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ORIGINAL

Detection of incipient decay in tree stems with sonic tomography after wounding and fungal inoculation

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Abstract Picus® acoustic tomography was used to map incipient stages of fungal decay in the sapwood of standing Douglas fir, beech, oak, and sycamore trees 2, 16, and 27 months after wounding and artificial inoculation with brown-, soft-, and white-rot decay fungi. Some wood properties were additionally measured before (velocity of sound) and after (moisture content, weight loss, and density of sound, discoloured and/or decayed wood) tree felling (28 months). With the exception of *Trametes versicolor* in sycamore, wood decay was not evident from the tomograms in any host-fungus combination. In comparison to measurements after two months, the device recorded a reduction in sound velocity in some host-fungus combinations after 16 and 27 months. In beech, there was a significant reduction in sound velocity after inoculation with *Ganoderma applanatum*, *Kretzschmaria deusta*, and *Trametes versicolor*. Similarly, a reduction in sound velocity was recorded in sycamore inoculated with *Kretzschmaria deusta* and *Trametes versicolor*. In all these combinations, losses in wood weight and wood density were also found. Results showed that the detection of incipient fungal decay at the periphery of tree stems needs to be improved such that tomograms of the Picus® acoustic tomograph are capable of identifying decay progressing from the sapwood inwards.

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Introduction

Wood decay in standing trees is a major concern in relation to human safety. Wood decay often weakens tree stems, branches or roots such that chances of mechanical failure are exponentially increased after infection of wood by decay fungi (Blanchette et al. 1985; Rayner and Boddy 1988; Kucera and Niemz 1998; Schwarze and Baum 2000). However, not all fungi are equally dangerous to trees. For example, trees are not at risk of mechanical failure if only small decay volumes are found (Lonsdale 1999; Schwarze et al. 2004), or if trees are infected with weakly invasive decay fungi (Schwarze et al. 2004; Deflorio 2006). Therefore, specialists carrying out tree hazard assessment are asked to distinguish between host-fungus combinations that render trees hazardous and those that are of little or no consequence for human safety.

Wood decay fungi represent the main organisms causing wood decay. They are classified as brown-, soft-, and white-rot fungi depending upon the wood components they degrade (Eaton and Hale 1993). In living trees, decay fungi can be classified as either weakly, moderately, or strongly invasive. Invasiveness may depend on host specificity, i.e. on fungal adaptation to some wood substrates (Nobles 1958; Gilbertson 1980; Watling 1982). In addition, probability of wood colonization by decay fungi is exponentially increased if heart- or ripewood is exposed via stem and/or branch wounds (Shigo 1972, 1976; Roll-Hansen and Roll-Hansen 1980a, b; Rayner and Boddy 1988). Nevertheless, a recent survey on urban trees with mechanically inflicted stem wounds found low incidence of wood decay, even after decades (Schwarze and Heuser 2006).

Several methods are used to assess wood decay in standing trees. Decay detecting devices are classified as strongly (increment borer, Resistograph®), moderately (Shigometer), weakly (Arbotom®, Fakopp 2D, Picus® acoustic tomography), or non-invasive devices (computer tomography, thermal imaging) (Schwarze and Fink 1994; Lonsdale 1999; Bucur 2003; Catena 2003; Catena and Catena 2003; Rinn 2003, 2004). Strongly invasive devices have the main disadvantage of increasing wood susceptibility to decay by drilling or boring holes from which large columns of discoloured and/or decayed wood are formed (Lorenz 1944; Hepting et al. 1949; Schöpfer 1961; Shigo 1972, 1976; Kersten and Schwarze 2005). Moreover, the latter devices may produce different results depending on the spatial direction in which measurements are carried out (Wang et al. 2005). In contrast to strongly or moderately invasive diagnostic devices, weakly or non-invasive devices damage less wood, as only small and confined columns of discoloured and/or decayed wood are inflicted (Ouis 2003; Kersten and Schwarze 2005). Among the weakly invasive devices, the Picus® acoustic tomograph has been recently introduced for tree hazard assessment (Gilbert and Smiley 2004; Rabe et al. 2004; Schwarze and Heuser 2006).

So far, studies carried out with diagnostic devices focused on the detection of central columns of decayed wood (Habermehl and Ridder 1995; Niemz et al. 1998; Lonsdale 1999; Rust et al. 2002; Gilbert and Smiley 2004; Kaestner and Niemz 2004; Rabe et al. 2004; Wang et al. 2005). Little knowledge exists on the detection of initial stages of stem wood decay advancing from the tree periphery inwards. Furthermore, the effect of weakly, moderately, and strongly invasive wood decay fungi on decay detection with weakly invasive diagnostic devices has not been assessed yet.

The objective of the present study was to investigate whether initial stages of different decay types developing from stem wounds can be detected at the stem periphery with the Picus® acoustic tomography. For this purpose, four tree species, i.e. Douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco], beech (*Fagus sylvatica* L.), oak (*Quercus robur* L.), and sycamore (*Acer pseudoplatanus* L.) were artificially inoculated with a range of brown-, white-, and soft-rot fungi. Cross sectional maps (tomograms) of inoculated tree stems were made with the Picus® acoustic tomograph after 2, 16, and 27 months. To interpret the tomograms, additional response variables were measured before (i.e. sound velocity) and immediately after tree felling (i.e. dry wood weight loss, wood moisture content, and wood density).

