

Case Study –Ancient, Veteran Beech Trees; Blenheim Palace, Woodstock, Oxfordshire. Inspected July 2007.

Background

Many of the beech trees at Blenheim Palace were planted as part of the re-landscaping of the estate by Lancelot (Capability) Brown. This dates them at around 250 years old. It was appreciated by staff at Blenheim Palace that the majority of beech in the parkland would require careful monitoring and management to avoid major branch shedding or complete failure. While this is a natural phenomenon for beech of this age that can enhance their habitat value; it can cause extreme difficulties when preserving trees that are an important part of the landscape heritage but which can pose a risk to public safety in areas of high public access. The concept of '**preserving the worth of the trees**', was developed to embrace the overall benefits the trees impose on the landscape. This goes beyond the risk to the public and only thermal imaging can be used to do this since it is the only technology that can evaluate physiological functionality of wood throughout the tree.

Where options to divert or exclude the public were limited, it was recognised that the veteran beech might require heavy crown reduction to stop the trees 'ripping themselves apart'. Beech trees do not respond well to heavy reductions and as a result canopy management may accelerate the dieback process. Therefore, management should allow it to happen in a controlled and predictable way but without acceleration of the process. Therefore the objective was to '**use thermal imaging to identify the viable parts of each tree that remain in balance with any dysfunction present so that the individual elements of trees could be manipulated to reduce the likelihood of branch or tree failure while ensuring the best possible chance of recovery from tree work**'.

The trees inspected were identified as potential hazards to the public and surrounding property by staff at Blenheim Palace. Numerous fungal fruiting bodies had already been identified in beech trees but the extent of dysfunction and decay associated with these fungi had not been determined. All the trees were located in public areas of the parkland where it is known there are high incidences of public activity.

Thermal properties of highly decayed trees

Thermal processes and changes in wood functionality

As a whole, trees produce very little heat energy in comparison to other living organisms particularly animals. This means that ultimately the heat energy given off at the surface of the trunk and limbs of a tree is heat that has been previously absorbed from the environment. The IR energy detected by thermal imaging cameras is a heat flux as a result of the amount of heat energy absorbed. This means that firstly, if something alters the properties of wood such that they absorb less heat, there will be less heat flux at the surface and conversely wood that absorbs more heat will

have a greater heat flux at the surface. Secondly the amount of heat flux changes constantly throughout the day as the environmental heat sources change.

Sound, healthy wood has good physiological functionality i.e. it allows physiological processes, including heat transport, to occur efficiently. The connectivity between cells allows heat to flow at close to optimal rates, part of this process is a diffusive process along temperature gradients and part is through the mass flow of water. The result is a relatively even distribution of heat at the surface. If something interrupts the functionality of wood, the flow of heat is interrupted and cooler volumes are generated internally. These lead to a cooling of the surface area in the proximity of the cooler internal parts due to a reduction in heat flux. The greater the extent of cooling of an internal volume of wood, the greater the effect on the temperature at the surface.

The presence of microorganisms and the creation of barriers (e.g. inclusions, barrier zones and growth abnormalities) obstruct the flow of heat and alter surface temperature. The extent of all these changes in comparison to optimal wood functionality can be detected and quantified but to do this, thermal images must be calibrated against changes in environmental temperature.

Decay is one of the processes that can cause physiological dysfunctionality of wood and as a result alter its heat holding properties. As decay progresses it alters the amount of heat that is emitted from the surface. As a result, cooler areas appear at the surface that is associated with the altered or destroyed tissues below the surface. Warmer areas can be interpreted as being associated with healthy tissues and cooler areas can be interpreted as being associated with altered or destroyed tissues.

Advanced stages of decay and superheating

Given the age of the beech trees there was potential for advanced decay close to the surface. When volumes of decay or dead tissues are close to surfaces that are heated by the sun, the heat energy can become 'trapped'. This comes about because dead wood and enclosed volumes of air heat up and cool more slowly so that they retain heat above ambient air temperature. These are described as being superheated volumes. When trees are in an advanced state of decay such that the cross-section of wood on the North-side is also very thin, excess heat can conduct through to the North-side as well. In addition in advanced states of decay some fungi can give off heat that can be trapped inside the tree and that will also bring about superheating.

Superheating can lead to an apparent temperature inversion where warmer areas indicate decay and cooler areas indicate small amounts of healthy tissues. However where functional wood tissues are thick enough to stop superheating there is little heat conduction from this source and so what is actually apparent are surfaces that appear very hot because they are superheated next to surfaces that are relatively cold due to a thin wall of functional wood and so there is little change in the interpretation of the amount of functional wood from images. The superheated areas are simply discarded from the analysis of healthy areas by attributing a separate colour scheme called an alarm colour. In the data sheets below, bright green is used to highlight superheated areas.

Thermal Imaging Survey

Following a visual inspection by staff at Blenheim Palace a thermal imaging survey was commissioned. Images were taken using a FLIR[®] P65 camera and processed using Tree Thermal Matrix Software (TTMS; Trees Project Limited, 2006). Using TTMS the balance between functionality and dysfunctionality was visually described in a red to blue colour scheme with red indicating surfaces over relatively thick volumes of functional wood and blue indicating surfaces over relatively thin volumes of functional wood. To analyse the balance between functionality and dysfunctionality TTMS was used to calculate the % dysfunction at a given point such as the base of the tree, a portion of the main-stem or a position behind a branch.

The balance between functionality and dysfunctionality (the extent of dysfunctionality) was taken into consideration along with the position of the dysfunctionality in order to make a probability of failure assessment. Both the extent and position of dysfunctionality in the wood need to be taken into consideration, since small amounts of well progressed dysfunctionality can be important considerations in crucial positions such as at critical points in branch unions where it can cause branches to fail. Once these factors were taken into consideration, then the surrounding wind environment could be considered and taken into account. Given the position of the trees surveyed within the undulating topography of the parkland, all surveyed trees were considered at least Semi-sheltered. Therefore trees were classified as either **Sheltered** trees (i.e. sheltered by other trees, the local topography or buildings); or open single **Semi-sheltered** trees.

