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Ministry of Urban Development
- Plant Protection Service -

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In cooperation with
The German Phytomedical Society

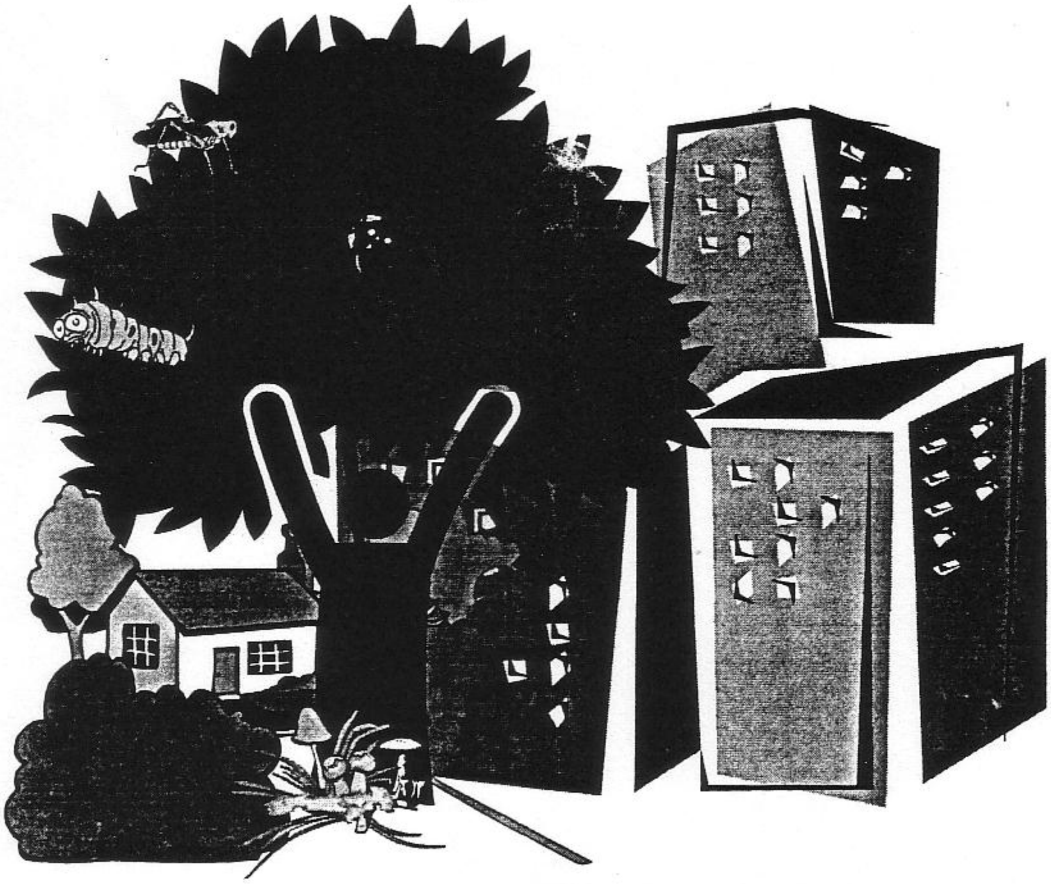
Under the patronage
of the Federal Minister of
Consumer Protection, Food and Agriculture

2. International Symposium on

PLANT HEALTH IN URBAN HORTICULTURE

27 – 29 August 2003
in Berlin, Germany

Final Circular
Programme



14:15 – 16:00	**Poster Session** (Presenters are asked to stay with their posters)

Posters may be displayed during the full duration of the symposium.

S. Antonatos, Greece G. Papadoulis N. Emmanouel M. Papafotiou	*Gynaikothrips ficorum* Marschal (Thysanoptera: Phaeothripidae) and its natural enemies on *Ficus microcarpa* in Greece
H. Balder, Germany I. Feilhaber B. Jäckel	Effect of organized leaf-collections in the control of *Cameraria ohridella* in the city of Berlin
J. Barcic, Croatia A. Mesic M Maceljski	Insect Pests of ornamental trees in Croatia and some results of their control
M. Biocca, Italy	Aspects of the stability of Italian stone pines (*Pinus pinea* L.) in Rome
M. Brandstetter, Austria U. Hoyer Ch. Tomiczek	Cultivation, breeding and diagnosis of *Anoplophora glabripennis* in the laboratory
B. Campanella, Belgium	The use of resistograph F-400 and the processing of data
A. Catena, Italy G. Catena	Thermography: a truly non invasive method to detect cavities and rot in trees (roots, trunk and branches) at a distance and from the ground
D. Czokajlo, USA	New Trap Intercept PT and lures for monitoring Coleopteran tree pests
W. Dmuchowski, Poland	Health condition of trees growing along municipal trees in the center of Warsaw
W. Dmuchowski, Poland	Growth and development of Tilia x euchlora K. Koch in Warsaw street tree lines
O. Ezhov, Russia	Biodiversity insect and fungi disease on introduction and local of the trees at Archangels region
F. Ferrini, Italy	Trees and the human culture
I. S. Floistad, Norway	Use of slury and compost for weed control in green areas
M. Glavendekic, Serbia/Mont.	Significance of nursery production on plant´s health after transfer to urban stands

Catena, A.[1]; Catena, G.[2]

THERMOGRAPHY

a truly non invasive method to detect cavities and rot in trees (roots, trunk and branches) at a distance and from the ground

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Abstract

Thermography is a well-known investigation method that is widely used in many scientific and technical sectors. This method detects the presence of discontinuities and/or unhomogeneity in the bodies investigated, thanks to the different thermal properties between the damaged and healthy areas. In the case of trees, the surface temperature is generally lower in the damaged area. Investigations are performed with the use of an IR camera, that can detect the surface temperatures of bodies from a distance, provide black-and-white or pseudo-colour images in real time and store them onto a magnetic card, so that they can be later downloaded and processed on a PC. The many fields of application of this technique range from medicine to engineering, from geology to biology with an extensive bibliography that dates back to the 1960s: the use of this method to detect tree decay was introduced by G. Catena and co-workers in 1985.

