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THE RELATIONSHIP BETWEEN TREES, DISTANCE TO BUILDINGS AND SUBSIDENCE EVENTS ON SHRINKABLE CLAY SOIL

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Abstract

An investigation of the incidents of trees causing building subsidence was undertaken as a re-investigation of the data reported in the Kew Root Survey undertaken by Cutler and Richardson in 1981, and expanded in 1989. This investigation was undertaken 26 years after the Kew Root Survey was first reported. The databases of the major loss assessor (Cunningham Lindsey UK Ltd); the site investigation company (The CET Group Ltd); the tree root identification Labs (Tree Root Investigations Ltd) and the major arboricultural consultancy company involved in subsidence (OCA UK Ltd) were interrogated. The study reveals that although there are some minor differences between the data reported in the Kew Root Survey of 1981 and the data in the present study, the findings of the Kew Root Survey are vindicated. A discussion about tree rooting strategies is included because of the historic reliance that Arboriculturists and others place on the straight line distances between trees and building damage.

Key words: subsidence; tree; influencing distance; Kew Root Survey, rooting strategies; shrinkable clay.

Introduction

Subsidence damage to low rise buildings, which is often caused by trees has become the largest tree related insurance problem in Britain. The potential for trees to cause damage to the foundations of buildings was first

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highlighted by WARD, (1947). Ward's paper in the *Journal of the Institute of Architects* (now the RIBA Journal) assessed the effects of fast growing trees and shrubs on building foundations. However, the issue of tree related subsidence as a major cause of claims for property owners and insurance companies dates from the severe drought period of 1975/1976. At that time when private home ownership was increasing, the competitive buildings insurance market resulted in companies offering to cover additional perils, one of which was subsidence.

During and following the 1975/1976 drought there was a significant increase in insurance claims for crack damage to buildings as a result of subsidence with trees implicated as significant causes of the damage. Tree roots extract moisture from soil during the growing season and if the soil is shrinkable clay, then shrinkage occurs when water is removed and swells again when water is returned through precipitation during the late autumn, winter and early spring. If water is removed from shrinkable clay soil underneath building foundations, the subsequent shrinkage can cause the foundation to move downwards, i.e. to subside, which results in cracks in the building's superstructure and that in turn precipitates a claim on the owner's buildings insurance.

This paper does not discuss the mechanics of tree related subsidence or the investigations needed to verify or repudiate claims. Comprehensive reviews of the tree related subsidence problem can be found in BIDDLE (1998); O'CALLAGHAN and KELLY (2005); and ROBERTS *et al.* (2006).

During the 1970s and concomitant with increased levels of subsidence claims, the Jodrell Laboratory at the Royal Botanic Gardens Kew surveyed the incidents where tree roots were implicated in subsidence damage to buildings by means of producing record cards of tree root morphology and the distance between a tree and the building damage caused. These record cards were sent back to the laboratory by investigators in the field. This is known as 'The Kew Root Survey' and was published as *'Tree Roots & Buildings'* (CUTLER and RICHARDSON 1981). Their work describes distances at which 50%, 75% and 90% of the incidents were various genera of tree caused damage to buildings were recorded. It also sets out the 'maximum' distance which the genera had been recorded as causing damage The survey involved over 2,000 record cards where the distance between the tree and the damage had been measured.

The second edition of *Tree Roots & Buildings* (CUTLER and RICHARDSON, 1989) added over 11,000 additional records, but these were records only of the identifications of tree roots recovered from the underside of foundations in subsidence cases. No distance data was included. CUTLER and RICHARDSON (1989) has become the text upon which engineers, loss adjusters, arboricultural consultants/experts, local authority tree officers, solicitors, barristers and the Courts rely when considering tree to damage distances and implicating trees in subsidence damage. Although now out of print, the data it contains are still relied upon by those working in the subsidence arena. The simplistic straight line distance between the tree and the damage assessed against the 75%, 90% and 'maximum' distances recorded for the various genera in CUTLER and RICHARDSON (1989), is typically used.

