

Thermography reveals Hidden Tree Decay

Alessandra Catena

Expert in Thermography
Email: alessandra.catena@tiscali.it

Keywords: tree safety assessment, tree hazard evaluation, Thermography, Infrared (IR) camera, VTA, cavities in trees, urban trees, tree decay

Abstract

The detection of hidden cavities and/or rotten tissue in trees has now become of major interest for plant pathologists, curators of historic gardens and arboriculturists. A damaged tree poses a threat to public safety, if part or all of the tree is allowed to fail.

Currently available diagnostic systems are generally time-consuming and require the presence of a crew if parts of a tree to be examined cannot be reached from the ground. Many systems are invasive requiring that holes be made into the tree that can then become the access and spread routes for pathogens.

The use of a hand-held infrared (IR) camera allows the presence and size of internal cavities/damage to be identified, this includes aerial parts of large trees that can be assessed from the ground and in real time. The apparatus can also detect the presence of damage in the root system, simply by examining the tree collar. The method proposed is non invasive and totally harmless to people. It is a

quick, safe and user-friendly system of investigation that provides images of the internal condition of trees.

Repeated image capture over a period of time can monitor the progress of the pathology and is advantageous over other methods.

1. Introduction

In most urban centres there are large numbers of imposing trees, which besides their aesthetic value greatly improve people's quality of life. These trees undergo stress as part of their survival in a hostile, unnatural environment and may be subjected to poor management techniques. As a result, many of them are unable to respond to attack from pathogens, and show signs of serious damage.

The dangerousness of the phenomenon is made worse by the fact that from the outside only small signs of damage are visible that only an expert can relate to the presence and size of decayed internal tissues or of a cavity. In fact, damage is often only revealed when parts or all of the tree fails. Hence, the health of trees in public areas has become an important part of tree care for consultants and government officers.

At present, prevention is via the early detection of damage by arboriculturists or tree consultants; this requires regular inspections to prevent damage to people or property but also to protect the trees.

Current methods of detection can be divided into five categories:

1. Percussion of the trunk with a hammer and interpretation of the sound produced: the system is very common, quick and cost-effective, but the results are dependent on the operator's skill and experience;
2. Sampling tree tissue with a Pressler auger, visual assessment of the samples and possible measurement of their resistance to fracture with a Fractometer (Mattheck and Breloer, 1994);
3. Insertion of probes into the tissue, e.g., a Shigometer (Ostrofsky and Shortle, 1989), a Vitamat (Kučera and Bucher, 1988), a Resistograph (Rinn, 1994), a Decay Detecting Drill – DDD (Seaby, 1990), or a Portable Compression Meter – PCM (Barrett et al., 1987);
4. Use of sound or ultrasound devices, e.g., an Arbosonic Decay Detector – AD² (Fujikura Europe), a Sylvatest (Sandoz and Truan, 1992), a Picus (IGeL), or an Impulse-hammer (Mattheck and Breloer, 1994);
5. Use of radioisotopes (Filler, 1972), radiographic (Onoe et al., 1983) or radar systems (Hruska et al., 1999; Nicolotti et al., 1998).

The apparatus mentioned are described in Catena and Catena (2000) and Moore (1994) who, besides showing their practical use, assesses their performances and indicates their advantages and disadvantages.

All these systems require direct contact with the area to be assessed. One or two people are needed for measurements at ground level and up to man's reach but the involvement of a crew is necessary to reach the tree's aerial parts with climbing equipment. The interpretation of data can be lengthy because of the need

to elaborate gathered data and difficult dependent on variable elements such as excess of resin or moisture in tissue.

Of particular concern are invasive methods that can further aggravate already existing damage (Shigo, 1984). Systems that use radioisotopes or radiographic apparatuses are also of concern because of the perceived danger to the public.

The currently used apparatus have a common limit in that they provide an assessment at the point/level of use. Therefore, information on the condition of the entire plant can only be collected either by extrapolation, or via a prolonged series of investigations.

The time necessary for a complete investigation with existing methods is dependent on several factors:

- facility to reach the plant,
- wood resistance, in the case of invasive investigations,
- the number of measures necessary to have an exhaustive assessment of the condition of tree tissue,
- a requirement to take measurements higher up the tree where climbing equipment is required,
- and the dimensions of the trunk.