Taking the extent and position of dysfunction into account along with the positioning of the tree; the probability of failure of each tree was then categorised on a scale of Low, Moderate, High and Severe. In this system Low to High describes the probability of failure, within a twelve month time period, at some part of the tree if action is not taken to rectify the situation as a '**risk assessment probability of occurrence**' indicator. The additional Severe category is used to describe an imminent probability of failure where felling or major works may be the only option to avoid limb shedding or the tree falling down anyway. In this way the overall risk could be assessed by the client. No tree can be considered as having complete wood functionality and so only those areas of dysfunction that were obvious and significant were commented upon. In this way the tree is looked upon as having optimal wood (the best that can be expected) in balance with sub-optimal wood (below this level).

Recommendations for work

The ethos of the '**worth**' of the tree means that work may be considered to preserve the tree even if there is little risk to the public. ***The classification of optimal and sub-optimal wood functionality not only allows identification of risks but also allows a tree's strength to recover to be assessed. This is not only important in terms of the ability to overcome fungal decay but also to overcome work carried out on the trees and can only be assessed with thermal imaging.*** Only when trees are in a high or severe classification should there be a sense of necessity for work and even then the work should complement the growth processes already taking place in the tree. If they do not and the risk to the public is

acceptable then the tree should be left to get on with things. The concept behind the work recommendations is that trees are moved from a high or severe probability of failure to a lower probability of failure (moderate or low) whilst preserving the worth of the tree wherever possible. If a tree is already a low or moderate probability of failure there are probably few cases where carrying out work can be justified.

This process can only be carried out with the aid of thermal imaging since only thermal imaging can evaluate wood functionality throughout the whole tree.

Recommendations for re-inspection

The use of thermal images allows the tree survey team to understand the strengths and weaknesses of each tree. This can be reflected in management recommendations but also in recommendations for re-inspection periods. Following a thermal image survey it is not necessary to have follow-up thermal images for around three years providing the tree has been 'stabilised' i.e. it already resides within or has been moved to a low or moderate probability of failure. Visual inspections can take their place since the strengths and weaknesses have been identified and they can be closely monitored. One exception to this would be if a root plate decay organism was thought to be present, in such cases trees will require more regular monitoring to detect the progression of decay into the base of the tree. Re-inspection should always reflect pragmatic time periods and presuppose that thermal imaging will not necessarily be the method used for re-inspection. It should be remembered that trees in the Low or Moderate probability categories are unlikely to fail in the coming 12 months but are not immune to failure. Trees in higher probability categories are more likely to fail but are not destined to fail within the next 12 months. Even trees that are considered a Severe probability of failure have not yet failed it is purely that there is a greatly increased probability of failure based on the results found not on a persons opinion of the results.

Further investigations

If it had been established that the amount of dysfunction present was well progressed such that it cause the tree to fail then a further invasive study of wood quality might be recommended depending on circumstances. Increment cores were used for this purpose.

Summary of inspections

Due to the generally sheltered environment within the parkland only one of the trees (Tree 15) was recommended for felling. This was due to the position of the tree next to a neighbouring property the amount and location of the dysfunction and the lean in the tree towards the property. In addition the structure of the canopy and the presence of *Ustulina deusta* did not allow the canopy to be sufficiently reduced to reduce the probability of failure to an acceptable level.


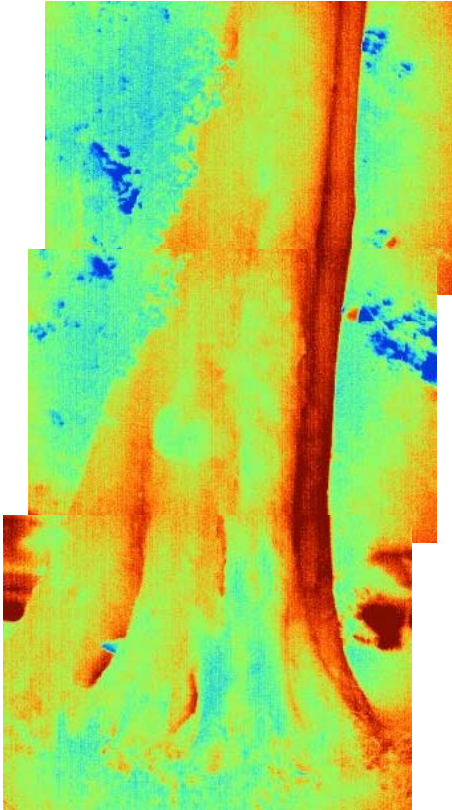
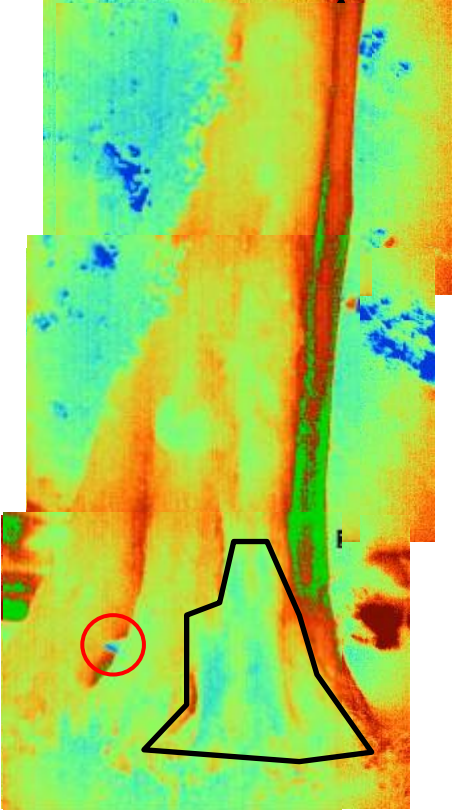
Despite the presence of decay fungi, only Tree 8 had sufficient dysfunctionality extending into the crown such that the canopy would be

compromised if tree work were carried out. This tree was in a state of natural decline and little work was necessary. The remaining trees had enough functionality in the canopy to sustain light canopy work to be phased in over two to three growing seasons. Only Trees 7 and 14 required work to be started in the next 12 months. Tree 7 had an over weighted branch that required wind pressure and weight to be reduced and Tree14 had a area of dead wood above which wind pressure needed to be reduced.

The nature of the dysfunctionality required re-inspection on an annual basis.

