BEFORE THE HEARINGS PANEL
FOR THE QUEENSTOWN LAKES PROPOSED DISTRICT PLAN

IN THE MATTER	of the Resource Management Act 1991
AND	
IN THE MATTER	of Hearing Stream 3 (Protected Trees chapter 32)

STATEMENT OF EVIDENCE OF DAVID SPENCER
ON BEHALF OF QUEENSTOWN LAKES DISTRICT COUNCIL

PROTECTED TREES

1 JUNE 2016

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1. INTRODUCTION

1.1 My full name is David Spencer. I am an Arboriculture Consultant at Aborlab Consultancy Services Limited. I have been in this position since June 2014, and have 15 years' experience in Arboriculture. I have a Business Technology and Education Council (**BTEC**) National Diploma in Horticulture and a Technicians certificate in Arboriculture.

1.2 I was engaged by Queenstown Lakes District Council (**Council**) during February to April 2015 to identify and assess trees in the Queenstown Lakes District (**District**) that are suitable for inclusion in 32.8 Schedule of Protected Trees District Wide of the Proposed District Plan (**PDP**).

1.3 I have now been engaged by Council to provide evidence in relation to the Protected Trees Chapter 32 of the PDP.

1.4 Although this is a Council hearing, I confirm that I have read the Code of Conduct for Expert Witnesses contained in the Environment Court Practice Note 2014 and that I agree to comply with it. I confirm that I have considered all the material facts that I am aware of that might alter or detract from the opinions that I express, and that this evidence is within my area of expertise, except where I state that I am relying on the evidence of another person.

1.5 The key documents I have used, or referred to, in forming my view while preparing this brief of evidence are:

(a) Chapter 32 Protected Trees as notified;
(b) Section 32 report for Chapter 32 Protected Trees;
(c) Standard Tree Evaluation Method (**STEM**);
(d) Quantified Tree Risk Assessment (**QTRA**) Practice Note (V5); and
(e) Contemporary Concepts of Root System Architecture of Urban Trees – Day et al.

1.6 I undertook site visits to perform my initial assessment of each tree in February, March and April 2015 and carried out further site visits at the location of the trees contained in listed items 240, 275, 603, 1002 and 1005 on Monday 18 April 2016, to inform this statement of evidence.

1.7 I have attached the following to this evidence:

(a) **Appendix A** – the STEM Score Spreadsheet that I provided to the Council following my initial assessment of the trees now contained within Schedule 32.8 Protected Trees District Wide;

(b) **Appendix B** – Quantified Tree Risk Assessment Practice Note (V5);

(c) **Appendix C** – Contemporary Concepts of Root System Architecture of Urban Trees – Day et al; and

(d) **Appendix D** – the STEM scores for the Spruce and Larch trees that are subject to submissions 365 and FS1258.

2. SCOPE

2.1 My evidence covers the following matters:

(a) an explanation of the methodology that I used to recommend the inclusion of trees in 32.8 Schedule of Protected Trees District Wide;

(b) response to submissions made on the definition of root protection zone;

(c) response to submission of the Parks and Reserves Department of the Council (**Parks Team**) (#809) made in relation to:

  (i) the frequency of permitted minor trimming of protected trees; and

  (ii) works within the root protection zone of trees more than 4 m tall, in public places, within the Arrowtown Historic Management Zone (**ARHMZ**); and

(d) response to submissions relating to the protected status of individual trees.

3. EXECUTIVE SUMMARY

3.1 The key conclusions in my evidence are that:

(a) the definition of the root protection zone contained within the PDP is adequate. It would not be appropriate to set the radius of the root protection zone at 2m out from the outermost branches of columnar trees as this would not provide adequate protection for taller trees;

(b) the diagram provided by the Parks Team more accurately represents the true canopy spread and root area of a spreading tree than the diagram currently contained in the PDP;

(c) it is not necessary to limit the minor trimming of protected trees to once in a calendar year as the rules in the PDP that relate to significant trimming and the trimming of hedges provide adequate protection;

(d) it is appropriate for the carrying out of works within the root zone of trees greater than 4m in height, in public spaces, within the ARHMZ to be a discretionary activity;

(e) items 240, 603, 1002 and 1005 have been correctly included in Schedule 37.8 Protected Trees District Wide; and

(f) when carrying out my initial assessment of protected trees, I omitted to assess the avenue of Spruce and Larch trees located at 343 Arrowtown-Lake Hayes Road, leading up to the Ayrburn Homestead. This avenue of trees is a significant feature in the District and the STEM results qualify the trees to receive protected status.

4. BACKGROUND

Protected trees

4.1 It is my understanding that, as a result of sections 76(4A) to 764(D) of the Resource Management Act 1991 (**RMA**), any tree, group of trees or hedge on an urban environment allotment that the Council wishes to be protected must be identified and noted in a schedule to the PDP.

4.2 The Operative District Plan (**ODP**) contains a schedule of protected trees on a district wide basis at Appendix 3. However, some trees are not accurately located. Further, there is no record of a complete assessment of the trees contained in the schedule, in relation to their suitability for protection.

4.3 The ODP also identifies an area of 'blanket' tree protection in the ARHMZ. This rule has been revisited in light of the amendments to the RMA mentioned above.

4.4 In February 2015 the Council engaged me to assess the suitability of a number of trees and groups of trees for their suitability as protected trees. These were:

(a) trees identified in the schedule contained within Appendix 3 of the ODP (the majority of trees assessed);

(b) trees of significance in the ARHMZ that were previously subject to the blanket protection rule contained within the ODP; and

(c) trees nominated by the public for protection.

4.5 The Council has received submissions on some of the trees that I recommended for protection. I address these submissions below.

Rules relating to the protection of trees

4.6 The Council also identified issues with the ODP rules relating to the management of protected trees. These issues are that the ODP:

(a) restricts the significant trimming of trees but does not define the term 'significant trimming';

(b) does not distinguish between maintenance and trimming; and

(c) does not appropriately provide for the avoidance of damage to the root system of protected trees.

4.7 The Council has rectified these issues by amending the rules in the PDP. The Council has received some submissions on the amended rules and I comment on these below where requested by the Council.

5. PROTECTED TREES – METHODOLOGY FOR IDENTIFICATION IN PDP

5.1 I used the STEM assessment to identify which of the trees identified by the Council, as discussed in my paragraph 4.4 above, were appropriate for protection in the PDP. STEM is a nationally recognised method for tree evaluation. It was reviewed in 1996 prior to publication during a seminar at

Waikato Institute of Technology run by Martin Herbert the Head of Arboricultural Studies at that time and assisted by Rob Graham, tutor. It is considered by local authorities that the method is best practice in New Zealand and is used by councils throughout the country. The STEM scores of all the trees that I assessed are attached as **Appendix A** to this evidence.

5.2 In addition, the method was consulted on with the Royal New Zealand Institute of Horticulture and the New Zealand Arboricultural Association.

Standard Tree Evaluation Methodology (STEM) – Summary

5.3 STEM uses a set of established criteria developed for New Zealand conditions to evaluate trees. It is a quantitative assessment protocol for scoring trees based on their varying attributes using a series of ordinal scales. Points are awarded in each of the categories in increments of three from 0 to 18 inclusive, depending on how well the tree fits a particular descriptor within the ordinal scaling system. The final STEM score is the sum of all the points in each of the categories. The assessment relies on the objectivity and experience of the assessor.

5.4 The evaluation criteria are separated into four major sections;

(a) condition;
(b) amenity;
(c) notability; and
(d) value.

5.5 Aesthetic (amenity) considerations are a separate issue to that of the health (condition) of trees, but are equally important. This separation prompts objectivity and includes different points of view.

5.6 Arborists are normally concerned with these first two considerations as it may be necessary to consult other recognised professionals for a historical, botanical or ecological context. An example of a STEM score sheet is set out below as **Figure 1**.

Figure 1 – Full Tree Evaluation Score Sheet

Condition Evaluation

Points	**3**	**9**	**15**	**21**	**27**	**Score**
Form	Poor	Moderate	Good	Very Good	Specimen	
Occurrence	Predominant	Common	Infrequent	Rare	Very Rare	
Vigour and Vitality	Poor	Some	Good	Very Good	Excellent	
Function	Minor	Useful	Important	Significant	Major	
Age (yr)	10yrs. +	20yrs. +	40yrs. +	80yrs. +	100yrs. +	
Subtotal Points						

Amenity Evaluation

Points	**3**	**9**	**15**	**21**	**27**	**Score**
Stature	3 to 8	9 to 14	15 to 20	21 to 26	27 +	
Visibility	0.5	1.0	2.0	4.0	8.0	
Proximity	Forest	Parkland	Group 10 +	Group 3 +	Solitary	
Role	Minor	Moderate	Important	Significant	Major	
Climate	Minor	Moderate	Important	Significant		
Subtotal Points						

Notable Evaluation

Recognition	**Local**	**District**	**Regional**	**National**	**International**	**Score**
Points	**3**	**9**	**15**	**21**	**27**	
Stature						
• **Feature**						
• **Form**						
Historic						
• **Age 100 +**						
• **Association**						
• **Commemoration**						
• **Remnant**						
• **Relict**						
Scientific						

• **Source**						
• **Rarity**						
• **Endangered**						
Subtotal Point						
Total Points						

Visual Tree Assessment

5.7 I also carried out a Visual Tree Assessment (**VTA**) of each tree that I assessed in response to submissions to identify any structural defects or issues which presented a cause for concern.

5.8 VTA is a process by which a tree is inspected to determine if there are any structural anomalies or defects that may warrant further investigation or remedial works. The tree is inspected from the ground up to the upper canopy. The following is a list of potential issues that may cause concern:

Rooting Environment

(a) Restricted rooting environment;
(b) Signs of previous activities;
(c) Compaction;
(d) Ground cover/vegetation;
(e) Signs of herbicide use; and
(f) Fungal fruit bodies.

Basal Flare and Root Collar

(a) Basal Flare Visible;
(b) Signs of rotation;
(c) Physical damage;
(d) Fungal fruit bodies;
(e) Oozing/Exudate;
(f) Cavities;
(g) Cracks;
(h) Loose bark; and
(i) Other anamolies.

Trunk

(a) Normal taper;

(b) Lean;

(c) Previous pruning;

(d) Physical damage;

(e) Fungal fruit bodies;

(f) Staining;

(g) Cavities/decay;

(h) Cracks;

(i) Oozing/exudate;

(j) Loose bark; and

(k) Other anomalies.

Branches

(a) Co-dominant stems;

(b) Inclusions;

(c) Hazard beams;

(d) Deadwood;

(e) Torsional loading;

(f) Excessive lever arm;

(g) Previous pruning;

(h) Physical damage;

(i) Crossing/rubbing;

(j) Fungal fruit bodies;

(k) Staining;

(l) Cavities/decay;

(m) Cracks;

(n) Oozing;

(o) Loose bark; and

(p) Other anomalies.

Canopy Condition

(a) Leaf size;

(b) Leaf colour;

(c) Leaf shape;

(d) Foliage volume;

(e) Seasonal change;

(f) Growth Increment;

(g) Insect pest; and

(h) Other pathogens.

5.9 In general these items are looked for and used as visual prompts to determine whether further work is required.

Quantified Tree Risk Assessment

5.10 In the circumstances that a submitter has raised an issue of risk in relation to a tree, I have also used a Quantified Tree Risk Assessment (**QTRA**) method to evaluate the level of risk. The QTRA is based on international risk thresholds.

5.11 QTRA is an internationally recognised tree risk assessment tool created in the United Kingdom and is to be used by registered and trained assessors only.

5.12 Asset safety management is a matter of balancing the Risk of Harm (**RoH**) with the benefits of that asset or the cost of eliminating or mitigating that risk.

5.13 Although seemingly counterintuitive, when assessing a tree asset, the condition of the tree should not be the first consideration. Instead, tree managers should first consider the usage of the land or the land around the tree (the target zone), which in turn informs the process of assessing the tree.

5.14 QTRA applies established and accepted risk management principles to tree safety management. By quantifying the annual risk of harm as a probability, QTRA enables the tree manager to manage the risk from the tree to within widely accepted thresholds.

5.15 The QTRA method moves the management of trees away from labelling them as either 'safe' or 'unsafe', thereby requiring definitive statements of tree safety from tree managers. Instead, QTRA quantifies the risk of harm from trees in a way that enables tree managers to balance safety with cost, and tree value, and operate within predetermined risk thresholds which can be seen in **Figure 2** on the following page.

Figure 2: The QTRA advisory thresholds:

Thresholds	Description	Action
	Unacceptable Risks will not ordinarily be tolerated	• Control the risk
1/1 000		
	Unacceptable (where imposed on others) Risks will not ordinarily be tolerated	• Control the risk • Review the risk
	Tolerable (by agreement) Risks may be tolerated if those exposed to the risk accept it, or the tree has exceptional value	• Control the risk unless there is broad stakeholder agreement to tolerate it, or the tree has exceptional value • Review the risk
1/10 000		
	Tolerable (where imposed on others) Risks are tolerable if ALARP	• Assess costs and benefits of risk control • Control the risk only where a significant benefit might be achieved at reasonable cost • Review the risk
1/1 000 000		
	Broadly Acceptable Risk is already ALARP	• No action currently required • Review the risk

5.16 When taking the QTRA approach, tree managers often find they spend fewer resources on assessing and managing tree risk, whilst maximising the benefits trees provide. Furthermore, in the event of a 'tolerable' or 'acceptable' tree risk being realised, they are in a robust position to demonstrate that they have acted reasonably and proportionately.