In this paper, an assessment method based on Thermography, thermal imagery, is described and critically examined. At present the Visual Tree Assessment (VTA) introduced by Mattheck and Breloer (1994) is widely used to assess trees. This system focuses on an accurate visual exam of the plant, so as to

find external signs and/or symptoms that reveal possible internal decay; after this three investigation systems can be applied: impulse-hammer, Resistograph and Fractometer. The systems have to be used in the specified order, from the least to the most invasive, so as to damage the tree the least. This paper investigates the role of thermography as a non-invasive assessment after a visual assessment has been completed.

2. The Proposed System

The proposed system (Catena, 1992; Catena and Catena, 2000; Catena et al., 1990) uses an infrared (IR) camera that can measure differences in surface temperatures of targets: in this way the camera detects the presence of discontinuities in the tree tissue which are due to cavities or rotten tissue. This is possible because of the difference in the thermal properties (conductivity and capacity) between the damaged and undamaged area. In fact, decayed and damaged tissue contains less humidity of sound one, where the vessels of the tissue are safe and transport liquids and chemical up and down. As it has been recognised that thermal conductivity of wood depends on its humidity content, Decayed and safe areas present different surface temperatures, which are shown by the apparatus by providing an actual black-and-white or alternatively a pseudo-colour image that is a true “thermal map” of the tree portion studied. The section where the discontinuity lies, i.e. the damaged area, generally has a lower surface temperature than an undamaged one.

In addition to assessments of aerial parts of the tree, an assessment of the collar allows the presence of decay within the root system to be detected.

Thermography has its limits that are mainly due to the very nature of the IR radiation. First of all, the system only “sees” the tree surface, therefore it must not to be obscured by other vegetation, leaves, climbers, moss, etc. For the same reason, when a species is assessed for the first time, it is advisable to check how its bark is rendered on the thermal image. The furrowed barks of a horse chestnut tree or a cedar, for example, are displayed differently from the smooth bark of a bay tree. Without considering this aspect, thermograms could be misinterpreted (see Figures 3, 6 and 10).

Since water absorbs the IR radiation, the system cannot be used when it's raining or to examine a wet area of the trunk (Catena and Catena, 2000).

To date, over 2000 trees of many different species have been successfully assessed including broad-leaved, coniferous and palm trees.

The system has been used at temperatures ranging from +2 to +35°C, both during the day and at night. Since the system detects tree surface temperature, the presence of sun-drenched, and therefore heated parts distorts images, since temperature differences between damaged and undamaged parts tend to disappear but this is avoided by examining the plant from the side in the shade.

When possible, the presence of serious damage spotted by thermography has been checked by felling the tree under investigation (Catena, 1997; Catena, 2000; Catena and Catena, 2000). In some cases, trees seemed to be very damaged when visually assessed, but thermography showed that it was not necessary to fell

them (Catena, 1991). In the case of non-serious damage identified by thermography, and when it was deemed appropriate to determine the thickness of residual undamaged tissue, a dendrodensimeter has been used.

The system has also shown its usefulness in controlling the progress of tree decay, through comparison of the two series of images.

2.1 Camera technology

For this non invasive investigation, any type of currently available IR camera can be used. Hence, components and features such as a scanning camera or a solid state sensor, operational wavelength intervals of 2.5-5.6 μ m or 8-14 μ m and IR radiation cooled sensors make little difference to their application to thermal imaging of trees. However, it is a fundamental requirement that these cameras have high geometric resolution and thermal sensitivity and be able to visualise the images of the area filmed on a monitor. It is also necessary for the images to be stored so that they can be used to assess the progress of any damage. Therefore, it is best to use a camera that allows the processing of images on a computer.

The system currently in use is a hand-held AVIO TVS 610 IR camera which is sensitive in the 8-14 μ m wavelength interval. It has a thermal sensitivity $\leq 0.1^{\circ}\text{C}$ (at room temperature) and a geometrical resolution of 1.4mrad, i.e. it is capable of distinguishing between two objects 1.4cm x 1.4cm at a distance of 10m with a difference in surface temperature greater than 0.1°C (IFOV, Instantaneous Field of View – Figure 1). At a distance of 10m, the system has a FOV (Field of

View – Figure 1) of 4.5m x 3.3m hence, this is the limit to the size of portion of tree that can be viewed at this distance.

