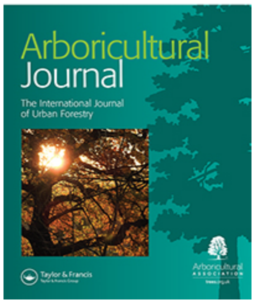

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Introducing the "Derived Root-system Radius" – An attempt at an evidence-supported-calculation for calculation of buffer zone size in respect of Ancient Semi-natural Woodland, Ancient Trees & Veteran Trees

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ABSTRACT
Governmental Standing Advice in England recommends a minimum 15 m buffer zone from Ancient Semi-natural Woodland (ASNW), or potentially longer distances for Ancient Trees (AT) and Veteran Trees (VT). This "one-size-fits-all" approach does not account for differences in the biology of individual tree species, or the environmental niches they occupy. The effective capillary range of trees further suggests that in some situations the Standing Advice potentially underestimates the zone of water influence. On the basis of published data linking root area to canopy spread, the estimated root areas of trees in a field sample (n = 112) were defined as the Derived Root-system Radius (DRSR). These results were significantly different from distances recommended within the Standing Advice, which might, therefore, be inadequate to safeguard the full extent of the roots in the greater proportion of the field study samples. In the case of AT and VT, the sensible approach will be to also anticipate any reduction in canopy area by applying both the diameter approach of the Standing Advice, and the DRSR, and adopting the greatest buffer zone.

KEYWORDS
Ancient Semi-natural Woodland; Ancient Trees; Veteran Trees; buffer zone distance; Derived Root-system Radius

Introduction

Although trees can be legally protected, for example, by Tree Preservation Orders, there is no legislation in England specifically for the purpose of protecting Ancient Semi-natural Woodland (ASNW), Ancient Trees (AT) or Veteran Trees (VT). Notwithstanding, the National Planning Policy Framework requires that planning applications which will result in impacts which have the potential to negatively affect ASNW, AT or VT should be refused, unless there are wholly exceptional reasons for the development to proceed (Ministry of Housing, Communities and Local Government, 2018).

Increasingly, arborists and ecologists are being asked to identify impacts that might be damaging within specific development proposals, in order to inform development designs that have inbuilt mitigation that can be demonstrated to be effective in safeguarding ASNW, AT and VT. This is born from Standing Advice – *Ancient woodland, ancient trees and veteran trees: Protecting them from development* (Forestry Commission & Natural England, 2018).

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Under the heading of "Providing evidence", the Standing Advice states that practitioners and developers should work together to make sure decisions are made on a suitable evidence base. Direct impacts which may result in a negative effect include the severing of roots, ground compaction and increases in ground-levels, which may suffocate areas of the root system (Corney et al., 2008; Ryan, 2012). These impacts typically affect the tree through die-back in the canopy, and even death of the tree (Corney et al., 2008; Ryan, 2012).

Providing an appropriate physical buffer zone from ASNW, AT or VT is the fulcrum of any attempt to safeguard the root system, whilst facilitating sustainable development. The Standing Advice recommends a minimum 15 m buffer zone from ASNW and "*at least 15 times larger than the diameter of a veteran or ancient tree or 5 m from the edge of its canopy, if that is greater*".

This differs from previous guidance for calculating Root Protection Areas set out in BS 5837: 2012 – *Trees in relation to design, demolition and construction – Recommendations* (British Standards Institution, 2012). The British Standard recommends that, for a single-stemmed tree, the Root Protection Area should be calculated "*as an area equivalent to a circle with a radius 12 times the stem diameter*" and that "*The calculated Root Protection Area for each tree should be capped to 707 m^2*" (15 m radius). BS5837 defines a Root Protection Area as a "*layout design tool indicating the minimum area around a tree deemed to contain sufficient roots and rooting volume to maintain the tree's viability*". BS5837 Root Protection Areas are not intended to protect all of the tree's roots, instead they are a compromise between the needs of the tree and the needs of development. However, this is clearly at odds with the policy protection afforded to ASNW, AT and VT against "loss or deterioration". The Standing Advice adopts the Ancient Tree Forum and Woodland Trust's recommendations for the size of buffer zones in an attempt to reduce negative impacts upon these trees.