5.17 The QTRA model also incorporates a cost benefit analysis in which a threshold is set for managing the risk to a level which is as low as reasonably practicable (**ALARP**). Where the cost of risk management exceeds the ALARP cost benefit value, then the cost of the risk management becomes disproportionate to the risk. These figures are thresholds proposed by the QTRA model, ultimately it is the decision of the risk manager (tree owner) whether or not the risks are acceptable or not given peoples' different tolerances to risk.

5.18 For more detailed information see the attached QTRA Practice Note (Version 5) at **Appendix B**.

6. RESPONSE TO SPECIFIC SUBMISSION POINTS

Root protection zone definition

6.1 Vodafone New Zealand Limited (#179), Spark New Zealand Trading Limited (#191), Two Degrees Mobile Limited (421), Chorus New Zealand Limited (781) and Aurora Energy Limited (#FS1121) have all made submissions seeking that the definition of Root protection zone be changed to provide perceived greater clarity and consistency with other districts in the country. Specifically, these submitters seek a change, in relation to columnar trees, from the radius of the root protection zone being half the height of a tree to being 2m beyond the outermost extent of the spread of a tree's branches.

6.2 In my view this is not consistent with other local authorities in the country. Auckland Council (various Operative District Plans (pre-amalgamation) and the Proposed Auckland Unitary Plan (**PAUP**)), Wellington City Council, Dunedin City Council and Christchurch City Council do not use this method. These local authorities use the half height method, where the root zone is represented by a radial distance out from the tree, which is half the height of the tree (i.e. a 30m tree would have a 15m radial root zone).

6.3 In my view, the most accurate method for determining the root zone of a tree is to assess the radius or diameter of the root zone in relation to the girth of the trunk of a tree. Both the British and the Australian standards recommend such an approach. I have attached a research paper on Contemporary Concepts of Root System Architecture of Urban Trees at **Appendix C**. At page 153 this discusses trunk diameter as a predictor of root spread. However, this is a specialist technique that would require the involvement of an arborist.

6.4 The PDP uses dripline methods to determine tree root zones. I consider that this method is appropriate when used as a guide for determining when to engage an arborist to provide specialist advice. See page 153 under the heading Trunk Diameter as a Predictor of Root Spread of the research paper attached at **Appendix C**.

6.5 In my view, it would not be appropriate to define the dripline of columnar trees as being 2m out from the outermost extent of the branches as is requested by the submitters. In many cases this would not provide for a sufficient root protection zone and as a result there would be detrimental effects on tree health. For example, it is conceivable that a 30m tall tree could have a tree root protection radius of 5m. In such circumstances a 5m radius root protection zone would be grossly inadequate. Further, it is my view that the submitters' proposal is not consistent with the method used by the other major councils in the country, being Auckland Council (the PAUP), Wellington City Council, Dunedin City Council and Christchurch City Council.

6.6 Submission (#809), on behalf of Parks Team, has provided a diagram clarifying the dripline for a spreading tree. In my view, the submitter's diagram is more accurate than the diagram currently contained in the PDP as it more accurately represents the true canopy spread and root area of a tree, and I recommend that it is included in the chapter.

7. RULE 32.4.1. FREQUENCY OF MINOR TRIMMING

7.1 The Parks Team (#809) requests that Rule 32.4.1 be changed to restrict minor trimming of protected trees and hedgerows to no more than once in a calendar year. The rule currently allows minor trimming as a permitted activity. The purpose of this request is to attempt to stop trees and hedges from being pruned regularly by minor amounts to the point that they are dead, dying or no longer worthy of protection.

7.2 I do not believe that it is necessary to change Rule 32.4.1 in the manner requested. In my view, Rule 32.4.2 adequately prevents the pruning of trees by making the significant pruning of a tree or a hedgerow a discretionary activity. Further, Rule 32.4.4 limits the permitted trimming of protected hedges to a maximum of 50% of the canopy (permitted only with the supervision of an approved arborist). Trimming any hedge by 50% is the upper limit of what most hedge species can tolerate. The only hedge protected under the PDP consist of Hawthorn, which can be pruned by this amount, but this is often not required to maintain the form and shape of the hedge if it is well maintained (i.e. 10% every year).

8. RULE 32.4.12 WORKS WITHIN A ROOT PROTECTION ZONE

8.1 Currently, Rule 32.4.12 makes the removal or significant trimming of a tree greater than 4m in height, in the public spaces, within the ARHMZ, a discretionary activity. The Parks Team (#809) submits that works within the root protection zone of such trees should also be included as a discretionary activity. I agree with this submission.

8.2 The carrying out of work within the root zone of trees can cause damage to tree roots and can alter the soil structure in which trees grow. Root loss, and changes to soil structure and permeability can cause detrimental health effects to trees. The damage can be so significant that trees can be lost. The amount of disturbance that trees can tolerate varies between species. Accepted industry best practice dictates that disturbance to the root zone of a tree should be limited to prevent damage and loss of trees.

8.3 It is my opinion that works within the root zone of a protected tree need to be considered from an arboricultural perspective before they are carried out. The Council should have the opportunity to ensure that root damage and alterations to the soil will not occur to the point that trees are adversely affected. Therefore, in my view, it is appropriate for works within the root zone of trees greater than 4m in height, in public spaces, within the ARHMZ, to be a discretionary activity.

9. SITE SPECIFIC SUBMISSIONS ON PROTECTED TREES – REMOVAL OF TREES FROM SCHEDULE

37.8 Protected Tree Number 240

9.1 These two eucalyptus trees are large trees with a high visual catchment alongside the main route into Queenstown. Their aesthetic value is significant, which has led to their STEM score achieving a level warranting inclusion into the PDP.

9.2 Manor Holdings Limited and Body Corporate 364937 (#359) submit that item 240 should be removed from the Schedule in 32.8. The submitters state that the trees contained in item 240 drop leaves and debris onto and around buildings owned by the submitters. The submitters also raise concerns about the perceived risk to buildings and people should branches fall from the trees.

9.3 It is my view that there is no sound basis upon which the Council should reconsider the protective status of these trees. Regular maintenance and minor trimming, which is a permitted activity under the PDP, in conjunction with building maintenance, will alleviate any nuisance caused by the dropping of these leaves and debris. I have assessed the risk relating to the trees using the QTRA method and have found it to be within tolerable limits. The highest level of risk is to users of State Highway 6 from large limb failure. This was assessed to be 1 in a million or yellow risk within the tolerable band (Target 1, Size 2, and Probability of failure (**PoF**) 6). There is one long limb that sits over the building, which I agree could be reduced in length. This would mitigate any risk further and reduce debris and leaf fall on the building. I understand that the trimming of this limb would be a Discretionary Activity under the PDP.

37.8 Protected Tree Number 275

9.4 Simon Beale (#365) seeks for the Spruce and Larch trees located on Arrowtown-Lake Hayes Road, leading up to the Ayrburn Homestead, to be included in the Schedule in 32.8. I agree with submission 365 and think the trees are worthy of inclusion as protected trees in the PDP.

9.5 I omitted to assess this avenue of trees in error when carrying out the STEM assessment of the list of trees contain in Appendix 3 of the ODP. I visited the homestead and assessed item number 196, but did not realise that the avenue of Spruce trees was also included in the schedule of protected trees contained in Appendix 3 of the ODP.

9.6 I have visited the site again and assessed the Spruce trees using the STEM method. I also carried out VTA and QTRA assessments of the trees. I have included the STEM scores for the Spruce and Larch trees in the list of results attached at **Appendix D**.

9.7 The Spruce and Larch trees form an avenue, which is a significant feature when viewed from Arrowtown-Lake Hayes Road. The STEM evaluation of the Spruce and Larch trees resulted in the majority of the individual trees scoring enough points to be listed in their own right. However, their contribution is even greater when they are viewed as an avenue (i.e. as a group of trees).

9.8 In my view it is also unusual to find avenues of coniferous tree species of this length. The only other such avenue that I know of in the region is the Redwood avenue at Mt Baker Road, which is also included as a protected item in the ODP and has been put forward for inclusion in the Schedule at 32.8.

9.9 Ayrburn Farm Estate Limited (#FS1258) submit that the trees pose a potentially significant hazard in that they are 100 years old. The submitter raised the issue that protection of the trees in perpetuity will prevent necessary hazard management should the trees degenerate further.

9.10 I carried out a QTRA assessment of the trees and assessed the risk that they currently pose as broadly acceptable. This includes the risk to users of Lake Hayes-Arrowtown Road. The risk to users of the driveway and farmstead is considered broadly acceptable as the occupancy is anticipated to be so low as to be within Target Range 4, which requires whole tree failure with a PoF of 3 or greater to provide a RoH greater than 1 in a million. Further, the PDP allows for regular maintenance and risk mitigation work to be carried out on a permitted and discretionary basis if necessary. In my opinion, the risk posed by the trees is not significant enough to prevent them from being included in 32.8.

37.8 Protected Tree Number 603

9.11 George Ritchie (#39) has requested that item 603 be removed from the Schedule in 32.8. The reason given in his submission is that the tree poses a potential safety risk.

9.12 During my initial assessment of the tree, I carried out a VTA to determine if there was any cause for concern in terms of the level of risk posed by this tree to people or property.

9.13 After being notified of Mr Ritchie's submission by the Council, I carried out a QTRA assessment of the tree. I assessed the risk posed by the tree to:

(a) the property upon which it sits (Target 2, PoF 7 gives RoH of greater than 1 in a million or green risk);

(b) neighbouring properties (Target 3, PoF 5 gives and RoH of 1/300,000 or yellow risk);

(c) Lakeside Road; and

(d) people within the fall distance of the tree or its parts (both are considered Target 1 with whole tree failure (Size 1) and PoF of 7. This gives an RoH of greater than 1 in a million).

9.14 I consider that the level of risk in relation to this tree is tolerable and is not a sufficient ground for removing protected status of the tree.

9.15 The PDP allows for minor pruning and the removal or significant trimming of a protected tree where the tree is dead, diseased or damaged and likely to cause an imminent hazard to life or property. This provides the submitter with significant scope to manage any risk caused by the tree in relation to deadwood or damaged limbs.

32.8 Protected Tree Number 1002

9.16 Sam Gent (#223) and Kerry Hapuku (#329) have requested the removal of item 1002 from 32.8 (submission 223 mistakenly refers to tree 2001). Item 1002 sits within the ARHMZ and was included in the schedule following my assessment in March 2015.

9.17 Both submissions provide a report from a structural engineer, Mr Andrew Morris. Mr Morris's report states that the tree has caused structural damage to both the house and the adjoining pathway at 5 Berkshire Street. I am not qualified to comment on Mr Morris's assessment or the damage caused to the house.

9.18 Kerry Hapuku further submits that the tree is intruding on the building platform located on the vacant section at 22 Wiltershire Street. Specifically, the tree's root protection zone extends over a significant part of the property. I note that construction within the root protection zone can be carried out as a discretionary activity in accordance with the PDP. I consider that such construction is viable but would require arboricultural input into the design and construction process.

9.19 The submission of Kerry Hapuku also questions why the building is listed as a potential conflict in my STEM report provided to Council in relation to item 1002. This reference to a conflict relates to the likelihood that any construction in the root protection zone of the tree, that is not carried out in an arboriculturally sensitive manner, could be detrimental to the health of the tree.

9.20 Kerry Hapuku also raises issues of leaf fall, branches rubbing on the house, and shading. In my view these reasons are not sufficient to remove the protected status of item 1002. The issues of leaf fall and branch rubbing can be alleviated by appropriate maintenance, which is a permitted activity in accordance with rule 32.4.1 of the PDP.

9.21 The submitters have also raised health and safety concerns in relation to the tree. After being informed of the submissions, I carried out a QTRA assessment of item 1002. I assessed the risk posed by this tree as Broadly Acceptable and the risk is therefore as low as reasonably practicable. The PoF for this tree is 7; therefore the RoH is greater than 1 in a million. QTRA therefore indicates then spending more than $3 on remedial works to mitigate any risk is disproportionate.

9.22 Part of the STEM assessment is to define the level of function (usefulness) of the tree assessed. The scale of usefulness includes minor, useful, important, significant and major in order of increasing significance. I have assessed the function of the tree as useful. In essence I have assessed the tree as having some useful attributes to the community. Overall the tree can be seen from some well used areas of Arrowtown and provides a significant landscape feature, which affords a STEM score sufficient to include it in the PDP.

37.8 Protected Tree Number 1005

9.23 Alan Stewart (#49) requests that item 1005 be removed from Schedule 37.8. The submitter did not give any reason for requesting the removal of the protective status of this tree. In my opinion the tree is a nice specimen. The tree is of good form and a well-balanced and visible specimen, which are infrequent in the district. For these reason the STEM score is 138. There is no arboricultural reason to remove the protective status of this tree.

