Advances in utility arboriculture research and the implications for the amenity and urban forestry sectors

Abstract

The electricity distribution companies in the UK have a statutory obligation to provide a continuous supply of quality power, safely and efficiently. The Government and Regulatory Authorities require that the companies must try to minimise interruptions to supply caused by trees. As part of the discharge of their statutory obligations, the electricity distribution companies are undertaking research into the growth rates of trees following pruning in relation to projected changes in the UK climate in 2020 and 2050, and into the possible use of tree growth regulators to slow the rates of re-growth without harming the trees. In addition, research has been initiated into the possible development of a system of assessing trees in order to predict the likelihood of them failing, and causing supply interruptions and/or damage to apparatus in extreme adverse weather conditions. This paper describes the research projects and the results to date.

The failure of small to medium sized branches within the crowns of trees is also described; the implications of this, and the other research for the arboriculture and urban forestry sectors, is discussed.

Keywords:

distribution line clearance study, resilience, tree growth rates, tree growth regulator, utility space degradation

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Introduction and background

In Britain electric utility companies are under a legal duty to maintain their overhead power line (OHPL) networks free of interruptions where reasonably practicable. Trees are one of the principal causes of unplanned service interruptions on the OHPL networks and since 2002 electric utilities have been under increasing pressure from the regulatory authorities to reduce the number of interruptions/faults that are caused by trees and other vegetation. After privatisation of the electricity industry in 1989 the trend in tree-related interruptions to supply was increasing. It reached a peak in 2004/05 when it was estimated that in the five years from 2000 20% of all interruptions on the low voltage (LV) networks and 12% of all interruptions on the high voltage (HV) networks were caused by trees (Department of Trade and Industry, DTI, 2006). In reality, the figures were probably higher as a significant number of tree-related faults may have been attributed to 'windborne materials' or 'wind and gale'.

In 2002 the British Regulator, Ofgem (Office for the Gas and Electricity Markets), and the Department for Energy and Climate Change (DECC) replaced the Electricity Safety Regulations (ESR) with the Electricity Safety, Quality and Continuity (ESQC) Regulations. Following a major storm in October 2002, when tree-caused service interruptions left millions of customers across Britain off supply for long periods of time, the regulations were amended to strengthen the obligation they place upon the electric utilities to eliminate tree-related interruptions where reasonably practicable. The amended regulations are cited as the ESQC (A) Regulations 2006.

DECC requires that the electric utilities must maintain progressive and proactive tree and vegetation management programmes. This is a reasonable expectation, but in reality, since privatisation of the electricity industry in 1989, the 14 distribution licence areas maintained tree and vegetation clearance programmes to varying degrees; some operated proactive and effective programmes, while others operated reactive programmes and did the minimum amount of tree cutting necessary, typically in response to faults. Consequently, when the

2002 Regulations and the amended 2006 Regulations came into force the licence areas were at different stages in vegetation management; some were well advanced, while others had not started proactive management programmes.

In 2006 the DECC imposed an additional obligation on the electric utilities to make their OHPL networks 'resilient' against tree and vegetation damage in 'abnormal weather conditions'. This obligation means that in addition to the routine proactive cycles of cutting to safeguard the OHPL networks throughout the normal annual weather patterns, they must, where reasonably practicable, try to secure the OHPL networks against damage from trees and vegetation during major storm events that occur periodically (i.e. storm events that have return periods of once in 10 years, 25 years, etc.). The guidance for this is found in the Electricity Networks Association (ENA) publication ETR 132 (2005).

The result of the changes to the regulations and the imposition of the 'resilience' obligation was that the budgets for utility vegetation management (UVM) were increased significantly, from about £87 million per annum across all 14 licence areas between 2004 and 2009 to £134 million per annum for the period 2010 to 2015.

It follows therefore that any developments that can assist in reducing the amount of money that has to be spent on tree cutting and enhancing the security and continuity of the supply of electricity is to be welcomed. The utility sector monitors research developments in the fields of arboriculture and forestry and implements new developments that are appropriate. However, research initiatives in arboriculture and forestry are not aimed specifically at the utility sector and it is only when a development is relevant to that sector that it is adopted, visual tree assessment (VTA) and decay detection techniques being examples.

There are specific areas where expanded knowledge would greatly assist the utilities to improve their UVM programmes. These include: (i) information on the growth rates of the most common genera of trees that occur on and adjacent to the OHPL networks; (ii) whether the growth rates of trees can be regulated to slow them down and thus extend the cutting cycle; (iii) whether a reliable system can be developed that could predict the likelihood of trees failing in abnormal weather conditions; (iv) the failure patterns of the commonly occurring trees; (v) how tree branches fail. Research into these aspects is in progress, and is described below.

It is essential that any electric utility should know with a reasonable degree of accuracy the species/genera of trees that occur most frequently on/adjacent to its OHPL networks, yet some do not have this basic information. The essential information on the OHPL networks of an electric utility can be gathered to greater than 90% confidence through a distribution line clearance (DLC) survey assessment. This is the starting point from which an effective proactive UVM programme, which can include research developments, can be developed.