Marcus Bellett-Travers

<p>Data Sheet: Tree 4 Date: 03/05/07 Client: Paul Orsi, Blenheim Palace Tree No.: 4 TAG No.: 503 Species: <i>Fagus sylvatica</i> Location: Above Seven Arches Position: Bank away from road side. Direction Images Taken: 186°</p>	<p>Summary of inspection details: There are areas of superheating associated with decay probably from <i>Ganoderma spp</i> (fruiting bodies apparent, see inset photo)there is an area of thin buttresses (blue areas at base) but also vigorous growth in the base of the tree (orange colours). Outcomes: There is 70-80% dysfunction in the base and it is highly probable most of this relates to <i>Ganoderma spp</i> related decay although the decay is not concentric being closer to the surface of some buttresses rather than others. The tree is a high probability of failure in its present state. An invasive inspection should be carried out.</p>
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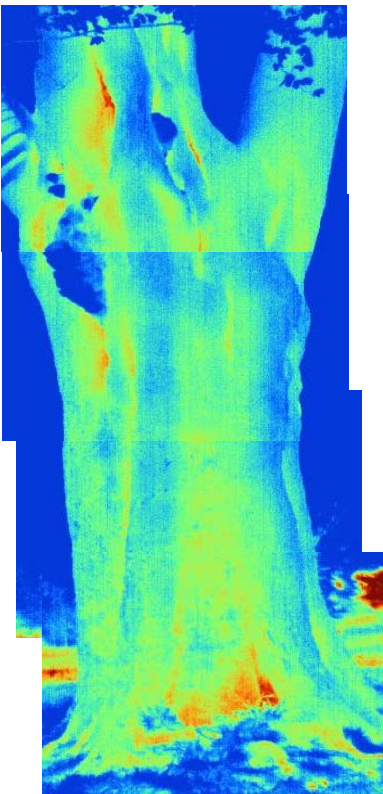
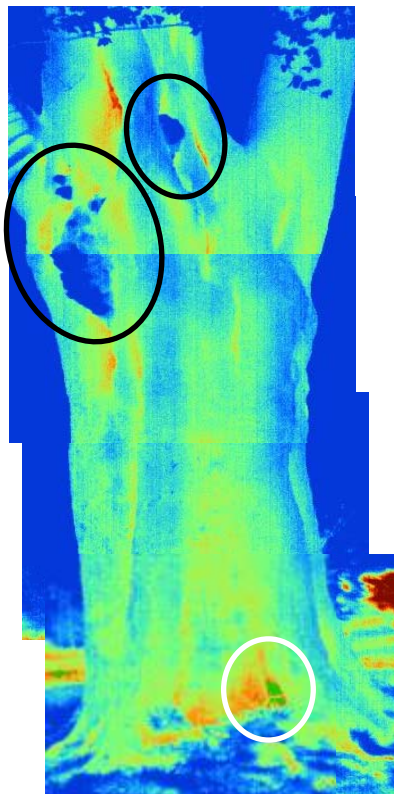
Visual Image	Thermal Image	Annotated Image	Annotation Details
			<p>Green coloured areas indicate areas of decay close to the surface (superheated).. The black enclosed area (blue-green) indicates buttresses over a large volume of dysfunctional wood, weak buttresses. Other buttresses are associated with thicker volumes of functional wood. A fruiting body of <i>Ganoderma spp</i> is circled red.</p>

Outcomes Tree 4.


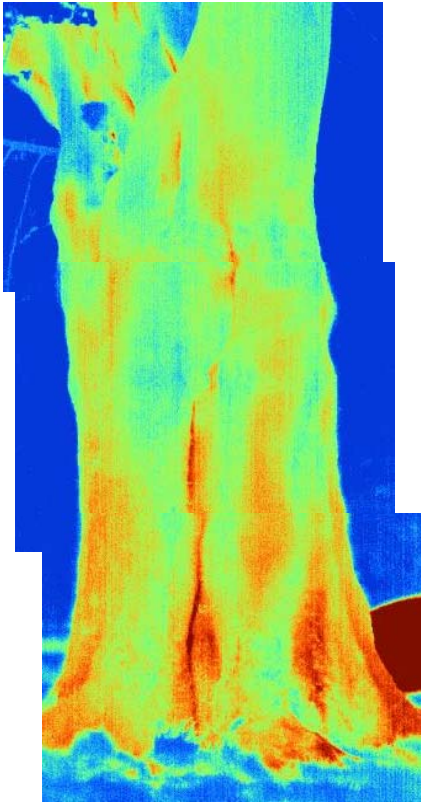

Core taken from the thickest part of the sound wood showing 16 cm of sound wood around 40 % of the radius. Around 74% of the wood is decayed at this height. The tree is currently sheltered and can be retained as it is followed by re-inspection 12 months.



<p>Data Sheet: Tree 6-1 Date: 03/05/07 Client: Paul Orsi, Blenheim Palace Tree No.: 6 TAG No.: 906 Species: <i>Fagus Sylvatica</i> Location: GB > Fisheries Position: Close to road Direction Images Taken: 32°</p>	<p>Summary of inspection details: There are distinct areas of superheating indicating areas of decay close to the surface. The cooler areas indicate large volumes of dysfunction but the warmer areas indicate this is not concentric with thicker areas of functional wood present. The two larger blue areas denote the presence of fruiting bodies. Outcomes: The tree has 70-80 %dysfunction in the base that progresses up the main stem and into the branching points. There is a high-severe probability of failure at the base and a high probability in the branches. An invasive inspection should be carried out at the base.</p>
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Visual Image	Thermal Image	Annotated Image	Annotation Details
			<p>Circled areas (blue) indicate the location of fruiting bodies. There are volumes of wood with good functionality (orange-yellow) but these are thin in some parts (blue areas). There is a small area of decayed wood at the base (superheated area coloured green, circled white).</p>