In the case of trees an IR camera, slightly bigger than a portable camera, is pointed to the specimen to be analysed: if the surface temperature distribution of the area investigated is homogeneous, no internal decay is present, and the investigation can proceed. Any discontinuity, in fact, is rendered in a shade of grey different from that of the neighbouring areas in black-and-white images, and in a colour different from that of the neighbouring areas in pseudo-colour images. If the image shows discontinuity, but no superficial damage that can modify the thermal image is seen on the plant (decortication, moss, scar of old damage, etc.), then internal decay is present. That is why, this technique finds its best use within the VTA (Visual Tree Assessment), to integrate the visual assessment.

Thermography allows the presence of possible tree decay to be detected, localised and quantified in 1/30 sec., that is the time necessary for the camera to provide images of wide portions of the tree examined, unlike what happens with most of the instruments currently used that only give information at the height or on the point assessed. Generally, 4-5 images are enough to know the situation of the whole tree: it is possible to diagnose the condition of branches up to 20-25m of height, from the ground; for greater distances, a telephoto lens is available. The fundamental importance of this method especially and mainly in the case of healthy-looking trees can be clearly understood. At present, it is not possible to tell a cavity from damaged tissue, but an expert user can judge if the damage is serious without resorting to invasive instruments that can anyway be employed by an unexpert operator on actually damaged plants and at the very points, that provide data on the plant's stability. Consequently, the screening of urban trees is time-saving, and safety is improved, thus avoiding

the dissemination of pathologies with the random use of invasive instruments to localise the extension of decay. Moreover, if the discontinuity is only present at the base, in contact with the ground, or it is particularly spread in this area, damage is certainly present at the root system level. However, this technique cannot "penetrate" the ground and give direct information on the condition and distribution of the root system.

The technique has been successfully used on thousands of plants of many different species, both broad-leaves and conifers, but also numerous palm trees. Ongoing research concerns mushrooms, of which interesting images were taken. Images of recent investigations are presented here.

Introduction

Thermography is presented as a truly reliable and non-invasive investigation system for the assessment of tree stability. This system shows the presence of damage (cavities, decay, damaged tissue) in the various tree parts, from roots to branches, from the ground and in real time.

The heavy deterioration of urban trees caused by environmental pollution, high anthropic pressure, wrong planting and cultivation techniques or other factors, poses serious threats to people, because of the sudden collapses and crashes that often occur with no external causes. Therefore, it is necessary to use reliable and quick investigation systems, in order to accurately assess thousands of plants in urban centres in a short time.

Most of the systems currently used provide information only at the height or on the point assessed or are time-consuming and require a whole crew and lifting apparatuses to reach the parts out of a man's reach. As far as the authors know, no one can provide reliable information on the root system in real time.

The method proposed consists in assessing the various parts of a tree from a distance with an instrument that can measure surface temperature. The apparatus produces a thermal image (in black-and-white or in pre-set color palettes – pseudo colors). This image constitutes an actual thermal map of the area examined and reaveals the presence and size of possible decay. Images can be recorded, processed on a PC, included in a database and used to reliably monitor the development of the phenomenon, by simply comparing two series of images. The system proved capable of detecting decay in the root system, trunk, and aerial parts of trees and is being studied with regard to its capacity of spotting the presence of fungal attacks.

What is Thermography?

Thermography has been well known and widely used in many scientific and technical sectors for many years. This technique is applied when the investigation of an area with a surface temperature different from the "normal" one, or different from the one in neighbouring areas shows the presence of anomalous, dangerous situations or situations that deserve further analysis. Unlike the traditional temperature measurement systems (thermometer, thermocouple and thermistor) that require point-by-point measurements to build the thermal map of the object under investigation, Thermography provides a simultaneous and instant measure of all the temperatures present also in wide areas from a distance. The apparatuses used detect the infrared radiation (IR) coming from the body under investigation because of its surface temperature and visualise it in the form of black-and-white or pseudo-colour images: thus, every temperature respectively corresponds to a precise shade of grey or colour. Therefore, identifying the presence of internal anomalies on the basis of a different shade of grey or colour is easy and immediate, because damaged areas have surface temperatures different from the ones in healthy neighbouring areas.

Thermography is a Remote Sensing technique, used to study the environment: in fact, for instance, it was discovered that the presence of a difference in temperature in water bodies can reveal drains (CATENA G., 2000; CATENA G. and PALLA, 1980; CATENA G. et al. 2002; FERRIER and ANDERSON, 1996) or algal blooms (ANDERSON, 1995; CATENA G. et al., cited) or again spilled hydrocarbons. Thermography is used in geology to study volcanos and geothermal phenomena (CASSINIS et al., 1974) and to assess slope dynamics and stability (TONELLI, 2000; TONELLI, 2001). This technique has been widely used in medicine, as a mass screening system to diagnose breast cancer (ROCCHI, 1976) and is still currently used in state-of-the-art studies on the cutaneous malignant melanoma (DI CARLO, 1995). In engineering, Thermography highlights insulation problems in buildings (PALJAK and PETTERSSON, 1972) and the ensuing heat losses, also with a view to energy conservation. Thermography has become one of the Non Destructive Testing (NDT) techniques to detect flaws in structures obtained by fusion (bow thrusters, drive shafts, etc.) or, in the wood-processing industry, to find internal flaws in rolled sections, composites and plywoods, for instance, that generally need pre-heating (BUCUR, 2003). Moreover, this method is widely used in the car and electronic industries. It is also used to assess the insulation of industrial furnaces and to detect the hot spots in high-tension electricity mains (particularly, in the assessment of insulators), that could lead to dangerous and harmful power cuts. Moreover, Thermography is used in archaeology and architecture to restore monuments and works of art. There exist tens of applications for Thermography, that are too many to be listed.