Although we acknowledge the good intentions within the Standing Advice, the buffer zone suggested does not allow the significant differences in the biology of individual tree species, or the environmental niches they occupy, to be taken into account when designing mitigation. Nor does it anticipate the widely different structures that result from management (e.g. coppicing or pollarding). Furthermore, despite the stipulation within the Standing Advice that decisions are made using a suitable evidence base, the recommendation is based on a formulaic approach which is unaccompanied by any data, nor an account of any controlled study, and cannot, therefore, be critically assessed or adapted to suit site- specific circumstances. Fundamentally, the lack of any evidence foundation means that there is no way anything above the minimum might be calculated. It has been our perception that minimum thresholds recommended may be adopted as the maximum offered, in a "one-size-fits-all" approach. The question is, therefore, is there data available that might be used to inform whether the minimum buffer zones recommended to safeguard root systems, are adequate in a particular situation involving ASNW, AT or VT?

A literature review[1] found a paucity of data. However, one study by Stout (1956) did include raw data and was compelling. These data comprise measurements of the maximum root lengths for 25 trees of nine deciduous species native to North America. Stout (1956) concluded that the most reliable predictor of root area was canopy spread. This contradicts the suggestion advanced in BS 5837, that root radius has a linear relationship with stem girth (British Standards Institution, 2012). The average ratio across all the trees Stout (1956) sampled is 1:9.6, meaning the roots occupy an area 9.6 times greater than the canopy.

As the trees were growing in a temperate climate, the average ratios of crown spread and root spread recorded are potentially comparable with deciduous species in the British Isles, although it is important to note that the trees Stout (1956) studied were in a closed canopy woodland setting, and it is likely that the canopy spread and root spread would be different for open-grown or woodland-edge trees. We applied this rationale to field data comprising 47 trees on the edges of ASNW, 39 AT and 26 VT in lowland England (Berkshire, Devon, Gloucestershire, Hampshire and Somerset). ASNW was identified from the Ancient Woods (England) Inventory (Natural England, 2018), ground-truthed by the presence of Ancient Woodland vascular plants (Rose, 1999) and structural features (Rackham, 2006). AT and VT were defined based on diameter at breast height (1.3 m above ground-level) following published guidelines (Rural Development Service, 2006; Woodland Trust, undated), although we recognise that additional criteria are available (Castle & Mileto, 2005; Fay & de Berker, 2003). These data are provided in Table 1, with an average for each species.

An additional concern remained; that the trees themselves have a perceptible impact on the water and soil environment beyond the physical reach of their roots. Any attempt to define a buffer zone above the minimum will logically combine the physical spread of the roots and the effective capillary range in the context of the soils present. Helliwell (1993) suggests that the capillary range differs with soils, with the greatest distance through clay soils (1–2 m) followed by: loams and fine sand (0.8–1.2 m); unfractured chalk (up to 0.6 m); and, coarse sands and gravels (0.2–0.4 m).

In order to factor in capillary range, we collated data provided by Biddle (1998) and Cutler and Richardson (1989). These data give an insight into how root systems of living trees have an impact on built structures as a result of the shrinking of clay soils. The data are limited to clay soils. However, as Helliwell (1993) suggests clay has the greatest range, we concluded that if the buffer zone was adequate to safeguard the catchment required for clay, these data might be used to safeguard the extent beyond the root-mat that trees require for water catchment in all soils. We collated the data provided by Biddle (1998) and applied the result to define an average distance away from the stem in which a significant reduction in soil moisture was perceivable for seven species; referred to as the Distance of Significant Reduction (Di.S.R). We also collated the data provided

Table 1. Field data.