<p>Data Sheet: Tree6-2 Date: 03/05/07 Client: Paul Orsi, Blenheim Palace Tree No.: 6 TAG No.: 906 Species: <i>Fagus Sylvatica</i> Location: GB > Fisheries Position: Direction Images Taken: 313°</p>	<p>Summary of inspection details: There are distinct areas of superheating indicating areas of decay close to the surface. The cooler areas indicate large volumes of dysfunction but the warmer areas indicate this is not concentric with thicker areas of functional wood present. The small blue area denotes the presence of fruiting body. In addition the remains of another unidentified fruiting body was found in the grass close to the tree (see photo inset). Outcomes: Refer to the previous sheet.</p>
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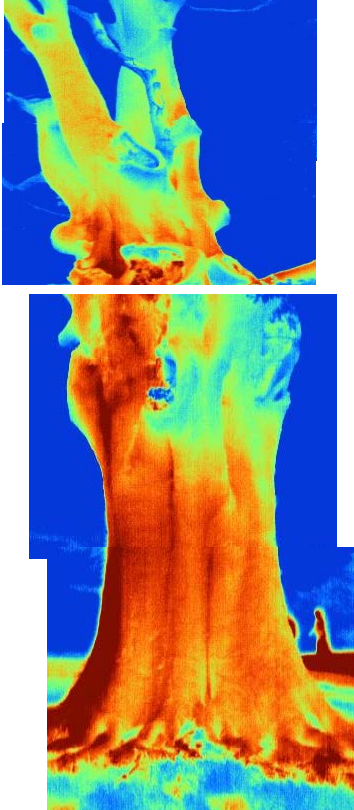
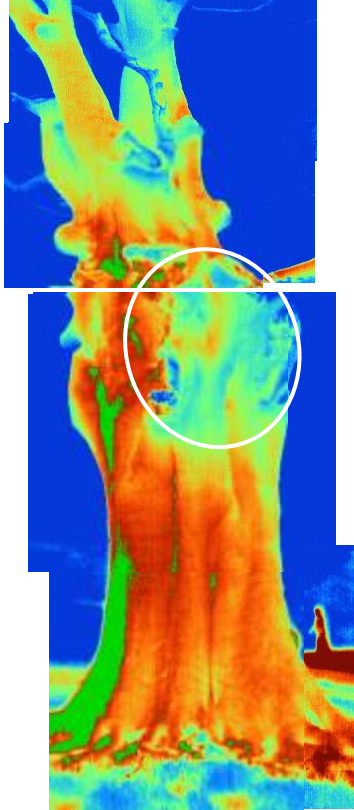
Visual Image	Thermal Image	Annotated Image	Annotation Details
			<p>The green coloured areas indicate areas of decay close to the surface (superheated). There are volumes of wood with good functionality up the main-stem and extending into the branches indicated by the red-orange colours.</p>

Tree 6 Outcomes.

The core taken where the radius of the tree is 63 cm shows 19.5 cm of sound wood with the tree having around 73% decayed tissue at the height. Fruiting bodies were present at several points on the main-stem. Tree 6 has already shed some major branches and has had some major reduction to a branch (white arrow) the functionality extending into the canopy indicates that the tree could withstand some moderate reduction and the tree could be further protected by reducing the height back to the points indicated by the black arrows. This would reduce the canopy below the surrounding trees and would be best done as smaller amounts over two or three growing seasons. Re-inspect in 12 months.


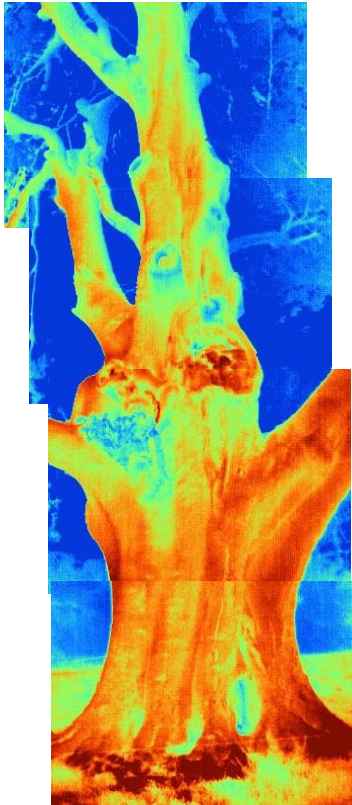
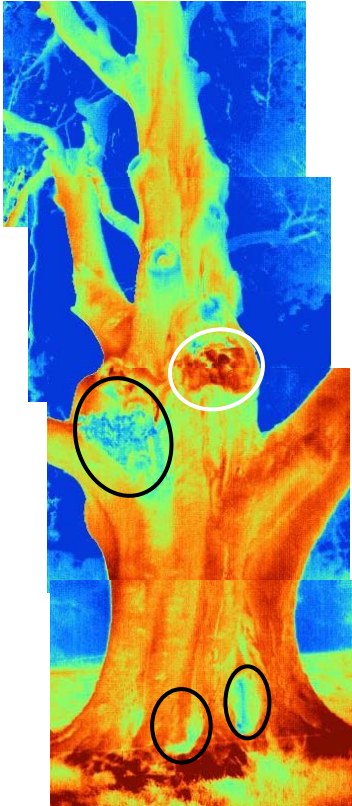


<p>Data Sheet: Tree7-1 Date: 03/05/07 Client: Paul Orsi, Blenheim Palace Tree No.: 7 TAG No.: No Tag Species: <i>Fagus Sylvatica</i> Location: Near Tree 900 Position: Close to road Direction Images Taken: 13°</p>	<p>Summary of inspection details: The tree has substantial amounts of dead tissue close to the surface (green coloured areas) but there are also thicker volumes of functional wood (red-orange areas) that continue up the main-stem into the branches. Blue areas indicate open cavities from which heat is being lost. Fruiting bodies of <i>Ustulina deusta</i> and possibly <i>Ganoderma spp.</i> Are also present (see below). Outcomes: The tree has 70-80 dysfunction in the base that progresses up the main stem and into the branching points. There is a high probability of failure in the base, main-stem or branches. Although dysfunction is high, the functional wood extending into the branches gives possibilities for crown reduction to retain the tree.</p>
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Visual Image	Thermal Image	Annotated Image	Annotation Details
			<p>The green coloured areas indicate superheated areas where dead wood is close to the surface. White circled area (blue-green) indicates where large volumes of dysfunctional wood are close to the surface extending from the wounds.</p>

Data Sheet: Tree7-2
Date: 03/05/07
Client: Paul Orsi, Blenheim Palace
Tree No.: 7
TAG No.: No Tag
Species: *Fagus Sylvatica*
Location: Near Tree 900
Position:
Direction Images Taken: 262°

Summary of inspection details:
 The tree has substantial amounts of dysfunctional solid wood (red areas). Blue areas indicate open cavities from which heat is being lost.
Outcomes:
 Refer to the previous sheet.