Materials and methods

Tree and fungal material

Douglas fir, beech, oak, and sycamore trees (eight trees per tree species) were artificially inoculated in the Mooswald forest (Freiburg, Germany) with six wood decay fungi and one control treatment (Table 1). Eight replicates of each treatment were set up at the end of May 2002 as a complex split-plot design with four main effects, namely "host" (four levels), "inoculum type" (two wood types, i.e. pine and beech wood), "fungus" (seven types including the control), and "tree" nested within "host" as block effect. Details on the laboratory and field operations carried out before (cultivation of fungal isolates, preparation of the inoculum, inoculation of

Table 1 Tree and fungal material used for the stem inoculations in Mooswald forest (Freiburg, Germany)

Tree material	Diameter (cm ± SE)	Height (m ± SE)	Age[a] (years)
Pseudotsuga menziesii (Mirb.) Franco	42.0 ± 3.4	23.3 ± 1.3	40
Fagus sylvatica L.	49.8 ± 1.6	29.1 ± 0.5	65
Quercus robur L.	46.9 ± 3.1	26.7 ± 1.3	70
Acer pseudoplatanus L.	41.4 ± 1.6	24.3 ± 0.4	55

Fungal material	Decay type[b]	Isolate n.	Host	Location
Fomitopsis pinicola (Sw.: Fr) P. Karst	BR	150801.1	ex *F. sylvatica*	Wutach
Kretzschmaria deusta (Hoffm.: Fr.) P. Martin	SR	271098.3	ex *A. pseudoplatanus*	Freiburg
Ganoderma resinaceum Boud. in Pat	WR	250501.1	ex *Quercus rubra* L.	Freiburg
Ganoderma adspersum (Schulz.) Donk	WR	99.2	ex *F. sylvatica*	Freiburg
Ganoderma applanatum (Pers.) Pat	WR	260202.1	ex *Q. rubra*	Freiburg
Trametes versicolor (L.: Fries) Pilát	WR	260202.1	ex *F. sylvatica*	Freiburg

[a] The average age was determined by counting the tree rings after felling

[b] Decay type: *BR* brown rot, *SR* soft rot, *WR* white rot

standing trees) and after felling (reisolation of the causal agent, assessment of dysfunctional wood, wood moisture content, wood weight loss, and total phenols in the reaction zone) have been reported in Deflorio (2006).

Assessment of decay development

Assessment of decay development was carried out with the Picus® acoustic tomograph (Dr. Gustke GmbH, Germany) at two tree heights (70 and 140 cm above ground) of each tree species 2, 6, 16, and 27 months after wounding and artificial fungal inoculation (i.e. in July 2002, November 2002, October 2003, and August 2004, respectively). The first measurement (e.g. 2 months after inoculation) was used for time 0 and provided the reference value for comparison with each subsequent measurement. Values obtained after 6 months were not used, as they were influenced by low temperatures and frost conditions (during measurement, average daily air temperature was 9.4, 9.7, 12.5, 8.7, and 6.7°C; source: Deutscher Wetterdienst), although temperature range of the Picus® acoustic tomograph lies between –5 and +40°C (Picus 2007).

Fourteen sensors, spaced regularly around the tree stem (Fig. 1a, b), measured the transit times of manually produced sound impulses (stress waves). From all of the available frequencies (DIRAC), the device chooses the most appropriate frequency based on wood properties of each tree species being assessed (Pohlmann, personal communication). Frequency between 1 and 3 kHz is recorded by the device (Goecke, personal communication). Velocity of sound is governed by two mechanical characteristics, the modulus of elasticity and the wood density, as shown in the following formula:

$$v = \sqrt{\frac{E}{\rho}},$$

where v = velocity of the stress wave (m/s), E = modulus of elasticity, and ρ = wood density (g/cm^3). The modulus of elasticity is a wood property, which can be altered during wood decay, even at an early stage (Schwarze and Fink 1994).

A two-dimensional, four-coloured tomogram was generated by each measurement. To interpret tomograms, brown colour is indicative for sound wood, green and violet show early and moderate wood decay, whereas blue illustrates strongly degraded wood (Fig. 2; Rabe et al. 2004). Findings shown by the tomograms were compared with the raw data of the device, which was used to obtain the velocity of sound (m/s). This was done by dividing the distance between each sensor (expressed in m) with the time elapsed from one sensor to reach all the others (expressed in s).