The distribution line clearance survey

This approach to analysing the OHPL networks was developed in the USA in response to continued pressure upon expenditures in line clearance (Johns and Holewinski, 1981). Essentially it involves undertaking a statistically valid random sample of the entire OHPL network and at each sample point walking 1.6 km of the line and recording the following data:*

1. The number of trees present.
2. The species/genera of tree present.
3. The number of hazard (resilience) trees present.
4. The distance between the trees and the conductors.
5. The type of work required to obtain clearance, e.g. felling or pruning.
6. The type of pruning required, e.g. top, side or overhang.
7. The lengths of any hedges or hedgerows impacting the OHPLs, i.e. linear metres.
8. The number of square metres of brush, i.e. self-seeded saplings present.

*The DLC also collects data on demographics, operating procedures, crew size and type, management of the programme and much more but this is outside the scope of this paper. From the UVM perspective what the DLC provides is a measure of the actual workload on the OHPL networks, which is accurate to greater than 90% confidence. For example it would produce typical results from a distribution network operator (DNO) with two regions as shown in Table 1.

All these data are extremely useful in facilitating the design and implementation of proactive UVM programmes. However, for the purposes of this paper the interesting data that emerges is the identification of the most frequently occurring species/genera of tree on the DNO's OHPL networks. Typically, between 60% and 70% of the trees are of five or six species.

The Central Networks (CN, now Western Power Distribution, WPD) DLC recorded a total of 89 species/genera present on

Table 1 Projected tree and brush workload on a typical electric utility's extra high voltage (EHV), high voltage (HV) and low voltage (LV) overhead power line networks.

	Tree pruning	Tree removal	Hazard trees	Total trees	Tree line contacts	Overhang	Hedge / hedgerow (km)	Brush (ha)	% error
Region A	78 000	31 000	3200	112 200	21 000	12 250	3120	265	+/- 9.3%
Region B	86 500	28 200	2950	117 650	11 200	10 200	3750	370	+/- 8.4%
Total	164 500	59 200	6150	229 850	32 200	22 450	6870	635	+/- 7.2%

These figures are an amalgamation of figures from utilities in the USA and are not figures from any UK DNO.

the OHPL networks and five genera accounted for 57% of the total trees (Environmental Consultants, 2009). These were as follows:

- Ash (*Fraxinus* spp.) – 19%
- Thorn (*Crataegus* spp.) – 13%
- Oak (*Quercus* spp.) – 10%
- Sycamore (*Acer pseudoplatanus*) – 8%
- Willow (*Salix* spp.) – 7%

Analysis of the re-growth rates of these genera following pruning provided an accurate measurement of how fast these trees grow following pruning, as shown in Figures 1 and 2.

The information on growth rates allowed CN (now WPD) to calculate how much needs to be cut from these trees to ensure that they remain clear of the conductors for the duration of the pruning cycles, which are four years on 132 kV and EHV and five years on 11 kV and LV. This information is provided in tabular form to the tree cutting contractors as part of the *Tree Management Specification* (Central Networks, 2011). This essential knowledge allows CN (now WPD) to comply with the required minimum clearances distances between its OHPL networks and trees as defined by the Energy Networks Association (ENA, 2004).

Knowing the most commonly occurring trees allows for other research to be undertaken to gather more information on those trees. By undertaking investigations of tree-caused faults when they occur to determine the species and the exact mechanism by which the tree(s) caused the fault (i.e. broken/failed branch, broken/failed trunk, tree uprooted, leaning on the line, growth, etc.) it is possible to determine if patterns emerge over time. For example is one species more prone to causing outages? What is the most common mechanism of the causes of outages? These data will then inform future pre-cutting surveys such that resources can be targeted to those trees most likely to cause outages. A Tree Fault Database to gather this information is being developed.

Figure 1 Measured mean side growth and standard deviation four years after pruning on the five most abundant genera on the CN (now WPD) OHPL networks representing 57% of the total tree population.