The data that CUTLER and RICHARDSON published in 1981 were collected between 1971 and 1979 and at the time of this investigation has been in existence and used for 26 years. The urban environment has altered over the last quarter of a century. The number of residential homes has increased markedly with Government approval and encouragement such that the UK is heavily urbanised and the interface between buildings and trees is not always an easy one (O'CALLAGHAN and KELLY, 2005). When the second edition of the Kew Root Survey was published in 1989, the annual number of tree related insurance claims was in the region of 15,000 per annum in a drought year and the cost to the insurance industry less than £250 million. In 2003/2004 the number of claims was over 40,000 and the cost of repair exceeded £500 million in a drought year.

Since 1981 the incidents of tree related subsidence have increased exponentially during every drought period, i.e. 1984/1985, 1989–1992, 1995–1997 and 2003 to 2006, but there has been no re-verification of the tree distance to damage data using the increased number of claims to compare with that reported by CUTLER and RICHARDSON (1981). This paper reports on a re-investigation of the tree to damage distances from the records contained within the databases of companies involved in subsidence investigation, and compares the results with those of the Kew Root Survey (CUTLER and RICHARDSON, 1981). The comparison is made with the 1981 Kew Root Survey as that contained distances, while the additional records included in the 1989 version did not have distance data associated with them.

Methods

In order for a valid comparison to be made between this study and that of CUTLER and RICHARDSON (1981) a similar approach to data gathering was adopted. In this study database records were used rather than cards completed in the field. However, the principle is the same, i.e. analysis of data collected in the field during arboricultural surveys and site investigations.

The sources of the data in this study were the database records of OCA UK Ltd, which, between 2001 and 2006 was the largest Arboricultural Practice working in the area of tree related subsidence. The database of OCA's principal client, Loss Adjusters and Engineers, Messrs Cunningham Lindsey UK (CL), was also used. Both companies agreed to the release of data on all available subsidence cases subject to statutory restrictions imposed under the Data Protection Act, 1998.

Additional data sources included the database of the site investigation company, The CET Group, now CET Safehouse Ltd. (CET); and the tree identification records of Tree Root Investigations Ltd. (TRI), were made available, again subject to the statutory restrictions of the Data Protection Act, 1998.

All records were evaluated based on the following parameters. Each file had to contain clear and unambiguous records of:

- The Species or Genus of the implicated tree(s);
- Certificates of Root Identification;*
- The measured distance between the implicated tree(s) and the damage on site.

Because multiple databases and records from discrete companies involved in subsidence investigation were used, it was necessary to cross reference between all sources of data. This was done because not all of the tree data were held on all the databases. The tree root identification certificates from TRI are not held in database format, but were individual certificates created in spreadsheet format filed by date and site. CET holds records of the Reports of Factual Investigations of the Site, and the reports include the tree root identification certificates. Both the CET and TRI records contain a common entry field, i.e. the Cunningham Lindsey 'Order Number'. Therefore it was possible to link the root identifications with the site investigation reports (SIs) and thus to individual sites.

The CET database has an entry field in common with that of the CL database, i.e. the CL 'Core File Reference' and this enabled a link to be made between the SI, including the root identification, and the CL database.

The OCA database also contained the CL 'Core File Reference', and therefore it was possible to link all the data together and track it to the OCA Job Number and the location of the physical and/or digital file.

Completion of the data matching involved linking the root identification and the SI and adding the measured tree data (species, distance *etc*). This in turn involved locating and retrieving the OCA file and matching the root identifications to the tree(s) recorded on site. In this study, as in the Kew Root Survey (1981 and 1989) the data for *Chamaecyparis* and *Cupressocyparis* are included in the *Cupressus* figures.

*The tree root identifications were made by TRI using light microscopy and comparison with type specimens. DNA was not used for routine tree root identifications at the time of the study (2005). Although it was available at the time of this study it was considered too expensive for routine identifications.

Once the process had been established the time involved equated to an average of four minutes per file. Over 12,800 files were interrogated and all of the records covered the period between 2002 and 2005, which included three of the four major drought years of 2003–2006.

In many cases it was not possible to match the trees to the root identifications and these records were discarded.

