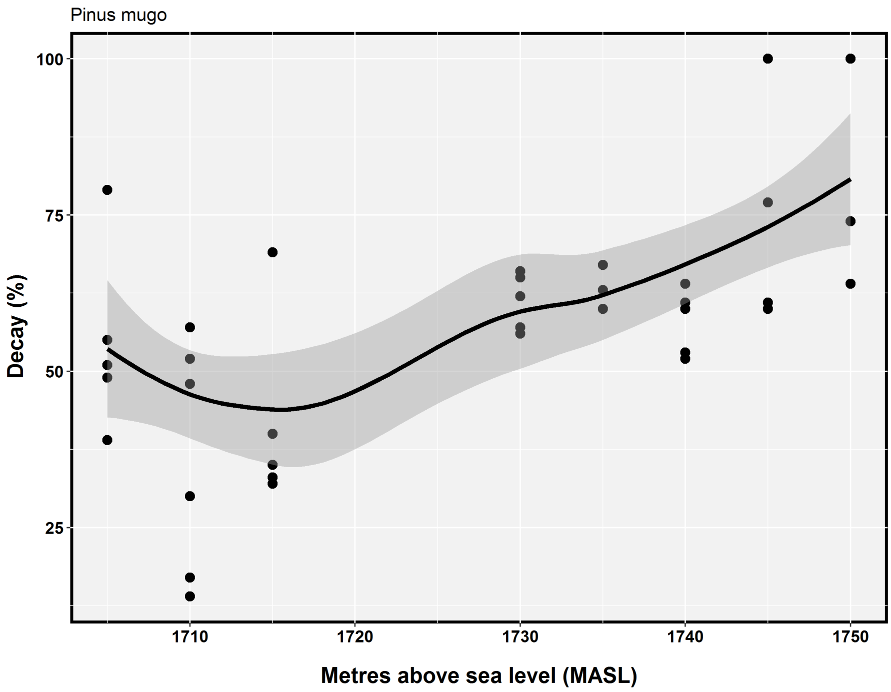

Figure 2. Spatial changes of the decay of *Pinus mugo* along an elevation gradient.

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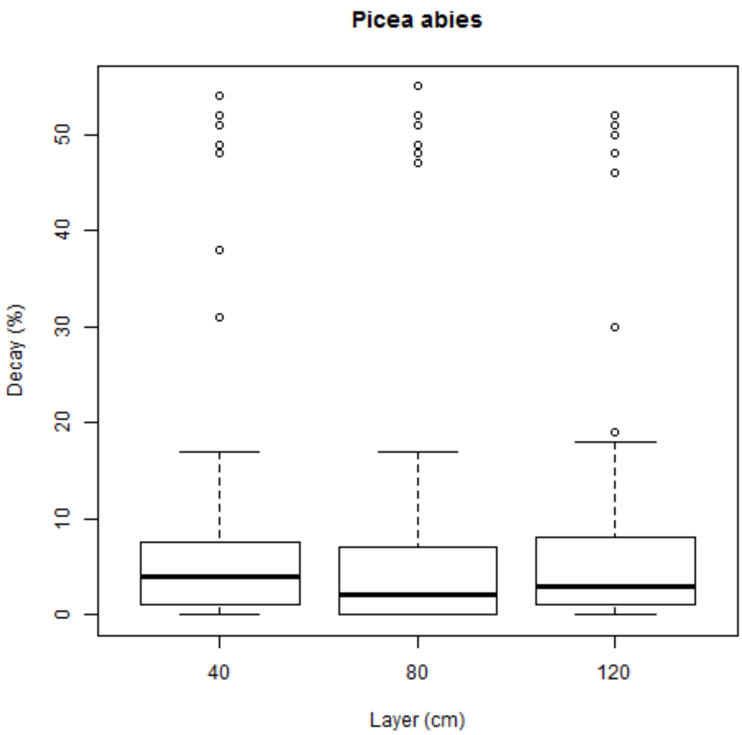

Figure 3. Comparison of the wood decay among different layers in Norway spruce stands.