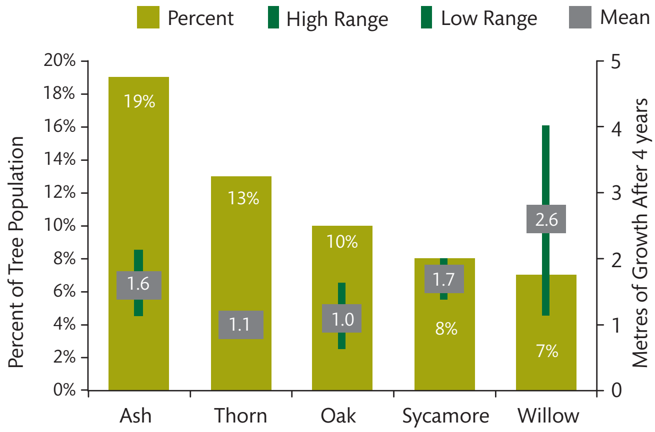
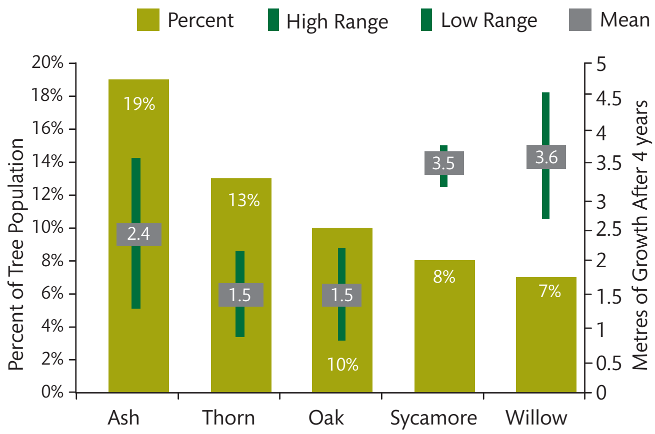


Figure 2 Measured mean top growth and standard deviation four years after pruning on the five most abundant genera on the CN (now WPD) OHPL networks representing 57% of the total tree population.



Tree growth rates and climate change

Background

The importance of knowing the growth rates of the most common trees on the OHPL networks has been demonstrated. However, the growth rates shown in Figures 1 and 2 above are for trees on the CN (now WPD) OHPL networks and do not represent growth rates across the whole of the UK. Nor do they take account of how the growth rates might change in response to the projected change in climate as set out in the UK Climate Impact Projections (UKCIP) (Murphy *et al.*, 2009).

Apart from the growth rate study undertaken as part of the CN (now WPD) DLC there has been little work completed studying the impact of tree growth around OHPLs and in particular the manner in which utility space (US) (i.e. the physical volume occupied by the utility apparatus and the additional space required to ensure its safe and reliable operation) is degraded by tree growth over time. Consequently, in 2008 a project was commissioned with the aim of improving our understanding of tree growth rates in relation to overhead power lines across the UK. The project is led by ADAS and funded through the Ofgem innovation fund initiative (IFI), with four DNOs representing seven licence areas and National Grid (NG) participating. The DNOs are Central Networks, CN (now WPD); Scottish Power, SP; Electricity North West, ENW (formerly United Utilities); and UK Power Networks, UKPN (formerly EDF).

Climate change

There is much debate on the issue of climate change and the causes, but whether it is a natural cycle or man-made or both there are clear signs that the climate is changing. For example, the Meteorological Office reports that the longest thermal growing season in the 350-year daily Central England series occurred in 2000, when it extended for 328 days from 29 January to 21 December and 10 of the 12 warmest years in the 350-year daily temperature series occurred in the last 20 years (Ray *et al*., 2010). The thermal growing season for this region of the UK is now longer than at any time since the start of the daily temperature series in 1772 (DECC, 2010). Other signs include:

- In southern England oak leaves are sprouting 26 days before they did in 1950.
- Wild cherries are now blossoming two weeks earlier than in the 1970s.
- Rowan, box and cow parsley are all flowering 9 to 15 days earlier than they did 20 years ago.
- Sycamore is responding fastest to climate change through earlier bud burst compared with other large trees. Hawthorn and hornbeam are also coming into leaf earlier.

Therefore, an analysis of utility space degredation by trees and vegetation in relation to climate change is essential if proactive tree clearance programmes are to be planned and implemented with any degree of reliability.

Materials and methods

Over 1700 experimental sites were established across the country covering the participating licence areas and the National Grid network in representative bioclimatic zones. At each site trees under and adjacent the OHPLs were cut and over the succeeding years measurements were taken to determine the annual re-growth rates and the rate at which the utility space was degraded by tree growth. This parameter is called utility space degradation (USD). This is an important concept because it integrates tree species, tree shape, soils, land use, location, etc. along the overhead spans. It differs from average growth rates in that it focuses on the key aspect, which is the fastest growing vegetation relative to the infrastructure.

The baseline measurements taken during this investigation were then analysed to see if there was any significant variation due to the land use at the locations, or to exposure, shading or regional location. The measurements were also interpolated, using bioclimatic zones, to give a continuous dataset of USD across the UK based on the meteorological conditions observed during the experimental period. This dataset was then used in conjunction with climate forecast data from UKCIP (Murphy *et al*., 2009) to project the likely impact of the high and low climate impact projections of UKCIP on the magnitude and spatial distribution of USD at 2020 and 2050.

Results and discussion

The results indicate that there is no significant variation in USD in relation to the land use where the trees are located, (i.e. arable, forested, grassland, roadside, sparse woodland or urban). Nor were there significant differences in USD in relation to exposure or shading. However, significant differences were observed in relation to company, (i.e. regional differences) as shown in Figure 3.

