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INTERNAL DECAY ASSESSMENT USING DRILLING RESISTANCE IN MATURE COMMON ALDER (*ALNUS GLUTINOSA* (L.) GAERTN.) STANDS

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Abstract
The occurrence of wood decay in common alder stems (*Alnus glutinosa* (L.) Gaertn.) was studied based on data obtained in seven matured stands in Latvia age ranging from 65 to 122 years. The study was intended as a pilot study to test the possible use of nondestructive micro-drill (Rinntech Resistograph® R650) for detection of the different stages of wood decay within common alder stems. The drilling profiles were visually compared with the wood samples obtained from increment borer or cross-cut sections at actual drilling height.
The study confirmed initially proposed hypothesis that drilling profiles obtained using the Resistograph enabled the diagnosis of the common alder stem health condition. Wood decay stages – spongy rot and cavity can be detected successfully by the Resistograph; however, this non-destructive method does not detect discoloration in the wood, which is the earlier stage of wood decay. We found significant ($p<0.05$) positive correlation between decay occurrence and some of examined forest stand characteristics such as mean stand diameter, stand age and mean tree volume.
The tree inspection showed that the preservation of old common alder stands can lead to a significant loss of wood quality. Based on this pilot study, we conclude that if the economic interests are prioritized in management of studied stands, the reduction of actual harvesting age of the common alder stands have to be considered.
Key words: health condition, Resistograph, wood quality, decay occurrence, degraded wood.

Introduction

Common or black alder (*Alnus glutinosa* (L.) Gaertn.) is a deciduous tree with wide distribution area preferring moist and fertile soils with relatively high groundwater level, that are unfavorable conditions for most of other tree species (Laganis *et al*., 2008). Common alder forests play a very distinct role particularly to riparian ecosystems fostering the services they provide. Alders have very strong, deep and vertically oriented root system able to anchor a tree in wet soils; therefore, it is widely used for soil protection and strengthening banks around rivers, lakes and other water bodies (Salca, 2019; Thoirain *et al*., 2007). This tree species have great potential in nitrogen fixation in soil by root system, which increases the fertility of it (Rodríguez-González *et al*., 2014). In sites where tree roots cannot reach groundwater for a notable time and with low precipitation level, common alder is not capable to effectively produce annual height and diameter increments, being the reason why the species distribution area gradually reduces towards the south (Marques *et al*., 2018; Rodríguez-González *et al*., 2014) or to the north, where winters last more than six months and soil is frozen for a long period (Salca, 2019).

According to national forest inventory (NFI) data, common alder forest stands cover 6.0% of the total forest area in Latvia (Official statistics portal, 2021a). Common alder is second most popular broadleaved species in forest planting in our country, and it lags only behind silver birch. Along with birch (*Betula* spp.), European aspen and grey alder, the common alder prevails on abandoned lands naturally overgrown after cessation of agricultural activities (Liepins *et al*., 2008). In the year 2021, 280 thousand m^3 of common alder's roundwood was harvested in Latvia (Official statistics portal, 2021b) with the main use for wood particle board industry, energy-wood production and carpentry. The wood of common alder is well suited for the woodworking industry and can be easily machined, stained and otherwise treated (Salca *et al*., 2015). Common alder breeding activities are launched in Latvia indicating good potential for improvement of productivity and wood quality (Gailis & Jansons, 2010).

Common alder stands reaches its growing peak at 70 years (8 – 14 m^3 ha^{-1} per year); however, by increasing age, growth becomes less intense and tree resistance to various pathogens starts to decrease. After reaching 50 years, the risk of internal stem decay rapidly increases, the similar observation is also for trees with large diameter (Claessens *et al*., 2010). In Europe north region countries the lowest occurrence of decay is observed in first 20 growing years while at this age common alder stands can reach even 150 – 190 m^3 ha^{-1} of wood stock (Vares *et al*., 2004). A high proportion of wood decay in stems may cause significant losses of roundwood yield.