The criteria for matching the survey details to identified roots were as follows:

1. **Multiple Trees:** In cases where more than one tree was present from which the roots could have emanated, the most probable tree was selected using a combination of experience, the actual tree size and distance from the damage. For example if two Maples were possible owners of a root identified as *Acer*, a 16m tree 6m from the damage was selected over a 6m tree 5m from the damage;
2. **Root Identification is either or:** Where a root was identified to family level, *Saliaceae* for example, the species present within influencing distance that corresponded was selected; i.e. if only Willow was present then that genus was selected, if only Poplar was present then that genus was selected. Where both genera were present, the record was discarded from the data;
3. **No tree matching the root:** Where there were no trees matching the root on the property, in neighbouring properties, or on public land adjacent, the record was discarded from the data;
4. **Roots emanating from hedges or groups:** In these instances the closest matching specimen was selected;
5. **Shrubs:** Where roots were identified as emanating from woody shrubs the records were discarded from the data, as shrubs are rarely if ever implicated in subsidence damage.

A total of 1,268 of 12,800 records were positively matched that contained verified distance measurements between the tree and the damage, i.e. @ 10% of all records analysed.

Results

The 1,268 positively matched records represented 35 genera of tree (Table 1), demonstrating that 35 tree genera were implicated in subsidence events. The results show that ten genera of tree accounted for 83% of tree related subsidence events, with *Acer*, *Cupressus*, *Fraxinus*, *Quercus* and *Salix* the dominant genera, each being involved in over 100 subsidence incidents,

TABLE 1. The Genera of Tree and the No. of Subsidence Incidents Associated with each one

Species/Genus	No. Samples	%
Oak	171	13.49
Ash	157	12.38
Cypress	149	11.75
Maple	118	9.31
Willow	110	8.68
Prunus	85	6.7
Poplar	70	5.52
Lime	62	4.89
Apple	54	4.26
Plane	54	4.26
Hawthorn	41	2.23
Birch	30	2.37
Beech	28	2.21
Sorbus	20	1.58
Horse Chestnut	15	1.18
False Acacia	13	1.03
Pear	13	1.03
Pine	12	0.95
Eucalyptus	10	0.79
Hornbeam	10	0.79
Cedar	9	0.71
Elm	8	0.63
Yew	6	0.47
Alder	5	0.39
Walnut	4	0.32
Laburnum	3	0.24
Hazel	2	0.16
Spruce	2	0.16
Ginkgo	1	0.08
Holly	1	0.08
Larch	1	0.08
Liquidambar	1	0.08
Monkey Puzzle	1	0.08
Tree of Heaven	1	0.08
Wellingtonia	1	0.08

(Figure 1). The remaining five genera *Malus*, *Platanus*, *Populus*, *Prunus*, and *Tilia* were involved in between fifty-five and eighty-five incidents each, (Figure 1).

Table 2 shows a comparison of the 50% and 75% and 'maximum' distances for twenty two of the genera observed in this study that were also included in the Kew Root Survey (CUTLER and RICHARDSON, 1981). The total number of samples analysed in this investigation was lower than the number in the Kew Root Survey at 1,239 samples compared with 2,001 in the Kew Root Survey.

The sample population of three genera (*Fagus*, *Fraxinus* and *Cupressus*) was larger in this study than in the Kew Root Survey. *Fagus* and *Fraxinus*

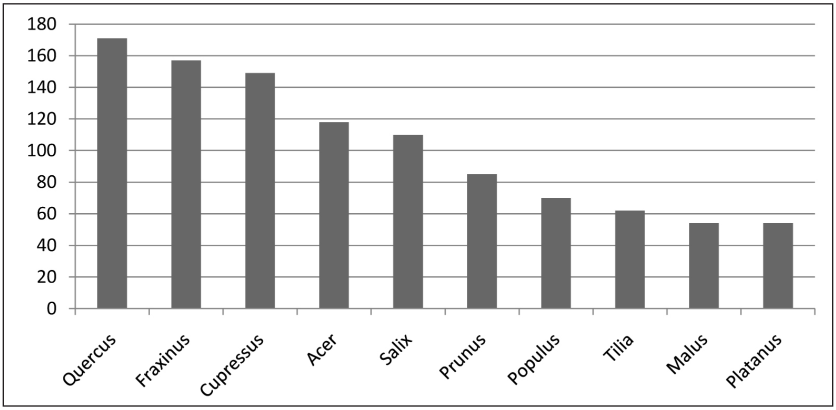

FIGURE 1. The Plot of Incidents against genus from this study.

were marginally larger but in the case of *Cupressus* almost five times as large (Table 2).