Tree classification	Vernacular	Scientific	Number of trees	Average tree height (m)	Average canopy radius (m)
ASNW	Ash	*Fraxinus excelsior*	11	19.0	8.3
ASNW	Grey poplar	*Populus x canescens*	5	16.6	8.5
ASNW	Pedunculate oak	*Quercus robur*	31	16.4	8.4
AT	Sweet chestnut	*Castanea sativa*	8	20.9	10.8
AT	Pedunculate oak	*Quercus robur*	31	20.6	11.9
VT	Pedunculate oak	*Quercus robur*	26	19.2	11.8

by Cutler and Richardson (1989) and identified a maximum distance at which damage to buildings due to subsidence occurred for 12 species.

Biddle (1998) and Cutler and Richardson (1989) investigated different species in with overlap in seven instances. We paired overlaps and included an additional five species that we have encountered in ASNW or as AT/VT but for which Cutler and Richardson (1989) alone had data. However, as Biddle (1998) and Cutler and Richardson (1989) do not provide the canopy spread of their samples, a value was derived using published data presented by Russell (2012). This meant that it had to be assumed that canopy spread would develop in ratio to height, and this assumption is unlikely to be true across all species (if at all). However, it did allow an approximate canopy spread to be defined and married with the environmental data. The results are provided in Table 2.

Methods

We based the calculation upon the relationship between canopy area and root-system area. The average ratio across all trees sampled by Stout (1956), which we adopted, is 1:9.6, meaning the roots occupy an area 9.6 times greater than the canopy. It should be noted that this approach assumes the root-system is circular and the stem is situated centrally within it. This was sufficiently uncommon for Stout (1956) to specifically draw attention to its rarity. Other confounding factors will include historic management, such as coppicing or pollarding, which can result in depletion of carbohydrates (due to the reduction in foliage area) and the corresponding loss of individual roots, which may result in lower root density but greater root spread.

The method used is hereon referred to as the Derived Root-system Radius (DRSR) and has been set out in a stepwise manner so that it can be applied in the field by any ecologist or tree-care professional equipped with a trundle-wheel and calculator.

Step 1: Measure the **maximum living canopy radius (LCR)** of the tree's canopy in metres on any one plane; i.e. the spread of the canopy from the trunk to the tips of the buds.

Step 2: Calculate the **canopy area** (**CA**) using the following equation, where **π** = 3.14:

$$CA = \pi LCR^2$$

Using a standard calculator this can be achieved as follows:

(1) Multiply the **LCR** by itself to square the number;
(2) Multiply the resulting number by **π** (3.14) and press equals;
(3) The resulting number is the **CA** in m^2.

Step 3: Calculate the estimated **root-system area (RSA)** using the **CA** and the standardised ratio of 1:9.6 as follows:

(1) Multiply the **CA** by the ratio (9.6);
(2) The resulting number is the **RSA**, in m^2.

Step 4: Calculate the estimated **Derived Root-system Radius (DRSR)** using the following equation, where **π** = 3.14:

$$DRSR = \sqrt{\frac{RA}{\pi}}$$

Table 2. The collated root spread data presented by Biddle (1998) and Cutler and Richardson (1989) along with canopy spread data for equivalent-sized trees inferred from Russell (2012).

	Biddle (1998)			Cutler & Richardson (1989)		
SPECIES	Tree height (m)	Estimate of canopy radius† (m)	Di.S.R (m)	Tree height (m)	Estimate of canopy radius† (m)	Max tree to damage distance (m)
Horse chestnut *Aesculus hippocastanum*	14.9	3.7	19.9	25	6.3	23
Silver birch *Betula pendula*	10.5	1.1	12.1	14	1.4	10
Hornbeam *Carpinus betulus*	No data	No data	No data	18	5.9	17
Beech *Fagus sylvatica*	No data	No data	No data	20	5.0	15
Ash *Fraxinus excelsior*	No data	No data	No data	23	5.8	21
Hybrid poplar *Poplar* x *canadensis*	22.2	9.2	32.8	28	11.6	30
Cherry *Prunus* sp.	No data	No data	No data	12	3.6	11
Pedunculate oak *Quercus robur*	15.0	5.6	22.5	23	8.6	30
Whitebeam *Sorbus aria*	7.5	5.0	9.7	12	8.0	11
Large-leaved lime *Tilia platyphyllos*	16.0	4.0	22.4	24	6.0	20
Lime *Tilia* sp.	15.5	3.9	20.3	24	6.0	20
Elm *Ulmus* sp.	No data	No data	No data	24	10.0	25