Comparison of the USD between the individual genera/species of tree produced some interesting results, (see Figure 4). The error ranges recorded on lime (*Tilia* spp.), larch (*Larix* spp.),

Figure 3 Regional differences in USD as indicated by company location.

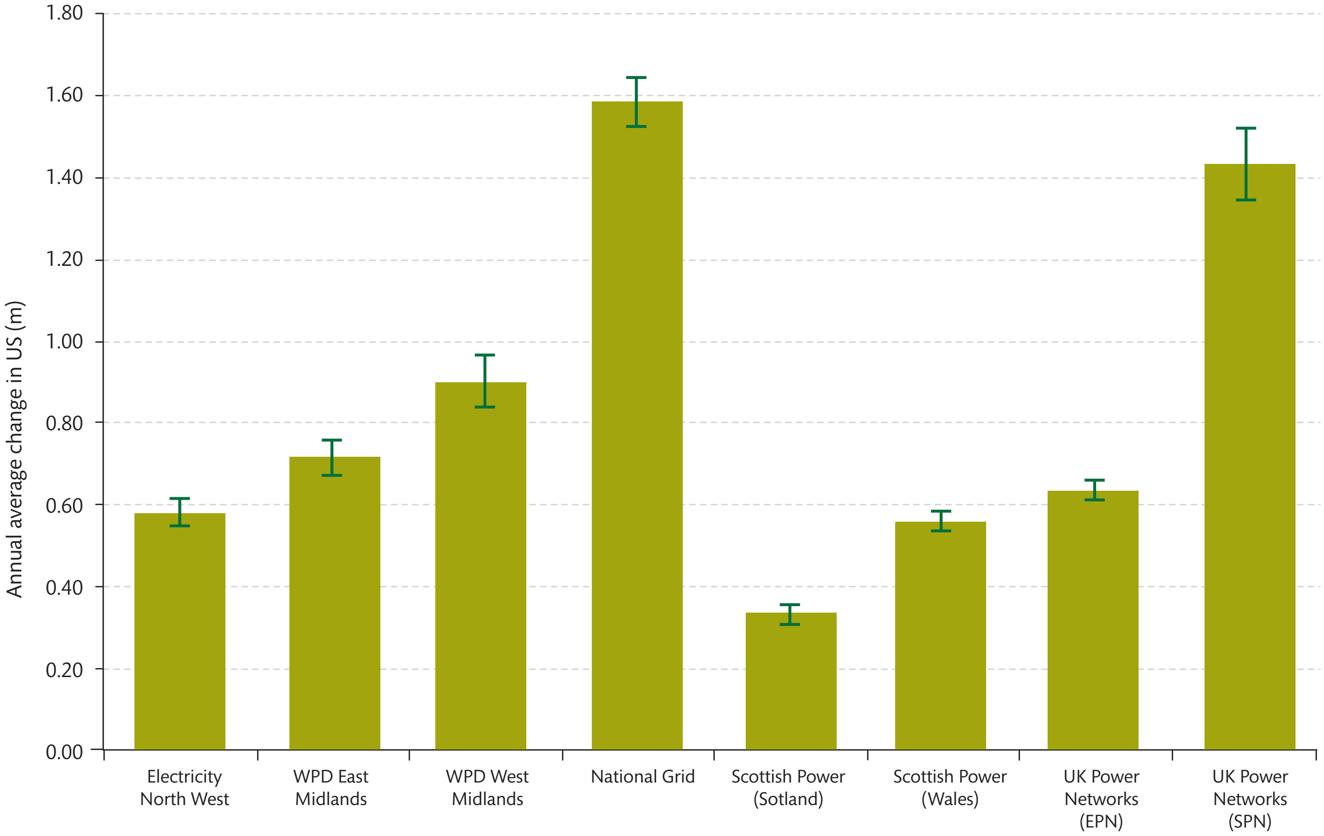
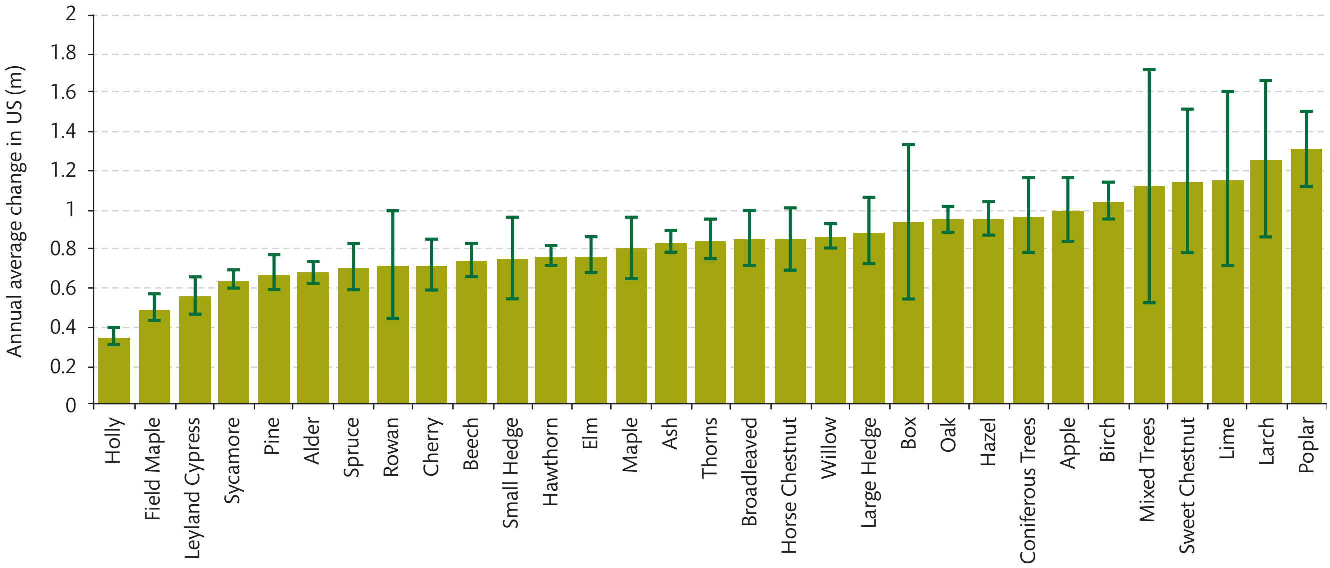