The European Union (EU) has taken responsibility to achieve climate neutrality by 2050. Forests play a crucial role for reaching the EU objectives enhancing ambition on climate change mitigation and adaptation. This means that impact of economic activities potentially contributing to climate change mitigation or causing significant harm to any of the other environmental objectives needs to be assessed

(Official Journal of the EU, 2021). Studies approves that grey alder stands at middle-age stages act as carbon sink, while mature stands become carbon source (Uri *et al*., 2017). It can be hypothesized that also common alder matured stands at some stage can become a carbon source because of declined net primary production and stem decay. It is still poorly studied; however, internal stem decay in living trees most likely results in the release of stored carbon back into the atmosphere (Marra *et al*., 2018) and can be a primary cause of tree failures during storms. Better understanding of factors affecting spread of decay within stems of common alder could help to improve the guidelines both for management of stands for quality roundwood production and enhancing of carbon storage capacity.

Internal stem decay is wood cell degradation process, which usually is almost impossible to identify just by external tree visual assessment, and in many cases destructive sampling (tree felling) is not possible or reasonable (Terho, 2009). This is why it is attractive to use in internal decay studies innovative, cost-effective and non-destructive solutions for its identification (Fundova *et al*., 2018; Rinn *et al*., 1996). Rinntech Resistograph® R650 is the one of devices which allows to assess stem decay presence and distribution without limiting future tree growing or endangers potential uses of wood material (Rinn, 2016). It is a mechanical micro-drill which penetrates fine needle (diameter up to 3 mm) at constant rotation speed and straight line movement, and very precisely measures the resistance of the study object (Fundova *et al*., 2018). Adjusting the needle rotation and straight-line movement speed makes it possible to ensure even measurements for each tree species (Todoroki *et al*., 2021). The changes in the resistance and density, also changes the energy consumption of drills engine, which is represented graphically (Rinn, 2016). With analyzing these graphical changes, obtained after Resistograph work, it is possible to derive conclusions about tree internal condition – to detect decay, deep insect damages, cracks and to collect data about annual radial increments as well as track natural changes in wood density (Wang & Allison, 2008). When it comes to decay, gradual decline or rise in the graph during drilling indicates that stem may have different wood decay development stages – from slightly colored wood to even cavity (Todoroki *et al*., 2021).

The aim of this study is to test the potential of micro-drill to nondestructive detection of decay in stems of common alder and assess the occurrence of the internal tree decay in common alder stands. We hypothesized that the quality and health status of a common alder stems can be assessed by visual inspection of the drilling profiles produced by the Resistograph.

Materials and Methods

Seven mature (age ranged from 65 to 122 years) naturally regenerated stands dominated by common alder were chosen for the present study (Table 1) located in central-eastern part and southern-western part of Latvia (Madona, Smiltene, Auce municipalities). All investigated stands were growing on fertile soils with increased groundwater level. Forest types were determined based on Latvian forest site classification (Zālītis & Jansons, 2013). Study material was collected during the spring and summer of 2021. Four investigated common alder stands were growing in *Dryopteriosocaricosa* forest type, and one stand was growing in *Oxalidosa turf. Mel*, *Caricoso-phragmitosa* and *Myrtilloso-sphagnosa* forest types.

To assess the occurrence of stem decay in forest stands dominated by common alder, 500 m^2 circular sample plot was established in each of it. Plots were placed subjectively into spots most accurately representing the actual situation in each forest site. To evaluate relationships between stand characteristics and tree health conditions, the measurements of

Table 1

Main characteristics of studied common alder stands

Stand No.	Stand age, years	DBH_g, cm	H_g, m	G, $m^2 ha^{-1}$	Mean tree volume, m^3	Stand volume, m^3 ha^{-1}	Number of trees, ha^{-1}	Forest type (according (Zālītis & Jansons, 2013))
1	98	31.8	25.3	52.4	0.95	647.9	660	*Dryopteriosocaricosa*
2	87	31.2	26.8	45.9	0.97	591.2	600	*Oxalidosa turf. mel.*
3	122	32.3	23.7	19.7	0.92	227.5	240	*Dryopteriosocaricosa*
4	111	32.6	25.4	25.0	1.00	307.0	300	*Caricoso-phragmitosa*
5	65	23.3	26.2	33.3	0.53	419.1	780	*Myrtilloso-sphagnosa*
6	74	20.6	24.1	24.6	0.38	286.2	740	*Dryopteriosocaricosa*
7	72	23.1	22.8	37.7	0.45	418.4	900	*Dryopteriosocaricosa*