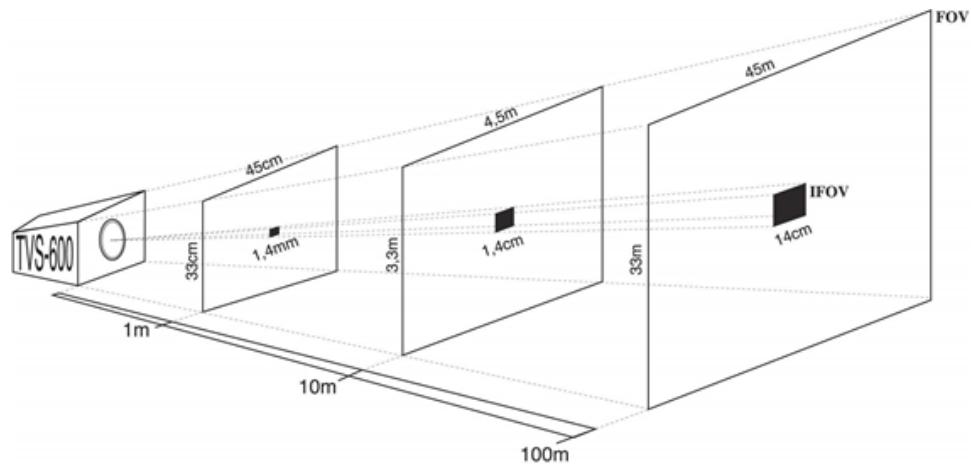


Figure 1. Variation depending on the distance of the geometric resolution (IFOV - Instantaneous Field of View) and of the Field of View (FOV) of the first IR camera used for the shots

The IR sensor (that measures surface temperature) is made up by a 320x240 microbolometers matrix which doesn't need to cool down. The sensor, the command module, and the display on which the thermal image appears in real time (updated every 1/30 s) are in a single apparatus which is slightly bigger than a common camera. The camera which weighs only 3kg is battery powered for up to 4 hours of continuous use. The camera can be fixed to a normal tripod for easy use by only one person. The AVIO system allows thermal images to be stored with a PCMCIA Compact Flash card (a 16Mb card can contain 80 images). Images can be transferred onto a computer to be processed and transformed into black-and-white or pseudo-colour bitmap images with a reference scale using purpose-built software. This allows the differences in temperature present to be immediately assessed.

In black-and-white images, the existence of damaged tissue is shown by the presence of a darker shade of grey than the surrounding area the size of which is related to the size of the damaged part. In pseudo-colour images, the damage is revealed by areas of a different colour to the surrounding area.

The investigation is carried out by pointing and focusing the lens to the chosen tree from the ground and assessing the images of the various areas filmed. The shooting, interpretation and storage of thermal images onto a PCMCIA card takes 2-3min, whatever the shooting distance.

Aerial parts of the tree can also be assessed from the ground, to a distance of between 20-25m between the camera and the object. At greater distances the operator is likely to fail to detect small areas of damaged tissue, due both to the smaller geometric resolution and the reduced size of the image on the camera display.

The thermograms in Figures 3, 6 and 10 are examples of those taken during the many investigations carried out between 1985 and the present day. Images of other trees are listed in Catena and Catena (2000).

3. Thermal Investigation

The photograph in Figure 2 shows a badly damaged casuarina (*Casuarina* sp.). Both of the larger branches were lost above the fork and only small branches remained. The black-and-white thermal image in Figure 3 shows a greatly



Figure 2. A casuarina (*Casuarina* sp.) is visible in the foreground. Its main branches broke above the fork



Figure 3. Close view of the fork. The black and white thermal image shows the presence of large regions of damage shown in dark grey which extends from the fork to the two stumps



Figure 4. What was left of the casuarina after a violent storm confirms the accuracy of the thermal diagnosis