Figure 4 National average variation in USD by vegetation type.



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sweet chestnut (*Castanea sativa*) rowan (*Sorbus* spp.) and box (*Buxus sempervirens*) are very large, suggesting perhaps that the shape of the tree and its position relative to the conductors may be a key factor.

When comparisons are made with the climate change projections it can be seen that the changes from baseline measurements taken between 2008 and 2010 are projected to be between 16% and 30% higher in 2020 in the UKCIP 2020 low projection, and between 16% and 40% in the 2020 high scenario (Table 2). There is a spatial variation in growth rates and an obvious climatic variation between the different company locations. It seems that there are likely to be substantial changes in growth and variation over the next 10

Table 2 USD comparisons between the spatially averaged baseline readings and the 2020 low and 2020 high climate projections.

Company	USD (m)			% Change	
	Baseline	2020 Low	2020 High	Baseline to 2020 low	Baseline to 2020 high
National Grid	0.88	1.12	1.10	27	25
UK Power Networks (SPN)	1.08	1.38	1.29	28	19
UK Power Networks (EPN)	0.90	1.07	1.26	19	40
Electricity North West	0.67	0.83	0.78	24	16
WPD East Midlands	0.86	1.00	1.09	16	27
WPD West Midlands	0.90	1.10	1.07	22	18
Scottish Power (Wales)	0.78	1.00	0.94	28	21
Scottish Power (Scotland)	0.53	0.69	0.65	30	23

years with the UKCIP high end projections suggesting maximum variation in USD rates occurring in 2020. If the changes are more severe than are currently being projected, there may be some limitations to growth rates due to a reduction in rainfall and concomitant reduction in the availability of water.

Implications

The implications of the projected climate change impacts are significant, not just for the utility sector in planning their proactive tree clearance cycles based on growth rates but also for the amenity/urban forestry sectors where tree pruning activities constitute a significant part of core business. Local authorities and private landowners alike will have to consider adjusting their maintenance regimes in line with the projected increasing growth rates, and also consider more carefully the selection of tree species for new and replacement planting schemes and select species that are resilient and suited to current conditions and to the changing climate in the 21st century and beyond.

Controlling tree growth

Background

As can be seen, trees are currently growing faster than had been anticipated and it is projected that the rates of re-growth will increase over the next 10 years. The projected changes in tree growth rates will have an impact upon the tree clearance cycles within the DNOs and the result is likely to be shorter cutting cycles and an increased emphasis on tree removal rather than pruning.

The projected increased growth rates notwithstanding, a major problem for most DNOs in the UK is that of pruning high value amenity trees and restricted cuts on the LV network. The former is where trees are located in prominent locations such as rural villages and village greens, conservation areas or prominent street trees where the overhead LV network is close to or through the crowns (see Figure 5). There is understandable public resistance to pruning these trees.

Figure 5 Typical bare wire overhead low voltage conductors with high value amenity trees adjacent to the conductors.

Restricted cuts occur when a landowner refuses consent for the full amount of cutting necessary to provide the required clearances that would last for the duration of the cutting cycle (four or five years), but allows the minimum amount of cutting to keep the lines clear of the conductors at that point in time. This means that the DNO has to return to the site every year at worst or every other year at best to re-prune the tree(s) to maintain the clearance distances and to comply with ESQC (A) R 2006. Most of the trees concerned are garden trees to which the owners are understandably attached.

Restricted cuts are a major drain on the DNO's resources, as it must send a cutting team back to the property every year or every other year and such visits typically cost three to five times as much as the cost of keeping the same team busy day to day on the regular clearance work. In addition, it can be very disruptive to the landowner, although it could be argued that s/he has brought the disruption upon themselves. However, if the rates at which the pruned trees re-grow could be slowed down without harming the trees, this would reduce the number of repeat visits and minimise disruption for the landowner.