Thermography and trees

The idea to apply Thermography to tree assessment saw the light at Rome-based Istituto Superiore di Sanità after over 10 years of experience developed in the use of the technique in some of the above-mentioned sectors. In 1984, G. Catena and his coworker L. Palla studied plants as pollution indicators with aerial shootings, and wondered "Can Thermography detect structural discontinuity within trees as it does in the human body, metal structures, walls, the ground, etc?". The answer was experimentally obtained on a *Celtis australis* of the Botanical Garden of the University of Rome and was positive (CATALANO et al., 1986). In fact, the thermal properties (conductivity and capacity) of damaged tissue are different from those of healthy tissue. Consequently, the two areas present different surface temperatures, easily detectable in thermal images. Since the different thermal behaviour is probably caused by the different tissue metabolism, the technique as such can only be used on living trees, and not, on poles, beams, lumber, composites, plywood, dead trees or dried branches, etc. In fact, these are influenced by ambient temperature and are cold in the winter and warm in the summer, so no internal decay can be detected in them, Figure 14. The damaged area has a generally lower temperature than the one in the healthy area, Figure 1. When no internal damage is present, the surface temperature of the tree is uniform, Figure 2.

If decay is detected at the collar, or if it is more serious there than in the rest of the trunk, the presence of decay at the root system can be inferred (CATENA A., 2003; CATENA A. et al., 2003). This can be explained thanks to the different metabolic activity of damaged tissue vis-a-vis healthy tissue: the system cannot "see" through the ground.

The advantages of the system reside in its quickness and non-invasiness. An image appears in a fraction of a second and it takes 2-3 minutes to assess the condition of plants, also imposing ones. The system does not damage plants in any way and does not spread the possible diseases present.

Since the first investigation, the system has been widely used in this sector and a few thousand plants of different species, conifers and broad-leaves have been assessed, and more recently good results have been obtained with palm trees too. A very promising sector that is still being studied concerns the fungi that colonise trees: the first experience was described in A. CATENA (2000), but others are being studied.

Precautions, limits and....advantages of the method

Since the system measures the temperature on the tree surface, the latter should not be covered by climbers, leaves, moss, other vegetation, etc.

A precaution to adopt when a species is assessed for the first time consists in seeing how its bark is rendered on the thermal image. The smooth bark of a nettle-tree is rendered differently from the one of an holm-tree or a pine. An image can be misinterpreted if this is not taken into account. The IR camera detects all that is on the tree surface, therefore moss, leaves, ivy, scars, other vegetation are represented on the image (Figure 3 and 12) and can lead to misinterpretations, if they are not recognised as surface damage, disturbance or foreign body. That is why the use of Thermography is recommended after an accurate visual tree assessment. Therefore, it is a good rule to take a picture of the area filmed, during the Thermography and from the same angle. This is useful to avoid misintepretation, when an image is interpreted after some time or when thermograms are shown to other people. It should be highlighted that an expert in tree assessment and in the use of the instrument can analyse most of the plants investigated without resorting to other instruments.

The limits of the method are mostly due to the nature of the infrared radiation.

Sundrenched, and therefore heated parts cannot be assessed: to an inexperienced operator, this could hide the possible presence of damage. In those cases, it is enough to assess the plant from the side in the shade, thanks to the very low thermal conductivity of wood.

The water absorbs the infrared radiation, therefore assessments cannot be carried out in the rain or on wet tree parts (Figure 6B).

The system cannot tell a cavity from damaged tissue (Figure 7), nor it can recognise the type of disease present, just like all non-invasive systems.

The system has been used in every season of the year, in Northern and Central Italy, with temperatures ranging from +2 and +35 °C, with no significant differences in results. The system has not suffered from the anomalous presence of water or resin in tissue.

Thermography can detect the presence and size of internal damage, even if they are small and/or not visible from the outside (Figure 11, 12, 13 and 14). The investigation is totally harmless to trees, does not spread the diseases present, and is quick, because in a single image wide tree portions can be examined.

Images can be stored in a database. This allows the phenomenon to be monitored over time, by simply comparing the relative series of images.

The available apparatuses

This type of investigation can use various types of apparatuses currently on the market, from modern IR cameras to time-honoured thermal scanners. Systems that work in the 2.5-5.6 and 8-14μm wavelength intervals can be used. They can have a low-temperature cooled sensor or a sensor working at ambient temperature. The fundamental property that they shall have is high thermal sensitivity and geometrical resolution so as to show small phenomena. These systems shall have a built-in monitor to visualise the images that will be recorded onto a card so that they can be later processed on a PC and reused.

The latest systems are more performing than old ones, in terms of manoeuvrability and ease of use, they are lighter and smaller, and no parts are in motion. These systems are portable and, most importantly, can work at ambient temperature.

The apparatus currently used is a portable AVIO TVS 610 IR camera, working in the 8-14μm wavelength interval. Its thermal sensitivity is 0.1 °C and its geometrical resolution is 1.4x1.4cm^2 (IFOV, Instantaneous Field Of View, Figure 4) at 10m of distance. This means that at the distance indicated, the system can visualise an object having a size bigger than that indicated and with a surface temperature differing of at least 0.1 °C from the one in neighbouring areas. At 10m of distance, the system has a Field of View (FOV – Figure 4) of 4.5mx3.3m: this is the maximum dimension of a tree portion that can be visualised in a single image from that distance.

In this system, the sensor that measures the IR radiation is made up of a plane array of 320x240 microbolometers and works at ambient temperature. The system is portable, weighs 3kg and is powered by a normal camera battery, allowing up to 4 hours of functioning. The sensor, screen (images are shown on the screen in real time and with a refresh of 1/30 sec.), mini processor, command module and battery are contained in a single case. The apparatus is slightly bigger than a normal camera, can be fixed on a tripod (Figure 6A) and operated by a person only. The images recorded on a Compact Flash card can be transferred onto a PC to be processed with a proprietary software, PE, to draw up Reports on paper, and to be transformed into bitmap images, that will be used and processed by any image- and text-processing software. The presence of the reference scale immediately allows the temperatures to be assessed (Figure 11 and 13). The numerical values of the temperatures in the various points of the image can be visualised both when the image is still on the screen and when it is later processed.

In black-and-white images, the existence and size of damaged tissue can be inferred by the presence and extension of an area in a darker shade of grey than the neighbouring areas. In colour images (pseudo-colours), the damage is detected thanks to an area of colour different from the neighbouring areas. The investigation is carried out by pointing the camera from the ground to the area of concern and then by assessing the images filmed. The assessment of a whole plant, including its aerial parts requires a few minutes. For distances greater than 20-25m, the standard lens could not detect small damage, both because of the lower resolution (IFOV, Figure 4) and the limited size of the image of the tree on the screen. In those rare cases, a telephoto lens available as an optional can be used.