DBH_g – basal area weighted mean diameter at breast height; H_g – basal area weighted mean height; G – weighted average stands basal area.

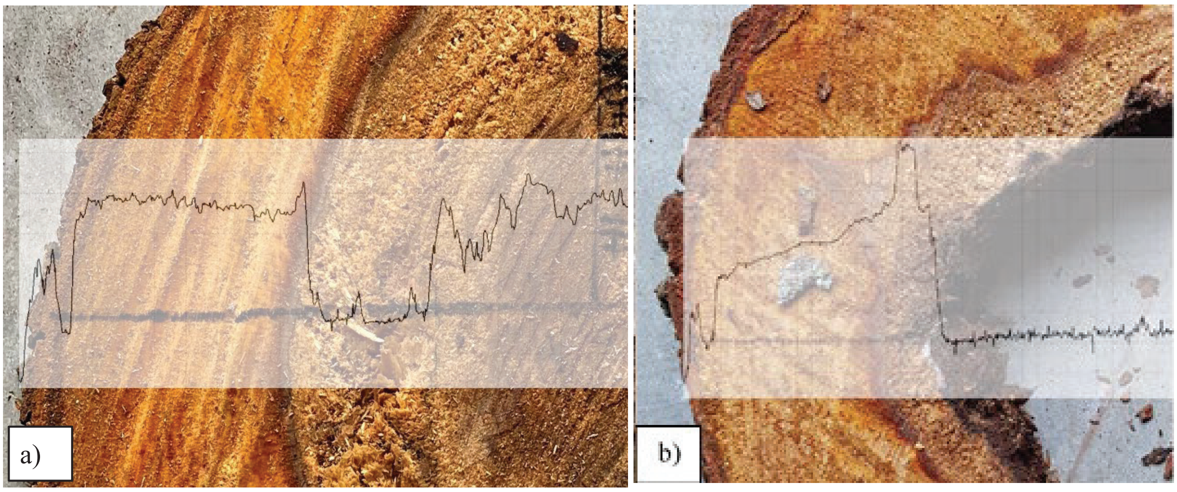

Figure 1. Rinntech RESISTOGRAPH® R650 drilling profile and actual cross-cut at corresponding height: a) intact wood, spongy rot and discoloration; b) intact wood, spongy rot and cavity.

diameter at breast height and tree height were made in all sample plots. Average tree age in a stand is determined according to the forest inventory information but the other stand characteristics are calculated from the obtained tree measurement data. During primarily visual inspection, information about any significant tree damage that may cause internal wood condition changes also was fixed.

In plots, all common alder trees were drilled by mechanical micro-drill Resistograph horizontally at stump level from three different directions towards the core. Altogether, 211 sample trees were drilled in seven common alder stands. It was done with the aim to detect decay presence in stem as precisely as possible. Each drilling has an individual graph or so-called drilling profile and after quick visual analysis of it, it allows to make assumption about sample tree internal condition. Figure 1 represents individual drilling profiles in comparison with actual cross-cuts at a stump level. When drilling profile is stable and has no changes, there is intact or healthy wood, fluctuations may indicate on changes on wood mechanical properties caused by internal stem decay presence. In field conditions, it is possible to distinguish two wood decay development stages – a) spongy rot and b) cavity, because graph line fluctuations are very notable.

In each sample plot, all common alder trees were chosen for detection of decay via Resistograph. Trees without considerable fluctuations in the drilling profile were also inspected with increment borer, while trees with internal decay were felled to obtain more precise assumptions about internal stem condition (5 sample trees per plot). After all field works, data from Resistograph was exported to computer where detailed micro-drill profiles were analyzed with scientific program Rinntech e.K. DecomTM.