Tree growth regulators

Research has shown that compounds known as tree growth regulators (TGRs) can slow the growth rates of trees for three to five years depending upon species and are effective in extending pruning cycles in utility tree cutting (Burch and Wells, 1995; Chaney, 2002; Hotchkiss, 2003; Moore, 1998). The most effective compound of the TGRs available currently is paclobutrazol (PBZ) and previous research has shown that PBZ significantly reduced the growth rates of *Fraxinus excelsior* (ash), *Tilia x europea* (lime), *Acer pseudoplatanus* (sycamore) and *Cupressocyparis leylandii* (leyland cypress) in the UK (Hotchkiss, 2003).

PBZ is licensed in the UK for use on apple, pear, plum and cherry and for some nursery container stock, but not for use on amenity trees. PBZ has been shown to have beneficial effects on treated trees, that is it increases drought tolerance and the production of fine roots, and it has fungicidal properties that can combat vascular wilt diseases and tar spot on sycamore for example (Chaney, 2002; Hotchkiss, 2003).

A project to assess the efficacy of PBZ on amenity trees that impact overhead power lines in the UK was initiated in 2009, with four DNOs representing 10 licence areas participating (i.e. WPD including what was formerly CN, CE Electric (CE-E), Scottish & Southern Energy (SSE) and UKPN). As with the Climate Change Growth Study, this research is funded through the IFI Scheme. The research is led by the Bartlett Tree Research Laboratory at Reading University with assistance from ADAS. The aim of the project is to determine if PBZ is effective in slowing the post-pruning growth of the fastest growing tree species in the UK. If it is shown to be effective, the aim is to apply for a licence from the Chemicals Regulation Directorate (CRD) for its use on amenity trees.

Materials and methods

Six field trial sites were selected located throughout the UK representing a diverse range of bio-climatic zones with at least one research site covering each of the participating network operators' licence areas (i.e. Boxworth in Cambridgeshire, Drayton in Warwickshire, Hull in Humberside, Myerscough in Lancashire, Raglan in Monmouthshire and Reading in Berkshire). The tree species selected for PBZ evaluation represented those that occur commonly on or near overhead networks (i.e. alder, ash, birch, leyland cypress, lime, poplar, hawthorn, sycamore and willow). Trees selected for project purposes were tagged and measured (diameter at breast height, dbh, 1.4 m).

The PBZ dosage for each tree was calculated and details provided to the contractor responsible for application of PBZ. Trees were treated in July and August 2009, under an experimental licence from the CRD. This was followed by a 15% top and side pruning of both treated and untreated trees.

PBZ was applied using a Rainbow Treecare Soil Injection System™ (see Figure 6) based on 1 x 1 metre spacing to a circular area the radius of which is three times the trunk diameter. A maximum of 250 ml of TGR plus dilutant was injected per point to a depth of 20–25 cm at a pressure of 30 psi (13.6 kg-f). This was split into a minimum of four equal applications around the base of the tree. The only exception to this was where the application was significantly less than 250 ml; in this case the injections were reduced to three. The quantity of PBZ injected was based on manufacturers' recommended rates as determined by tree species and diameter at breast height (Rainbow Treecare, 2007).

Figure 6 Paclobutrazol applied using the Rainbow Treecare Soil Injection System™.

At each field site 30 trees per species were used: 15 PBZ treated and 15 water treated controls in three replicates of five pairs of trees. This experimental design was adopted in line with Official Recognition of Efficacy Testing Organisations (ORETO) guidelines for efficacy testing as below and analysed as a three randomised complete block design (Table 3).

Table 3 Three randomised block design of PBZ experiment.

PBZ (T1)	Control	PBZ (T1)	Control	PBZ (T1)	Control
T1	C	T1	C	T1	C
T1	C	T1	C	T1	C
T1	C	T1	C	T1	C
T1	C	T1	C	T1	C
T1	C	T1	C	T1	C

During the 2009 and 2010 growing season (July–August) a number of tree vitality measurements were recorded on PBZ treated and non-treated trees. These included chlorophyll fluorescence, chlorophyll measurement and leaf electrolyte leakage, all of which are reliable indicators of vitality (Percival, 2004, 2005). In addition, measurements were taken of the girth of the trees at dbh (1.4 m above ground). In 2010 the girths of the trees were measured again as was the extension growth of the test and control trees. Root cores were taken from all the trees pre and post treatment to measure the density of fine roots, pre and post application.

Results and conclusions

In the first year (2009) there was no significant influence ($P<0.001$) of PBZ application on tree vitality at any of the field sites. Lack of statistical significance between PBZ treated and control trees during the first few months after PBZ application indicated no phytotoxic response during the first growing season. In the second year (2010) no long-term phytotoxic effects induced by PBZ application were recorded any tree irrespective of planting site and species (Percival *et al*., 2010).