† Russell (2012)

Using a standard calculator this can be achieved as follows:

(1) Divide the **RSA** by **π** (3.14) and press equals;
(2) Then press the $\sqrt{}$ button. This is occasionally represented by the symbol $\sqrt[2]{x}$ (if you are using a smart phone calculator, this symbol can be found by turning the phone to landscape orientation);
(3) The resulting number is the **DRSR**, in metres. This represents the estimated spread of the root system in any direction from the stem and might be adopted as an appropriate buffer zone from the edge of the ASNW, AT or VT.

We applied this calculation to the Biddle (1998) and Cutler and Richardson (1989) water environment data and made comparisons between the DRSR estimated root spread and the distances recorded in these two studies. To apply the method to a real situation, we collected field data relating to ASNW, AT and VT and used the DRSR to determine a potential buffer zone. We then compared the results against the minimum buffer zone recommended in the Standing Advice (Forestry Commission & Natural England, 2018). Finally, we identified where further investigations might be focused to improve the accuracy of the method, with specific consideration to the environmental conditions in which the woodland/tree is growing.

Results

The results of the field study are illustrated in Figure 1.

A Mann–Whitney U Test showed a statistically significant difference ($U = 1899$; $p < 0.0001$) between the DRSR and the minimum recommended buffer zone within Standing Advice. Assuming the 1:9.6 average canopy to root ratio is a fair average for broadleaved trees, the results of the field study suggest that the minimum buffer zone recommended in the Standing Advice would be insufficient for the majority of ANSW, AT and VT. Notwithstanding, it is important to note that in 8 of the 112 trees in the field sample (one within ASNW and seven AT), the Standing Advice produced a greater buffer zone distance. These trees were those with the largest trunk diameters where the canopy had been either managed (e.g. pollarded) or had collapsed.

The water environment assessment results are illustrated in Figures 2 and 3.

The results calculated using the DRSR underestimated the zone of influence recorded by Biddle (1998) for six out of seven tree species by an average 7 m, and over-estimated for one tree species by 6 m. The results in respect of the Cutler and Richardson (1989) data underestimated the zone of influence for six out of 12 tree species by an average 3 m, and over-estimated the distance for six tree species by an average 5 m.

Discussion

Metaphorically speaking, there is always a danger that attempting to predict something using third-party data might stray from astronomy into astrology. Notwithstanding, the field study has demonstrated that a one-size-fits-all method, comprising a single fixed buffer zone, does not take into account differences in the tree root spread of individual species or trees. Discrepancies relating to individual tree species can be expected when acknowledging the caveats identified; that the DRSR:

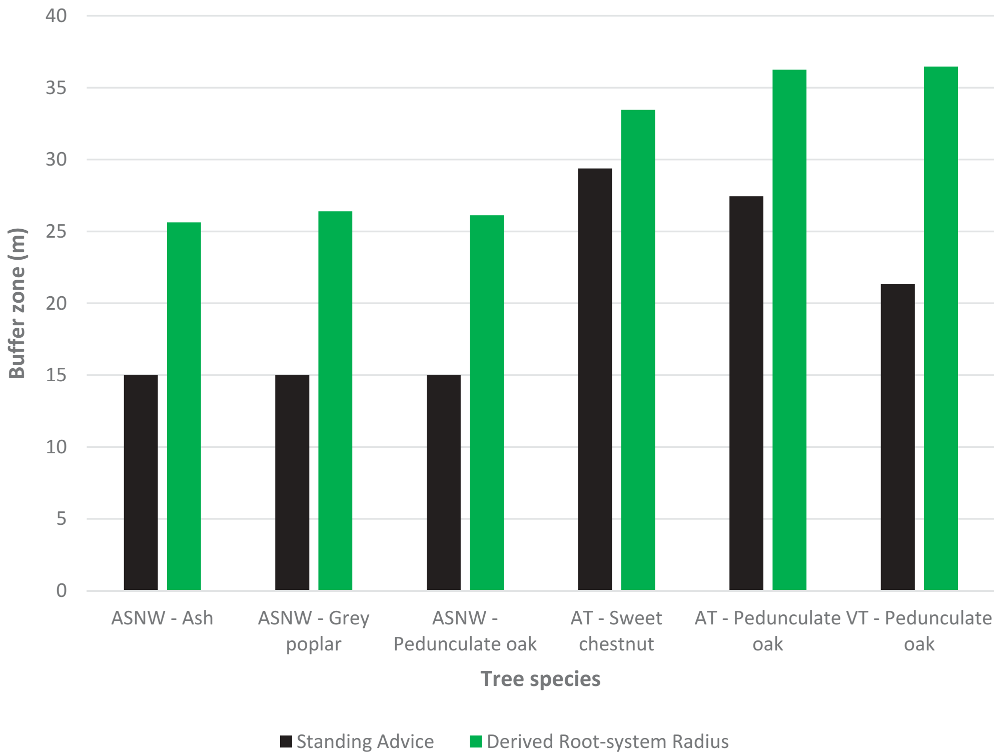

Figure 1. Comparisons based on the field data between the buffer zone calculated using the Standing Advice and the Derived Root-system Radius (DRSR). N.B. The calculations were based on average tree dimensions presented in Table 1.

(1) Assumes the root system is circular and the stem is situated centrally within it; and

(2) Assumes that canopy spread develops in ratio to tree height.

In respect of caveat 1; investigation using dyes has demonstrated that in the ring-porous species (oak, ash, sweet chestnut, etc.) a specific root feeds a particular set of branches, usually on the same side of the tree (Kozlowski & Winglet, 1963; Zimmermann & Brown, 1971). The concept of "functional units" presented by Lonsdale (2013) is also pertinent when considering the location and extent of roots for AT and VT. Although it is accepted there will be anomalies specific to certain trees, measuring the maximum canopy radius might represent a proportionate safeguard for the roots.

Considering caveat 2; in the results of the comparison between the DRSR and the zones of influence reported by Biddle (1998) and Cutler and Richardson (1989) it was the whitebeam that most heavily skewed the results. The radius was also taken from a notional circular canopy in the absence of data, when the maximum radius is almost invariably greater in our field sample, as the stem is not located centrally within the canopy. By removing whitebeam from the analysis, the DRSR does not overestimate the Biddle (1998) dataset, and overestimated the Cutler and Richardson (1989) data in five of the 12 species by an average 2 m.

Looking more closely at the whitebeam, we find it is cited as being wider than it is tall at maturity (Russell, 2012). When applying the DRSR to data presented by Biddle (1998)