Spearman's rank-order correlation coefficient was used to measure the strength and direction of association between stand characteristics and the occurrence of internal wood decay because our data set is limited and does not follow a normal distribution. Data normality assumptions were tested using the Shapiro-Wilk test. All the tests were performed at a level $\alpha = 0.05$ using R statistical software (Bates *et al*., 2015).

Results and Discussion

Our study revealed high variation in occurrence of decayed stems in studied mature common alder stands ranging from 6.7% to 93.3% (Table 2). With increased age and dimensions of common alder, the risk of reduced stem quality because of internal decay is more profound. Although based on limited stand data, there is a distinct pattern that incidence of decay in stems of common alders sharply increases in stands older than 60 years (Figure 2). This is in line with Claessens et al., (2010) who referenced that onset of wood decay in common alder stands starts at the age 50…70 years. The highest proportion of decay-affected wood is located within the heartwood at the bottom of stem indicating that this disease is a significant threat for commercial wood usage for high quality products. In Latvia, common alder trees felling age is 71 years and Arhipova (2012) concluded that by that age on average 75% of all trees may be infected with internal wood decay. According to the Latvian NFI data, the total wood volume in common alder stands is approximately 42.16 million m^3, and most of it consists of stands older than 51 years.

Age-related decline of stand biomass accumulation and loss of productivity in old growth forest is well described process (Ryan *et al*., 1997). The life span of the trees is often dictated by size-related stress,

Table 2

Decay occurrence in mature common alder stands

Stand No.	Number of inspected trees	Healthy, %	Spongy rot, %	Cavity, %	Occurrence of decayed trees in stand, %
1	33	54.5	36.4	9.1	45.5
2	30	56.7	26.7	16.6	43.3
3	12	50.0	33.3	16.7	50.0
4	15	6.7	40.0	53.3	93.3
5	39	82.1	12.8	5.1	17.9
6	37	86.5	10.8	2.7	13.5
7	45	93.3	4.4	2.3	6.7

abiotic stress, pathogens or rot-inducing fungi that digest their woody bodies (Ryan *et al*., 1997). Similar relationship between spread of decay within stems of matured living trees showed by our results were observed in grey alders stands (Arhipova *et al*., 2011) and trembling aspen (Schneider *et al*., 2008). Analysis revealed a significant positive correlation between such stand characteristics as mean diameter (r=0.964), age (r=0.857), mean tree volume (r=0.821) and total occurrence of stem internal decay (Table 3). This is confirming that preserving of old common alder stands leads to loss of wood quality if the economical interests are prioritized in management of these stands. It has to be mentioned that our study is based on just seven stands, and there is high variation of decay spread among them indicating that other factors than studied ones also could be involved in the loss of vitality of trees.

To accurately interpret Resistograph data, it should be taken into account that internal stem decay is a natural process of wood cell decomposition during which their density rapidly decreases, and it may occur differently for each tree species or growing conditions (Rinn, 2016). Two wood decay stages – spongy rot and cavity was detected with Resistograph (Table 2). Spongy rot dominated in all investigated decayed common alder stands (on average 38.6%), whereas the cavity was found less frequently – on average in 15.1% of drilled trees in a stand. The highest occurrence of cavity (decay development stage where no more wood is observed) was in oldest study stands, respectively, with greater diameter at breast height and mean tree volume (Table 1).