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Figure 1 – Thermography of a damaged tree. This holm-oak (*Quercus ilex*) shows damage at the root level (in blue, light blue and dark green) going upwards with a lower intensity (in yellow, orange and light green) and also affects the fork. Two cavities are present to the right of the trunk, indicated in light green and by two red arrows. The most damaged part of the trunk is on the left, as it was verified by introducing a probe in the above-mentioned openings.

Figure 2 – A healthy lime tree (*Tilia* spp.): the uniform distribution of grey is observed. The dark stains at the top are the thermal images of leaves.

Figure 3 – The thermogram seems to show some small-size damage rendered in dark blue in this cedar (*Cedrus* spp.), but the tree is healthy instead. In fact the exam of the picture of the same area, shot at the same moment, shows the presence of surface damage (slight decortications and patches of detached bark). The need to always observe the surface of the tree under examination and not to interpret the thermogram without the relevant picture available of the tree is clear.

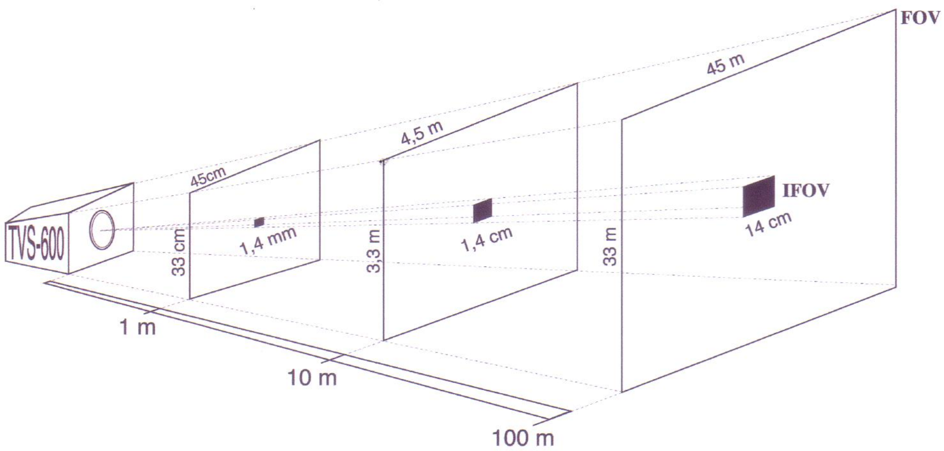


Figure 4 – Geometrical resolution (Instantaneous Field of View – IFOV) and Field of View (FOV) of the apparatus now used for assessments, on the basis of the distance from the object examined.

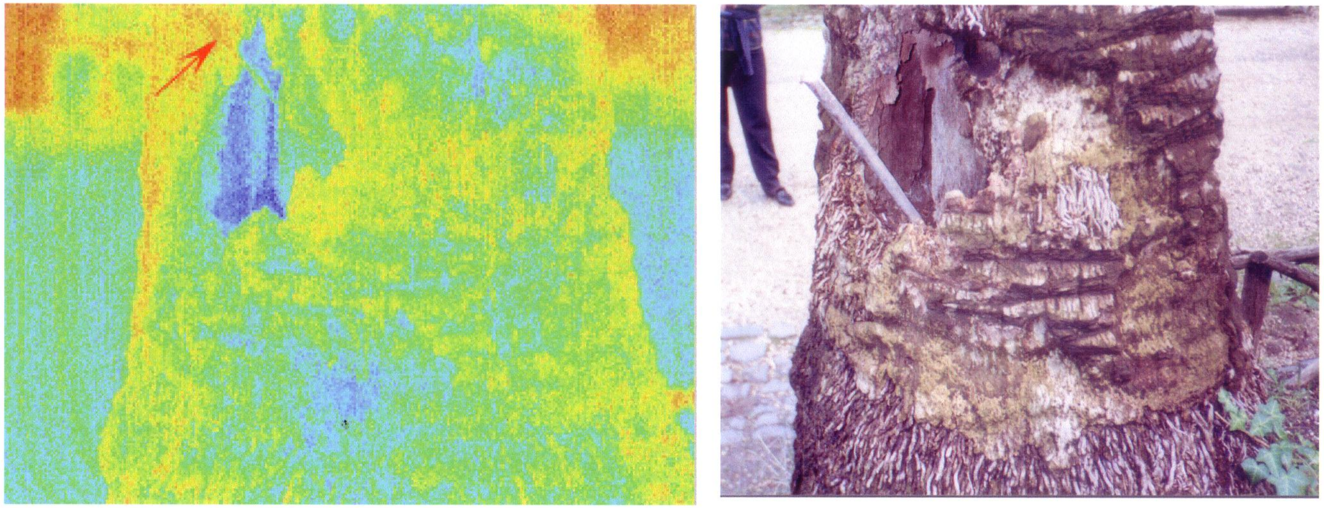


Figure 5 – This palm tree (*Phoenix canariensis*) presents a cavity in the trunk. The size of the cavity cannot be measured because of its shape and the debris present in it. The thermogram allows outlining the size of the cavity, in light blue and green, that was checked with the probe indicated by the red arrow.