Wood moisture content, wood weight loss, and wood density

Immediately after tree felling, wood samples measuring $2 \times 1 \times 1$ cm^3 were sawn from the columns of discoloured and/or decayed wood that developed from woody

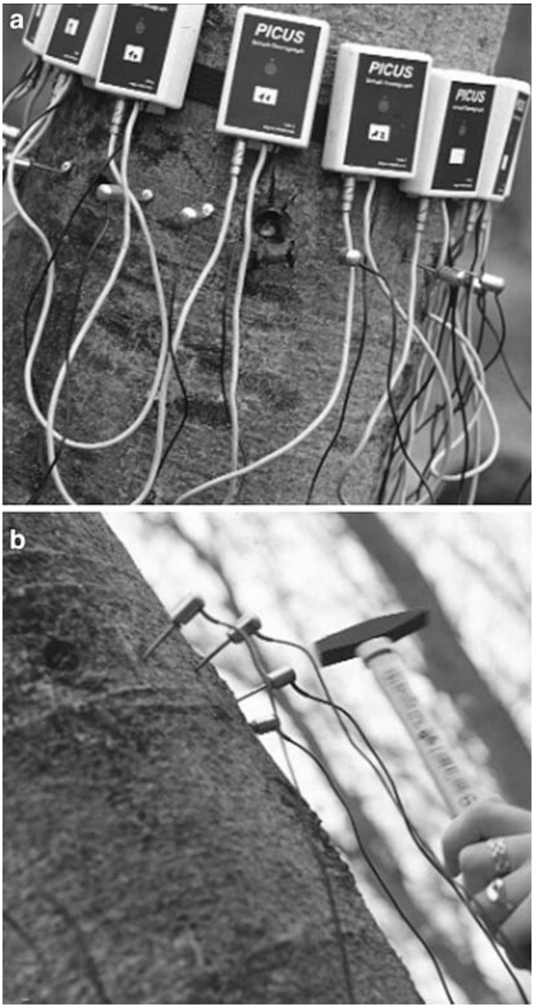

Fig. 1 Preparatory operations before measurement: **a** positioning of Picus® sensors on the tree stem during the field experiment (Freiburg, Germany); **b** activation of Picus® sensors by gently knocking with a hammer

inocula. A reference sample (sound sapwood) of identical size was sawn adjacent to the decayed wood. For comparison, both wood samples were cut at the same height and distance from the bark (Deflorio 2006).

Wood moisture content was obtained as a difference between fresh and dry weight (oven dried at 104°C for 48 h) of each wood sample. Wood moisture content is expressed as percentage of oven dry weight. Dry weight loss was calculated as a difference between reference (sound sapwood) and discoloured or decayed wood sample, and also expressed as a percentage of dry weight. Wood density was obtained by dividing the dry weight with the volume of each sample.

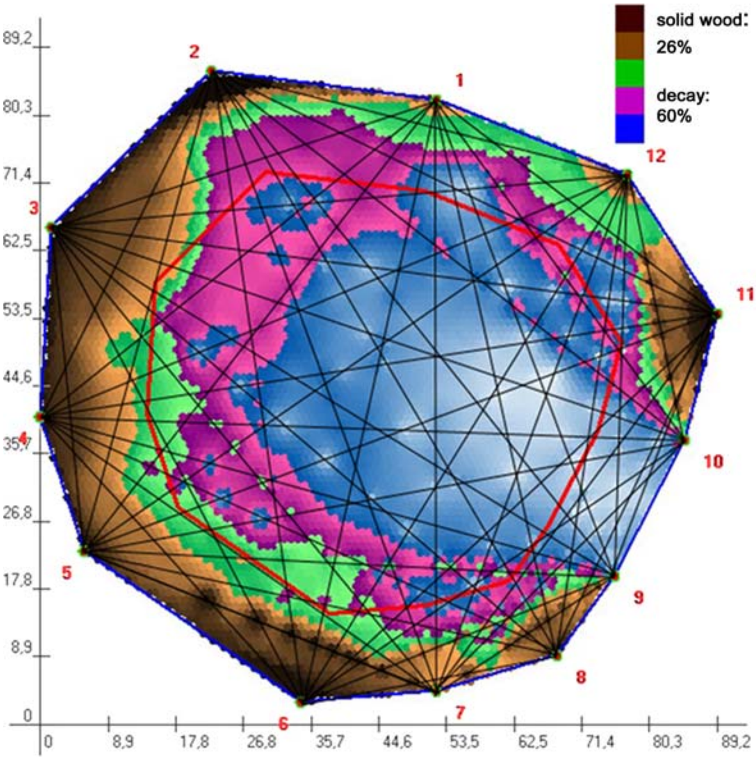

Fig. 2 An example of a coloured tomogram showing internal decay (*blue area*). *Green* and *violet* depict early and moderate decay, whereas *brown colour* resembles intact wood. Reproduced from Rabe et al. (2004)

Statistical analysis

The mean values of the response variable "sound velocity" were investigated using a two-tailed *t* test. Only host-fungus combinations having at least 10% loss in wood weight were tested. Within each host and for each fungal species, the difference between the mean sound velocity recorded at time 0 (i.e. after 2 months) and the mean sound velocity recorded after 16 and 27 months time, respectively, was analysed, assuming unequal variance. A significance level of $\alpha = 0.05$ was adopted. The statistical analysis was undertaken using the SISA package (Uitenbroek 1997).

Results

A high tree-to-tree variation in the velocity of sound recorded by the Picus® acoustic tomograph was found in each host. Exemplary measurements for each host species (one tree level per tree species) are therefore shown.

Measurement on Douglas fir trees

Initial stages of wood decay were not displayed in Douglas fir by means of tomograms after either 2, 16, or 27 months (Fig. 3a, b, c). This finding was confirmed after tree felling, whereby wood decay was not apparent, although discoloured wood was sometimes present (Fig. 3d).

Sound velocity decreased in all treatments from 2 to 16 months time, however, values recorded after 27 months were greater than after 16 months (Table 2). Correspondingly, an increase in wood weight instead of a loss was found in all treatments except for *F. pinicola*.

