Beech tree at Blenheim Palace a worked example of the TTMS System.

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 required 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***'.

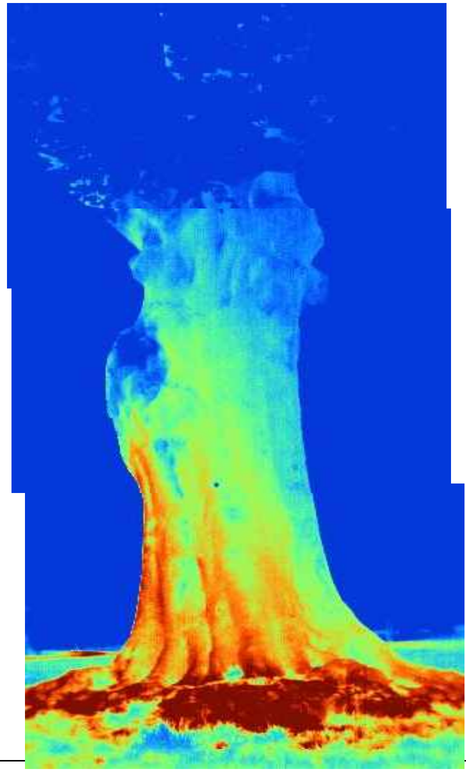
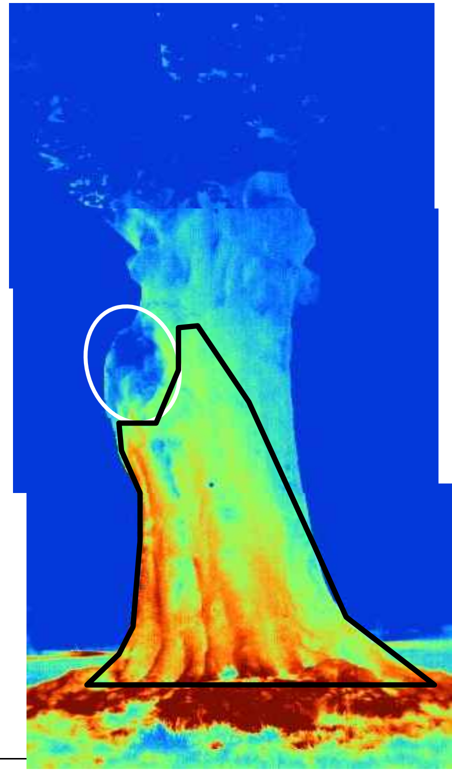
The trees inspected were identified as potential hazards to the public and surrounding property by staff at Blenheim Palace. Numerous fungal fruiting bodies had already been identified in beech trees but the extent of dysfunction and decay associated with these fungi had not been determined. All the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

The example tree, Tree 8.