David Spencer
1 June 2016

Appendix A – David Spencer Evidence – 1 June 2016 - the STEM Score Spreadsheet that I provided to the Council following my initial assessment of the trees now contained within Schedule 32.8 Protected Trees District Wide

Tree Number	**193**	**240**	**240**	**275**	**275**	**275**	**275**	**275**	**275**	**275**	**275**
Botanical Name	Acer psuedoplatanus	Eucalyptus gunnii	Eucalyptus gunnii	Larix decidua	Larix decidua	Larix decidua	Larix decidua	Larix decidua	Larix decidua	Larix decidua	Larix decidua
Common Name	Sycamore	Cider Gum	Cider Gum	Deciduous Larch	Deciduous Larch	Deciduous Larch	Deciduous Larch	Deciduous Larch	Deciduous Larch	Deciduous Larch	Deciduous Larch
Height (m)	20	28.2	28.8	27.2	23.8	25.6	24.2	20	24.2	17.6	23.2
Girth (m)	4830	5690	4700	2690	2950	3330	3620	3060	3025	3230	2680
Crown Spread E/W (m)	11	15	13	9	7.5	8	6	9	7	10	8
Crown Spread N/S (m)	9	13	10	6	6	6	6	6	5.5	6	6.5
Health	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Age Class	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature
Form	Good	Specimen	Good	Moderate	Moderate	Moderate	Moderate	Poor	Moderate	Poor	Moderate
Form Score	15	27	15	9	9	9	9	3	9	3	9
Occurance	Common	Common	Common	Common	Common	Common	Common	Common	Common	Common	Common
Occurance Score	9	9	9	9	9	9	9	9	9	9	9
Vigour	Very Good	Excellent	Excellent	Good	Good	Good	Good	Good	Good	Good	Good
Vigour Score	21	27	27	15	15	15	15	15	15	15	15
Function	Minor	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful
Function Score	3	9	9	9	9	9	9	9	9	9	9
Age	100+	100+	100+	100+	100+	100+	100+	100+	100+	100+	100+
Age Score	27	27	27	27	27	27	27	27	27	27	27
Condition Evaluation Total	**75**	**99**	**87**	**69**	**69**	**69**	**69**	**63**	**69**	**63**	**69**
Stature	21 - 26	21 - 26	21 - 26	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20
Stature Score	21	21	21	15	15	15	15	15	15	15	15
Visibilty (km)	0.5	4	4	1	1	1	1	1	1	1	1
Visibility Score	3	21	21	9	9	9	9	9	9	9	9
Proximity	Parkland	Solitary	Solitary	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+
Proximity Score	9	27	27	15	15	15	15	15	15	15	15
Role	Important	Important	Important	Important	Important	Important	Important	Important	Important	Important	Important
Role Score	15	15	15	15	15	15	15	15	15	15	15
Climate	Minor	Moderate	Moderate	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Climate Score	3	9	9	3	3	3	3	3	3	3	3
Amenity Evaluation Total	**51**	**93**	**93**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**
STEM Evaluation Total	**126**	**192**	**180**	**126**	**126**	**126**	**126**	**120**	**126**	**120**	**126**

Tree Number	**275**	**275**	**275**	**275**	**275**	**275**	**275**	**275**	**275**	**275**	**275**
Botanical Name	Larix decidua	Larix decidua	Larix decidua	Picea breweriana	Larix decidua	Larix decidua	Larix decidua	Larix decidua	Larix decidua	Picea breweriana	Larix decidua
Common Name	Deciduous Larch	Deciduous Larch	Deciduous Larch	Brewer's Spruce	Deciduous Larch	Deciduous Larch	Deciduous Larch	Deciduous Larch	Deciduous Larch	Brewer's Spruce	Deciduous Larch
Height (m)	26.4	22.4	25	27.2	23.8	22.6	26.8	28.4	22.6	26.2	23
Girth (m)	4000	2920	4200	2230	3380	2940	2640	3820	2910	1720	1850
Crown Spread E/W (m)	8	7	8	5	8	6	8	8	7	4	7
Crown Spread N/S (m)	8	6	6.5	5	6	6	6	6	6	4	6
Health	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Age Class	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature
Form	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Good	Moderate
Form Score	9	9	9	9	9	9	9	9	9	15	9
Occurance	Common	Common	Common	Infrequent	Common	Common	Common	Common	Common	Infrequent	Common
Occurance Score	9	9	9	15	9	9	9	9	9	15	9
Vigour	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Vigour Score	15	15	15	15	15	15	15	15	15	15	15
Function	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful
Function Score	9	9	9	9	9	9	9	9	9	9	9
Age	100+	100+	100+	100+	100+	100+	100+	100+	100+	100+	100+
Age Score	27	27	27	27	27	27	27	27	27	27	27
Condition Evaluation Total	**69**	**69**	**69**	**75**	**69**	**69**	**69**	**69**	**69**	**81**	**69**
Stature	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20
Stature Score	15	15	15	15	15	15	15	15	15	15	15
Visibilty (km)	1	1	1	1	1	1	1	1	1	1	1
Visibility Score	9	9	9	9	9	9	9	9	9	9	9
Proximity	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+
Proximity Score	15	15	15	15	15	15	15	15	15	15	15
Role	Important	Important	Important	Important	Important	Important	Important	Important	Important	Important	Important
Role Score	15	15	15	15	15	15	15	15	15	15	15
Climate	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Climate Score	3	3	3	3	3	3	3	3	3	3	3
Amenity Evaluation Total	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**
STEM Evaluation Total	**126**	**126**	**126**	**132**	**126**	**126**	**126**	**126**	**126**	**138**	**126**

Tree Number	275	275	275	275	275	275	275	275	275	275	275
Botanical Name	Larix decidua	Larix decidua	Picea breweriana	Larix decidua	Larix decidua	Larix decidua	Picea breweriana	Larix decidua	Larix decidua	Larix decidua	Larix decidua
Common Name	Deciduous Larch	Deciduous Larch	Brewer's Spruce	Deciduous Larch	Deciduous Larch	Deciduous Larch	Brewer's Spruce	Deciduous Larch	Deciduous Larch	Deciduous Larch	Deciduous Larch
Height (m)	24.8	21	24.6	19.8	21.4	18.8	27.8	23.6	25	28	25
Girth (m)	2580	3110	1610	2190	3270	2900	1880	4320	2860	2510	2550
Crown Spread E/W (m)	6	6	4	8	8	7	4	5	4	4	5
Crown Spread N/S (m)	6	6	4	6.5	6	6	4	5	5	5	5
Health	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Age Class	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature
Form	Moderate	Moderate	Good	Moderate	Moderate	Moderate	Poor	Poor	Poor	Moderate	Moderate
Form Score	9	9	15	9	9	9	3	3	3	9	9
Occurance	Common	Common	Infrequent	Common	Common	Common	Infrequent	Common	Common	Common	Common
Occurance Score	9	9	15	9	9	9	15	9	9	9	9
Vigour	Good	Good	Good	Good	Good	Good	Some	Some	Some	Some	Some
Vigour Score	15	15	15	15	15	15	9	9	9	9	9
Function	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful
Function Score	9	9	9	9	9	9	9	9	9	9	9
Age	100+	100+	100+	100+	100+	100+	100+	100+	100+	100+	100+
Age Score	27	27	27	27	27	27	27	27	27	27	27
Condition Evaluation Total	**69**	**69**	**81**	**69**	**69**	**69**	**63**	**57**	**57**	**63**	**63**
Stature	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20
Stature Score	15	15	15	15	15	15	15	15	15	15	15
Visibilty (km)	1	1	1	1	1	1	1	1	1	1	1
Visibility Score	9	9	9	9	9	9	9	9	9	9	9
Proximity	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+
Proximity Score	15	15	15	15	15	15	15	15	15	15	15
Role	Important	Important	Important	Important	Important	Important	Important	Important	Important	Important	Important
Role Score	15	15	15	15	15	15	15	15	15	15	15
Climate	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Climate Score	3	3	3	3	3	3	3	3	3	3	3
Amenity Evaluation Total	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**
STEM Evaluation Total	**126**	**126**	**138**	**126**	**126**	**126**	**120**	**114**	**114**	**120**	**120**

Tree Number	275	275	275	275	275	275	275	275	275	275	275
Botanical Name	Larix decidua	Larix decidua	Larix decidua	Larix decidua	Larix decidua	Larix decidua	Picea breweriana	Picea breweriana	Picea breweriana	Larix decidua	Picea breweriana
Common Name	Deciduous Larch	Deciduous Larch	Deciduous Larch	Deciduous Larch	Deciduous Larch	Deciduous Larch	Brewer's Spruce	Brewer's Spruce	Brewer's Spruce	Deciduous Larch	Brewer's Spruce
Height (m)	25.8	27.2	22	27	24.2	26	28	27.8	23.6	23.4	30.6
Girth (m)	3830	3600	2890	3380	4270	4270	2190	1970	2070	2990	2340
Crown Spread E/W (m)	6	6	6	6	6	6	4	3	4	4	4
Crown Spread N/S (m)	6	6	6	6	6	6	6	3	3	3	5
Health	Good	Good	Good	Fair	Fair	Good	Fair	Fair	Fair	Fair	Fair
Age Class	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature
Form	Moderate	Moderate	Poor	Moderate	Moderate	Moderate	Poor	Moderate	Poor	Moderate	Moderate
Form Score	9	9	3	9	9	9	3	9	3	9	9
Occurance	Common	Common	Common	Common	Common	Common	Infrequent	Infrequent	Infrequent	Common	Infrequent
Occurance Score	9	9	9	9	9	9	15	15	15	9	15
Vigour	Good	Good	Some	Good	Good	Good	Some	Good	Some	Good	Good
Vigour Score	15	15	9	15	15	15	9	15	9	15	15
Function	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful
Function Score	9	9	9	9	9	9	9	9	9	9	9
Age	100+	100+	100+	100+	100+	100+	100+	100+	100+	100+	100+
Age Score	27	27	27	27	27	27	27	27	27	27	27
Condition Evaluation Total	**69**	**69**	**57**	**69**	**69**	**69**	**63**	**75**	**63**	**69**	**75**
Stature	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20
Stature Score	15	15	15	15	15	15	15	15	15	15	15
Visibilty (km)	1	1	1	1	1	1	1	1	1	1	1
Visibility Score	9	9	9	9	9	9	9	9	9	9	9
Proximity	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+
Proximity Score	15	15	15	15	15	15	15	15	15	15	15
Role	Important	Important	Important	Important	Important	Important	Important	Important	Important	Important	Important
Role Score	15	15	15	15	15	15	15	15	15	15	15
Climate	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Climate Score	3	3	3	3	3	3	3	3	3	3	3
Amenity Evaluation Total	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**
STEM Evaluation Total	**126**	**126**	**114**	**126**	**126**	**126**	**120**	**132**	**120**	**126**	**132**

Tree Number	275	275	275	275	275	275	275	275	275	275	275
Botanical Name	Picea breweriana	Picea breweriana	Larix decidua	Picea breweriana	Picea breweriana	Picea breweriana	Picea breweriana	Picea breweriana	Larix decidua	Larix decidua	Picea breweriana
Common Name	Brewer's Spruce	Brewer's Spruce	Deciduous Larch	Brewer's Spruce	Brewer's Spruce	Brewer's Spruce	Brewer's Spruce	Brewer's Spruce	Deciduous Larch	Deciduous Larch	Brewer's Spruce
Height (m)	28.8	27	24.5	30	32	33.2	27	26	20	18	19
Girth (m)	1990	2170	2770	1390	2540	2710	2290	2160	2450	2490	2510
Crown Spread E/W (m)	4	4	4	4	4	4	4	5	6	7	5
Crown Spread N/S (m)	5	5	4	4	5	4	8	5	6	5	5
Health	Fair	Fair	Fair	Fair	Fair	Fair	Good	Good	Good	Good	Good
Age Class	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature
Form	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Poor	Moderate
Form Score	9	9	9	9	9	9	9	9	9	3	9
Occurance	Infrequent	Infrequent	Common	Common	Common	Infrequent	Infrequent	Infrequent	Common	Common	Common
Occurance Score	15	15	9	9	9	15	15	15	9	9	9
Vigour	Good	Some	Some	Some	Some	Some	Good	Good	Good	Good	Good
Vigour Score	15	9	9	9	9	9	15	15	15	15	15
Function	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful
Function Score	9	9	9	9	9	9	9	9	9	9	9
Age	100+	100+	100+	100+	100+	100+	100+	100+	100+	100+	100+
Age Score	27	27	27	27	27	27	27	27	27	27	27
Condition Evaluation Total	**75**	**69**	**63**	**63**	**63**	**69**	**75**	**75**	**69**	**63**	**69**
Stature	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	3 - 8	9 - 14	15 - 20
Stature Score	15	15	15	15	15	15	15	15	3	9	15
Visibilty (km)	1	1	1	1	1	1	1	1	1	1	1
Visibility Score	9	9	9	9	9	9	9	9	9	9	9
Proximity	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+
Proximity Score	15	15	15	15	15	15	15	15	15	15	15
Role	Important	Important	Important	Important	Important	Important	Important	Important	Important	Important	Important
Role Score	15	15	15	15	15	15	15	15	15	15	15
Climate	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Climate Score	3	3	3	3	3	3	3	3	3	3	3
Amenity Evaluation Total	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**45**	**51**	**57**
STEM Evaluation Total	**132**	**126**	**120**	**120**	**120**	**126**	**132**	**132**	**114**	**114**	**126**

Tree Number	275	275	275	275	275	275	275	275	275	275	275
Botanical Name	Picea breweriana	Picea breweriana	Picea breweriana	Larix decidua	Picea breweriana	Picea breweriana	Larix decidua	Larix decidua	Larix decidua	Picea breweriana	Picea breweriana
Common Name	Brewer's Spruce	Brewer's Spruce	Brewer's Spruce	Deciduous Larch	Brewer's Spruce	Brewer's Spruce	Deciduous Larch	Deciduous Larch	Deciduous Larch	Brewer's Spruce	Brewer's Spruce
Height (m)	27	20	18	24	29	22	23	23	20	27	27
Girth (m)	1550	1880	1380	3670	3040	2030	2910	3150	3600	2320	2180
Crown Spread E/W (m)	4.5	4.5	4	8	8	5	8	8	8	6	6
Crown Spread N/S (m)	4	4	3	8	8	4.5	8	8	8	6	6
Health	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Age Class	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature	Mature
Form	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate	Moderate
Form Score	9	9	9	9	9	9	9	9	9	9	9
Occurance	Infrequent	Infrequent	Infrequent	Common	Infrequent	Infrequent	Common	Common	Common	Infrequent	Infrequent
Occurance Score	15	15	15	9	15	15	9	9	9	15	15
Vigour	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good	Good
Vigour Score	15	15	15	15	15	15	15	15	15	15	15
Function	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful	Useful
Function Score	9	9	9	9	9	9	9	9	9	9	9
Age	100+	100+	100+	100+	100+	100+	100+	100+	100+	100+	100+
Age Score	27	27	27	27	27	27	27	27	27	27	27
Condition Evaluation Total	**75**	**75**	**75**	**69**	**75**	**75**	**69**	**69**	**69**	**75**	**75**
Stature	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20	15 - 20
Stature Score	15	15	15	15	15	15	15	15	15	15	15
Visibilty (km)	1	1	1	1	1	1	1	1	1	1	1
Visibility Score	9	9	9	9	9	9	9	9	9	9	9
Proximity	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+	Group 10+
Proximity Score	15	15	15	15	15	15	15	15	15	15	15
Role	Important	Important	Important	Important	Important	Important	Important	Important	Important	Important	Important
Role Score	15	15	15	15	15	15	15	15	15	15	15
Climate	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor	Minor
Climate Score	3	3	3	3	3	3	3	3	3	3	3
Amenity Evaluation Total	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**	**57**
STEM Evaluation Total	**132**	**132**	**132**	**126**	**132**	**132**	**126**	**126**	**126**	**132**	**132**