After tree felling, *F. pinicola* was associated with the highest wood weight loss (38.8%, Table 2) and the lowest wood density values (0.30, Table 2). Wood

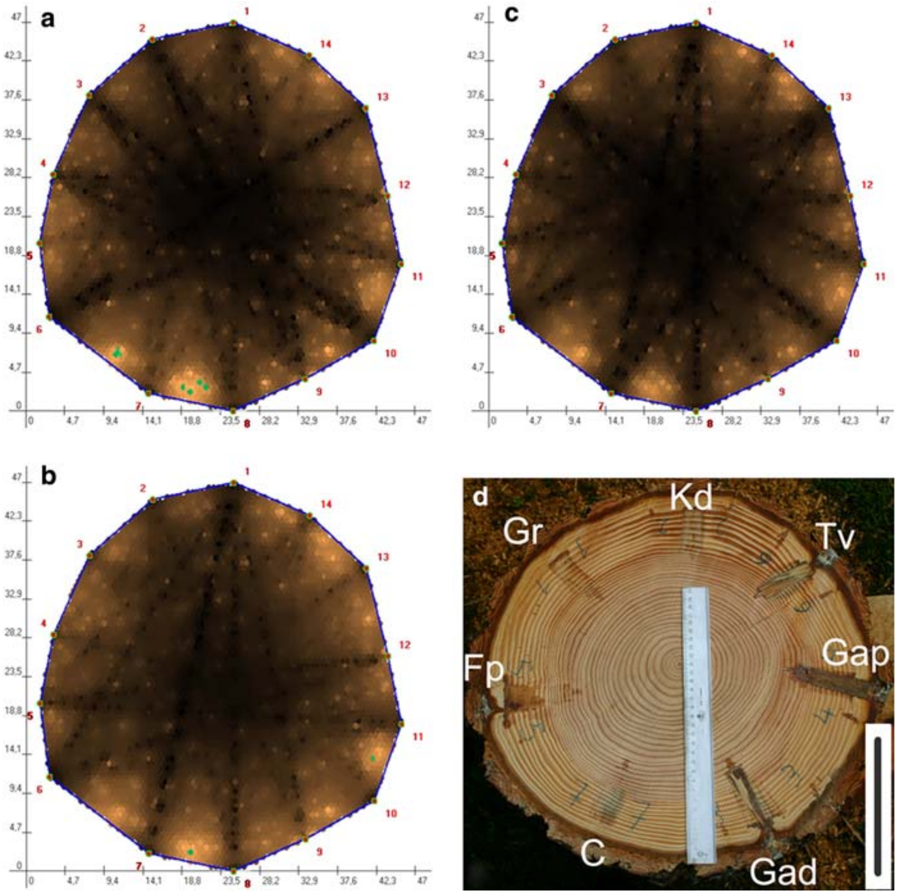

Fig. 3 Tomograms displayed in Douglas fir (tree number 8, 70 cm above ground; DBH = 45.9 cm) after 2 months (**a**), 16 months (**b**), and 27 months (**c**) measurement with the Picus® device (*x*-, *y*-axis = DBH); **d** transverse section found after tree felling. Scale bar = 12 cm. *C* Control; *Fp*, *Fomitopsis vinicola*; *Gad*, *Ganoderma adspersum*; *Gap*, *Ganoderma applanatum*; *Gr*, *Ganoderma resinaceum*; *Kd*, *Kretzschmaria deusta*; *Tv*, *Trametes versicolor*

Table 2 Sound velocity (m/s ± SE) detected in Douglas fir (tree number 8, 70 cm above ground) 2, 16, and 27 months after wounding and inoculation; moisture content (%), weight loss (%), and density (g/cm^3) of wood recorded after tree felling (28 months after inoculation)

Fungal species	Sound velocity (m/s ± SE)			Moisture content (%)	Weight loss (%)	Wood density (g/cm^3)
	2 months	16 months	27 months			
G. resinaceum	1,262 ± 22	1,002 ± 37	1,174 ± 19	35.1	–2.1	0.48
G. adspersum	1,248 ± 19	1,175 ± 79	1,258 ± 91	20.7	–15.6	0.56
G. applanatum	1,156 ± 34	953 ± 27	1,295 ± 75	24.2	3.2	0.46
T. versicolor	1,587 ± 33	1,234 ± 28	1,127 ± 35	20.9	–7.8	0.55
K. deusta	1,233 ± 10	1,116 ± 21	1,205 ± 18	23.8	1.0	0.50
F. pinicola	961 ± 53	908 ± 26	919 ± 31	29.4	38.8	0.30
Control	1,200 ± 29	1,181 ± 24	1,196 ± 28	24.8	1.1	0.44

moisture content was particularly low in samples for which a wood weight gain was recorded (20.7 and 20.9% in *G. adspersum* and *T. versicolor*, respectively; Table 2).

Measurement on beech trees

In beech, brown-coloured tomograms were displayed after every sampling time (Fig. 4a, b, c), thereby indicating absence of wood decay in tree stems. However, tree felling revealed decayed wood which was particularly evident where the sapwood had been inoculated with *T. versicolor* and *K. deusta*, as illustrated in Fig. 4d.