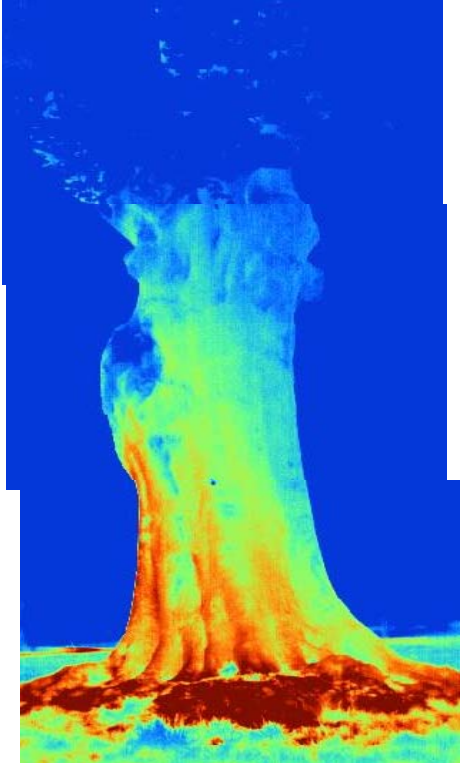
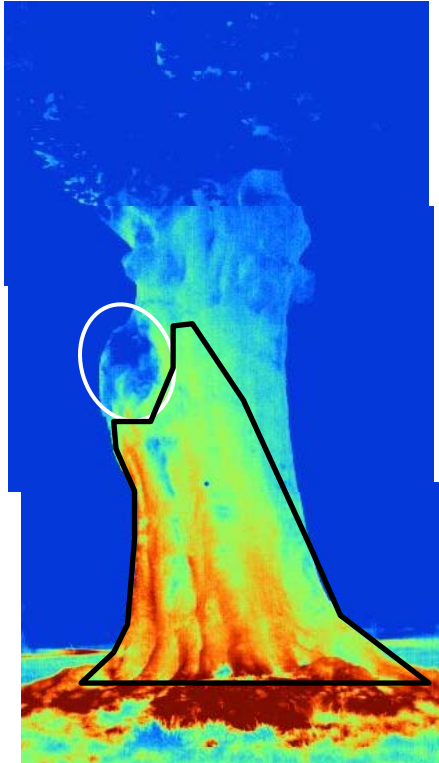
Visual Image	Thermal Image	Annotated Image	Annotation Details
			<p> Black circled areas (blue-green) indicate surfaces close to large cavities. White circled area (dark-red) indicates dead tissue. There are volumes of good functional wood in the main-stem and extending into the canopy (red-orange colours). </p>

Tree 7 Outcomes.

Tree 7 has already been through a process of major branch shedding and most of the remaining branches appear functional and stable. They do however sit on a large area of complex dysfunctional wood which is likely to be an unstable volume that might be a point of failure in the future. In addition there is an over-weighted branch (white arrow in photographs). It is recommended that the canopy associated with this branch (circled black) is initially reduced in height and width so that the volume is reduced by $\frac{1}{4}$ followed by monitoring of re-growth and reduction by a further $\frac{1}{4}$ in two to three years time if it response well. The remainder of the canopy should be reduced to retain the overall appearance of the tree This would be best done as smaller amounts of crown management phased in over two or three growing seasons. *Ustulina deusta* and old fruiting bodies possibly *Ganoderma spp.* present. Re-inspect in 12 months.


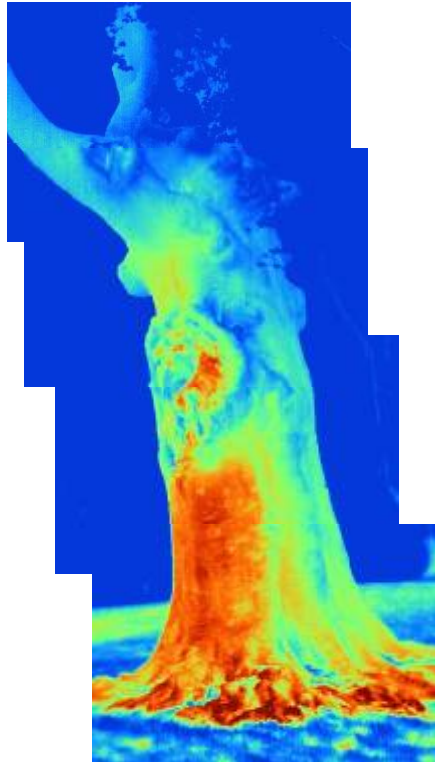
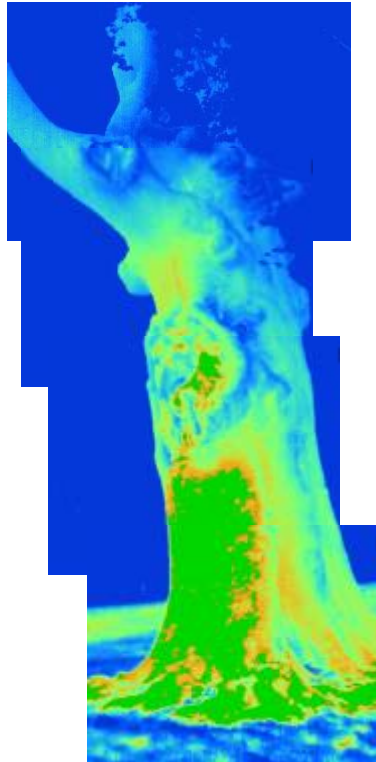


<p>Data Sheet: Tree8-1 Date: 03/05/07 Client: Paul Orsi, Blenheim Palace Tree No.: 8 TAG No.: 900 Species: <i>Fagus Sylvatica</i> Location: GB > Fisheries first tree on RHS. Position: Few meters from road Direction Images Taken: 302°</p>	<p>Summary of inspection details: There is an area of good functionality at the base of the tree but this does not continue into the canopy where cooler blue colours are evident. There is a large open cavity at 17° with a large area of dead tissue close to the surface (coloured green) that is also apparent at 302° white circled area. Some fruiting bodies were also present (see appendices). Outcomes: The tree has 70-80 % dysfunction in the base that progresses up the main stem and into the branching points. There is a high probability of failure in the base, main-stem or branches. Although dysfunction and decay are high, the crown is naturally reducing and the tree can be retained followed by re-inspection in 12 months.</p>
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Visual Image	Thermal Image	Annotated Image	Annotation Details
			<p>There is an area of good functionality (enclosed in black) indicated by the red-orange colours. However this does not continue further up the canopy where cooler blue colours are evident. The white circled area (blue) indicates a large cavity.</p>