Figure 5. Base of a bay-tree (*Laurus nobilis*) showing some small cavities

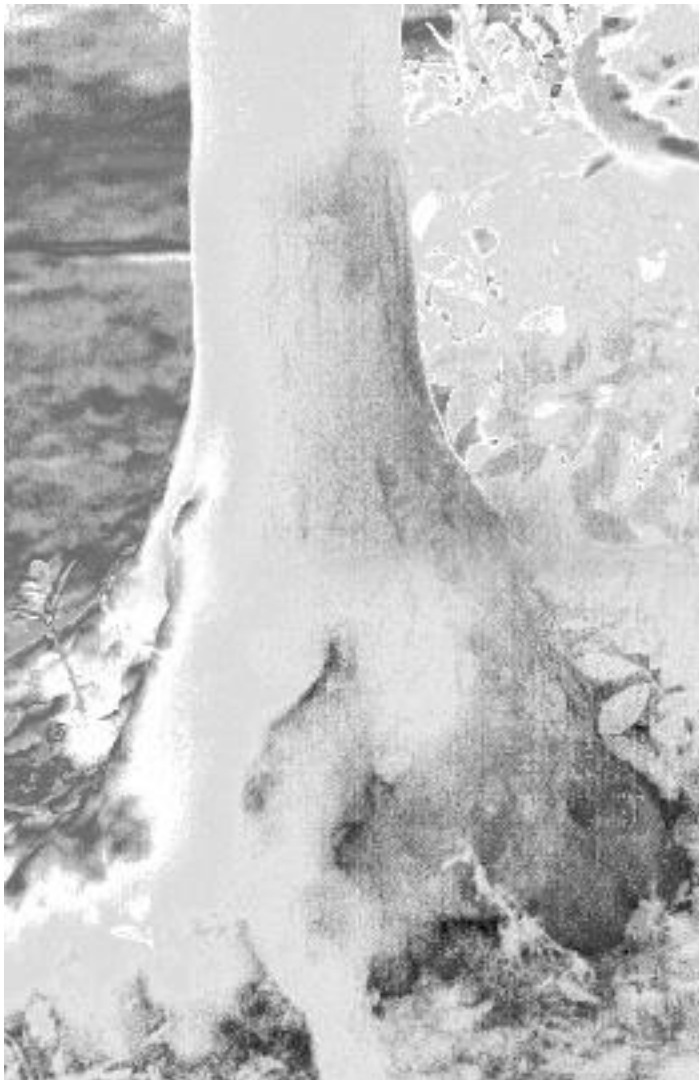


Figure 6. Collated image from three b&w thermograms, taken from the position shown by the black arrow in Figure 4. Note the presence of a large damaged region shown in dark grey, which extends from the roots upwards along the trunk

damaged area, in dark grey, that extends from below the fork towards the two stumps present. On closer inspection, the two stumps were found to be hollow. It was deemed appropriate to cut down the tree, but before any further measurements could be taken, a violent storm felled the tree and only the stump shown in Figure 4 was left. The thermogram of Figure 3 was taken in 1990 with an AGA THV 680 thermal scanner dating back to the 70's. Even though image quality was slightly inferior to that obtained with modern cameras (see Figures 6 and 10), the internal damage was still clearly visible.



Figure 7. Felling the tree has allowed a check of the presence and size of the damage detected by the thermographic investigation. The metallic probe showed that the two cavities indicated by the white arrows in Figure 5 were in contact with each other. The direct control revealed that the base was characterised by a large cavity which extended up the trunk



Figure 8. Logs confirm the presence of the cavity along the trunk and branches

The photograph in Figure 5 shows a bay-tree (*Laurus nobilis*) with small cavities at the trunk base. The composite (Figure 6) of three b&w thermograms taken from the position shown by the black arrow in Figure 5 shows the presence of greater internal damage, shown in dark grey, which extended up the trunk. The tree was cut down, and Figures 7, 8 and 9 show the internal structure of the trunk. Figure 7 indicates the condition of the trunk base: the thin white metal probe shows that the two openings, indicated by the white arrows in Figure 5, are communicating and that the base contains a large cavity which extends upwards. In Figure 8, the logs clearly show the damage in the upper part of the trunk and the branches. Figure 9 shows the cross section of a log of the lower part of the trunk, where barrier zones (Shigo, 1984) are clearly visible.



Figure 9. A sectioned log coming from an area closer to the trunk base shows the dimensions of the cavity and pinpoints the presence of barrier zones

Figure 10 shows the base of a *Celtis australis* in a row of urban trees. One of the trees suddenly inclined by 45° without signs of external damage or external causes. The tree was felled and the stump showed a wide area affected by decay, and a large cavity below ground level. The remaining trees were in good vegetative conditions, without external signs of damage, except for those with carpophores of *Ganoderma* sp. at the base or along the trunk. Some trees also had carpophores of *Coprinus* sp. in the bare area around the trunk.

Thermographic investigations carried out on 60 trees showed that while some had a homogeneous distribution of surface temperature, many others showed an anomalous temperature distribution in the collar area, similar to the thermogram shown in Figure 10.