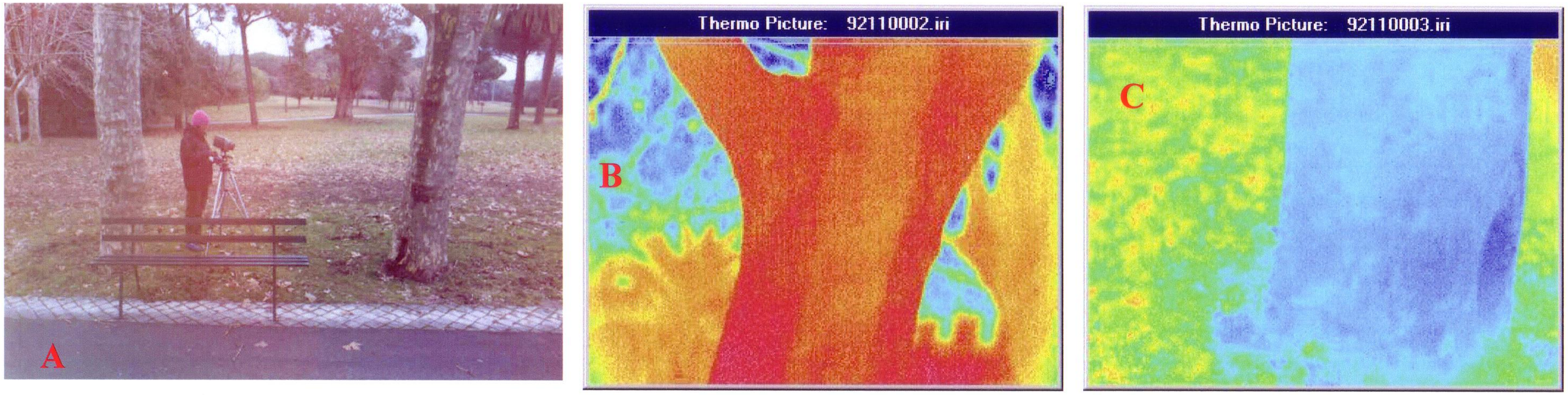
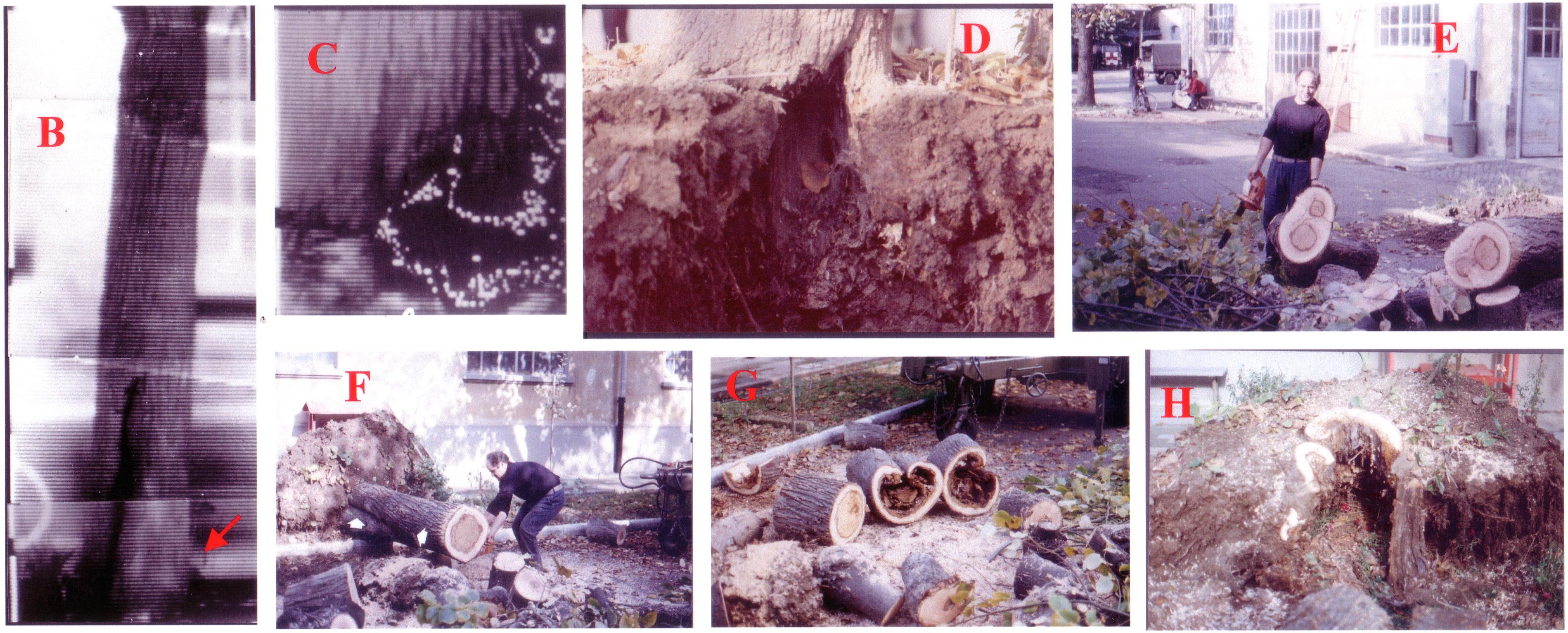


Figure 6 – A This plane-tree (*Platanus hybrida*) is being assessed with the IR camera: the tree has a straining on the trunk, due to the rain that fell in the previous days. The base presents an oval wound with healthy tissue exposed; at the top of the wound, a small cavity going upwards is noticed. B This thermogram, shot at the fork, shows how liquid water is rendered in a colour different from the rest of the trunk, thus disturbing the interpretation of the thermal image. C This thermogram, filmed at about 90° to the left of the first, shows the existence of internal damage at the height of the wound, and how damage moves upwards, near the surface (in blue). The root system looks undamaged. The first damage was checked by hitting the trunk with a hammer, the second with a probe.



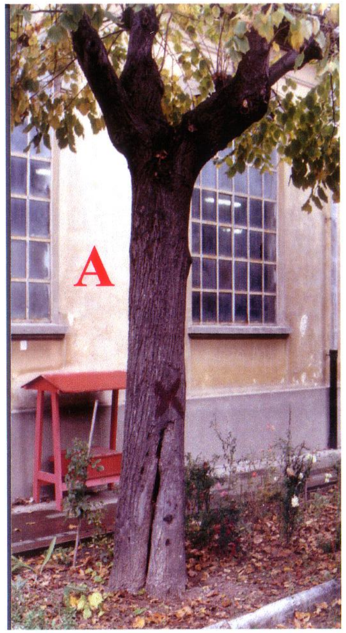


Figure 7 – A A lime tree (*Tilia* spp.) that presented a lengthwise crack at the base and pollard-induced scars at the branches. B Its thermogram, taken with a thermal scanner, shows serious damage going from the collar area to the fork. Lighter stains are due to the sunlight filtering through the branches. Damage is present in the branches too, with less intensity (thermograms not shown). C This image relative to the point indicated by an arrow in B shows how damage affects the whole collar. The tree was deemed unstable and uprooted with a crane. D This is how, with no manual operation, the clod from the side the thermogram C was shot appeared. The trunk is reduced to a hollow cylinder. As the trunk was cut from the top, decay appeared in the branches, the fork and in the top part of the trunk, E and F. In G stumps above the collar are shown, at the crack level, that are totally hollow. The thinness of the healthy tissue remained is observed. Finally H shows the stump at the base, that was easily opened flat, and showed the absence of tissue in the root area.