Data Sheet: Tree8-2
Date: 03/05/07
Client: Paul Orsi, Blenheim Palace
Tree No.: 8
TAG No.: 900
Species: *Fagus Sylvatica*
Location: GB > Fisheries first tree on RHS.
Position:
Direction Images Taken: 17°

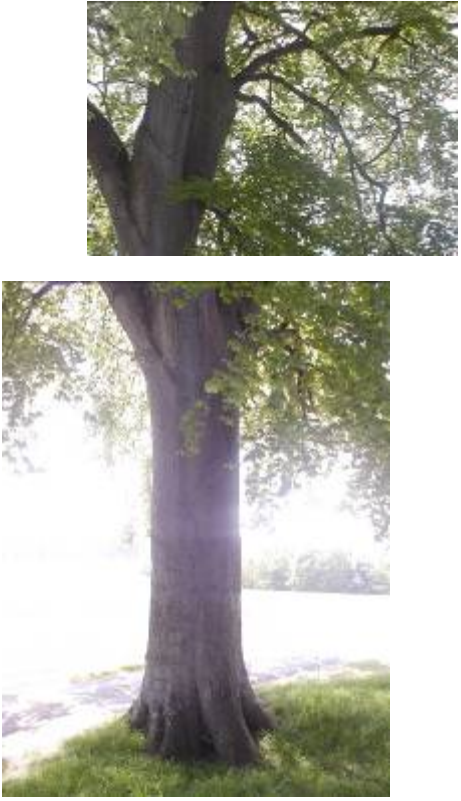
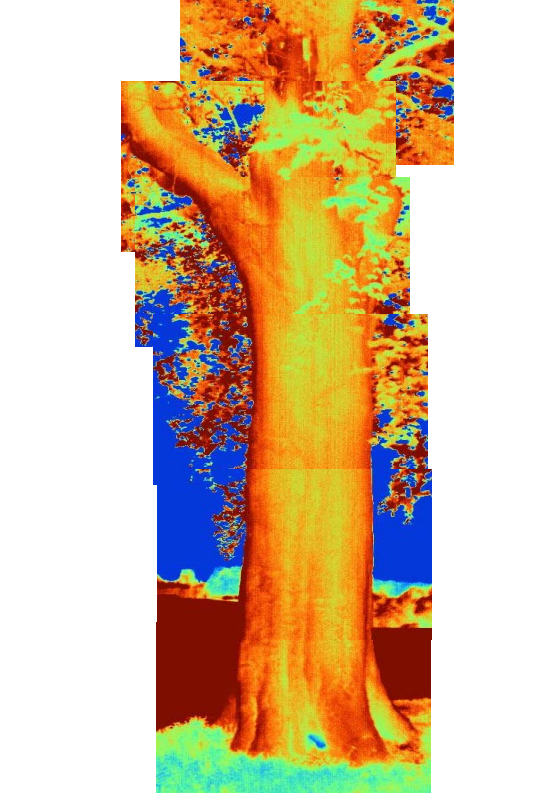
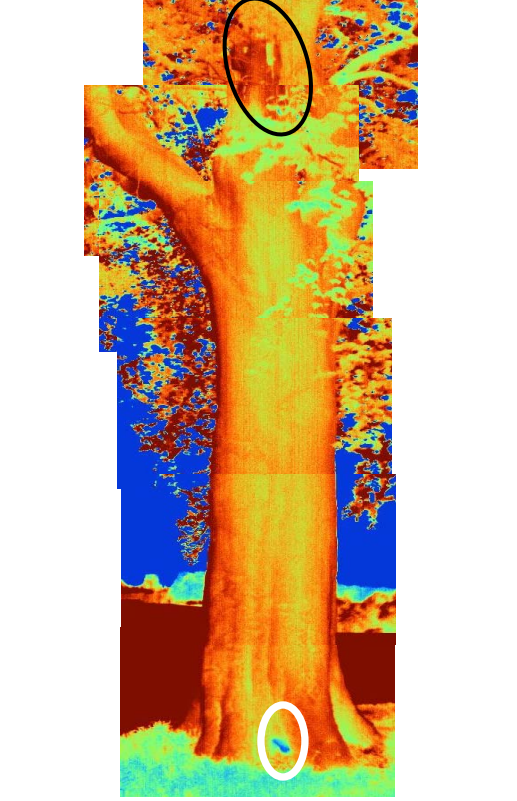
Summary of inspection details:
 There is a substantial superheat area indicating decayed bark. Temperature inversion is present with cooler areas in the lower stem indicating healthier tissues. There area areas of cooling associated with venting from open cavities.
Outcomes:
 Refer to the previous sheet.


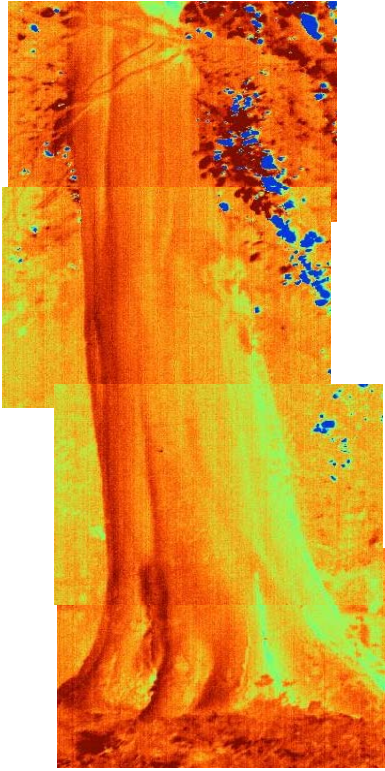
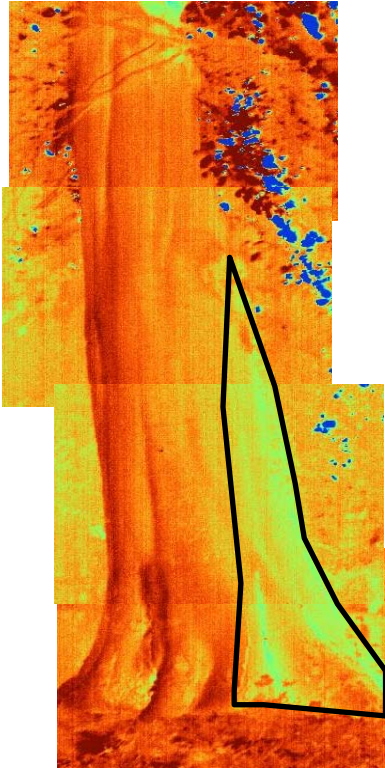
Visual Image	Thermal Image	Annotated Image	Annotation Details
			<p>Green coloured area indicates large area of decay close to the surface (superheated area) indicating a probable large cavity extending from the opening apparent in the photograph. Behind this are orange colours indicating strong area of functional tissue probably reactive growth.</p>

Outcomes Tree 8.