After visual inspection of wood samples obtained via increment borer, in many cases a wood discoloration was found. This is usually considered as the earliest decay development stage, when wood has already changed its color, but it has no significant effect on mechanical properties. This stage was hardly detectable with drilling resistance in this study, because at early stages wood cell degradation process only slightly affects wood basic density and hence the drilling resistance. Also, Quarles (1999) concluded that Resistograph cannot detect decay at early decay stages when wood weight loss is less than 20%, which contradicts with consumptions made by Rinn, (2016)

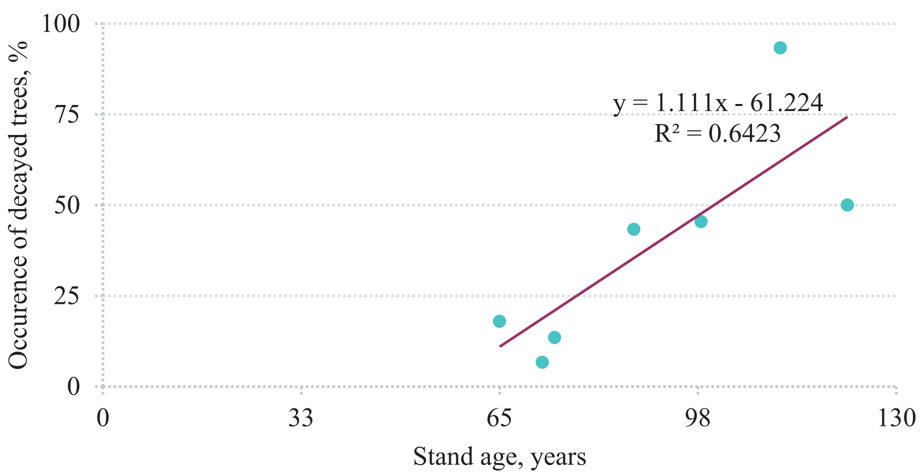

Figure 2. Occurrence of decayed trees in mature and common alder stands.

Table 3

Spearman's correlations between common alder stand characteristics and occurrence of internal stem decay

Decay occurrence, %	DBH_g, cm	H_g, m	Stand age, years	Stand volume, m^3 ha^{-1}	Mean tree volume, m^3	G, m^2
Total	0.964*	0.286	0.857*	-0.107	0.821*	-0.179
Spongy rot	0.929*	0.357	0.786	0.107	0.857*	0.035
Cavity	0.920*	0.392	0.821*	-0.142	0.857*	-0.214

*labelled correlation coefficients are significant at $p < 0.05$. DBH_g – weighted average diameter at breast height; H_g – weighted average tree height; G – weighted average stand basal area.

that micro-drill is capable to detect decay in every development change. This is leading to presumption that amount of decay damaged trees in studied common alder stands is higher than detected with Resistograph. Spongy rot and cavity were successfully detected by the drilling resistance method for all trees sampled; however, it could be quite difficult to accurately predict the extent of decay because the internal decay is irregularly shaped and the drill needle not always can be pointed towards the center of the stem.

Most likely the biological age of the trees is the main trigger of spreading of decay in mature common alder stands, and the possibilities to slow down this process is limited. In this study, we did not have information on the actual age of trees in the stand (forest inventory data was used) which probably explains why the occurrence of the stem decay was most closely correlated with the mean diameter of trees. To obtain more accurate data about the internal decay occurrence in common alder stands in Latvia, we recommend continuing the study with more extensive data set. In the ongoing study, we will assess the carbon concentration and its changes affected by internal stem decay presence of different development stages. This will make contribution to better understand the carbon sequestration processes in matured and old-grown common alder stands and to plan the silvicultural measures that can increase the climate mitigation capabilities of our forests.

Conclusions

The presence of cavities and internal decay in tree stems results in the release of stored carbon back into the atmosphere and has been noted as the primary cause of tree failures. Study approved that occurrence of internal stem decay in mature common alder stands depend on tree size and stand age. We found significant positive correlation between occurrence of decayed trees at various stages and stand characteristics such as mean diameter, age, mean tree volume. Preserving of old-grown common alder stands leads to loss of wood quality because of internal decay. If the wood industry interests are prioritized in management of these stands, the reduction of actual harvesting age of the common alder stands have to be considered.

Two wood decay stages – spongy rot and cavity were successfully detected with a drilling resistance method; however, the presence of discoloration in common alder wood cannot be noticed with this non-destructive method.

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