One genus, *Eucalyptus*, was recorded in this study that was not recorded in the Kew Root Survey (1981 & 1989), although the number of incidents associated with it was low, i.e. ten, (Table 2). *Carpinus* was recorded in both studies but only 90% distances were reported in the Kew Root Survey, and while *Cedrus* is reported in the Kew Root Survey, there are no distance data for that genus.

The results show that in nine genera, *Aesculus*, *Cupressus*, *Platanus*, *Populus*, *Pyrus, Robinia*, *Sorbus, Salix* and *Tilia*, the 75% distance increased over those reported by CUTLER and RICHARDSON (1989); in four genera, *Betula*, *Fagus*, *Crataegus* and *Ulmus*, the 75% distances reported in this study were lower than those in the Kew Root Survey (Table 2).

In four instances the maximum distances were exceeded, i.e. *Crataegus*, *Platanus*, *Populus*, and *Prunus*. However, in thirteen genera; *Acer*, *Aesculus*, *Betula*, *Carpinus*, *Cupressus*, *Fraxinus*, *Fagus*, *Pyrus*, *Quercus*, *Robinia*, *Salix*, *Tilia* and *Ulmus*, the maximum distances recorded in this study were lower than those reported in the Kew Root Survey (Table 2).

Those genera which comprised less than 4% of the total sample and accounted for less than 20% of all subsidence damage cases, were regarded as not important from a subsidence risk perspective and eliminated from the data. This reduced to ten the number of genera that are regarded as being important with respect to the subsidence risk that they pose, (Figure 1). Elimination of the genera that were not regarded as important from the subsidence risk perspective reduced the number of samples from 1,268 to 1,030 or 83.1% of the total number of samples.

Although the resultant population of 1,030 records represents 51.5% of the number of records in the Kew Root Survey of 1981, there are

TABLE 2. Comparison Between the number of records, the 50%, 75% and Maximum distances recorded in this study and the Kew Root Survey.

Species/Genus	No. Samples	C&R No Samples	50% Dist.	C&R 50%	75% Dist.	C&R 75%	Max. Dist.	C&R Max.
Acer (Maple & Sycamore)	118	135	6	6	9	9	18	20
Aesculus (Chestnut)	15	63	9	7.5	15	10	18	23
Betula (Birch)	30	25	4	4	6	7	7	10
Carpinus (Hornbeam)	10	8	5		9		10	17
Cedrus (Cedar)	9	12	6		12		17	
Crataegus (Hawthorn & Blackthorn)	41	65	4	5	6	7	12	11.5
Cupressus (Cypress)	149	31	2	2.5	4	3.5	17	20
Eucalyptus	10	0	5.5		10		15	
Fagus (Beech)	28	23	6.5	6	8	9	13	15
Fraxinus (Ash)	157	145	7	6	10	10	20	21
Malus (Apple)	54	61	4	4	6	6	10	10
Pinus (Pine)	12	5	7		10		14	8
Platanus (Plane)	54	327	7.5	5.5	10	7.5	18	15
Populus (Poplar)	70	191	12	11	17	15	30	30
Prunus (Cherry, Plum, Damson etc)	85	114	4	3	6	6	14	11
Pyrus (Pear)	13	19	4	4	6.5	6	9	10
Quercus (Oak)	171	293	10	9.5	13	13	28	30
Robinia (False Acacia)	13	20	8	7	9	8.5	12	12.4
Salix (Willow)	110	124	9.5	7	12	11	20	40
Sorbus (Rowan & Whitebeam)	20	32	5	5	8	7	12	11
Tilia (Lime/Linden)	62	238	7	6	10	8	18	20
Ulmus (Elm)	8	70	9	8	10	12	15	25
Total No. Samp.	**1239**	**2001**						

interesting trend differences between the two datasets. The contribution of the various genera to the total number of claims was different between the two datasets. Specifically the numbers of claims associated with *Cupressus* and *Fraxinus* in this study was significantly higher than in the Kew Root Survey of 1981. Claims associated with *Acer*, *Malus*, *Quercus*, *Prunus* and *Salix* were also higher in this study. However the number of claims associated with *Platanus* was significantly lower in this study (Figure 2).