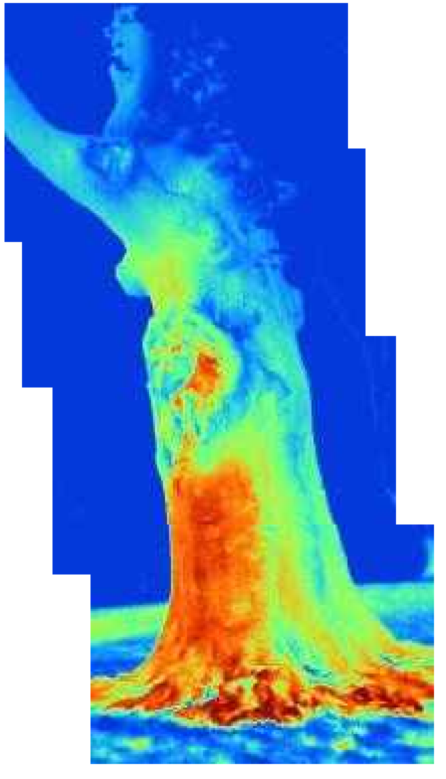
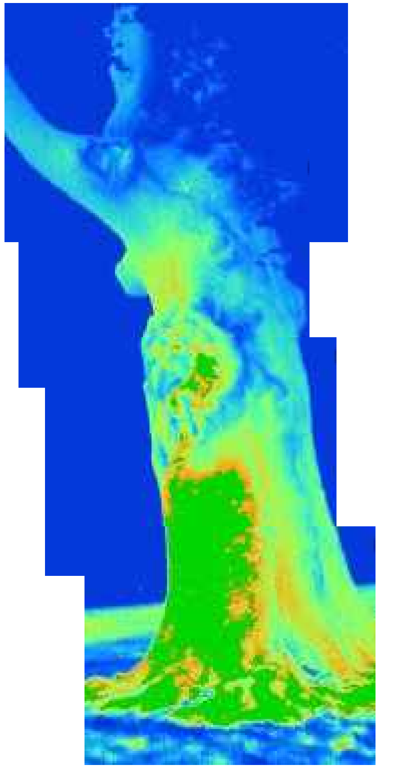
VTA: Tree 8 is already in a state of natural decline caused by the restricted functionality from the main-stem into the canopy (see thermal report below). This is reducing the canopy back to points indicated by the black arrows. Fruiting bodies present possibly *Ganoderma spp.* Tree was first analysed for % basal dysfunction using the statistical comparison of the overall temperature distribution.

The evaluation of 70-80% dysfunction at the base (see bleow) shows that the tree is beyond the 50-60% critical mark and therefore based on dysfunction, the tree should be further analysed for likelihood of basal failure.

Data Sheet: Tree8-1 **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:** Few meters from road **Direction Images Taken:** 302^{O}	**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^{O} with a large area of dead tissue close to the surface (coloured green)that is also apparent at 302^{O} 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.

Visual Image	Thermal Image	Annotated Image	Annotation Details
			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.

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^{O}	**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
			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.