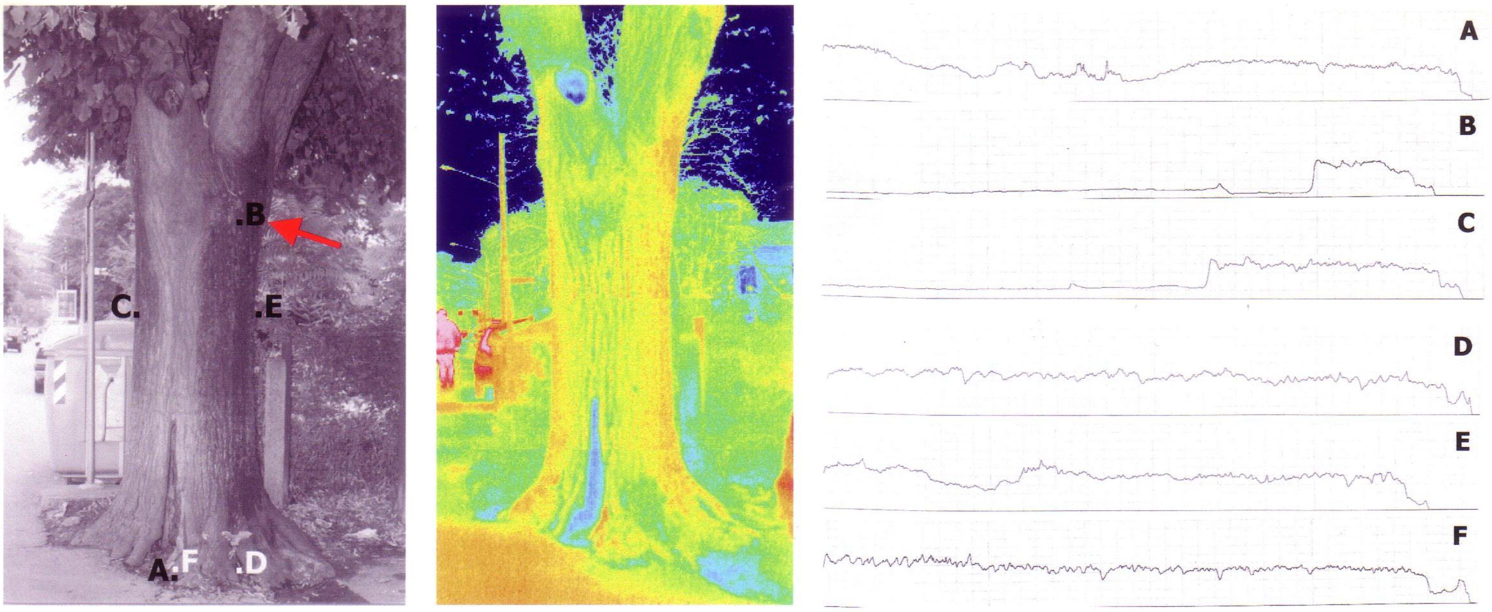


Figure 8 – This lime tree (*Tilia* spp.) shows a deep lengthwise fissure at the trunk base and a cavity at the fork, due to the cut of a big branch. The thermogram shows how the two cavities (both in blue) are connected and all the branches are very damaged (in green and yellow). The damage also affects the area under the fork and a small area at the base, to the right of the fissure (both in green). The left part of the trunk is more damaged than the right one. Damage was later checked with a dendrodensimeter, inserted in the points indicated by the letters; in A and D, the probe was inclined by 30° downwards, in C, E and F it was horizontal, in B (red arrow) it was inclined by 30° upwards. F and D were probed on the opposite side of the trunk. The graphs correspond to what the thermograph detected.

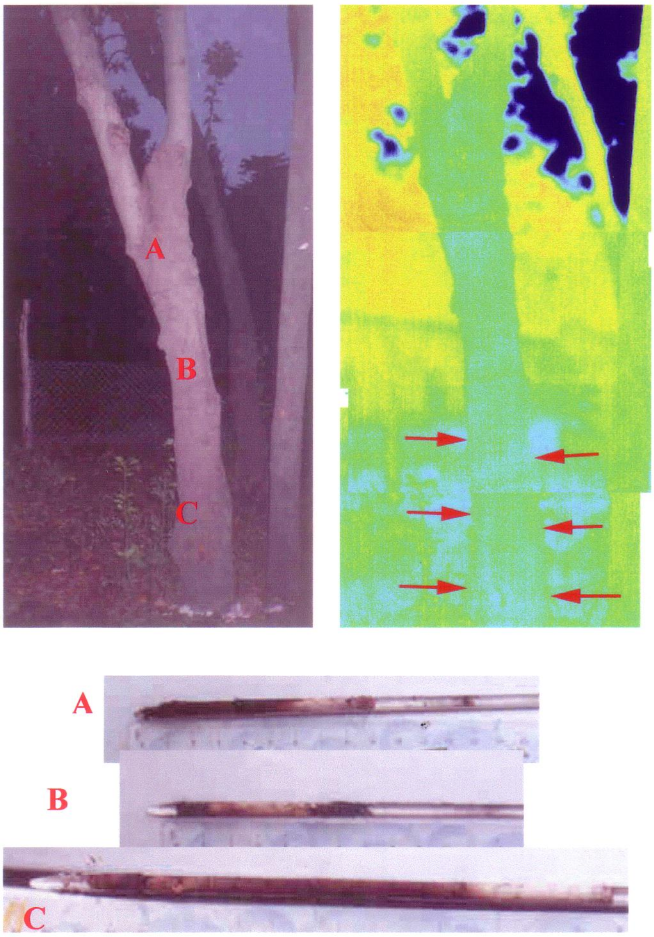
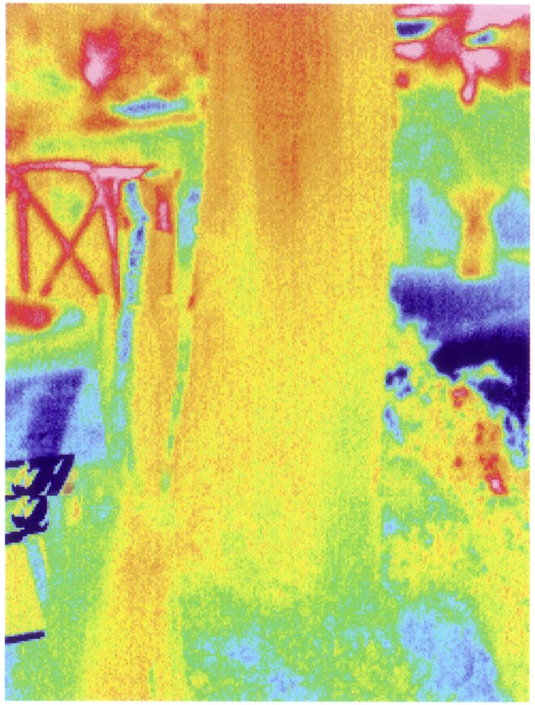