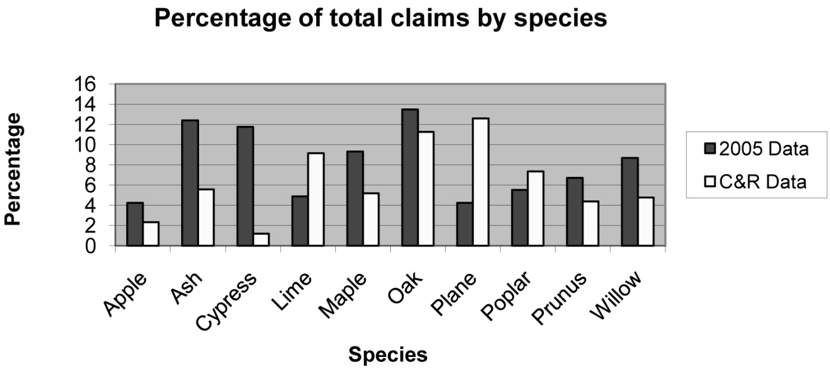

FIGURE 2. Comparison of the percentage of claims by genus of CUTLER and RICHARDSON (1981) and the present study.

Discussion

Other than the differences revealed in the present study set out above, the principal conclusion of this study is that the Kew Root Survey (CUTLER and RICHARDSON, 1981) is vindicated. The data from this investigation support the findings of CUTLER and RICHARDSON (1981) but with minor differences in influencing distances, which can be attributed to differences between individuals of the same species growing on different sites in different parts of the country. Overall the Kew Root Survey has withstood the test of time and its results are supported and reinforced by the findings of this investigation.

There are differences between the results of the Kew Root Survey (1981) and this study. One possible explanation is the location and timing of each of the surveys. The Kew Root Survey data were collected between 1971 and 1979, a considerably longer period than the present study. In addition, most of the data in the Kew Root Survey were collected from the south east and London, whereas the current study collected data nationally, between 2002 and 2006.

The number of subsidence events in which certain genera are implicated in this study differs markedly from that of the Kew Root Survey, (Figure

2). For example, Elm (*Ulmus*) occurs ten times more frequently in the Kew Root Survey than in the present study and this is probably the result of the impact of Dutch Elm Disease (DED) that devastated the Elm population of the UK in the 1980's. The decline of Elm as a dominant tree in the urban/ sub-urban landscape most likely explains the lower number of incidences and the lower 'maximum' distance recorded in the present study.

The significantly increased number of incidents ascribed to Cypress (*Cupressus*) may be attributed to two factors. First, the fashion/popularity for fast growing hedge species. In particular the Leyland Cypress (*Cupressocyparis leylandii*) is associated with the late 1970s and 1980s and the influence of the BBC Radio Programme Gardner's Question Time that promoted this species as an ideal boundary tree or hedging plant. At the time the Kew Root Survey reported the frequency of this species would have been increasing, but the relative immaturity of the specimens would have meant that they were unlikely to have been implicated in many subsidence events. A quarter of a century later the specimens have become established and their relatively fast growth rates suggest that they are more likely to be involved in subsidence events. Our data supports this conclusion (Tables 1 & 2). In addition this species is typically planted as a hedge for screening and privacy as a consequence of which it is often planted relatively close to properties, i.e. 3m to 6m distant. The abundance of specimens at this distance possibly skews the data and the true influencing distance of this species will be difficult to determine until sufficient data are available for individual trees as well as hedges.

In the same way as Cypress, *Eucalyptus* has also gained popularity and was planted more frequently as a garden tree during the 1990s and early 2000s. This study reveals that this genus is starting to feature as a cause of subsidence; representing 0.8% of the records and accounting for ten subsidence incidents (Tables 1 and 2). This suggests that *Eucalyptus* may become a high risk genus for subsidence in the future.