Tree Number	573	603	1002	1005
Botanical Name	Eucalyptus globulus	Sequoiadendron gigantium	Thuja plicata	Fagus sylvatica var. purpurea
Common Name	Eucalyptus	Wellingtonia	Western Red Cedar	Copper Beech
Height (m)	38	34	16	12
Girth (m)	11700	5900	2600	2000
Crown Spread E/W (m)	20	10	5	12
Crown Spread N/S (m)	16.5	7.5	5	12
Health	Good	Good	Good	Good
Age Class	Mature	Mature	Mature	Mature
Form	Very Good	Very Good	Very Good	Very Good
Form Score	21	21	21	21
Occurance	Common	Common	Common	Infrequent
Occurance Score	9	9	9	15
Vigour	Good	Very Good	Very Good	Very Good
Vigour Score	15	21	21	21
Function	Minor	Useful	Useful	Minor
Function Score	3	9	9	3
Age	100+	80 - 99	40 - 79	40 - 79
Age Score	27	21	15	15
Condition Evaluation Total	**75**	**81**	**75**	**75**
Stature	27+	21 - 26	15 - 20	15 - 20
Stature Score	27	21	15	15
Visibilty (km)	2	2	1	1
Visibility Score	15	15	9	9
Proximity	Solitary	Solitary	Solitary	Group 3+
Proximity Score	27	27	27	21
Role	Major	Significant	Moderate	Important
Role Score	27	21	9	15
Climate	Minor	Minor	Minor	Minor
Climate Score	3	3	3	3
Amenity Evaluation Total	**105**	**87**	**63**	**63**
STEM Evaluation Total	**180**	**168**	**138**	**138**

Appendix B – David Spencer Evidence – 1 June 2016 - Quantified Tree Risk Assessment Practice Note (V5)

QTRA Quantified Tree Risk Assessment

Simply Balancing Risks With Benefits

Quantified Tree Risk Assessment

PRACTICE NOTE

VERSION 5

Quantified Tree Risk Assessment Practice Note

"***When you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot measure it, when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind"***

William Thomson, Lord Kelvin, Popular Lectures and Addresses [1891-1894]

1. INTRODUCTION

Every day we encounter risks in all of our activities, and the way we manage those risks is to make choices. We weigh up the costs and benefits of the risk to determine whether it is acceptable, unacceptable, or tolerable. For example, if you want to travel by car you must accept that even with all the extensive risk control measures, such as seat-belts, speed limits, airbags, and crash barriers, there is still a significant risk of death. This is an everyday risk that is taken for granted and tolerated by millions of people in return for the benefits of convenient travel. Managing trees should take a similarly balanced approach.

A risk from falling trees exists only if there is both potential for tree failure and potential for harm to result. The job of the risk assessor is to consider the likelihood and consequences of tree failure. The outcome of this assessment can then inform consideration of the risk by the tree manager, who may also be the owner.

Using a comprehensive range of values[1], Quantified Tree Risk Assessment (QTRA) enables the tree assessor to identify and analyse the risk from tree failure in three key stages. 1) to consider land-use in terms of vulnerability to impact and likelihood of occupation, 2) to consider the consequences of an impact, taking account of the size of the tree or branch concerned, and 3) to estimate the probability that the tree or branch will fail onto the land-use in question. Estimating the values of these components, the assessor can use the QTRA manual calculator or software application to calculate an annual Risk of Harm from a particular tree. To inform management decisions, the risks from different hazards can then be both ranked and compared, and considered against broadly acceptable and tolerable levels of risk.

A Proportionate Approach to Risks from Trees

The risks from falling trees are usually very low and high risks will usually be encountered only in areas with either high levels of human occupation or with valuable property. Where levels of human occupation and value of property are sufficiently low, the assessment of trees for structural weakness will not usually be necessary. Even when land-use indicates that the assessment of trees is appropriate, it is seldom proportionate to assess and evaluate the risk for each individual tree in a population. Often, all that is required is a brief consideration of the trees to identify gross signs of structural weakness or declining health. Doing all that is reasonably practicable does not mean that all trees have to be individually examined on a regular basis (HSE 2013).

The QTRA method enables a range of approaches from the broad assessment of large collections of trees to, where necessary, the detailed assessment of an individual tree.

Risk of Harm

The QTRA output is termed the Risk of Harm and is a combined measure of the likelihood and consequences of tree failure, considered against the baseline of a lost human life within the coming year.

ALARP (As Low As Reasonably Practicable)

Determining that risks have been reduced to As Low As Reasonably Practicable (HSE 2001) involves an evaluation of both the risk and the sacrifice or cost involved in reducing that risk. If it can be demonstrated that there is gross disproportion between them, the risk being insignificant in relation to the sacrifice or cost, then to reduce the risk further is not 'reasonably practicable'.

Costs and Benefits of Risk Control

Trees confer many benefits to people and the wider environment. When managing any risk, it is essential to maintain a balance between the costs and benefits of risk reduction, which should be considered in the determination of ALARP. It is not only the financial cost of controlling the risk that should be considered, but also the loss of tree-related benefits, and the risk to workers and the public from the risk control measure itself.

[1] See Tables 1, 2 & 3.

When considering risks from falling trees, the cost of risk control will usually be too high when it is clearly 'disproportionate' to the reduction in risk. In the context of QTRA, the issue of 'gross disproportion'[2], where decisions are heavily biased in favour of safety, is only likely to be considered where there are risks of 1/10 000 or greater.

Acceptable and Tolerable Risks

The Tolerability of Risk framework (ToR) (HSE 2001) is a widely accepted approach to reaching decisions on whether risks are broadly acceptable, unacceptable, or tolerable. Graphically represented in Figure 1, ToR can be summarised as having a Broadly Acceptable Region where the upper limit is an annual risk of death 1/1 000 000, an Unacceptable Region for which the lower limit is 1/1 000, and between these a Tolerable Region within which the tolerability of a risk will be dependent upon the costs and benefits of risk reduction. In the Tolerable Region, we must ask whether the benefits of risk control are sufficient to justify their cost.

In respect of trees, some risks cross the Broadly Acceptable 1/1 000 000 boundary, but remain tolerable. This is because any further reduction would involve a disproportionate cost in terms of the lost environmental, visual, and other benefits, in addition to the financial cost of controlling the risk.

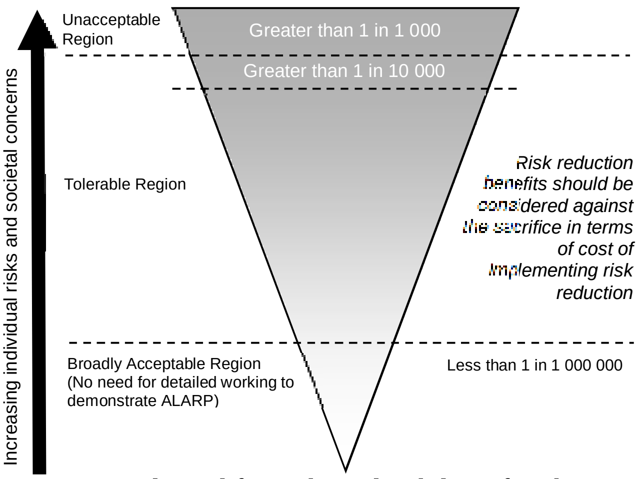

Figure 1. Adapted from the Tolerability of Risk framework (HSE 2001).

Value of Statistical Life

The Value of Statistical Life (VOSL), is a widely applied risk management device, which uses the value of a hypothetical life to guide the proportionate allocation of resources to risk reduction. In the UK, this value is currently in the region of £1 500 000 ($2 900 000), and this is the value adopted in the QTRA method.

In QTRA, placing a statistical value on a human life has two particular uses. Firstly, QTRA uses VOSL to enable damage to property to be compared with the loss of life, allowing the comparison of risks to people and property. Secondly, the proportionate allocation of financial resources to risk reduction can be informed by VOSL. "***A value of statistical life of £1 000 000 is just another way of saying that a reduction in risk of death of 1/100 000 per year has a value of £10 per year***" (HSE 1996).

Internationally, there is variation in VOSL, but to provide consistency in QTRA outputs, it is suggested that VOSL of £1 500 000 ($2 900 000) should be applied internationally. This is ultimately a decision for the tree manager.

2. OWNERSHIP OF RISK

Where many people are exposed to a risk, it is shared between them. Where only one person is exposed, that individual is the recipient of all of the risk and if they have control over it, they are also the owner of the risk. An individual may choose to accept or reject any particular risk to themselves, when that risk is under their control. When risks that are imposed upon others become elevated, societal concern will usually require risk controls, which ultimately are imposed by the courts or government regulators.

Although QTRA outputs might occasionally relate to an individual recipient, this is seldom the case. More often, calculation of the Risk of Harm is based on a cumulative occupation – i.e. the number of people per hour or vehicles per day, without attempting to identify the individuals who share the risk.

Where the risk of harm relates to a specific individual or a known group of people, the risk manager might consider the views of those who are exposed to the risk when making management decisions. Where a risk is imposed on the wider community, the principles set out in the ToR framework can be used as a reasonable approach to determine whether the risk is ALARP.

3. THE QTRA METHOD - VERSION 5

The input values for the three components of the QTRA calculation are set out in broad ranges[3] of Target, Size, and Probability of Failure. The assessor

[2] Discussed further on page 5.

[3] See Tables 1, 2 & 3.

estimates values for these three components and inputs them on either the manual calculator or software application to calculate the Risk of Harm.

Assessing Land-use (Targets)

The nature of the land-use beneath or adjacent to a tree will usually inform the level and extent of risk assessment to be carried out. In the assessment of Targets, six ranges of value are available. Table 2 sets out these ranges for vehicular frequency, human occupation and the monetary value of damage to property.

Human Occupation

The probability of pedestrian occupation at a particular location is calculated on the basis that an average pedestrian will spend five seconds walking beneath an average tree. For example, ten pedestrians per day, each occupying the Target for five seconds, is a daily occupation of fifty seconds. The total seconds in a day are divided to give a probability of Target occupation (50/86 400 = 1/1 728). Where a longer occupation is likely, as with a habitable building, outdoor café, or park bench, the period of occupation can be measured, or estimated as a proportion of a given unit of time, e.g. six hours per day (1/4). The Target is recorded as a range (Table 2).

Weather Affected Targets

Often the nature of a structural weakness in a tree is such that the probability of failure is greatest during windy weather, while the probability of the site being occupied by people during such weather is often low. This applies particularly to outdoor recreational areas. When estimating human Targets, the risk assessor must answer the question 'in the weather conditions that I expect the likelihood of failure of the tree to be initiated, what is my estimate of human occupation?' Taking this approach, rather than using the average occupation, ensures that the assessor considers the relationship between weather, people, and trees, along with the nature of the average person with their ability to recognise and avoid unnecessary risks.

Vehicles on the Highway

In the case of vehicles, likelihood of occupation may relate to either the falling tree or branch striking the vehicle or the vehicle striking the fallen tree. Both types of impact are influenced by vehicle speed; the faster the vehicle travels the less likely it is to be struck by the falling tree, but the more likely it is to strike a fallen tree. The probability of a vehicle occupying any particular point in the road is the ratio of the time it is occupied - including a safe stopping distance - to the total time. The average vehicle on a UK road is occupied by 1.6 people (DfT 2010). To account for the substantial protection that the average vehicle provides against most tree impacts and in particular, frontal collisions, QTRA values the substantially protected 1.6 occupants in addition to the value of the vehicle as equivalent to one exposed human life.

Property

Property can be anything that could be damaged by a falling tree, from a dwelling, to livestock, parked car, or fence. When evaluating the exposure of property to tree failure, the QTRA assessment considers the cost of repair or replacement that might result from failure of the tree. Ranges of value are presented in Table 2 and the assessor's estimate need only be sufficient to determine which of the six ranges the cost to select.

In Table 2, the ranges of property value are based on a VOSL of $2 900 000, e.g. where a building with a replacement cost of $29 000 would be valued at 0.01 (1/100) of a life (Target Range 2).

When assessing risks in relation to buildings, the Target to be considered might be the building, the occupants, or both. Occupants of a building could be protected from harm by the structure or substantially exposed to the impact from a falling tree if the structure is not sufficiently robust, and this will determine how the assessor categorises the Target.

Multiple Targets

A Target might be constantly occupied by more than one person and QTRA can account for this. For example, if it is projected that the average occupation will be constant by 10 people, the Risk of Harm is calculated in relation to one person constantly occupying the Target before going on to identify that the average occupation is 10 people. This is expressed as Target 1(10T)/1, where 10T represents the Multiple Targets. In respect of property, a Risk of Harm 1(10T)/1 would be equivalent to a risk of losing $29 000 000 as opposed to $2 900 000.