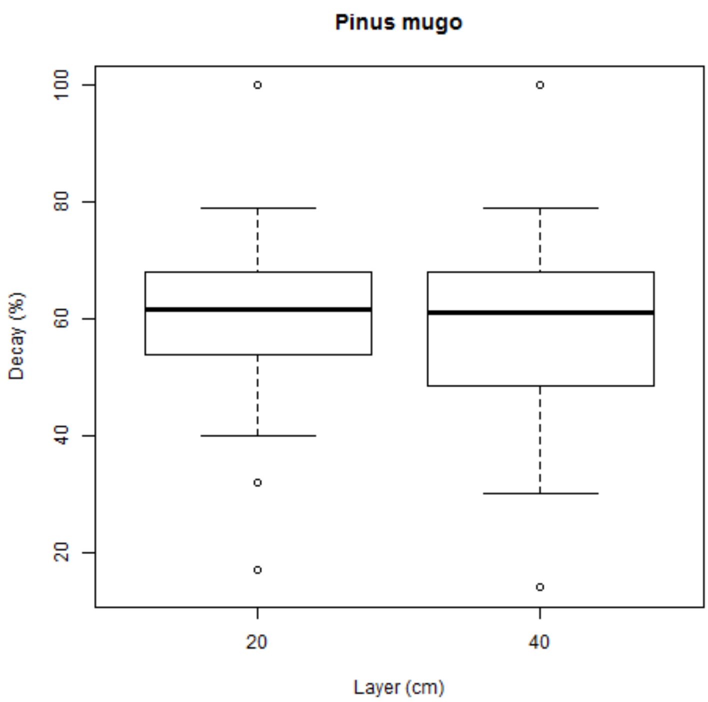

Figure 4. Comparison of the wood decay among different layers in shrubby pine stands.

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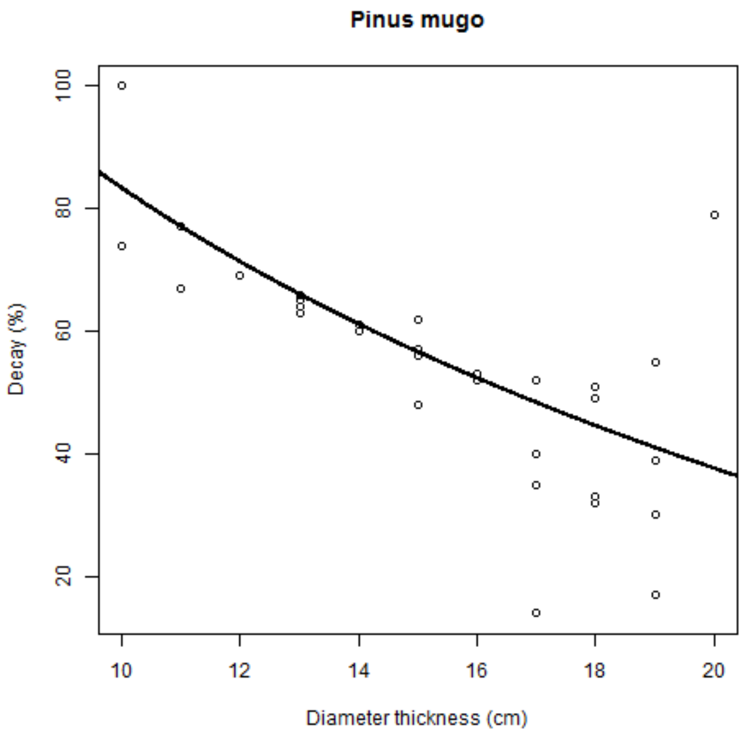

Figure 5. Correlation between the decay (expressed in percentage) and the wall thickness (ratio of whole trunk/ healthy wood) in case of *Pinus mugo*.

range of *Pinus mugo* (*Figure 2*.).

Statistical analyses did not show any significant difference among the different layers of *Picea abies* (*Figure 3*.; $F_{2,249} = 1.16$, $p = 0.85$) and *Pinus mugo* (*Figure 4*.; $F_{1,46} = 0.20$, $p = 0.66$). However, in both taxa the highest level of deterioration was found in the layer closest to the ground (*Picea abies*: 8.7% (95% CI [5.81, 11.60]), *Pinus mugo*: 62% (95% CI [53.8, 69.5]). Due to the results of linear regression analysis it can be conclude, that there are a middle stronger relationship between the decay and the wall thickness ratio of whole trunk/healthy wood only in case of *Pinus mugo* (*Figure 5*.; $F_{1,46} = 45.30$, $r^2 = 0.50$, $p < 0.001$).

Discussion

The results showed that the individuals of *Picea abies* and *Pinus mugo* had the worst health status in the lowest and uppermost range of the taxa in the studied area. The higher deterioration rate observed in the lower limits of Norway spruce and shrubby pine stands could be a sign of the upward shift of their range. The latter is in harmony with Máliš et al. (2016) findings, that ongoing climate change shift tree species distribution. In addition, the higher rate of decay at the uppermost range of *Picea abies* and *Pinus mugo* may indicate, that upward shift of trees coupled with increasing stress and declining fitness. The greater absolute and average decay of *Pinus mugo* compared to *Picea abies* could be explained by the most severe environmental conditions.

The reverse bell curve shape pattern (Fig1) of the decay indicates, that the altitudinal optimum of Norway spruce is presently between 1200-1450 m masl in Stuhleck Mountain. From 1100 to 1450 m, the decay of *Picea abies* had similar values than different-aged *Quercus petraea* stands in the Carpathian Basin (Trenyik et al. 2017, 2019).

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The measured data correspond with the field observations of Lenoir et al. (2008) and Liang et al. (2016), as well as the model of Vittoz et al. (2013) and Bussotti et al. (2015) which predicts the future expansion of species and vegetation belts to the higher alpine zone due to climatic warming.

It seems, that acoustic tomography measurements are adequate to indicate non-destructively the altitudinal optimum and upward shift of different taxa.

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