The differences between both datasets for Cypress, *Eucalyptus* and Elm suggests that involvement of these genera in subsidence events is linked to the frequency with which they are planted in the urban/sub-urban landscape. The increase in the number of cases involving Cypress and the reduction in the number of cases involving Elm directly supports this conclusion. There are no records for *Eucalyptus* in CUTLER and RICHARDSON (1981 and 1989) as it was comparatively rarely planted in the urban/sub-urban gardens at the time of that study. It is now a more commonly planted genus and the present study records ten instances where this genus was implicated. This also supports the conclusion of a link between frequency of planting and involvement in subsidence.

CUTLER (1995) explored the relationship between involvement in subsidence cases and frequency of planting in the landscape. He concluded that where the damage figures are close to the planting frequency figures then there is nothing exceptional about the species involved. Planting such species within the ‘influencing’ distances will result in those species causing subsidence on shrinkable clay soils. If the damage frequency is lower than the planting frequency, then those species are relatively safe to plant within the distances suggested by the Kew Root Survey (1981). Conversely where the damage frequency is much higher than the planting frequency those species can be regarded as problematic.

The figures for Plane (*Platanus*) also differ between the two datasets. Although the Kew Root Survey (1981) had significantly more records than the present study, 327 compared with 54, the influencing distances are between 2m and 3m greater in the present study than in the Kew Root Survey (Table 2). Plane is very commonly planted in London and the south east in avenues. Consequently, the urban environment in that part of the country is such that Plane is likely to be closer to buildings than it is elsewhere in the Britain. Although the number of records for Plane in the present study is a sixth of the number in the Kew Root Survey (1981), the fact that the data were gathered nationally suggests that our results probably present a more accurate picture of the influencing distance for Plane.

In this study the 50% distance for Plane is 7.5m as against 5.5m in the Kew Root Survey; the 75% distance is 10m as against 7.5m, while the ‘maximum’ distance is 18m as against 15m, (Table 2). Given the larger rooting space available to this species outside of the greater London area it is suggested that the distances reported in this study are more reliable than those of the Kew Root Survey.

The experience of one of the authors, (DPO) suggests that the maximum distance of 19m or more is more realistic for Plane than the Kew Root Survey maximum of 15m. There is evidence of ‘maximum’ distances of between 19m and 23m recorded for Plane in recent, (2008 and 2010) subsidence cases, where Planes were the only trees present at 19m to 23m from the damage and roots identified as *Platanus* were recovered from the underside of foundations and matched to the trees by DNA profiling.

Reasons for the differences between the datasets could also be due to trends in urban tree planting and changes in the urban environment. The difference in the frequency of claims attributed to Plane is most likely due to the fact that it is very commonly planted in London and the south-east, where space for Planes to grow is more confined and relatively less so in the rest of the country. Local Authority tree planting strategies impact the spatial data in both studies. Street trees are, in general, planted at similar distances from properties throughout the country, and the variety of species planted is relatively limited. This skews the data to some degree by creating significant numbers of incidents at similar distances for a narrow band of tree species.

Since the first publication of the Kew Root Survey in 1981 and the second edition in 1989 the 90% and 'maximum' distances recorded between trees and damage set out in those publications have influenced insurance companies consultants, experts and the courts. This is an area of concern as those involved in subsidence should take a more balanced view of the relationship between trees and buildings (CUTLER, 1995).

CUTLER (1995) argues that the 50% or perhaps the 75% distances should concern those involved in subsidence rather than the 90% and 'maximum' distances. However, insurance companies are more inclined to work with the 'maximum' distances to minimize their risk (CUTLER, 1995). Qualified arboriculturists who are consultants, experts or local authority tree officers, and who should know better, also rely heavily on the 90% and 'maximum' distances when arguing their respective cases for tree removal or retention. This is perhaps not surprising given the emphasis that insurance companies place on the 90% and 'maximum' distances. However, the adherence by the arboricultural professionals to the published 'maximum' distances as the absolute maximum distance to which roots of trees can grow is worrying, because tree biology dictates that the rooting patterns and strategies of trees are inherently variable.