Tree or Branch Size

A small dead branch of less than 25mm diameter is not likely to cause significant harm even in the case of direct contact with a Target, while a falling branch with a diameter greater than 450mm is likely to cause some harm in the event of contact with all but the most robust Target. The QTRA method categorises

Size by the diameter of tree stems and branches (measured beyond any basal taper). An equation derived from weight measurements of trees of different stem diameters is used to produce a data set of comparative weights of trees and branches ranging from 25mm to 600mm diameter, from which Table 1 is compiled. The size of dead branches might be discounted where they have undergone a significant reduction in weight because of degradation and shedding of subordinate branches. This discounting, referred to as 'Reduced Mass', reflects an estimated reduction in the mass of a dead branch.

Table 1. Size

Size Range	Size of tree or branch	Range of Probability
1	> 450mm (>18”) dia.	1/1 - >1/2
2	260mm (10$^{1}/_{2}$”) dia. - 450mm (18”) dia.	1/2 - >1/8.6
3	110mm (4$^{1}/_{2}$”) dia. - 250mm (10”) dia.	1/8.6 - >1/82
4	25mm (1”) dia. - 100mm (4”) dia.	1/82 - 1/2 500

* Range 1 is based on a diameter of 600mm.

Table 2. Targets

Target Range	Property (repair or replacement cost)	Human (not in vehicles)		Vehicle Traffic (number per day)	Ranges of Value (probability of occupation or fraction of $2 900 000)
1	$2 900 000 – >$290 000 (£1 500 000 – >£150 000)	Occupation: Pedestrians & cyclists:	Constant – 2.5 hours/day 720/hour – 73/hour	26 000 – 2 700 @ 110kph (68mph) 32 000 – 3 300 @ 80kph (50mph) 47 000 – 4 800 @ 50kph (32mph)	1/1 – >1/10
2	$290 000 – >$29 000	Occupation: Pedestrians & cyclists:	2.4 hours/day – 15 min/day 72/hour – 8/hour	2 600 – 270 @ 110kph (68mph) 3 200 – 330 @ 80kph (50mph) 4 700 – 480 @ 50kph (32mph)	1/10 – >1/100
3	$29 000 – >$2 900	Occupation: Pedestrians & cyclists:	14 min/day – 2 min/day 7/hour – 2/hour	260 – 27 @ 110kph (68mph) 320 – 33 @ 80kph (50mph) 470 – 48 @ 50kph (32mph)	1/100 – >1/1 000
4	$2 900 – >$290	Occupation: Pedestrians & cyclists:	1 min/day – 2 min/week 1/hour – 3/day	26 – 4 @ 110kph (68mph) 32 – 4 @ 80kph (50mph) 47 – 6 @ 50kph (32mph)	1/1 000 – >1/10 000
5	$290 – >$29	Occupation: Pedestrians & cyclists:	1 min/week – 1 min/month 2/day – 2/week	3 – 1 @ 110kph (68mph) 3 – 1 @ 80kph (50mph) 5 – 1 @ 50kph (32mph)	1/10 000 – >1/100 000
6	$29 – $2	Occupation: Pedestrians & cyclists:	<1 min/month – 0.5 min/year 1/week – 6/year	None	1/100 000 – 1/1 000 000

Vehicle, pedestrian and property Targets are categorised by their frequency of use or their monetary value. The probability of a vehicle or pedestrian occupying a Target area in Target Range 4 is between the upper and lower limits of 1/1 000 and >1/10 000 (column 5). Using the VOSL $2 900 000, the property repair or replacement value for Target Range 4 is $2 900- >$290.

Probability of Failure

In the QTRA assessment, the probability of tree or branch failure within the coming year is estimated and recorded as a range of value (Ranges 1 – 7, Table 3).

Selecting a Probability of Failure (PoF) Range requires the assessor to compare their assessment of the tree or branch against a benchmark of either a non-compromised tree at Probability of Failure Range 7, or a tree or branch that we expect to fail within the year, which can be described as having a 1/1 probability of failure.

During QTRA training, Registered Users go through a number of field exercises in order to calibrate their estimates of Probability of Failure.

Table 3. Probability of Failure

Probability of Failure Range	Probability
1	1/1 - >1/10
2	1/10 - >1/100
3	1/100 - >1/1 000
4	1/1 000 - >1/10 000
5	1/10 000 – >1/100 000
6	1/100 000 – >1/1 000 000
7	1/1 000 000 – 1/10 000 000

The probability that the tree or branch will fail within the coming year.

The QTRA Calculation

The assessor selects a Range of values for each of the three input components of Target, Size and Probability of Failure. The Ranges are entered on either the manual calculator or software application to calculate a Risk of Harm.

The Risk of Harm is expressed as a probability and is rounded, to one significant figure. Any Risk of Harm that is lower than 1/1 000 000 is represented as <1/1 000 000. As a visual aid, the Risk of Harm is colour coded using the traffic light system illustrated in Table 4 (page 7).

> Risk of Harm - Monte Carlo Simulations
>
> The Risk of Harm for all combinations of Target, Size and Probability of Failure Ranges has been calculated using Monte Carlo simulations[4]. The QTRA Risk of Harm is the mean value from each set of Monte Carlo results.
>
> In QTRA Version 5, the Risk of Harm should not be calculated without the manual calculator or software application.

Assessing Groups and Populations of Trees

When assessing populations or groups of trees, the highest risk in the group is quantified and if that risk is tolerable, it follows that risks from the remaining trees will also be tolerable, and further calculations are unnecessary. Where the risk is intolerable, the next highest risk will be quantified, and so on until a tolerable risk is established. This process requires prior knowledge of the tree manager's risk tolerance.

Accuracy of Outputs

The purpose of QTRA is not necessarily to provide high degrees of accuracy, but to provide for the quantification of risks from falling trees in a way that risks are categorised within broad ranges (Table 4).

4. INFORMING MANAGEMENT DECISIONS

Balancing Costs and Benefits of Risk Control

When controlling risks from falling trees, the benefit of reduced risk is obvious, but the costs of risk control are all too often neglected. For every risk reduced there will be costs, and the most obvious of these is the financial cost of implementing the control measure. Frequently overlooked is the transfer of risks to workers and the public who might be directly affected by the removal or pruning of trees. Perhaps more importantly, most trees confer benefits, the loss of which should be considered as a cost when balancing the costs and benefits of risk control.

When balancing risk management decisions using QTRA, consideration of the benefits from trees will usually be of a very general nature and not require detailed consideration. The tree manager can consider, in simple terms, whether the overall cost of risk control is a proportionate one. Where risks are approaching 1/10 000, this may be a straightforward balancing of cost and benefits. Where risks are 1/10 000 or greater, it will usually be appropriate to implement risk controls unless the costs are grossly disproportionate to the benefits rather than simply disproportionate. In other words, the balance being weighted more on the side of risk control with higher associated costs.

Considering the Value of Trees

It is necessary to consider the benefits provided by trees, but they cannot easily be monetised and it is often difficult to place a value on those attributes such as habitat, shading and visual amenity that might be lost to risk control.

A simple approach to considering the value of a tree asset is suggested here, using the concept of 'average benefits'. When considered against other similar trees, a tree providing 'average benefits' will usually present a range of benefits that are typical for the species, age and situation. Viewed in this way, a tree providing 'average benefits' might appear to be low when compared with particularly important trees – such as in Figure 2, but should nonetheless be sufficient to offset a Risk of Harm of less than 1/10 000. Without having to consider the benefits of risk controls, we might reasonably assume that below 1/10 000, the risk from a tree that provides 'average benefits' is ALARP.

In contrast, if it can be said that the tree provides lower than average benefits because, for example, it is declining and in poor physiological condition, it may be necessary to consider two further elements. Firstly, is the Risk of Harm in the upper part of the Tolerable Region, and secondly, is the Risk of Harm likely to increase before the next review because of an increased Probability of Failure. If both these conditions apply then it might be appropriate to consider the balance of costs and benefits of risk reduction in order to determine whether the risk is ALARP. This balance requires the tree manager to take a view of both the reduction in risk and the costs of that reduction.

[4] For further information on the Monte Carlo simulation method, refer to http://en.wikipedia.org/wiki/Monte_Carlo_method

Fig. 2

Lower Than Average Benefits from Trees

Usually, the benefits provided by a tree will only be significantly reduced below the 'average benefits' that are typical for the species, age and situation, if the life of the benefits is likely to be shortened, perhaps because the tree is declining or dead. That is not to say that a disbenefit, such as undesirable shading, lifting of a footpath, or restricting the growth of other trees, should not also be considered in the balance of costs and benefits.

The horse chestnut tree in Figure 3 has recently died, and over the next few years, may provide valuable habitats. However, for this tree species and the relatively fast rate at which its wood decays, the lifetime of these benefits is likely to be limited to only a few years. This tree has an already reduced value that will continue to reduce rapidly over the coming five to ten years at the same time as the Risk of Harm is expected to increase. There will be changes in the benefits provided by the tree as it degrades. Visual qualities are likely to reduce while the decaying wood provides habitats for a range of species, for a short while at least. There are no hard and fast measures of these benefits and it is for the tree manager to decide what is locally important and how it might be balanced with the risks.

Where a risk is within the Tolerable Region and the tree confers lower than average benefits, it might be appropriate to consider implementing risk control while taking account of the financial cost. Here, VOSL can be used to inform a decision on whether the cost of risk control is proportionate. Example 3 below puts this evaluation into a tree management context.

There will be occasions when a tree is of such minimal value and the monetary cost of risk reduction so low that it might be reasonable to further reduce an already relatively low risk. Conversely, a tree might be of such considerable value that an annual risk of death greater than 1/10 000 would be deemed tolerable.

Occasionally, decisions will be made to retain elevated risks because the benefits from the tree are particularly high or important to stakeholders, and in these situations, it might be appropriate to assess and document the benefits in some detail. If detailed assessment of benefits is required, there are several methodologies and sources of information (Forest Research 2010).

Fig. 3

Delegating Risk Management Decisions

Understanding of the costs with which risk reduction is balanced can be informed by the risk assessor's knowledge, experience and on-site observations, but the risk management decisions should be made by the tree manager. That is not to say that the tree manager should review and agree every risk control measure, but when delegating decisions to surveyors and other staff or advisors, tree managers should set out in a policy, statement or contract, the principles and perhaps thresholds to which trees and their associated risks will ordinarily be managed.

Based on the tree manager accepting the principles set out in the QTRA Practice Note and or any other specific instructions, the risk assessor can take account of the cost/benefit balance and for most situations will be able to determine whether the risk is ALARP when providing management recommendations.

Table 4. QTRA Advisory Risk Thresholds

Thresholds	Description	Action
	Unacceptable Risks will not ordinarily be tolerated	• Control the risk
1/1 000		
	Unacceptable (where imposed on others) Risks will not ordinarily be tolerated	• Control the risk • Review the risk
	Tolerable (by agreement) Risks may be tolerated if those exposed to the risk accept it, or the tree has exceptional value	• Control the risk unless there is broad stakeholder agreement to tolerate it, or the tree has exceptional value • Review the risk
1/10 000		
	Tolerable (where imposed on others) Risks are tolerable if ALARP	• Assess costs and benefits of risk control • Control the risk only where a significant benefit might be achieved at reasonable cost • Review the risk
1/1 000 000		
	Broadly Acceptable Risk is already ALARP	• No action currently required • Review the risk

QTRA Informative Risk Thresholds

The QTRA advisory thresholds in Table 4 are proposed as a reasonable approach to balancing safety from falling trees with the costs of risk reduction. This approach takes account of the widely applied principles of ALARP and ToR, but does not dictate how these principles should be applied. While the thresholds can be the foundation of a robust policy for tree risk management, tree managers should make decisions based on their own situation, values and resources. Importantly, to enable tree assessors to provide appropriate management guidance, it is helpful for them to have some understanding of the tree owner's management preferences prior to assessing the trees.

A Risk of Harm that is less than 1/1 000 000 is Broadly Acceptable and is already ALARP. A Risk of Harm 1/1 000 or greater is unacceptable and will not ordinarily be tolerated. Between these two values, the Risk of Harm is in the Tolerable Region of ToR and will be tolerable if it is ALARP. In the Tolerable Region, management decisions are informed by consideration of the costs and benefits of risk control, including the nature and extent of those benefits provided by trees, which would be lost to risk control measures.

For the purpose of managing risks from falling trees, the Tolerable Region can be further broken down into two sections. From 1/1 000 000 to less than 1/10 000, the Risk of Harm will usually be tolerable providing that the tree confers 'average benefits' as discussed above. As the Risk of Harm approaches 1/10 000 it will be necessary for the tree manager to consider in more detail the benefits provided by the tree and the overall cost of mitigating the risk.

A Risk of Harm in the Tolerable Region but 1/10 000 or greater will not usually be tolerable where it is imposed on others, such as the public, and if retained, will require a more detailed consideration of ALARP. In exceptional circumstances a tree owner might choose to retain a Risk of Harm that is 1/10 000 or greater. Such a decision might be based on the agreement of those who are exposed to the risk, or perhaps that the tree is of great importance. In these circumstances, the prudent tree manager will consult with the appropriate stakeholders whenever possible.

5. EXAMPLE QTRA CALCULATIONS AND RISK MANAGEMENT DECISIONS

Below are three examples of QTRA calculations and application of the QTRA Advisory Thresholds.

Example 1.