Tree 8 is already in a state of natural decline caused by the restricted functionality from the main-stem into the canopy. This is reducing the canopy back to points indicated by the black arrows. Therefore the tree is naturally reducing the wind pressure on the canopy and crown management should be phased in over two or three growing seasons to remove dead wood. Fruiting bodies present possibly *Ganoderma spp.* Further monitoring of decline will help with this process. Re-inspect in 12 months.



<p>Data Sheet: Tree14 Date: 03/05/07 Client: Paul Orsi, Blenheim Palace Tree No.: 14 TAG No.: 521 Species: <i>Fagus sylvatica</i> Location: China Corner next to lightning struck cedar. Position: Close to road and perimeter wall. Direction Images Taken: 220°</p>		<p>Summary of inspection details: The tree has a column of decay throughout the main-stem; this is not at a critical stage. However, there is an area advanced decay above the first branch (circled dark-red area). Outcomes: There is only 30-40% dysfunction in the main-stem and there is only a moderate probability of base or stem failure, however, the decay in the branching points is a high probability and weight above this point must be reduced by 1/3 over two growing seasons followed by re-inspection in every 12 months.</p>	
Visual Image	Thermal Image	Annotated Image	Annotation Details
			<p>Whit circled area (blue) indicates presence of <i>Ganoderma spp</i> fruiting body. Black circled area (dark-red) indicates larger area of dead wood.</p>

<p>Data Sheet: Tree 15 Date: 03/05/07 Client: Paul Orsi, Blenheim Palace Tree No.: 15 TAG No.: 941 Species: <i>Fagus sylvatica</i> Location: Hensington Clump next to CC football pitch. Position: Close to perimeter wall and neighbouring property Direction Images Taken: 220°</p>		<p>Summary of inspection details: Dysfunctional wood is restricted to the back half of the tree. Outcomes: There is 40-50% dysfunction in the base of the tree, However the tree has a lean of around 20° from vertical and the decay is predominantly in the back half of the tree. The tree is a high probability of failure. <i>Ustulina deusta</i> is present and an invasive inspection should be carried out.</p>	
Visual Image	Thermal Image	Annotated Image	Annotation Details
			<p>Black enclosed area indicate a volume of thin functional wood over a large volume of dysfunctional wood at the back of the tree. The front half of the tree contains a large volume of functional wood shown by the warmer surface (red-orange colours)</p>

Follow-on Invasive Inspection: Tree 15.


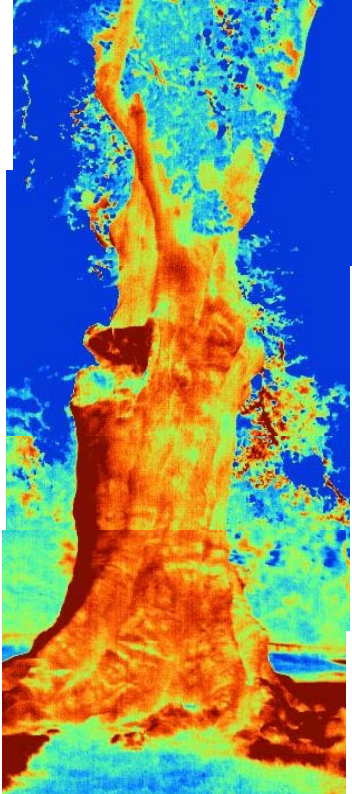
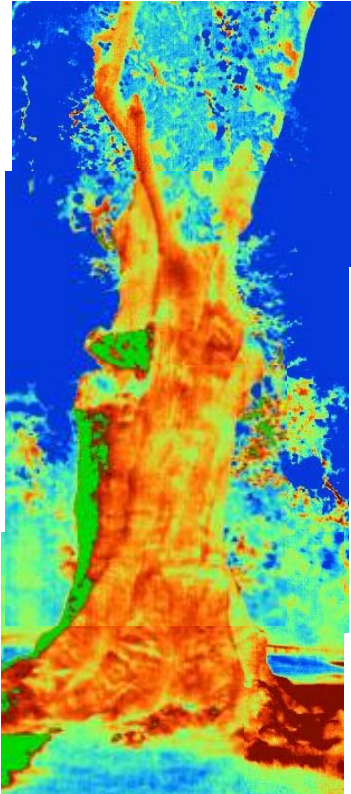
The radius of the base of the tree at the height where cores were taken from was 47cm. Cores taken from the more dysfunction part of the tree shown in the thermal images above (top photographs) had decay at 12 cm and the more functional part of the base had decay at 22 cm (bottom photographs).




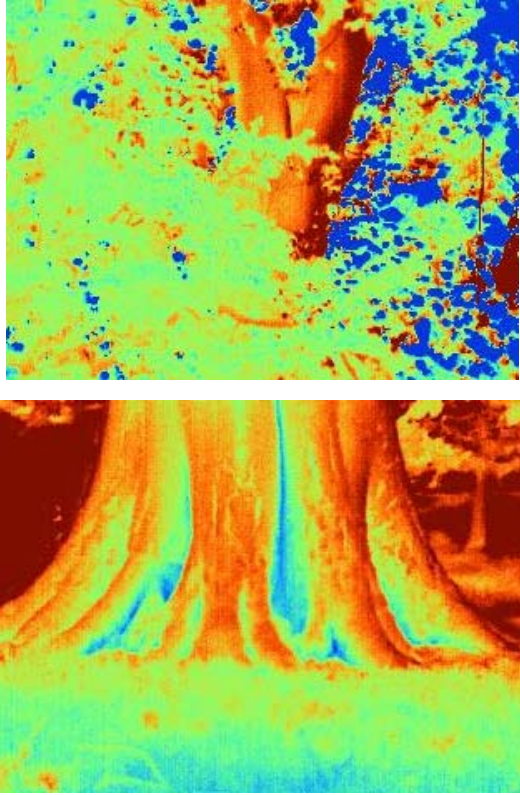
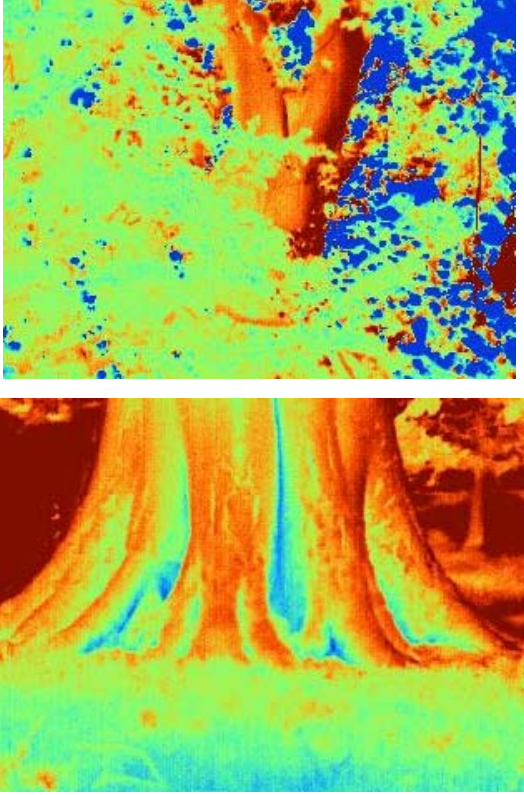
Outcomes Tree 15.