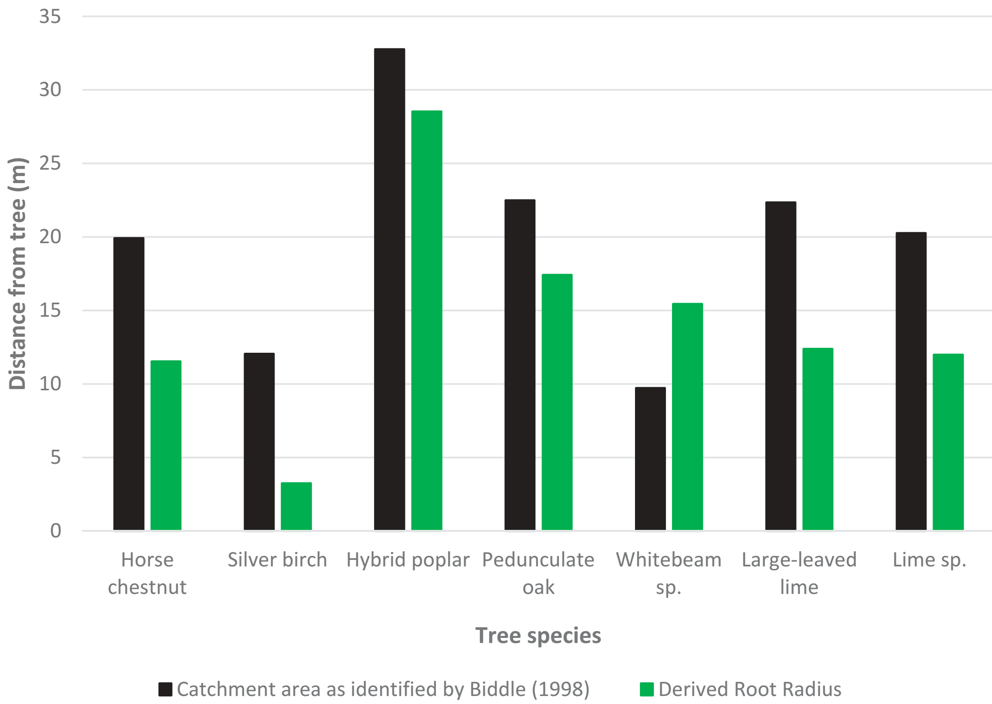

Figure 2. Comparisons between water environment data published by Biddle (1998) and the buffer zone calculated using the Derived Root-system Radius (DRSR).

and Cutler and Richardson (1989), estimates of canopy size were derived which assume a linear relationship between tree height and canopy spread. For most species, this is likely to be broadly true, whereas whitebeam has a broadly conical habit when young which matures into a rounded canopy which can be up to 20 m across on a 15 m tall tree (Russell, 2012). This has resulted in an overestimation of the extent of the root area of whitebeam in relation to these two studies.

Clearly, there are additional species-specific differences that might be explained by their habitat niche and the dampness of the habitats they occupy. However, when applying both the Standing Advice and DRSR in the field it was immediately apparent that maiden and coppiced trees had greater canopy reach than pollards and trees that exhibited a reduced crown. Neither the Standing Advice or the DRSR anticipate management and storm damage. To illustrate, the Standing Advice is based on stem diameter, and would be more likely to underestimate root spread of maiden and coppice, but the DRSR would be more likely to underestimate pollards, illustrated in Figure 4 where the Standing Advice suggests a 50 m buffer zone, whereas the DRSR suggests 46 m. This also applies to the largest AT which have smaller canopy spread due to a major collapse of the canopy, illustrated in Figure 5 where the Standing Advice suggests a 39 m buffer zone, whereas the DRSR suggests 32 m. A similar result may occur with trees that have retrenched.

We consider the DRSR to be a potential addition to the tools available for the calculation of a proportionate buffer zoned to safeguard the entirety of the zone of