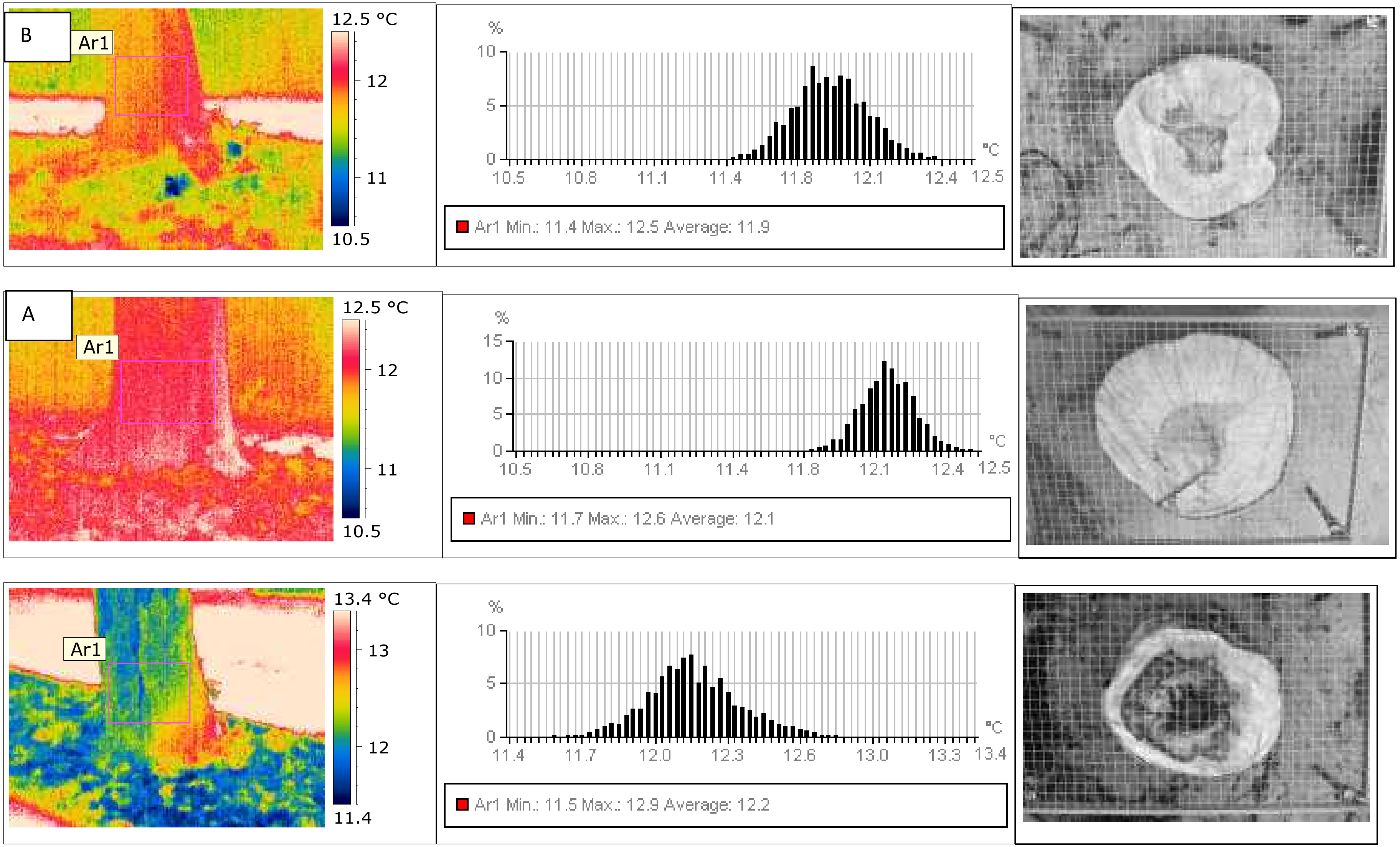


Figure 1 a shift from ≈80% (centre) to ≈70% (top) or ≈ 30% (bottom) functional wood in three Acer sp. thermal images taken within fifteen minutes of each other. Tmax and Tmin determined according to the size and position of the trees.

Figure 1 shows how dysfunction brings about a shift in temperature distributions, this is used to determine the % dysfunction. This allows the tree to be compared to a population distribution of dysfunction in 10% intervals from 0-100%. Figure 2 shows the distribution for trees within a sheltered woodland population. These data can then be compared with data form exposed sites where tree are under more wind pressure (Figure 3) and also urban areas (Figure 4). Where the populations diverge, significantly i.e. the populations are not the same it is likely that there is a change that has brought about the divergence in population. Between exposed and sheltered populations it is likely that features of exposure (such as wind) have some kind of effect on the population such that there are fewer trees with dysfunction in that category. Typically populations diverge at 50-60% dysfunction. This is used as a critical value for analysis

Figure 2 Population distribution of % dysfunction in 10% categories from 0-100% for a sheltered population.