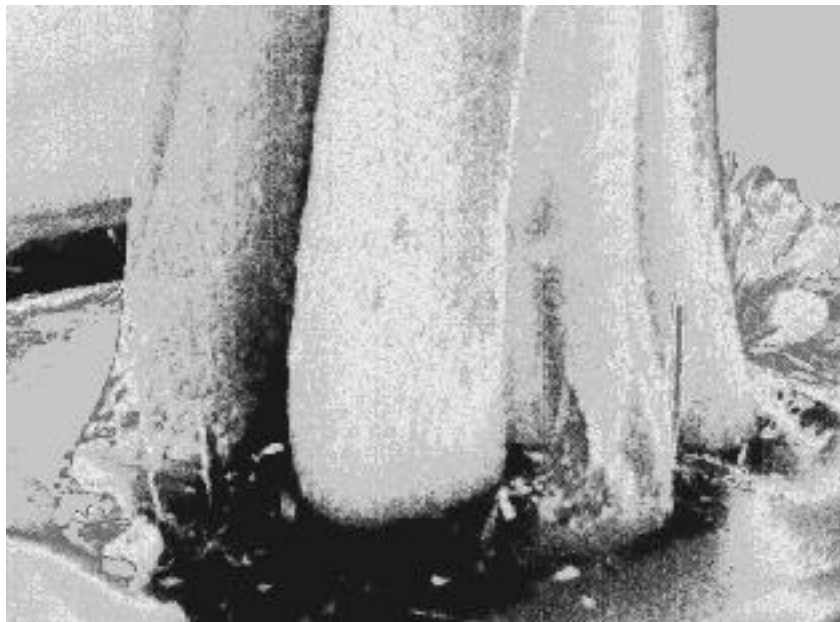


Figure 10. The thermogram of this *Celtis australis* shows the thermal discontinuity present at the collar that reveals damage at the root system. The damage, rendered in dark grey, extends along the trunk. Moist soil around the tree is responsible for the black spots at the base of the tree. The sun, illuminating from the left, was almost at the opposite side of the tree

The damage, shown in various shade of dark grey, extended up the trunk from the base. On the basis of past experience (Catena et al., 1990a) damage at the root system has been diagnosed. The results of the investigation imposed the necessity to fell a first lot of 14 trees and to periodically control the remaining trees. The presence of damage and thickness of residual undamaged tissue, was verified with the use of a dendrodensimeter. The situation found at stump level is shown in Figure 11. A wide area of damaged tissue is observed.



Figure 11. The appearance of the stump of the *Celtis* after felling the tree: widely damaged tissue is observed. The photograph was shot from a position about 45° to the left from the position from which the thermogram was taken

In this case, most of the trees felled didn't present any signs of damage along the trunk or at the crown that could reveal the presence of decay at the root system level.

4. Conclusions

Thermography has proved capable of identifying the presence of internal damage even at an early stage that cannot be seen with the naked eye, thus allowing an early diagnosis but importantly without damaging the tree.

The apparatus provides a quick, accurate and reliable indication of the damaged area. Moreover, the non invasiveness of the apparatus doesn't aggravate or spread damage already present in the plant, since it doesn't cause or favour the penetration of pathogens into the tree.

The reduction in people-hours needed to carry out investigations offsets the higher cost of the apparatus compared with other methods. A one-day course organised by the vendor is sufficient to understand how IR measures should be made. As with the other systems, it will then be necessary to take and assess a few tens of images to become familiar with and correctly apply the method.

As previously explained, thermograms cannot be filmed when it's rainy, and sun-drenched or water-covered parts cannot be assessed. The areas that can be filmed have to be uncovered and directly "seen" by the system.

Like all non-invasive methods, the system cannot detect the type of damage (rotten tissue or cavity), nor the agent which produced it. Therefore, it cannot precisely indicate the thickness of residual undamaged tissue, which needs invasive tools to be measured (Resistograph, DDD, etc.). However, the system can be used to identify damaged areas so that invasive methods of investigation are only used in the points where the damage has been detected, which again reduces the investigation time.

In addition, the ability to assess large portions of the tree and aerial parts makes thermography quick and appropriate to be carried out at the same time of a visual assessment (VTA – Mattheck and Breloer, 1994). This also allows external damage, scars in the bark, shoots, decortications, to be distinguished from internal sources.

The possibility to store thermal images allows the development of the pathology to be followed over time by simply comparing the images. Therefore, it is possible to establish with certainty where and when it is necessary to take measures.