A significant influence of PBZ on vitality and growth was recorded in 2010 (i.e. one year after PBZ application). Analysis of individual tree species (PBZ treated vs. non-PBZ treated control) at each field site shows that the influence of PBZ was manifest by:

- reduced shoot growth and trunk diameter;
- increased root growth;
- increased leaf photosynthetic activity (i.e. higher chlorophyll fluorescence);
- greener leaves (higher SPAD readings as a measure of leaf chlorophyll content);
- reduced electrolyte leakage (higher plant cell wall strength).

The effects of PBZ on growth varied between tree species. For example, reduction in stem extension in English oak and beech ranged from 39% to 75% and 13% to 42% ($P<0.05$) respectively, while effects on stem extension of poplar and willow ranged from 3% to 24% and 11% to 32% (not significant) respectively. However, conclusions are based on one growing season and should be interpreted with care.

Increased tree vitality recorded in PBZ treated trees over non-PBZ treated trees in 2010 indicates only beneficial effects caused by PBZ application (Percival *et al*., 2011).

Implications for the utility and amenity sectors

While it is risky to place reliance upon on one year's data, the indications are that PBZ is effective in reducing extension growth in the test trees. The results thus far support the findings of Hotchkiss (2003) on ash, lime, sycamore and leyland cypress in the northwest of England. Therefore, the indications are that PBZ can be effective in the electric utility sector to slow tree re-growth rates in the situations in which it is intended to be used, that is on high value amenity trees and locations where landowners will only allow restricted cuts.

The implications for the amenity sector are also positive as local authorities could use PBZ to extend the time intervals between pruning regimes of street and other publicly owned trees.

The positive effects of PBZ on tree vitality are good side effects to the application of PBZ. It has been shown that positive responses of root growth to PBZ are often associated with increases in fine root production or increased branching (Chaney, 2002; Blaedow, 2003; Watson, 2006). For example soil injection of PBZ around declining mature oak trees increased fine root development 60% to 80% within 20 cm of the base of the tree (Watson 1996). The results of the present study show similar responses with increased root dry weight recorded in most trees treated with PBZ. In the USA PBZ is regularly applied to trees where underground utilities have been installed through trenching to encourage increased production of fine roots (Chaney, 2003.). This is an area that could be further investigated in Britain.

Another aspect to the increased production of fine roots, some of which in time will develop into woody roots, is that perhaps this could result in increased stability in treated trees. However, this is an area that requires further research.

Research on trees and resilience

Since 31 January 2009 all DNOs are required to operate a progressive tree cutting and felling programme in accordance with industry standard ENA ETR 132 (ENA, 2005), which outlines a risk-based methodology for targeting strategic overhead line routes to improve network performance in abnormal weather conditions. Trees that are within falling distance of the overhead lines must be assessed to ascertain the likelihood of failure of the whole tree or parts of the tree, which in the event of failure in abnormal adverse weather conditions would cause service interruptions and/or damage to the infrastructure. In reality this means that any trees that are within falling distance of OHPLs are 'resilience trees' and must be assessed and managed to prevent them causing interruptions and/or damage in abnormal weather conditions.

The problem is that it is not the defective, dead, dying or dangerous trees that cause DNOs problems because these are identified as part of routine clearance work and managed appropriately. Nor are the trees that a competent and experienced tree assessor would recognise as possibly problematic and decide to investigate further to assess whether not they pose a danger, as these are identified, assessed and managed appropriately.

Trees that seem 'healthy' and not a cause for concern pose the most serious threat. Post-mortem analysis of six major storm events across the USA revealed that between 55% and 70% of the trees that failed and caused damage to the OHPLs and associated apparatus had no discernable defects and would have been regarded as 'safe' had they been assessed prior to the storm events (Guggenmoos, 2009). This finding has significant implications for understanding and mitigating tree-related damage and outages in major storm events. The degree to which the OHPLs are exposed to trees (i.e. the number of trees per kilometre edge) is the best measure of exposure, and in the USA this significantly correlates with the frequency of tree-caused outages, with a correlation coefficient of between 0.85 and 0.92 (Guggenmoos, 2009).

It was decided to investigate whether or not it is possible to devise an objective assessment system that would facilitate reasonable predications of the likelihood of such trees to fail in abnormal weather conditions. Central Networks (now WPD) is funding a two-year MPhil study based at Myerscough College, Preston, Lancashire, and in cooperation with Reading University, to see if such a predictive system can be devised. The project started in November 2010 and is due for completion in 2012. The project will investigate areas such as existing peer-reviewed tree assessment systems; risk assessment methods from other industries; the relevance of the International Tree Failure Database and California Tree Failure Database to assess the probability of failure of trees in the UK; Meteorological Office wind forecasting models; tree failure profiles; tree growth characteristics; etc.

It is hoped that the research will devise a system of predicting the failure potential of trees in abnormal weather conditions that is objective and based on measurable parameters, which are valid, robust, replicable, mathematically sound and easily applied.