Figure 9 – This bay tree (*Laurus nobilis*) only shows a small cavity full of debris, near an old cut at the fork level. The relevant thermogram shows serious damage in blue and dark green from the base to the fork. The two residual branches are not so damaged. The thermogram of the trunk base was marked with the help of arrows, because inexperienced observers might have mistaken it for the background. The presence of damage was carried out with a Pressler's auger. The points in which the auger was introduced and the relevant cores are indicated by the same letter. A The auger penetrated for 10cm before failing to grip tissue, which means that a cavity or badly damaged tissue were present; water flew out of the hole. B The auger penetrated for 10cm before failing to grip tissue, but no water came out of the hole. C The auger failed to grip tissue after penetrating for 20cm.



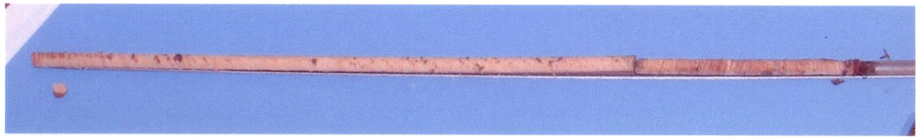
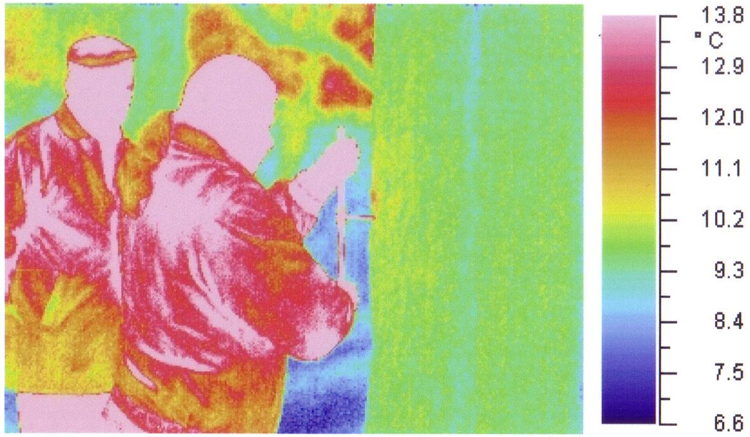
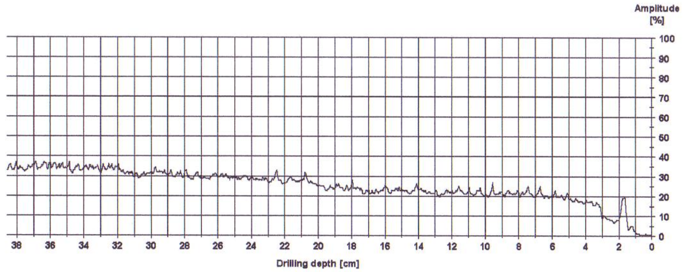


Figure 10 – A cypress (*Cupressus sempervirens*) the thermography of which shows small-size damage at the base, especially in the right part of the trunk (in light-green). The control was performed with a Pressler's auger, introduced in the point indicated by A. The exam of the core shows slightly damaged tissue only in the early centimetres beneath the bark.





FRATTOMETRO

Zona	H da terra (cm)	Diametro (cm)	L. campione (cm)	T/R	Giudizio
Fusto	148	88	35,00	0,57	Iniziale distruzione della cellulosa

Posizione misura: 290 ° N

Carico:	8	8	7	8	15
Angolo:	13	12	13	12	11

Figure 11 – Thermography of a horse-chestnut (*Aesculus hippocastanum*) that shows a thin strip of damaged tissue that goes up the trunk (in light-blue). The exam with a dendrodensimeter did not detect significant damage, whereas the exam with a Fractometer on a core of tissue extracted with the Pressler's auger showed the presence of an initial destruction of the cellulose.

Figure 12 – This 27 m-high plane tree shows signs of damage at the fork level that is difficult to quantify from the ground. The use of Thermography to assess aerial damage was required. Thermograms show how damage affects both branches towards observers and the bifurcation (in blue and light-blue). The analysis of the rest of the tree showed damage in the root system. At the base of the tree on the right it can also be observed how the thermal image of the limbs of the bush (in yellow and orange) hinders the reading of the thermogram.