Sound velocity decreased in all treatments from 2 to 16 months. However, compared to 16 months, values of sound velocity recorded after 27 months slightly increased (Table 3). A significant reduction in sound velocity was detected in wounds inoculated with *G. applanatum* and *T. versicolor* ($P = 0.00$ and 0.00, respectively; Table 3). A similar result was found after 27 months, whereby sound velocity of *G. applanatum*, *T. versicolor*, and *K. deusta* was significantly less than after 2 months ($P = 0.003$, 0.002, and 0.01, respectively; Table 3). By contrast, other fungal species (*G. adspersum*, *F. pinicola*) and the control treatment did not record any significant decrease in sound velocity with time (Table 3).

Losses in wood weight and wood density were particularly high in samples infected with *T. versicolor* (54.6% and 0.27, respectively; Table 3), thus followed by *G. applanatum* (29.4% and 0.42, respectively; Table 3), and *F. pinicola* (26.0% and 0.44, respectively; Table 3). The lowest wood moisture content was detected in samples infected with *K. deusta* (20.2%, Table 3), whereas the greatest was found in samples inoculated with *T. versicolor* (59.7%, Table 3).

Measurement on oak trees

In oak, signs of decay were found neither by means of tomograms after 2, 16, or 27 months (Fig. 5a, b, c), nor after tree felling (Fig. 5d). Accordingly, sound

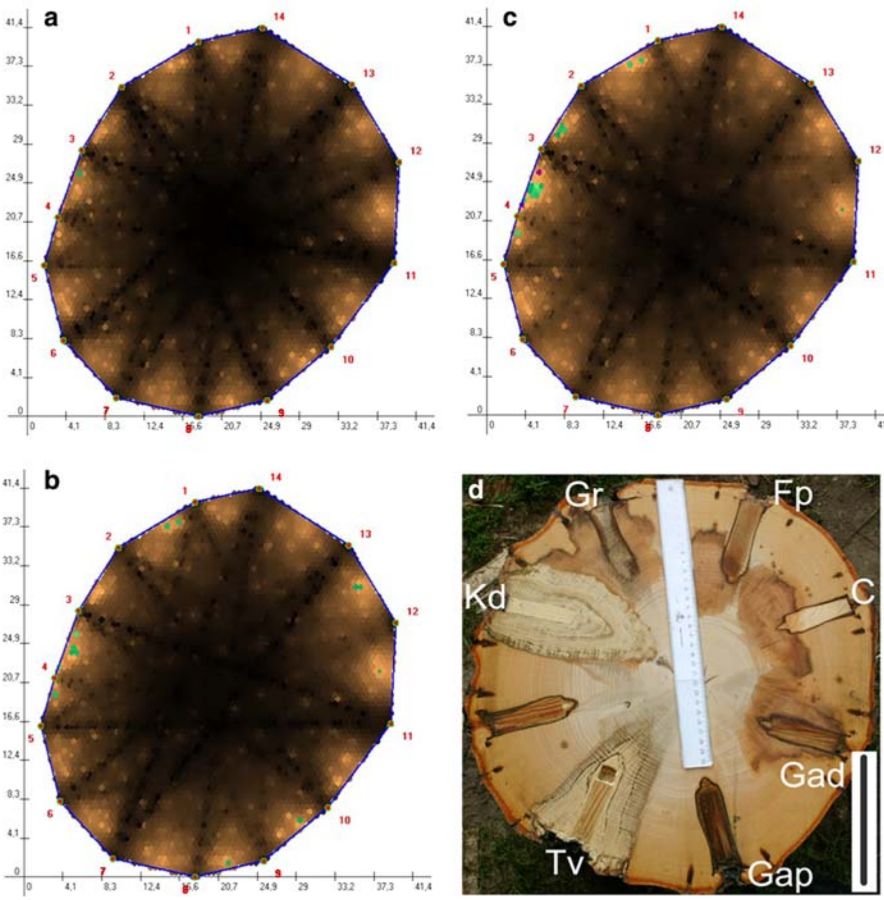

Fig. 4 Tomograms displayed in beech (tree number 7, 140 cm above ground; DBH = 41.7 cm) after 2 months (**a**), 16 months (**b**), and 27 months (**c**) measurement with the Picus® device (*x*-, *y*-axis = DBH); **d** transverse section found after tree felling. Scale bar = 10 cm. *C*, Control; *Fp*, *Fomitopsis vinicola*; *Gad*, *Ganoderma adspersum*; *Gap*, *Ganoderma applanatum*; *Gr*, *Ganoderma resinaceum*; *Kd*, *Kretzschmaria deusta*; *Tv*, *Trametes versicolor*

velocity recorded by the device for each treatment did not significantly differ between 2 and 27 months time (Table 4).

Although sound velocity did not significantly differ in any treatment, high losses in wood weight were found in oak sapwood infected with *G. applanatum* (45.1%, Table 4). Nevertheless, wood density of samples decayed by *G. applanatum* did not correspondingly decrease (0.37 vs. 0.36 for control, Table 4).