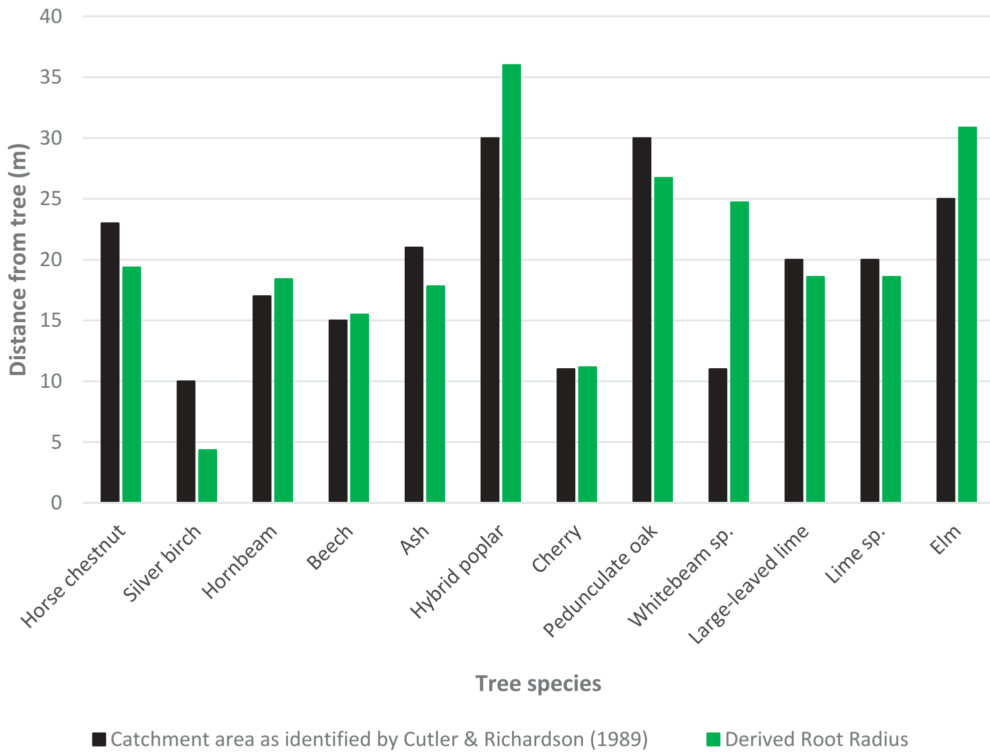

Figure 3. Comparisons between water environment data published by Cutler and Richardson (1989) and the buffer zone calculated using the Derived Root-system Radius (DRSR).

Figure 4. Ancient Tree exhibiting reduced canopy area due to pollarding.

influence to allow the trees to reach their maximum age. However, we would caution against the temptation to focus on a single "superpower" buffer zone calculation, but suggest that safeguarding utilises a combination of complementary methods that

Figure 5. Ancient Tree exhibiting reduced canopy area due to collapse.

anticipate different environments and management. Getting a buffer zone wrong would not only be ecologically catastrophic in the long-term, but would be a PR nightmare because the dead and dying trees would be visible from a great distance and might stand as a monument to failure for a significant period of time. Therefore, we would not advocate the replacement of the diameter approach cited in Standing Advice, but the widening of the methods to encompass both the existing advice and the DRSR. The sensible approach being to anticipate management influence, by applying the diameter approach of the Standing Advice, as well as the DRSR, apply an additional "engineering tolerance" of 2 m to allow for capillary-range, and adopt whichever is the greater buffer zone distance.

Notwithstanding, it might reasonably be argued that the buffer zone should anticipate the conditions that would allow the trees to attain maximum size in the context of a particular situation. If the tree has not reached its maximum size, a buffer zone defined by the physical dimensions at that point in time will only give an estimate of the root spread required to sustain it at that size. Therefore, while the Standing Advice and DRSR might be applied using field data in the context of temporary ground disturbance (e.g. a sand/gravel pit, pipeline installation), it may be insufficient in the context of permanent installations (e.g. housing, rail and roads). In the latter situation, it might be sensible to take account of the maximum recorded canopy spread the species can achieve and adopt this as the CR in the DRSR calculation. Finally, wherever a buffer zone is defined and applied, regardless of the approach or method; surveillance should be performed in order to assess its efficacy. A simplistic method might comprise the collection of baseline data and static photography prior to the development, and a return five and ten years later to see how the tree has fared.

Next steps

Further definitive progress will only be made with species-specific controlled investigations, that result in empirical data which is publicly accessible. To improve the accuracy and define a reliable safeguarding buffer zone, the following information would be required:

(1) A working understanding of the relationship between canopy spread and root spread for species native to the British Isles. This would allow for a species-specific ratio to be applied to the calculation.
(2) Investigation of habitat niche in respect of individual species, perhaps based upon the Ellenberg Indicator Values (Hill, Mountford, Roy, & Bunce, 1999) for "moisture". An understanding of root spread in different soil types would allow additional distance tolerances to be applied for each soil type.
(3) The water environment assessment could be improved by increasing our understanding of the relationship between tree height and canopy spread.

Note

1. Available upon request.

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Disclosure statement

No potential conflict of interest was reported by the authors.

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Henry Andrews is a Chartered Ecologist and the director of AEcol; an ecological consultancy specialising in planning advice to the quarrying industry. He is also the coordinator of the Bat Tree Habitat Key project.

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Jim Mullholland is an ecologist and Chartered Arboriculturist. He is the Training and Technical Officer for the Ancient Tree Forum; a charity that has pioneered ancient tree conservation for over 20 years.

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