	Target		Size		Probability of Failure		Risk of Harm
Range	6	x	1	x	3	=	<1/1 000 000

Example 1 is the assessment of a large (Size 1), unstable tree with a probability of failure of between 1/100 and >1/1 000 (PoF 3). The Target is a footpath with less than one pedestrian passing the tree each week (Target 6). The Risk of Harm is calculated as less than 1/1 000 000 (green). This is an example of where the Target is so low consideration of the structural condition of even a large tree would not usually be necessary.

Example 2.

	Target		Size		Probability of Failure		Risk of Harm
Range	1	x	4	x	3	=	1(2T) / 50 000

In Example 2, a recently dead branch (Size 4) overhangs a busy urban high street that is on average occupied constantly by two people, and here Multiple Target occupation is considered.

Having an average occupancy of two people, the Risk of Harm 1(2T)/50 000 (yellow) represents a twofold increase in the magnitude of the consequence and is therefore equivalent to a Risk of Harm 1/20 000 (yellow). This risk does not exceed 1/10 000, but being a dead branch at the upper end of the Tolerable Region it is appropriate to consider the balance of costs and benefits of risk control. Dead branches can be expected to degrade over time with the probability of failure increasing as a result. Because it is dead, some of the usual benefits from the branch have been lost and it will be appropriate to consider whether the financial cost of risk control would be proportionate.

Example 3.

	Target		Size		Probability of Failure		Risk of Harm
Range	3	x	3	x	3	=	1 / 500 000

In Example 3, a 200mm diameter defective branch overhangs a country road along which travel between 470 and 48 vehicles each day at an average speed of 50kph (32mph) (Target Range 3). The branch is split and is assessed as having a probability of failure for the coming year of between 1/100 and 1/1 000 (PoF Range 3). The Risk of Harm is calculated as 1/500 000 (yellow) and it needs to be considered whether the risk is ALARP. The cost of removing the branch and reducing the risk to Broadly Acceptable (1/1 000 000) is estimated at $670. To establish whether this is a proportionate cost of risk control, the following equation is applied. $2 900 000 (VOSL) x 1/500 000 = $5.8 indicating that the projected cost of $670 would be disproportionate to the benefit. Taking account of the financial cost, risk transfer to arborists and passers-by, the cost could be described as being grossly disproportionate, even if accrued benefits over say ten years were taken into account.

References

DfT. 2000. Highway Economic Note N. 1. '***Valuation of Benefits of Prevention of Road Accidents and Casualties***'. Department for Transport.

DfT. 2010. Department for Transport. ***Vehicles Factsheet***. Department for Transport, London. pp. 4. Available for download at http://www.dft.gov.uk/statistics

Forest Research. 2010. ***Benefits of green infrastructure*** - Report by Forest Research. Forest Research, Farnham, Surrey. 42 pp.

HSE. 1996. ***Use of Risk Assessment Within Government Departments***. Report prepared by the Interdepartmental Liaison Group on Risk Assessment. Health and Safety Executive. HSE Books, Sudbury, Suffolk. 48 pp.

HSE. 2001. ***Reducing Risks: Protecting People.*** Health and Safety Executive, [online]. Available for download at http://www.hse.gov.uk/risk/theory/r2p2.pdf (accessed 05/11/2013).

HSE. 2013. ***Sector Information Minute - Management of the risk from falling trees or branches***. Health & Safety Executive, Bootle, [online]. Available for download at http://www.hse.gov.uk/foi/internalops/sims/ag_food/010705.htm (accessed 05/11/2013).

ISO. 2009. ISO Guide 73. ***Risk Management Vocabulary***. International Organization for Standardization. Geneva. 17 pp.

Tritton, L. M. and Hornbeck, J. W. 1982. ***Biomass Equations for Major Tree Species***. General Technical Report NE69. United States Department of Agriculture.

Revision 5.1.2. Monetary values for non-uk versions updated at 1st January 2014

Appendix C – David Spencer Evidence – 1 June 2016 - Contemporary Concepts of Root System Architecture of Urban Trees – Day et al

Arboriculture & Urban Forestry 2010. 36(4): 149–159

Contemporary Concepts of Root System Architecture of Urban Trees

Susan D. Day, P. Eric Wiseman, Sarah B. Dickinson, and J. Roger Harris

Abstract. Knowledge of the extent and distribution of tree root systems is essential for managing trees in the built environment. Despite recent advances in root detection tools, published research on tree root architecture in urban settings has been limited and only partially synthesized. Root growth patterns of urban trees may differ considerably from similar species in forested or agricultural environments. This paper reviews literature documenting tree root growth in urban settings as well as literature addressing root architecture in nonurban settings that may contribute to present understanding of tree roots in built environments. Although tree species may have the genetic potential for generating deep root systems (>2 m), rooting depth in urban situations is frequently restricted by impenetrable or inhospitable soil layers or by underground infrastructure. Lateral root extent is likewise subject to restriction by dense soils under hardscape or by absence of irrigation in dry areas. By combining results of numerous studies, the authors of this paper estimated the radius of an unrestricted root system initially increases at a rate of approximately 38 to 1, compared to trunk diameter; however, this ratio likely considerably declines as trees mature. Roots are often irregularly distributed around the tree and may be influenced by cardinal direction, terrain, tree lean, or obstacles in the built environment. Buttress roots, tap roots, and other root types are also discussed.

Key Words. Root Depth; Root Extent; Root Restriction; Urban Forestry; Woody Plants.

Tree roots are supply lines for water and minerals, play important roles in carbohydrate storage and hormonal signaling, and physically anchor trees in the ground (Kozlowski and Pallardy 1997). To perform these functions, roots must be able to explore their environment and maintain their health. A root system has the potential to draw water and mineral resources from the soil it explores, so how the root explores its environment affects potential resource acquisition. In urban settings, the belowground environment is often inhospitable and restrictive to tree root growth. Impediments to a healthy root system are frequently pointed out as the underlying cause for a wide array of tree growth and health problems (e.g., Patterson 1977; Hawver and Bassuk 2006). Thus one seeks to understand how root systems develop and respond in this environment. This knowledge is essential for comprehending how trees grow in urban and landscape settings and how belowground features of the built environment, including landform, structures, and urban soils, interact with tree roots.

The study of trees is a vast area of scientific inquiry, yet the study of urban trees represents only a fraction of published research. In this review, the term "urban trees" refers to trees growing amongst buildings or other structures for human use regardless of overall land use. Thus the discussion may be germane to trees growing around a visitors' center at a national park, but may not be relevant to trees in a forest fragment within a large city. Roots are always difficult to study, simply because they are under ground and respond to localized environmental changes. These difficulties are exacerbated in urban trees because of the variety of circumstances where trees are grown. Earlier reviews of urban tree root systems (e.g., Perry 1982; Gilman 1990) have helped shape arboriculture research and practice for many years. More recent reviews have focused on specific aspects of root system development (e.g., Crow 2005). The aim of this paper is to present a survey of literature that is relevant to urban tree root systems around the world as well as to take a fresh look at these earlier works about urban tree root systems in the context of recent research. In addition to readily available sources, the authors made a concerted effort to uncover research from underrepresented arenas, including reports from various geographical regions in the world and research investigating root systems of urban trees.

The objectives here are to:

* Critically evaluate and present the current state of knowledge on tree root architecture in urban and landscape settings including depth and extent of root systems in a way that is useful to both researchers and practitioners.
* Identify knowledge gaps in this arena.
* Based on these knowledge gaps and the utility of past research results, propose areas where further research is a priority.

TREE ROOT STRUCTURE AND FUNCTION

Terminology used to describe tree roots is very diverse and not standardized. In their compendium of root system terminology, Sutton and Tinus (1983) defined more than 2,200 root terms, illustrating the wide variety of ways to describe tree roots. Classification of roots has historically been based on their anatomical or functional characteristics (Sutton and Tinus 1983; Kozlowski and Pallardy 1997). Anatomically, roots can be fundamentally classified as woody or nonwoody (e.g., Lyford and Wilson 1964). Woody roots are those that have undergone secondary growth, resulting in rigid structure and perennial lifespan. Functionally, these roots are often referred to as structural roots (see Sutton and Tinus 1983), acknowledging their role in anchoring the tree and creating a framework for the root system. Typically, a tree has 5–15 (or more) primary structural roots that emanate from the root collar and descend obliquely into the soil before becoming horizontal within a short distance of the trunk, although the pattern of root development can vary considerably. The area within 1–2 m of the trunk on larger trees is frequently referred to as the zone of rapid taper because structural roots found there often exhibit considerable secondary thickening not present on roots farther from the trunk (see Wilson 1964). Wilson (1964) additionally reviews the development of this zone and its relation to mechanical stability. Near the trunk juncture, structural roots on large trees may become thickened eccentrically in the vertical plane and are thus termed buttress roots, reflecting their shape and stabilization function (Sutton and Tinus 1983). These roots may have smaller diameter vessels than those found in the more rope-like roots found farther from the trunk (Wilson 1964). Although reaching phenomenal proportions on tree species in tropical forests, buttress roots are more modest on temperate tree species. The presence of pronounced buttress roots has been associated with soils that offer poor anchorage and trees that lack tap roots (see Henwood 1973), but other studies have found taproots on both buttressed and unbuttressed tropical trees (Crook et al. 1997). It is generally believed that the eccentric shape of buttress roots more effectively distributes mechanical stress on the root system [see Mattheck (1991) for a theoretical discussion; and Clair et al. (2003) for an empirical study of buttress roots and mechanics] and serve both tension and compression roles in stabilization (Crockett et al.1997). In some tree species, horizontal structural roots near the trunk produce sinker roots that plunge vertically into the soil, providing supplemental anchorage (Ghani et al. 2009).

Beyond the zone of rapid taper emanates a framework of woody structural roots that provide additional anchorage and serve as conduits for long distance transport of water, nutrients, and metabolites. The size of these roots may be influenced by mechanical stresses, with more large roots forming in the windward and leeward directions in trees subjected to winds from one direction (Stokes et al. 1995). Tree stability in urban settings is critically important. In Singapore, for example, 20% of tree failures have been attributed to uprooting (Rahjardo et al. 2009). Limited information is available about how urbanized sites affect root anchorage, although it can be expected that whenever root architecture is altered, such as by an urban growing environment, there is the possibility that tree anchorage could be affected. Physically confined planting holes must necessarily limit the development of buttress roots, for example. In addition, the wide variety of specialized soil mixes used in urban settings undoubtedly have different shear strengths, further altering the behavior of root systems as tree anchors. For example, Rahardjo (2009) found that an 80:20 mix of soil and granite chips, akin to a structural soil, enhanced tree resistance to uprooting. Although structural roots comprise most of the root biomass, they account for a small percentage of total root length and root surface area.

Root surface area is instead dominated by an extensive network of "nonwoody" roots, so called because they have not undergone secondary growth, proliferating from the structural root framework. Functionally, these roots are often referred to as fine or absorbing roots, acknowledging their primary role in water and nutrient uptake. These roots are generally small in diameter (<2 mm), have high metabolic rates, and have a lifespan that ranges from a few days to weeks (Black et al. 1998; Pregitzer et al. 1998; Pregitzer et al. 2002). In addition to uptake, nonwoody roots are the primary location of root hormone synthesis, nutrient assimilation, root exudation, and symbiosis with soil microorganisms (Smith 1976; Marschner 1996; Guo et al. 2008). Among these fine roots, function is variable and is often determined by position on the root system hierarchy (Pregitzer 2002; Pregitzer et al. 2002; Guo et al. 2008). First-order roots (the ultimate root tip) are the most likely point for mycorrhizal colonization and consistently have higher nitrogen (N) levels than higher order roots (Pregitzer et al. 2002). These fine roots require the least investment of carbon (C) to grow, but are the most metabolically costly for trees to maintain on a mass basis. Nonetheless, they provide the most plasticity for trees in responding to nutrient and water resources in the soil (Pregitzer et al. 2002). Despite their diminutive stature, fine roots can account for as much as 90% of total root system length (Roberts 1976). Indeed, first-order fine roots may have considerably greater root length density than other fine roots (Wang et al. 2006). Some nonwoody roots eventually undergo secondary development to become woody, structural roots and contribute to the root system framework, but most perish and are replaced (Fahey and Hughes 1994).

ROOT SYSTEM DEPTH AND SPREAD

"Where are the roots?" is a fundamental question in arboriculture and urban forestry. Estimating root depth and spread is a prerequisite for many arboricultural practices, such as tree preservation, and guides a wide range of research decisions. Although advances in remote detection technologies, such as ground-penetrating radar (e.g., Nadezhdina and Cermak 2003; Hirano et al. 2009) may enable accurate determination of root location in the future, rules of thumb are typically relied upon for estimating root extent and depth. Typical rules found in texts and educational materials estimate root spread as up to 3 × canopy spread (e.g., Elmendorf et al. 2005) or 1–1.5 × tree height (e.g., Mariotte, undated.) The exact origins of these rules are unclear or multiple, but may originate from studies with young nursery trees (e.g., Gilman 1988) and from early studies at Harvard Forest on four *Acer rubrum* (red maple) trees (Wilson 1964), respectively. Tree protection zones for sensitive older specimens are prescribed as a ground radius of 0.18 m per cm of trunk diameter (Harris et al. 2004); presumably this is intended to encompass the vast majority of the root system. Depth, described less consistently in educational publications, is sometimes vaguely described as being primarily or concentrated in the upper 0.3 m of soil, or as having the majority of fine roots in this region (Gilman 2003; Elmendorf et al. 2005).