Measurement on sycamore trees

No signs of decay were detected after 2 and 16 months by means of tomograms (Fig. 6a, b). Conversely, after 27 months, the tomogram depicted incipient wood

Table 3 Sound velocity (m/s ± SE) detected in beech (tree number 7, 140 cm above ground) 2, 16, and 27 months after wounding and inoculation; moisture content (%), weight loss (%), and density (g/cm^3) of wood recorded after tree felling (28 months after inoculation)

Fungal species	Sound velocity (m/s ± SE)			Moisture content (%)	Weight loss (%)	Wood density (g/cm^3)
	2 months	16 months	27 months			
G. resinaceum	1,109 ± 21	991 ± 28	991 ± 22	28.8	6.7	0.56
G. adspersum	1,209 ± 27	1,073 ± 34	1,299 ± 50	36.6	8.4	0.55
G. applanatum	1,064 ± 25	760 ± 15*	802 ± 34**	44.0	29.4	0.42
T. versicolor	996 ± 20	619 ± 43*	693 ± 10**	59.7	54.6	0.27
K. deusta	1,230 ± 30	1,059 ± 36	961 ± 21**	20.2	13.4	0.52
F. pinicola	876 ± 67	782 ± 61	846 ± 39	37.6	26.0	0.44
Control	970 ± 26	873 ± 55	1,131 ± 55	32.3	6.7	0.56

* Significantly different sound velocity 2–16 months ($P < 0.05$)

** Significantly different sound velocity 2–27 months ($P < 0.05$)

decay advancing from the area where *T. versicolor* had been inoculated (Fig. 6c). Wood decay indicated by the tomogram was ascertained after tree felling, whereby *T. versicolor* and *K. deusta* were found spreading from the inoculum point (Fig. 6d).

Compared to 2 months records, significant reduction in sound velocity was found in wounds infected with *T. versicolor* and *K. deusta*, both after 16 months ($P = 0.0001$ and 0.04, respectively; Table 5) and 27 months time ($P = 0.0003$ and 0.01, respectively; Table 5). Correspondingly, *T. versicolor* and *K. deusta* caused the highest wood weight losses in sycamore (41.8 and 28.2%, respectively; Table 5). Wood density recorded for *T. versicolor* (0.32, Table 5) was the lowest, thus followed by *K. deusta* (0.40, Table 5). Similarly, wood moisture content was the highest in samples infected with *T. versicolor* (61.0%, Table 5), and reached the lowest levels in *K. deusta* (26.2%, Table 5).

Discussion

Picus® stress-wave tomograph was used to detect incipient decay developing in Douglas fir, beech, oak, and sycamore trees after wounding and artificial inoculation with wood decay fungi causing brown, soft, and white rot. Except for sycamore, tomograms were not able to show wood decay advancing from the stem periphery inwards. However, in some host-fungus combinations, the sound velocity recorded by the device was significantly different between 2 months (time 0) and 16 or 27 months time. In all these host-fungus combinations, losses in wood weight and wood density were also recorded.

Except for *T. versicolor* inoculated in sycamore, the information shown by the tomograms differed from that ascertained after tree felling in all host-fungus combinations. This finding contrasts with previous investigations, whereby this device evidenced decay or damage occupying at least 20 or 10% of the transverse section of the tree trunk (Rust 2001; Rust et al. 2002). This dissimilarity might be