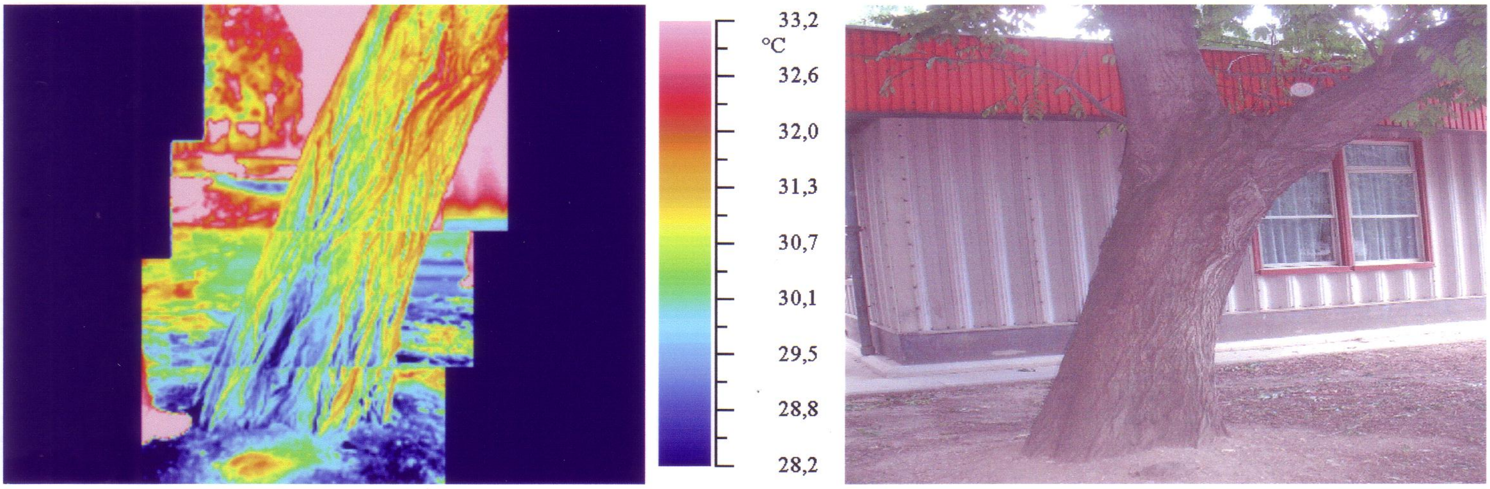


Figure 13 – A pterocaria (*Pterocarya*) growing nearby a school which inclined towards the building. The tree shows damage only at the fork due to the felling of a large branch. Thermography reveals (in dark blue, blue and yellow) wide damage at the root system, particularly on the left side of the image. The damage goes up to the fork but with lesser intensity. At the moment of the survey no mushroom was found. A quick survey found a ganoderma (*Ganoderma* spp.) at the base of an adjacent smaller dead pterocaria.

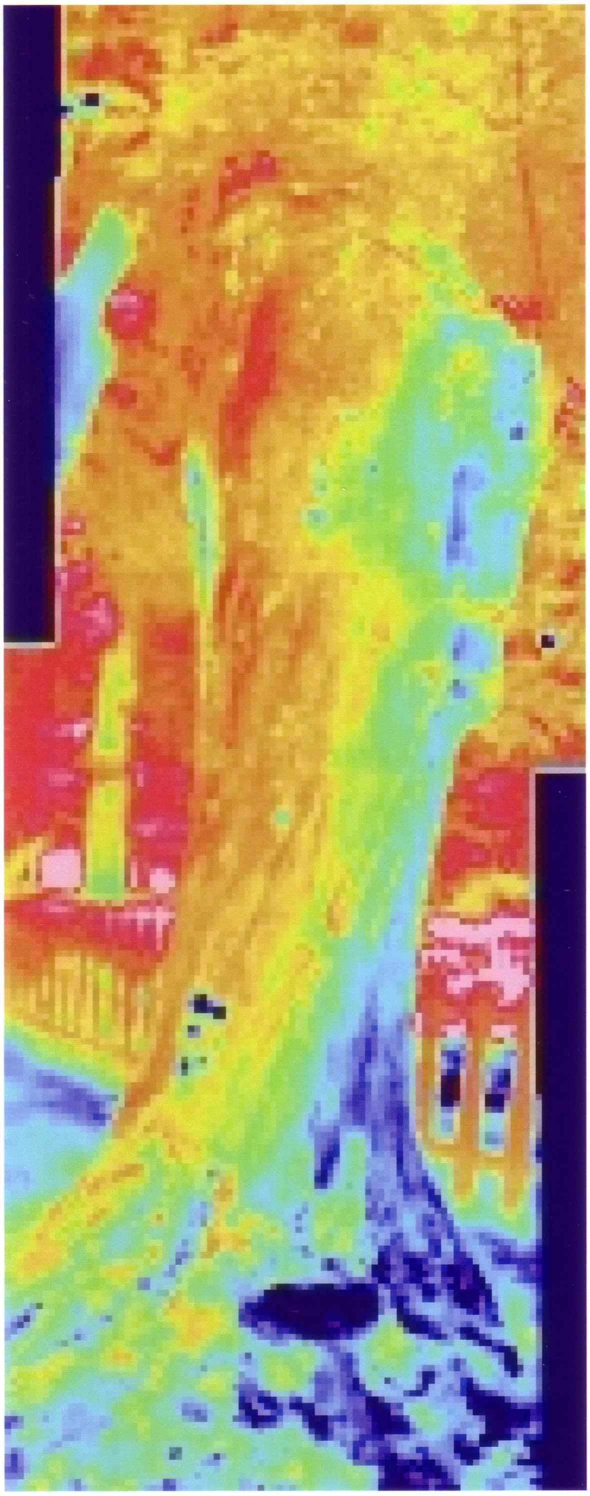


Figure 14 – This hornbeam (*Carpinus betulus*) shows the cut of two of the three branches, right above the bifurcation: the remaining branch has a scrubby vegetation. The stump towards the observer is dead, as shown by the thermogram (in red and yellow) and the saprophytes present. The thermogram also shows that the stump opposite is still alive, but greatly damaged, like the trunk base (in dark blue and light blue). The damage also affects the root system. At the base of the trunk various specimens of ganoderma (*Ganoderma* spp.) can be observed: a huge specimen towards the observer and other small ones on the left of the trunk.

Ongoing research