Root Depth

Inconsistencies in descriptions of root depth may reflect variability in soil profiles across landscapes (Coile 1937), as well as differences among tree species. Crow (2005) provides a concise review. There is certainly a tendency for roots to exploit upper soil regions (Wilson 1964; Crow 2005; Wang et al. 2006), and roots of deeply planted trees have been observed to quickly rise to the soil surface and adopt a more typical depth distribution as they extend from the tree (e.g., Day and Harris 2008). In addition to limiting soil conditions below, the presence of turfgrass has been associated with reduced tree fine root development in upper soil regions (Watson and Himelick 1982), perhaps limiting root development from above. Roots are opportunistic and will grow wherever environmental conditions permit. Species may differ in their foraging strategies, either proliferating in nutrient-rich pockets, or extending widely to explore the largest soil volume possible (Mordelet et al. 1996; Mou et al. 1997; Huante et al. 1998). Mordelet et al. (1996) found that mature palms (*Borassus aethiopum*) extended roots as far as 20 m before encountering a nutrient-rich soil patch where root proliferation was ten times that in ordinary soil. The roots of palms are likely not representative of hardwoods or conifers, but the same localized proliferation has been observed in *Liquidambar styraciflua* (sweetgum) (Mou et al. 1997). An analogous foraging opportunity presented in an urban environment might be when a broken seal in a sewer pipe creates a soil patch rich in water and nutrients—a common occurrence in cities (Rolf 1991; Randrup et al. 2001; see Schroeder 2005 for photographic documentation of such an instance). Not surprisingly, however, the ecology of root foraging has not been studied systematically in urban environments. For urban trees, three root depth issues are of particular interest: (1) Can root depth be influenced by species selection—is it under genetic control? (2) How deep can urban tree roots reach? (3) What role do deep roots play relative to surface roots in terms of resource acquisition?

Rooting depth varies among species in similar conditions (Watson and Himelick 1982; Jackson 1999); whether there is genetic control over root depth, independent of species' environmental tolerances is less clear. This is of considerable interest for urban forestry. For example, if rooting depth can be controlled genetically, then deep-rooting trees could be selected to minimize conflicts with pavement. There is evidence for this genetic control, but tolerances of soil conditions such as moisture (Hosner 1960; Hook and Brown 1973) and pH (Martin and Marks 2006) vary—even within a species—and it may be difficult or impossible to separate the influence of genetics on root architecture from the influence of genetics on tolerance of soil conditions, since these conditions also have a tendency to vary with depth.

Species differences in rooting depth within the same environment have been documented. For example, a study in Texas, U.S., linked roots penetrating underground caverns to surface vegetation using DNA sequence variation (Jackson 1999). Roots of *Quercus fusiformis* (Texas live oak) were consistently present in the deepest caves, with water uptake by roots verified at 25 m depth. On one site, Jackson (1999) found *Q. fusiformis* was the only species with roots that penetrated to 14 m, even though surface vegetation included other species, such as *Q. stellata* (post oak), with similar environmental tolerances (Stransky 1990). Whether the ability of *Q. fusiformis* to grow extremely deep roots in these environments reflects genetic control of geotropic response (i.e., directional growth in response to gravity), or simply genetic control of tolerance for soil environmental conditions is not known. Burger and Prager (2008) explored this question in a recent study addressing whether root architecture could be preserved in clones created through vegetative propagation. One species, *Pistacia chinensis* (Chinese pistache), clearly formed deeper root systems than two other species, *Fraxinus uhdei* (shamel ash) and *Zelkova serrata* (Japanese zelkova), when planted in a 2 m deep Yolo loam. However, when shallow- and deep-rooted genotypes from within the same species were selected and propagated vegetatively, their depth-of-rooting characteristic was not conveyed to their clones. Suspecting differences in geotropic response among root types, Burger and Prager (2008) surmised that the effect of vegetative propagation on root architecture may have obscured any genetic control of rooting depth. Vegetative propagation by cuttings depends upon adventitious roots being generated from the cut stem, which in some cases has been linked to shallower root systems (Yamashita et al. 1997; Mulatya et al. 2002). When the orientation of clonal tea plants (*Camellia sinensis*) grown in windowed boxes was altered, seminal roots displayed more pronounced geotropic response than adventitious and lateral roots (Yamashita et al. 1997). This behavior was linked to a more pronounced presence of amyloplast particles in the root cap of seminal roots. However, instances of deeply rooted vegetatively propagated trees have also been recorded. For example, tap roots of clonal *Pinus taeda* (loblolly pine) propagated by rooting cuttings, penetrated downward more than 2 m in a sandy clay loam soil (Fairview series) in the Piedmont region of Virginia, U.S. (Jeremy Stovall, pers. comm.). *P. taeda* typically forms tap roots, so there is a genetic propensity for such root architecture (Baker and Langdon 1990). Nursery production, regardless of propagation technique, alters root system architecture in various ways (see Day et al. 2009; Hewitt and Watson 2009). However, whether the tendency toward shallower root systems persists in mature urban trees has not been studied, and the relative influence of propagation and production factors in relation to soil environmental conditions remains unknown.

How deep are tree roots of urban and landscape trees? Several surveys documenting tree root depth have been published. Each review, however, has a different scope and intent, and results must be considered in such a light (e.g., Stone and Kalisz 1991; Schenk 2002). Stone and Kalisz (1991), for example, conducted a comprehensive survey of literature and observations reporting maximum rooting depth for more than 1,000 trees from dozens of species of different ages in hundreds of different settings, but summarized studies are almost entirely from forest or orchard settings. In addition, the methods of the collected research vary dramatically with many only entailing partial sampling or excavations. This is understandable because excavating tree roots is extremely laborious, and if the research question at hand can be answered with limited excavation (e.g., to 60 cm), then such excavating will prove to be the appropriate technique. Thus, in all but few cases (e.g., Lyford and Wilson 1964), root depth and distribution research on larger trees must be interpreted with caution, as it is generally impossible to follow every tree root to its tip. Indeed, although Lyford and Wilson (1964) excavated entire roots of *Acer rubrum* to their tips and documented all breaks where the tip was not found, the natural result is that only two trees were successfully excavated. Thus, literature reviews by necessity combine results from many different types of studies. Occasionally, a special occurrence, such as a storm that uproots trees, allows a methodologically consistent survey of root systems, but generally only a portion of the root system may be studied (e.g., Glasson and Cutler 1990). Interpretation of potential tree root spread is subject to the same limitations as root depth. Nonetheless, summary analyses provide a sense of the range of rooting depths across environments and are helpful for understanding the potential for soil exploration and infrastructure invasion by tree roots.

Stone and Kalisz (1991) found the shallowest maximum rooting depth of any tree surveyed to be 1 m, and the deepest exemplar surveyed was 61 m. Although open-grown or "horticultural" trees were included in this survey, results were not categorized by forest versus urban growing sites, and most of the horticultural examples were in orchards or other production agriculture settings. Although urban soils are heterogeneous and can defy generalization, it is common to find impenetrable horizons relatively near the surface; examples include buried asphalt, subsoils compacted by construction activity, and poorly drained horizons. Analogous conditions in forest settings (e.g., bedrock, hardpans, shallow water tables) result in shallower root systems than occur for the same species on less restrictive sites (Lyford and Wilson 1964; Stone and Kalisz 1991). Soil compaction is very common in urban areas and can result in severe root restriction (Alberty et al. 1984; Day et al. 2000). Species interaction with the environment plays a role here as well. Certainly there are instances of deep-rooted urban trees where conditions allow. For example, tree roots on the highly urbanized campus of the University of Costa Rica (San Jose, Costa Rica) were observed to penetrate several meters deep (personal observation of the authors). Similarly, roots of *Celtis laevigata* (hackberry) and *Ulmus americana* (American elm), common urban species in the U.S., have been found in natural settings at 6 m and 7 m depths, respectively (Jackson 1999), and young *Populus tomentosa* (Chinese white poplar) up to 14-years-old in Hebei Province in China were found to have root systems extending as much as 4.5 m deep in a sandy soil (Wong et al. 1997).

These studies and others (e.g., Stone and Kalisz 1991), indicate that some tree species commonly used in urban settings have the potential for rapid development of deep root systems. Do these species realize this genetic potential for exploration of deeper soil regions when planted in urban and landscape settings? Deep root systems have the potential to both exploit groundwater (Dawson 1996), and redistribute groundwater stores through hydraulic lift (Dawson 1993; Burgess et al. 1998), a process to which is attributed the ability of stands of young *Acer saccharum* (sugar maple) to obtain as much as 17% of their water supply from groundwater (rather than soil water originating from rainfall), during extended dry conditions. Urban trees frequently experience drought, but whether conditions can be created where urban trees can access deep groundwater stores has yet to be explored, and no instances of hydraulic lift in urban settings have been documented.

Root Spread

Many rules of thumb have been offered for estimating root spread in urban trees. Ratios of height, trunk diameter (typically "diameter at breast height" or approximately 1.3 m), and canopy diameter may be used for root system spread estimation (e.g., Smith 1964; Gilman 1988; Gerhold and Johnson 2003), but the accuracy of these methods can depend upon the species or cultivar (Gilman 1988), tree vigor (Balasubramanyan and Manivannan 2008), and the rooting environment (Gerhold and Johnson 2003). Moreover, estimates of root spread generally assume there are few physical impediments to root extent. This is rarely the case in very urbanized settings. For example, root system spread may be halted within approximately 10 cm after penetrating beneath roadways or sidewalks (Gerhold and Johnson 2003). Even where soil conditions are homogeneous, roots may not be uniformly distributed around the tree (Tubbs 1977; Watson Himelick 1982; Ghani et al. 2009). Root spread studies must also be interpreted with caution due to the potential methodological discrepancies as previously described.

Tree height as a predictor of root spread

How reliable is tree height for estimating root spread of urban and landscape trees? Open-grown trees have been documented to have wider root spread than forest-grown trees of the same species when considered as a function of tree height (Smith 1964). Drier sites have in some cases been observed to result in wider spreading root systems (Smith 1964; Belsky 1994). For the current study, the authors combined available published data (Appendix), including several examples from urban sites, to analyze the predictive capacity of tree height for root system radius using regression analysis (SigmaPlot v. 9.01, Systat Software, Inc., Chicago, IL) (Figure 1). Of the studies analyzed, tree height explained only 36% of the variation in root spread; however, the power of this analysis is limited by the dearth of published data. Yet, even with large numbers of trees of the same species and in the same region, Smith (1964) found that only 33%–50% of the variation in root spread could be explained by height. Although the relationship established in Figure 1 is approximately 1:1, it is instructive that almost none of the data points fall within the 95% confidence interval; thus for an individual tree, there is no assurance that any root estimate based on height will be accurate. In summary, tree height is a poor predictor of root spread in urban and landscape settings.

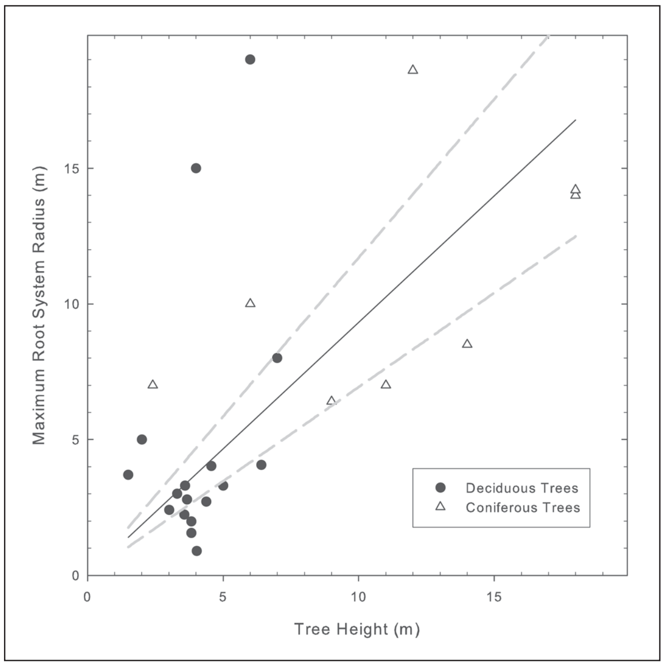

Figure 1. The relationship between tree height and maximum root radius from summarized literature. $R^2 = 0.359$ and $p = 0.002$. Dashed lines represent 95% confidence interval. When data for conifers and deciduous species were analyzed separately, data was transformed to achieve a more constant variance and relationships were as follows: Deciduous: $p = 0.25$ and $R^2 = 0.09$ Conifers: $R^2 = 0.28$ $p = 0.18$. Each data point represents a study average, see Appendix for data sources and N values.

Canopy diameter as a predictor of root spread

Canopy diameter is convenient for purposes of visually estimating tree root spread, but the relationship between canopy and roots is highly species dependent (Tubbs 1977; Gilman 1988). In one study, the largest roots of young nursery trees were excavated to their full length and the relationship between canopy and root spread determined (Gilman 1988). Root system diameter averaged 2.9 times the diameter of the canopy, but ranged from 1.68 times the canopy for *Fraxinus pennsylvanica* (green ash) to 3.77 for *Magnolia grandiflora* (Southern magnolia), and in *Quercus virginiana* (live oak), no relationship could be established. In a study of young forest trees on a clearcut, *Acer saccharum* (sugar maple) average root spread (not the maximum) was found to equal canopy spread, while in *Betula allegheniensis* (yellow birch) the average root spread was greater than canopy spread (Tubbs 1977). In addition to species variation, root spread may not be symmetrically situated beneath the canopy, even in unrestricted soil, especially if a tree is leaning. For example, Tubbs (1977) documented root systems that were approximately the same diameter as the canopy spread, but the distribution was not directly beneath the canopy—one side of the root system extended far beyond the dripline while the other side extended much less than half the canopy diameter. Tubbs (1977) also observed the root systems were generally distributed away from the lean of the tree. A similar phenomenon has been observed for trees on slopes: a majority of the root system may be located on the uphill side of the tree (Di Iorio et al. 2005). All reviewed studies relating tree canopy and root system spread used trees less than 18 cm in trunk diameter, meaning it is possible these relationships would change for mature trees. In summary, canopy spread is not likely to be a successful predictor of root spread unless a relationship is established for a particular species and it is clearly recognized that root distribution may not correspond to canopy distribution. Even then, these relationships may not hold for older trees.