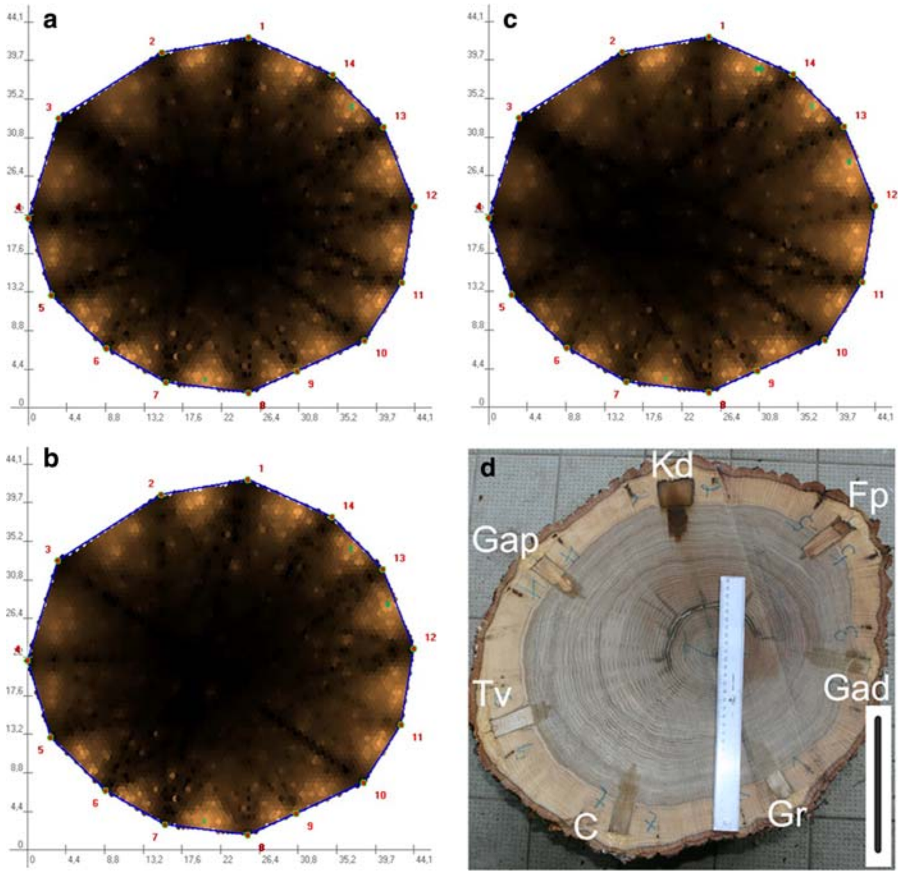

Fig. 5 Tomograms displayed in oak (tree number 1, 70 cm above ground; DBH = 48.1 cm) after 2 months (**a**), 16 months (**b**), and 27 months (**c**) measurement with the Picus® device (*x*-, *y*-axis = DBH); **d** transverse section found after tree felling. Scale bar = 12 cm. *C*, Control; *Fp*, *Fomitopsis vinicola*; *Gad*, *Ganoderma adspersum*; *Gap*, *Ganoderma applanatum*; *Gr*, *Ganoderma resinaceum*; *Kd*, *Kretzschmaria deusta*; *Tv*, *Trametes versicolor*

explained by the fact that this study attempted to detect initial stages of decay advancing from the tree periphery, whereas previous studies solely detected internal decay (Rust 2001; Rust et al. 2002; Nicolotti et al. 2003; Rabe et al. 2004; Wang et al. 2005) or peripheral wood decay of unknown date of origin (Schwarze and Heuser 2006). Therefore, the software used may not be suited for the detection of initial stages of decay advancing from the tree periphery inwards, as acoustic waves meet more often in the tree core than in the tree periphery (Picus 2003).

Tomograms did not show any decay evidence, although sound velocity decreased in inoculated stems where wood decay was present at the time of felling. However, detection efficacy was host-dependent. In particular, readings from Douglas fir and oak trees appeared less useful than readings made from beech and sycamore. In

Table 4 Sound velocity (m/s ± SE) detected in oak (tree number 1, 70 cm above ground) 2, 16, and 27 months after wounding and inoculation; moisture content (%),weight loss (%), and density (g/cm^3) of wood recorded after tree felling (28 months after inoculation)

Fungal species	Sound velocity (m/s ± SE)			Moisture content (%)	Weight loss (%)	Wood density (g/cm^3)
	2 months	16 months	27 months			
G. resinaceum	950 ± 35	1,064 ± 30	1,007 ± 114	52.5	9.6	0.37
G. adspersum	919 ± 28	1,112 ± 30	1,080 ± 83	43.9	11.9	0.42
G. applanatum	1,186 ± 74	1,180 ± 45	1,292 ± 17	33.8	45.1	0.37
T. versicolor	1,017 ± 28	998 ± 24	976 ± 47	56.4	8.4	0.22
K. deusta	1,026 ± 28	1,028 ± 35	1,002 ± 40	52.0	4.5	0.38
F. pinicola	969 ± 66	1,072 ± 35	1,016 ± 32	31.2	8.3	0.32
Control	935 ± 46	1,031 ± 37	940 ± 33	47.9	16.1	0.36

Douglas fir, the presence of abundant traumatic resin consequent to wounding may have increased sound velocity values as well as wood weight (Whitney and Denyer 1969; Deflorio 2006). In oak, high mass losses found in control samples may be a result of desiccation processes and consequent loss of wood moisture content. In the presence of decay fungi, mass losses may be compensated by the abundant production of polyphenols. Furthermore, the different wood density of sapwood and heartwood may account for its difficulty to detect decay. In contrast, sound velocity values of beech and sycamore did correspond with decay columns found after tree felling. These contrasting findings suggest that precaution is required whilst interpreting measurements originating from different tree species.

Sound velocity values were also influenced by environmental factors. For example, the readings recorded during the winter season could not be used, presumably due to the low temperatures and frost problems. These adverse effects have also been reported for computer tomography, another non-invasive equipment, where readings were affected by season of the year and climatic conditions (Habermehl and Ridder 1995). In order to avoid ambiguity, it is advisable that measurements are carried out in the same season, such that results are comparable.

In this study, strongly invasive fungi were not locally detected by the device. Therefore, it is suggested that precaution is taken in interpreting tomograms of host-fungus combinations, which are usually associated with a high safety risk, such as *K. deusta* (Wilkins 1934, 1936, 1939; Schwarze et al. 2004). For example, in beech and sycamore, the development of facultative parasites such as *T. versicolor* and *K. deusta* was not detected by the Picus® device, although wood decay was recorded by means of raw data before tree felling (sound velocity) and of losses in wood weight after tree felling. Possibly, the invasive behavior of the soft-rot fungus *K. deusta* could not be detected because wood density losses recorded for samples infected by this fungus were not greatly diminished after wood decay. This finding is in agreement with previous investigations which could not detect soft rot decay by *K. deusta* with the Metriguard® stress-wave timer (Schwarze et al. 1995, 1997).