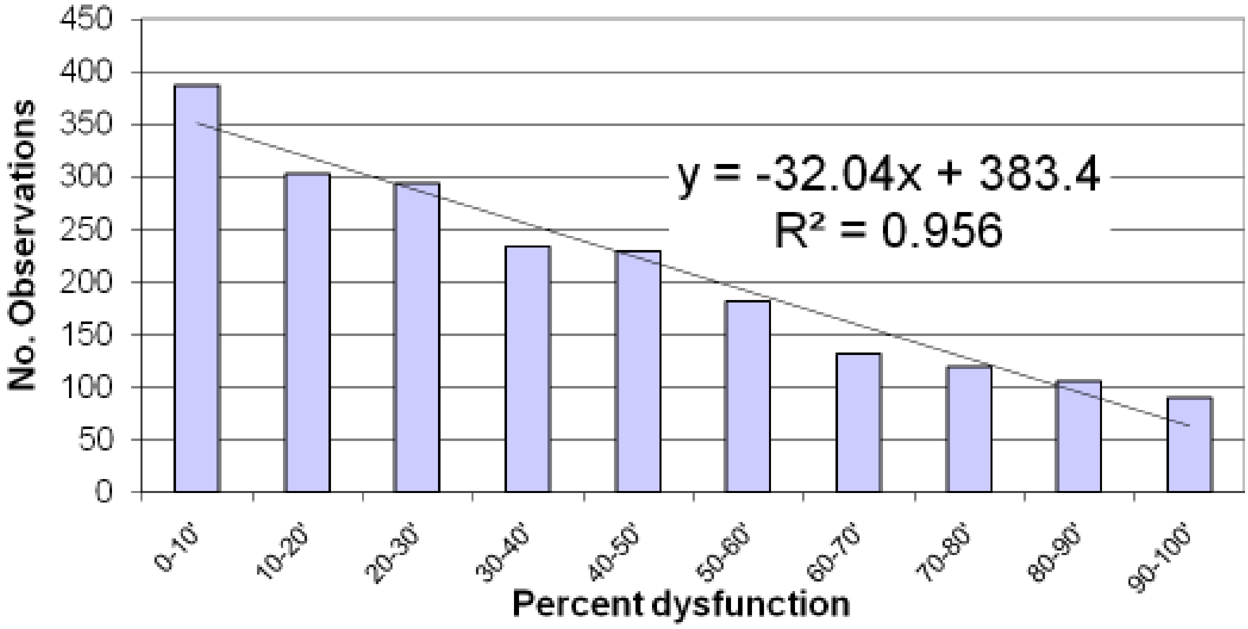


Figure 3 Dysfunction distribution of an exposed population (purple) in comparison with a sheltered population (light blue) in the same region.

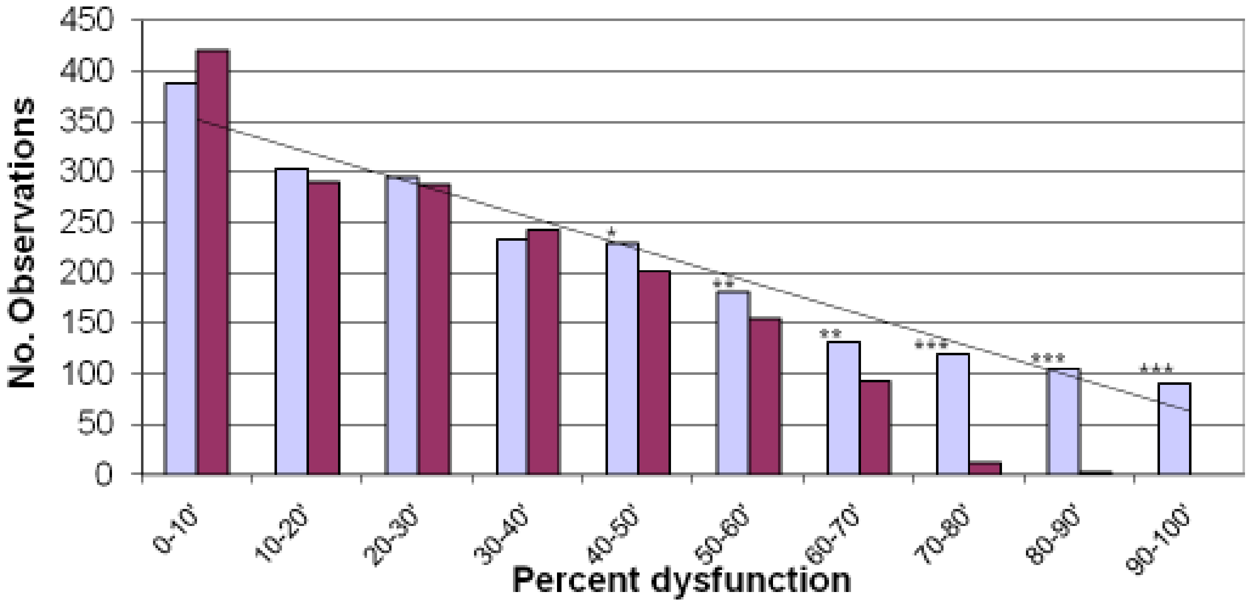
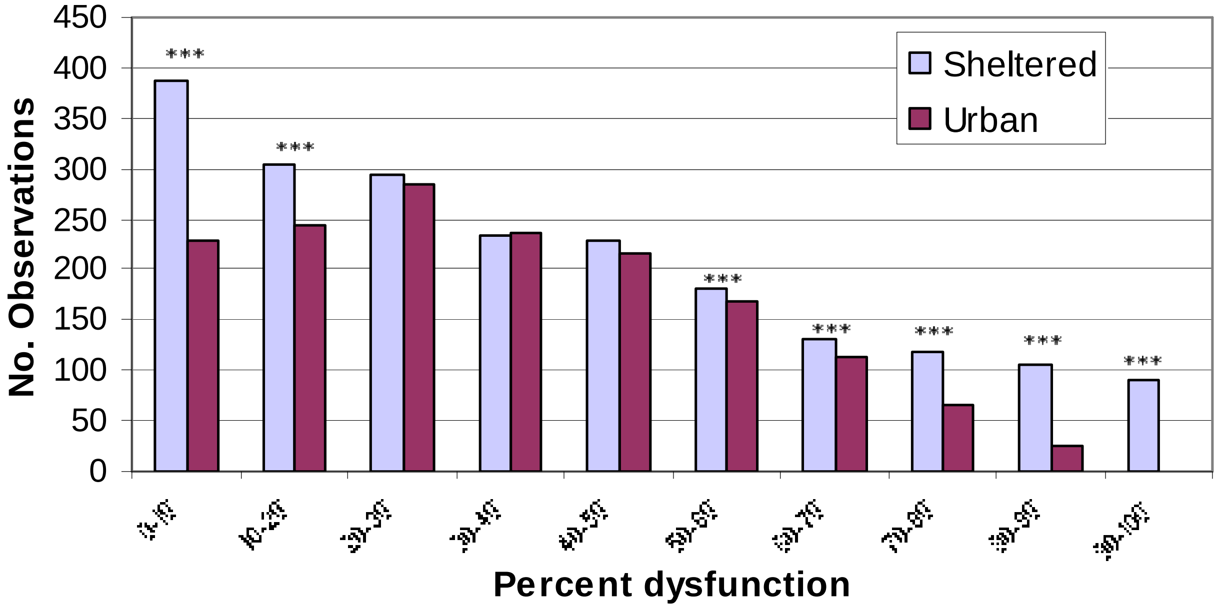