When legal proceedings are issued in subsidence to recover repair costs for example, the question as to whether or not a landowner or local authority should have reasonably foreseen that the tree(s) could potentially cause subsidence damage is a consideration for the Judge when s/he is assessing all the evidence before him/her. This is usually answered with reference to the 90% and/or 'maximum' distances. If for example a Plane implicated in subsidence damage is located 19m from the damage and the 'maximum' distance for Plane recorded in the Kew Root Survey (CUTLER and RICHARDSON, 1981 and 1989), is 15m, then the damage is regarded as not reasonably foreseeable.

This 'straight line' tree to damage distance approach is simplistic and does not take account of the rooting strategies of trees. However, a Judge has to make a decision on the evidence and nearly always this is presented to him/her in the 'straight line' tree to damage distance format. However, the tree to damage distances set out in both these datasets cannot account for the distances over which trees are naturally capable of producing roots.

The nature of the urban environment can affect tree rooting distances. Extremes are unlikely, (but not impossible), in the built urban environment, because obstructions to rooting, (e.g. underground services, large stones or lumps of concrete left over from construction and very compacted soil), are more commonly present. Roots may in fact travel longer distances than is reported in both studies but not in straight lines and neither study can make allowances for this.

By definition, subsidence only occurs where the soil type and conditions are such that the trees are suffering some degree of water stress. Tree rooting strategies and tree-water relationships are fundamental to interpreting the results of both studies, which should be regarded as guidelines rather than absolutes.

GASSON and CUTLER (1990) noted that when trees are grown in open isolated situations, without competition for nutrients or water, the root plate morphology tends to be symmetrical. ROBINSON (1994) recorded that plants grown with adequate nutrients often have smaller root systems than do plants grown in nutrient deficient situations.

Tree root systems adapt to moisture gradients or soil differences resulting in localised adverse rooting conditions by proliferating in locations where they encounter favourable conditions of oxygen and water. Likewise, the ability of tree roots to 'track' moisture gradients produces asymmetrical root plate morphology in response to drought stress and water gradients. Therefore the simple 'straight line' distance between tree and damage, as used in the courts and in negotiations between consultants and local authority tree officers, and between expert arboriculturists, is not an accurate representation of the actual length to which roots have grown. For example, roots could have grown considerably longer than the 'straight line' distance to get to the point of damage because of obstacles such as compacted soil etc. The maximum distances may have been achieved but at a root length considerably longer than the simplistic 'straight line' distance. Arboriculturists know, or at least should know this but in legal cases the tendency is to persist upon relying on the published 'maximum' distances as absolutes.

In 'normal' conditions the majority of roots are found in the top 600mm of soil (DOBSON, 1995). Research suggests that a tree will adapt its root system to take advantage primarily of water close to the surface and close to the tree, thus expending the minimum amount of energy and resources in fulfilling this function of the roots. Root proliferation at relatively shallow depths and radial extension is the usual response as the water requirement of the tree increases with size. Should resources become depleted in one area root frequency will diminish and conversely where a resource rich environment is available root frequency will increase. This should be relevant to any discussion about the involvement of a tree(s) in subsidence damage. In reality reliance is placed upon the published simple straight line 75%, 90% and 'maximum' distances between the tree(s) and the damage.

In response to drought stress, tree growth is lower. The leaf area decreases and the balance of resource allocation alters within the tree such that root growth is favoured (BROUWER, 1963; SCHULZE, 1982). Trees grown in water deficit conditions allocate more resources to the roots to enable them to extend. The root elongation associated with deep water tables does not extend the roots into the unfavourable anaerobic zone of saturated soil (SCHWINTZER and LANCELLE, 1983). However, this phenomenon could account for species of tree causing damage to buildings well beyond what is commonly held to be the 'maximum' distance'. There are many examples of trees causing damage to buildings beyond their published 'maximum' distances. In addition to the incidents involving Plane set out above, one of the authors, (DPO, Unpublished) recorded a False Acacia (*Robinia pseudoacacia*) at 15.5m that had caused damage. The published 'maximum' distance for this species is 12.4m, but the tree in question was matched to roots recovered from the underside of foundations by DNA profiling.

If the shallow surface layer becomes desiccated by a period of very dry weather for example, as happened in 2003 between March and the end of April the water uptake of deeper roots will increase significantly and root growth will be stimulated. However, even in this situation 'deep' rooting can only occur while the environmental conditions at depth will support root growth i.e. oxygen must be available at depth, (SCHWINTZER and LANCELLE, 1983).