Following the invasive inspection it was determined that the tree was around 43% decayed at the base and was a high probability of failure given the position of the decay in relation to the lean of the tree. Therefore the canopy would require reduction in height by a third to bring about stability, this was not thought to be feasible given the canopy structure of the tree and so felling was recommended.


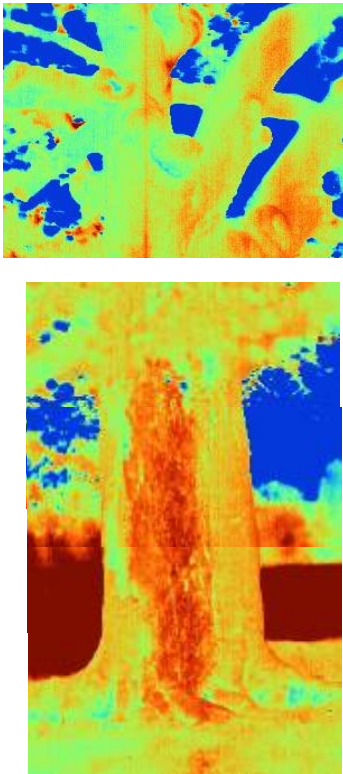
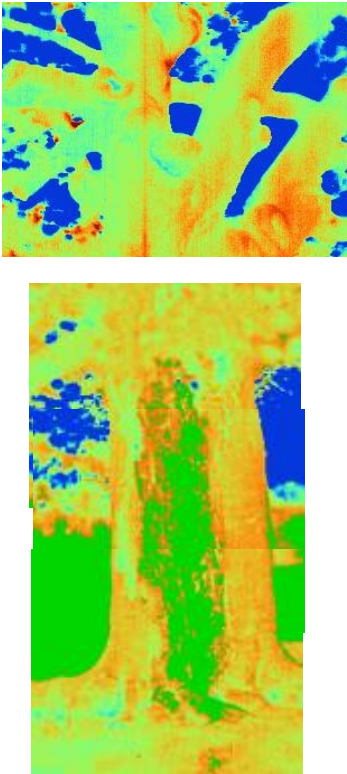
<p>Data Sheet: Tree 20 Date: 03/05/07 Client: Paul Orsi, Blenheim Palace Tree No.: 20 TAG No.: 620 Species: <i>Fagus sylvatica</i> Location: PF > GB RHS near cinder track. Position: Close to walking track some meters from road Direction Images Taken: 259°</p>	<p>Summary of inspection details: There are areas of superheating indicating areas where dead wood is close to the surface. Most of the main-stem shows good healthy growth though there is a central area of dysfunction. The client identified <i>Meripilus giganteus</i>. Outcomes: The tree has 50-60% dysfunction in the base that progresses up the main stem and into the branching points. The thin crown of the tree means it is a moderate probability of failure in the base, main-stem or branches. The crown will require some reduction to retain it if the dysfunction continues. An invasive inspection of the roots is recommended followed by re-inspection with thermal imaging on an annual basis.</p>
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Visual Image	Thermal Image	Annotated Image	Annotation Details
			<p>Green coloured areas marked indicate areas where dead wood is close to the surface.</p>

<p>Data Sheet: Tree 21 Date: 03/05/07 Client: Paul Orsi, Blenheim Palace Tree No.: 21 TAG No.: 621 Species: <i>Fagus sylvatica</i> Location: PF > GB LHS opposite 620. Position: Some meters from road Direction Images Taken: 236°</p>	<p>Summary of inspection details: Red colours show healthy buttresses, blue colours between indicate central decay caused in part by <i>Ustulina deusta</i> (see inset photo)</p> <p>Outcomes: The tree is 60-70% dysfunctional at the base and it is a high probably of failure in its present state. The tree has a dense differentiated canopy and the tree can be retained long-term if a programme of gradual canopy reduction is instigated now followed by regular re-inspection on an annual basis.</p>
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Visual Image	Thermal Image	Annotated Image	Annotation Details
			

<p>Data Sheet: Tree 22 Date: 03/05/07 Client: Paul Orsi, Blenheim Palace Tree No.: 22 TAG No.: 618 Species: <i>Fagus sylvatica</i> Location: PF > GB squat beech on LHS. Position: Close to road Direction Images Taken: 190°</p>	<p>Summary of inspection details: There is a substantial area of decay with <i>Ustulia deusta</i> fruiting bodies present. It is highly probable the decay extends into the root system. Outcomes: The base of the tree is 80-90% dysfunctional but is only a high probability of failure because of its low canopy. An invasive inspection is recommended since the tree has a very low canopy and might be retained if there is sufficient sound wood.</p>
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Visual Image	Thermal Image	Annotated Image	Annotation Details
			<p>Green coloured area indicates superheated area due to substantial decay.</p>

Outcomes Tree 22.

Core taken from healthy side of tree where the radius of the tree is 39 cm at this height showing 15 cm of sound wood. Showing around 83% decay. Inset, fruiting bodies of *Ustulina deusta*. Re-inspect in 12 months.