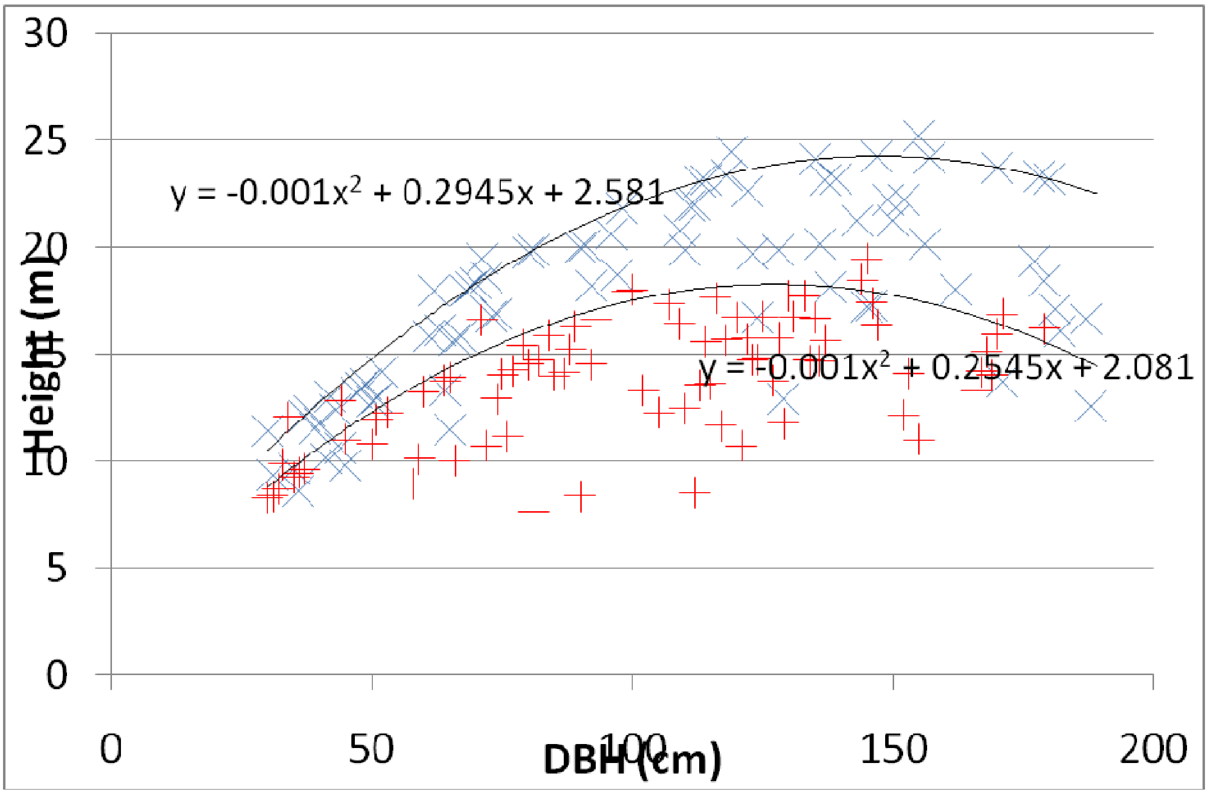
Figure 4 Dysfunction distribution of an urban population (purple) in comparison with a sheltered population (light blue).