It is suggested that the concern of CUTLER (1995) about the way the data from the Kew Root Survey (1991) is used applies to all distances, i.e. 50%, 75%, 90% and 'maximum'. Where 'maximum' tree to damage distances are being cited in negotiations and/or legal cases, the fact that trees can cause damage beyond the published 'maximum' distances should be taken into consideration. The number of times this would be an issue is probably small, but the examples cited above demonstrate that it does happen. However, this is not usually acknowledged in subsidence cases.

Clear differences exist between species with respect to rooting patterns and this can be attributed to a combination of rooting strategies and ability to penetrate adverse soil conditions. This is the actual basis for Table 12 in the National House Building Council (NHBC) Standards Document, Chapter 4.2 *'Building Near Trees'* (2003), a document that provides advice to builders in respect of foundation depth when building near trees. Although the table categorises tree species with respect to their 'demand' for water the term 'water demand' is not accurate in biological terms. The concept being conveyed by the term 'water demand' in that table, (which is intended only for the use of builders), is '*the lateral extent, depth and intensity of soil drying which is achieved by different tree species'* (BIDDLE personal letter to DPO, 1992). This seems to suggest that 'maximum' distances, as recorded in this study and in CUTLER and RICHARDSON (1981) should be regarded as guidelines and not irrefutable facts.

Research demonstrates that the spatial displacement of roots is primarily governed by the environment above and below ground. However, there is also a clear genetic element in the equation, which is what BIDDLE (1992) was suggesting. While the principal factor is the pursuit of water, i.e. an environmental factor, the ability of trees to 'exploit' water at distance and depth is genetically governed. ROBINSON (1996) concluded that the evolutionary legacy of the species will constrain the extent to which a root system can vary structurally.

While the majority of roots are found in the upper 600mm of soil, some grow down to depths of 1–2m, and exceptionally some species may penetrate as much as 5m and extend laterally to a distance equal to as much as three times the height of the tree (DOBSON, 1995). However, a significant proportion of roots travel long distances through soils, both horizontally and vertically (CUTLER *et al.*, 1987) and it is this aspect that is of particular importance in the prediction of tree related subsidence.

Conclusions

The Kew Root Survey has been shown to have withstood the test of time as the results of this study vindicate it. However, further work is required to cross reference the incidences of subsidence associated with the top ten genera considered to pose a significant risk of subsidence, with the frequency at which these genera are planted in local authority areas that have high levels of subsidence claims.

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Alan Reeves (deceased) was a Senior Lecturer in Arboriculture at Myerscough College where he worked for 27 years. He held many posts at the College but was quickly recognised for his expertise in entomology and pathology; he was a Fellow of the Royal Entomological Society (FRES). Alan lectured in many aspects of arboriculture including pests and diseases and tree planting and establishment and he directed a number of BSc student dissertations. He was active in the UKI Chapter of ISA and was the first editor of the newsletter 'Treeline' and served as Chapter President in 2003/2004. Alan passed away in June 2006.

Dr Dealga O'Callaghan was Head of the Arboriculture Programme at Myerscough College between 1998 and 2002. He is a Chartered Arboriculturist, (MICFor.); a Fellow of the Arboricultural Association, (F.Arbor.A.); and an Adjunct Professor of Arboriculture in the Forest Resources Dept at Clemson University, South Carolina USA. He is a founder member and the first President of the UKI Chapter of ISA and was the General Conference Chair for the ISA's 74th Annual Conference held in Birmingham in 1998 for which he received an Honorary Life Membership of ISA. He has worked in both education and private sector consulting for many years. He has published extensively in peer reviewed journals on many areas of Arboriculture including control of Dutch elm disease; management of mature trees, transplanting mature trees, arboriculture in the planning system; tree related subsidence; and utility arboriculture. He is an accredited Expert Witness and has acted in many cases in the English, Manx and Irish Courts. He is currently Tree & Vegetation Policy & Procedures Manager at Central Networks, which is a Company of E.ON UK Plc. (Dealga@blueyonder.co.uk)