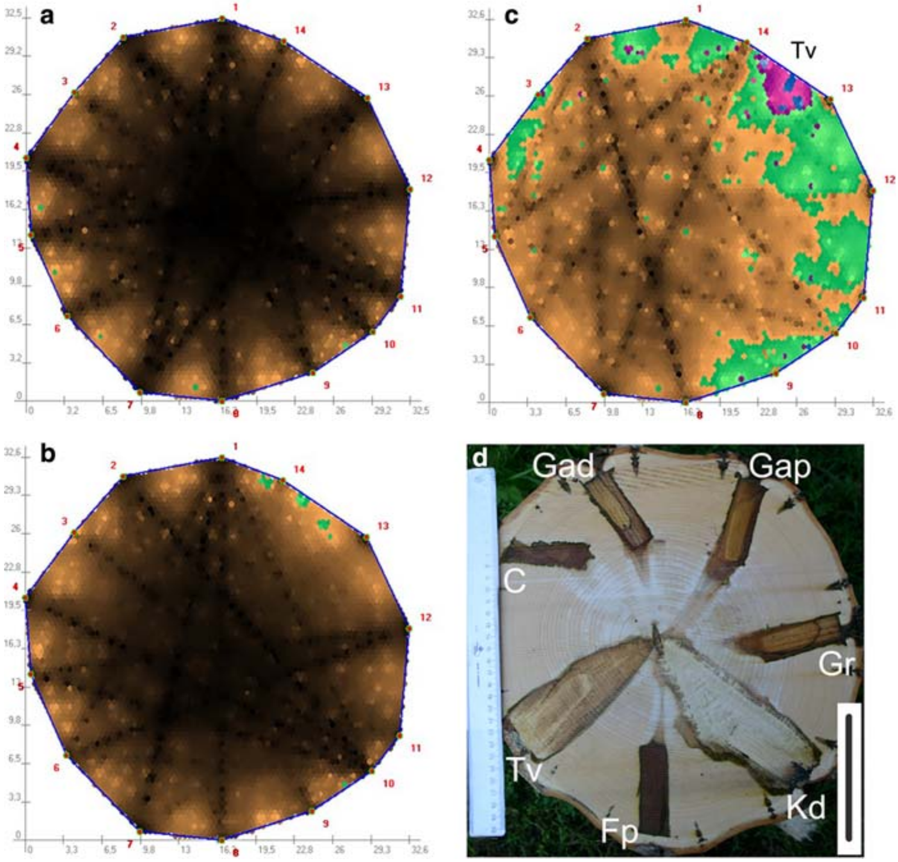

Fig. 6 Tomograms displayed in sycamore (tree number 6, 140 cm above ground; DBH = 33.1 cm) after 2 months (**a**), 16 months (**b**), and 27 months (**c**) measurement with the Picus® device (*x*-, *y*-axis = DBH); **d** transverse section found after tree felling. Scale bar = 10 cm. *C*, control; *Fp*, *Fomitopsis vinicola*; *Gad*, *Ganoderma adspersum*; *Gap*, *Ganoderma applanatum*; *Gr*, *Ganoderma resinaceum*; *Kd*, *Kretzschmaria deusta*; *Tv*, *Trametes versicolor*

The geometry of the tree trunk was also found to influence measurements made with the Picus® stress-wave tomograph (Rabe et al. 2004). Since this equipment is self-calibrating, it is possible that the altered tree trunk geometry (due to wounding and inoculation) affected the quality of resolution of tomograms of this study. Furthermore, both the mathematic equation used by the software as well as the frequency employed for measurement are relevant features contributing to the resolution quality of tomograms (Nicolotti et al. 2003). For example, it has been shown that a calculating formula based on isotropic properties of wood leads to a “ghost effect” (Nicolotti et al. 2003). Not all of these features have been mentioned by the producer (Picus 2003).

Table 5 Sound velocity (m/s ± SE) detected in sycamore (tree number 6, 140 cm above ground) 2, 16, and 27 months after wounding and inoculation; moisture content (%), weight loss (%), and density (g/cm^3) of wood recorded after tree felling (28 months after inoculation)

Fungal species	Sound velocity (m/s ± SE)			Moisture content (%)	Weight loss (%)	Wood density (g/cm^3)
	2 months	16 months	27 months			
G. resinaceum	847 ± 49	894 ± 16	905 ± 111	50.7	4.5	0.53
G. adspersum	906 ± 26	782 ± 38	818 ± 33	53.3	10.0	0.50
G. applanatum	864 ± 59	864 ± 44	1,052 ± 20	52.7	6.4	0.52
T. versicolor	1,036 ± 79	595 ± 20*	531 ± 71**	61.0	41.8	0.32
K. deusta	875 ± 46	718 ± 28*	565 ± 38**	26.2	28.2	0.40
F. pinicola	1,072 ± 47	1,008 ± 48	971 ± 91	54.6	10.0	0.50
Control	1,073 ± 58	1,171 ± 26	1,103 ± 55	51.8	2.7	0.54

* Significantly different sound velocity 2–16 months ($P < 0.05$)

** Significantly different sound velocity 2–27 months ($P < 0.05$)

Conclusions

This study highlights the extent to which Picus® sonic tomograph detects incipient decay over time in tree stems after wounding and artificial fungal inoculation. Although tomograms did not identify incipient decay at the tree periphery, this device has the potential for improvement in the near future. Enhancement of tomograms resolution may show the reduction in sound velocity recorded for most of the invasive host-fungus combinations. Use of this equipment for the prediction of decay in standing trees can lead to significant economic savings for city councils and may prove to be very valuable for tree hazard assessment.

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