The divergence between the populations can then be examined in more detail by investigating the differences between the populations in more detail. However, it should be realised that at this stage a large number of members of the population have been accounted for and so the number of trees for further investigation at this stage is greatly reduced. The Beech tree above has 70-80% dysfunction at the base and so is above the critical value of 50-60%. Therefore a further evaluation of the canopy was necessary.

Using the mechanistic models put forward by a number of researchers including Mattheck, Wessoly, Horacek, Clark and many others, it is possible to identify key components of structure that are likely to be good indicators of stability. Typically the models identify the thickness of the stem (such as DBH), tree height (lever arm length), canopy volume and canopy density (sail area) as being important attributes. By plotting the correlations between these attributes it is possible to understand how the relationships change between exposed and sheltered populations. Identification of potential outliers of the population that may require further investigation as to their stability can be achieve by using boundary layer analysis (see refs below) this is typically used in horticulture, agriculture and forestry to determine the limits to which systems can respond to nutrients or stresses for example. By setting the boundary layer analysis to separate out the 5% of the population at the extremity of the boundary, this can be used as a methodology to identify those trees that would have the most significant likelihood to behave abnormally form the rest of the population. These trees are still not seen as a potential to fail but instead highlight those trees for further investigation. Again the trees for further investigation are further whittled down. At this stage it is likely that less than 1 % would require further investigation such as cross comparison of factors, i.e. the tree is higher than would be expected for the amount of dysfunction and the DHB, but the canopy is very thin and is well within the 95% of the population. Typically once boundary layer analysis has been completed less than 0.1% of the population requires an invasive inspection.

Figure 8 Boundary Layer Analysis of tree height in response to stem DBH for trees with 70-80% basal dysfunction in exposed locations (red crosses) and in sheltered locations (blue crosses). Boundaries separate populations at the 95% confidence interval.



Outcomes

The height of the Beech tree above is 17m to the nearest 0.5m and the DBH is 123 cm to the nearest cm. Therefore the tree is well within the 95% boundary for even an exposed tree. Given that the canopy is also thin, then the likelihood of a basal failure is considered very low and the tree was not recommended for work on this basis. The tree was recommended for removal of large cross-section dead wood and annual inspection for dead wood.