The system is a valuable contribution to the process of assessment of the health and condition of trees, so that they are correctly managed and maintained in cities, parks and gardens.

5. References

- Arbosonic Decay Detector (AD²). Instruction manual, Fujikura Europe Ltd, UK.
- Picus. Instruction manual, IGeL – Institut für Gehölze & Landschaft, Germany
- BARRETT, D.K. SEABY, D.A. and GOURLAY, I.D. (1987). Portable “Compression Strength Meter”: a tool for the detection and quantification of decay in trees. *Agricultural Journal* vol. 11, 313-322.
- CATENA, A. (2000). Ricerche per la conservazione e la gestione del verde urbano a Roma: l'esempio di Villa Sciarra. Thesis.

- CATENA, G. (1991). La Termografia per la salvaguardia di esemplari arborei monumentali. *Linea ecologica* **6**, 18-20.
- CATENA, G. (1992). Une application de la Thermographie en phytopathologie. *Phytoma* **439**, 46-48.
- CATENA, G. (1997). Un albero appare molto danneggiato: lo si deve abbattere o conservare? La Termografia aiuta a prendere la decisione giusta. *Linea ecologica* **1**, 9-14.
- CATENA, G. and CATENA, A. (2000). Evidenziazione mediante la Termografia di cavità e tessuti degradati negli alberi. *Agricoltura ricerca* **185**, 47-64.
- CATENA, G. CATALANO, M. and PALLA, L. (1990). Thermal infrared detection of cavities in trees. *European Journal of Forest Pathology* **20**, 201-210.
- CATENA, G. PALLA, L. CATALANO, M. and MAZZOLA, S. (1990a). Indagine campione sullo stato del verde urbano di Roma. Seconda nota. *Agricoltura ricerca* **105**, 11-20.
- FILLER, T.H. Jr. (1972). Gamma radiation detects defects in trees and logs. *Phytopathology* **62**, 756.
- HRUSKA, J. CERMÁK, J. and SUSTEK, S. (1999). Mapping tree root systems with ground-penetrating radar. *Tree Physiology* **19**, 125-130.
- KUČERA, L.J. and BUCHER, H.P. (1988). Ein neuartiges Messgerät für Holzuntersuchungen. *Schweiz. Ing. Archit.* **45**, 1243-1246.
- MATTHECK, C. and BRELOER, H. (1994). Field guide for visual tree assessment (VTA). *Arboricultural Journal* vol. 18, 1-23.

- MOORE, M.W. (1998). Outillage pour la détection des défauts internes des arbres. Le point de vue du praticien – Résultats de 14 ans d'expérience. *La forêt privée*, 1^e partie, **239**, 31- 44;2^e partie, **240**, 23-39.
- NICOLOTTI, G. GODIO, A. and SAMBUELLI, L. (1998). Onde georadar. *Acer* **4**, 54-57.
- ONOE, M. TSAO, J.W. YAMADA, H. NAKAMURA, H. KOGURE, J. KAWAMURA, H. and YOSHIMATSU, M. (1983). Computed tomography for measuring annual rings of a live tree. *Proceedings of the IEEE* vol. 71, **7**, 907-908.
- OSTROFSKY, W.D. and SHORTLE, W.C. (1989). Applications of the Shigometer for assessing tree and forest health and wood product quality – a review. *Rev. Trop. Pl. Path.* **6**, 39-57.
- RINN, F. Drill resistance measurements on standing trees and timber. Wood quality, tree growth and decay assessment with Resistograph micro-drillings. In *Proceedings of IMEKO XIII World Congress*, Torino, Italy, 5 to 9 September 1994. CLEUP, Padova, Italy, 1994.
- SANDOZ, J.L. and TRUAN, R. (1992). Test de l'arbre sur pied par ultrason avec l'appareil Sylvatest, Brochure Arbosoins, Trélex/Nyon, Svizzera.
- SEABY, D.A. (1990). Recent advances in the detection of wood decay. *Research for practical arboriculture - Forestry Commission Bulletin* n. 97, S.J. Hodge Ed., pp. 168-176.

SHIGO, A.L. (1984). Compartmentalization: a conceptual framework for understanding how trees grow and defend themselves. *Ann. Rev. Phytopathol.* **22**, 189-214.

SHIGO, A.L. (1989). A new tree biology. Shigo and trees, Associates. Durham, NH.