If such a system can be devised, its use would extend far beyond the utility sector, where it would greatly assist DNOs to discharge the resilience obligation. For example the system could be used by local authorities to ascribe a probability of tree failure in extreme adverse weather conditions, which would assist in planning maintenance programmes and allocation of resources to deal with the most risky trees.

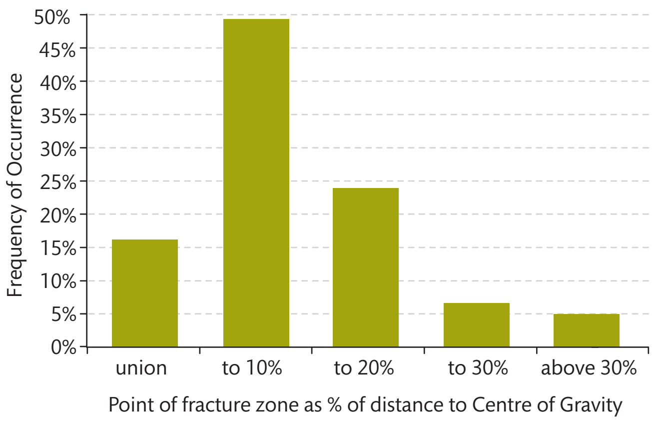
Branch failure research

Tree-caused outages are a major problem for DNOs. Traditionally the focus of utility vegetation managers has been on individual trees that have characteristics that would predispose them to failure. However, the failure of small- to medium-sized branches within the crowns of trees in proximity to or overhanging energised electricity conductors is also a consideration that has not been given as much attention as whole tree failure. Like whole tree failure, the failure of individual branches can cause mechanical damage to the infrastructure. Also branches can provide a fault pathway between phases which can result in an electric mode of failure.

In 2008 an investigation into the modes of failure of small- to medium-sized branches in the crowns of trees was initiated in the USA. It was funded by the ISA Tree Fund and National Grid (USA). The investigation included a literature review; interpretation of photographs of tree-caused outages; a survey of the industry's experience; and destructive testing of branches of six species of tree (Goodfellow, 2009).

The small- to medium-sized branches included in the experiments ranged between 2 cm and 8 cm in diameter and individual branches were mechanically loaded to the point of destruction. The research identified a critical zone of failure within 10% to 20% of the branch length to the union (Figure 7). The majority of branches tested (48%) failed at a point that was 10% of branch length from the union, and 24% failed 20% from the union. Very few branches (15%) failed at the union, which conflicts with common perceptions. The study also found that a relatively small reduction in branch length resulted in substantial reduction in load-induced stress in branches, and this may be an effective means of mitigating the risk posed by branches adjacent to, but particularly overhanging, conductors (Goodfellow, 2009).

Figure 7 The points of failure of mechanically loaded branches.



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More research is needed on this aspect to understand the effect that the reductions in branch length might have on the natural resonance of the tree, i.e. to study the dynamic effects of such reductions using the methodology developed by James (2010).

Summary and the future

The utility arboriculture sector in the UK has taken the initiative and invested in research that is environmentally sound and should lead to significant savings, efficiencies and more reliable networks. This is being done because the need has been identified and there is significant statutory pressure on the electric utilities to manage trees and vegetation effectively.

The principal driver in tree and vegetation management is the growth rates of the most commonly occurring trees on or adjacent to the OHPLs. Growth rate dictates the cutting cycles and indirectly the cost of managing those cycles (the shorter the cycle the higher the cost). Research set out above confirms regional differences in tree growth rates and that rates of growth are likely to increase significantly in the next ten years.

The possible use of the TGR paclobutrazol to slow re-growth rates is being investigated. If this proves to be effective it will provide a cost-effective way of bringing fast-growing trees into the clearance cycles and buy time to allow the DNOs to plan and implement diverting or undergrounding some of the OHPL network, specifically the LV network. It is also intended to apply for a licence from the CRD to use PBZ on amenity trees, so that its benefits can be realised in the local authority and private tree care sectors, as well as within the utility sector.

Trees that could damage the OHPLs and cause supply interruptions in abnormal weather conditions pose a particular problem to the DNOs. Most of the trees that fail and cause damage and supply interruptions are typically healthy specimens within falling distance of the OHPLs. Therefore, research has been initiated to investigate whether or not a system can be devised to assess these trees and predict the likelihood of them failing in extreme adverse weather conditions. This research is due to report towards the end of 2013.

Innovative research in the USA into the failure of small- to medium-sized branches within the crowns of trees has revealed that the critical failure point is not at the branch union but at a distance from the union equivalent to 20% of the length of the branch. It also revealed that relatively small reductions in branch length result in significant reductions in load-induced stress.

Although all the research described in this paper is principally aimed at the electrical utility sector to assist it to become more efficient and deliver safer networks, the implications go beyond that sector. The research has significant benefits to the amenity and urban forestry sectors as well.

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