Trunk diameter as a predictor of root spread

Trunk diameter is often used to estimate tree root spread; municipal ordinances frequently specify this method for determining tree protection zones (TPZs) and ensuring adequate soil resources for preserved trees. For the current study, the authors employed nonlinear regression to investigate the relationship between trunk diameter and maximum root spread using available published data (Figure 2). A much stronger relationship ($R^2 = 0.89$) was found when relating root spread to trunk diameter rather than tree height. The relationship reaches an asymptote at approximately 25–30 cm of trunk diameter. Analysis of the linear portion of the regression (0–20 cm trunk diameter range) determined the average ratio of predicted root system radius to trunk diameter is 38:1. Thus on young trees, root system radius may increase by 38 cm for every cm of trunk diameter. However, on older trees, this relationship changes, and root extent increases very slowly relative to trunk diameter. Most, but not all, of the species assessed were medium or large-stature trees, and all were trees that experience secondary growth (i.e., not palm trees). It would be expected that smaller stature species would exhibit diminished root system expansion at a smaller trunk diameter.

The strong relationship between trunk diameter and root spread shown above supports the practice of designating TPZs based on trunk diameter. Harris et al. (2004) suggest suitable TPZs have a ratio anywhere from 6:1 (radius of TPZ:trunk diameter) for young or tolerant trees, to 18:1 for old trees of sensitive species (note these ratios are unitless). According to the authors' predictive model, prescribing a TPZ on the low end of this scale protects a relative small portion of the root system. Thus, at young ages, root systems would only be partially protected. As trees age and become more vulnerable to injury from disturbance, more of the root system would be included in the TPZ. On very large and old trees, it is likely that the entire root system should be protected, even allowing for some irregularities in root distribution, which would be wise given their relative intolerance of root disturbance. In summary, trunk diameter can provide a reasonable estimate of tree root spread as long as one recognizes: 1) individual trees will vary from the estimate, perhaps considerably; 2) root spread may be irregular and not uniformly distributed around the trunk, especially when trees are leaning or located on a slope; and 3) physical constraints, such as confined urban planting pits (Gerhold and Johnson 2003), or other structures may limit root growth in certain dimensions.

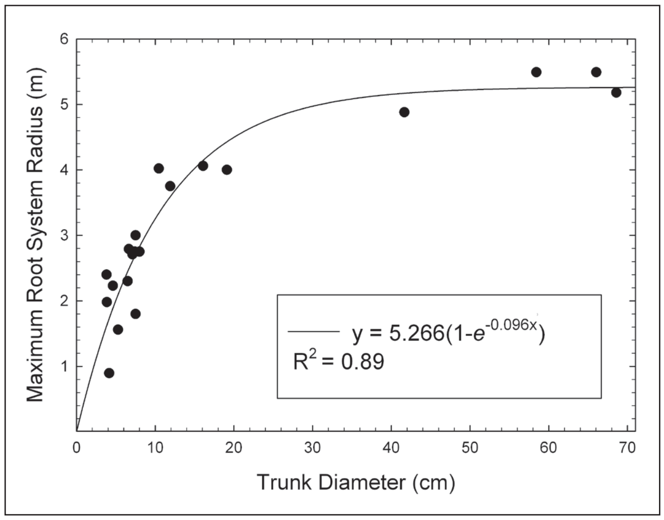

Figure 2. The relationship between trunk diameter and maximum root radius from summarized literature. Each data point represents a study average, see Appendix for data sources and N values.

CONCLUSIONS AND FUTURE RESEARCH

Root depth and extent can be severely limited and highly irregular in urban settings. When root restrictions are minimal, root spread shows a strong relationship with trunk diameter, which is a more reliable predictor than canopy diameter or tree height. During the first part of a tree's lifespan, the ratio of root system radius to trunk diameter is about 38:1. However, considerable variation can be expected due to species and site conditions. Expansion of the root system relative to trunk growth appears to slow down as a tree matures. Root depths greater than 2 m have been documented for several urban species, and genetic control over rooting depth is evident within species. Nonetheless, urban sites frequently restrict rooting depth, and vegetative propagation of deep-rooted selections has not been successful. Deep roots may confer a number of advantages including the acquisition of additional water and mineral resources, potential for hydraulic lift, and avoidance of conflicts with pavement. Root architecture and its interactions with soil properties influence tree stability, which has serious implications in urban settings.

This review has focused on the architecture of tree roots in the urban environment, particularly vertical and horizontal extent. How does this knowledge guide future research? There are many unanswered questions that relate to management of urban tree root systems, but here the authors confine comment to basic research questions to provide a greater understanding of the characteristics of the urban tree root system. The authors propose the following as possible areas of future research:

Root Architecture and Exploration of the Built Environment

Although the rhizosphere is traditionally understood as the plane of contact between roots and soil where the soil environment is dominated by root activity, rhizosphere here is considered in a broader sense to be the root-soil ecosystem. If both roots and soil are present, they cannot be viewed in isolation. What belowground situations allow for the greatest root exploration? Can this knowledge help advance techniques for avoiding tree-infrastructure conflicts? Although initial investigations indicate that selecting trees for their propensity for deep rooting may have limited success, further investigation is merited in this area because possible benefits are considerable. In addition, investigation of the genetic control of other facets of root architecture that may confer an advantage to urban trees (e.g., root systems that are more fibrous or regenerate more rapidly), may allow for selection of trees that can better exploit limited soil resources in urban settings.

Resource Acquisition by Urban Tree Roots

Urban trees may be exposed to long periods of drought, especially if global temperatures increase in the future. Urban species have the potential to grow deep roots, but are frequently limited by the soil environment. How can site design favor greater root exploration? If site design allowed for deep roots, would phenomena such as hydraulic lift allow for protection of vegetation during dry periods? Would drought tolerance be increased? Could access to nutrients and water be managed or engineered more effectively?

Mechanical Stability

If society is successful in growing large trees in the built environment, then research is needed on what root architecture characteristics are essential for tree stability and how the development of these characteristics can be assured. In addition, engineered soils and designed substrates are increasingly common and need to be evaluated in the context of tree stability.

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LITERATURE CITED

Adams, M.E. 1966. A study in ecology of *Acacia mellifera*, *A. seyal* and *Balanites aegyptiaca* in relation to land-clearing. Journal of Applied Ecology 4:221–237.

Alberty, C.A., H.M. Pellett, and D.H. Taylor. 1984. Characterization of soil compaction at construction sites and woody plant response. Journal of Environmental Horticulture 2(2):48–53.

Baker, J.B., and O.G. Langdon. 1990. *Pinus taeda* L. — loblolly pine. pp. 497–512. In: Silvics of North America: Volume 1. Conifers. Vol. Agriculture Handbook 654. R.M. Burns and B.H. Honkala (Ed.). United States Department of Agriculture (USDA), Forest Service

Balasubramanyan, S., and M.I. Manivannan. 2008. Root pattern studies in acid lime in silt clay soils. The Asian Journal of Horticulture 3(2):241–245.

Ballantyne, A.B. 1916. Fruit tree root systems: Spread and depth. Bulletin 143. Utah Agricultural Experiment Station. Logan, UT.

Bannan, M.W. 1940. The root systems of northern Ontario conifers growing in sand. American Journal of Botany 27(2):108–114.

Belsky, A.J. 1994. Influences of trees on savanna productivity: Tests of shade, nutrients, and tree-grass competition. Ecology 75(4):922–932.

Betanowny, K.H., and A.M.A. Wahab. 1973. Eco-physiological studies in desert plants. VIII. Root penetration of *Leptadenia pyrotechnica* (Forsk.) Decne. in relation to its water balance. Oecologia 11: 151–161.

Biswell, H.H. 1935. Effects of environment upon root habits of certain deciduous forest trees. Botanical Gazette 96(4):676–708.

Black, K.E., C.G. Harbron, M. Franklin, D. Atkinson, and J.E. Hooker. 1998. Differences in root longevity of some tree species. Tree Physiology 18(4):259–264.

Burger, D.W., and T.E. Prager. 2008. Deep-rooted trees for urban environments: Selection and propagation. Arboriculture and Urban Forestry 34(3):184–190.

Burgess, S.S.O., M.A. Adams, N.C. Turner, and C.K. Ong. 1998. The redistribution of soil water by tree root systems. Oecologia 115(3): 306–311.

Cable, D.R. 1977. Seasonal use of soil water by mature velvet mesquite. Journal of Range Management 30:4–11.

Cheyney, E.G. 1932. The roots of a jack pine tree. Journal of Forestry 30:929–932.

Clair, B., M. Fournier, M.F. Prevost, J. Beauchene, and S. Bardet. 2003. Biomechanics of buttressed trees: bending strains and stresses. American Journal of Botany 90(9):1349–1356.

Coile, T.S. 1937. Distribution of Forest Tree Roots in North Carolina Piedmont Soils. Journal of Forestry 35(3):247–257.

Crook, M.J., A.R. Ennos, and J.R. Banks. 1997. The function of buttress roots: a comparative study of the anchorage systems of buttressed (*Aglaia* and *Nephelium* ramboutan species) and non-buttressed (*Mallotus wrayi*) tropical trees. Journal of Experimental Botany 48(314):1703–1716.

Crow, P. 2005. The influence of soils and species on tree root depth. Information Note FCINO78 Forestry Commission Edinburgh 8 pp.

Davis, E.A., and C.P. Pase. 1977. Root system of shrub live oak: implications for water yield in Arizona chaparral. Journal of Water Conservation 32:174–180.

Dawson, T.E. 1993. Hydraulic lift and water-use by plants- implications for water-balance, performance and plant-plant interactions. Oecologia 95:565–574.

Dawson, T.E. 1996. Determining water use by trees and forests from isotopic, energy balance and transpiration analyses: the roles of tree size and hydraulic lift. Tree Physiology 16(1–2):263–272.

Day, S.D., and J.R. Harris. 2008. Growth, survival, and root system morphology of deeply planted *Corylus colurna* seven years after transplanting and the effects of root collar excavation. Urban Forestry & Urban Greening 7(2):119–128.

Day, S.D., J.R. Seiler, and N. Persaud. 2000. A comparison of root growth dynamics of silver maple and flowering dogwood in compacted soil at differing soil water contents. Tree Physiology 20(4):257–263.

Day, S.D., G.W. Watson, P.E. Wiseman, and J.R. Harris. 2009. Causes and consequences of deep structural roots in urban trees: From nursery production to landscape establishment. Arboriculture and Urban Forestry 35(4):182–190.

Di Iorio, A., B. Lasserre, G.S. Scippa, and D. Chiantante. 2005. Root system architecture of *Quercus pubescens* trees growing on different sloping conditions. Annals of Botany 95:351-361.

Elmendorf, W., H.D. Gerhold, and L. Kuhns. 2005. A guide to preserving trees in development projects. Vol. 2009. Penn State College of Agricultural Sciences, Agriculture Research and Cooperative Extension. <http://pubs.cas.psu.edu/FreePubs/pdfs/uh122.pdf>.

Fahey, T.J., and J.W. Hughes. 1994. Fine root dynamics in a northern hardwood forest ecosystem, Hubbard Brook Experimental Forest, NH. Journal of Ecology 82(3):533–548.

Gary, H.L. 1963. Root distribution of five-stamen tamarisk, seepwillow and arrowweed. Forestry Science 9:311–314.

Gasson, P.E., and D.F. Cutler. 1990. Tree root plate morphology. Arboricultural Journal: The International Journal of Urban Forestry 14(3):193–264.

Gerhold, H.D., and A.D. Johnson. 2003. Root dimensions of landscape tree cultivars. Journal of Arboriculture 29(6):322–326.

Ghani, M.A., A. Stokes, and T. Fourcaud. 2009. The effect of root architecture and root loss through trenching on the anchorage of tropical urban trees (*Eugenia grandis* Wight). Trees: Structure and Function 23(2):197–209.

Gilman, E. 1988. Predicting root spread from trunk diameter and branch spread. Journal of Arboriculture 14(4):85–89.

Gilman, E.F. 1990. Tree root growth and development. I. Form, spread, depth and periodicity. Journal of Environmental Horticulture 8(4):215–220.

Gilman, E.F. 2003. Where are tree roots? University of Florida, IFAS Extension, Gainesville, FL.

Glover, P.E. 1952. The root system of some Bristish Somaliland plants. IV. East African Agricultural Journal 17:38–50.

Guo, D., M. Xia, W. Xing , W. Chang, Y. Liu, and Z. Wang. 2008. Anatomical traits associated with absorption and mycorrhizal colonization are linked to root branch order in twenty-three Chinese temperate tree species. New Phytologist 180(3):673–683.

Harris, R., J. Clark, and N. Matheny. 2004. Arboriculture: Integrated Management of Landscape Trees, Shrubs, and Vines. 4th edition. Prentice Hall, Upper Saddle River, NJ.

Hawver, G., and N. Bassuk. 2006. Soils: The key to successful establishment of urban vegetation. pp. 137–152. In: Handbook of urban and community forestry in the Northeast. 2nd edition. J.E. Kuser (Ed.). Springer Publishing.

Hellmers, H., J.S. Horton, G. Juhren, and J. O'Keefe. 1955. Root systems of some chaparral plants in southern California. Ecology 36(4): 667–678.

Henwood, K. 1973. A structural model of forces in buttressed tropical rain forest trees. Biotropica 5(2):83–93.

Hewitt, A., and G. Watson. 2009. Nursery production can alter tree root architecture. Journal of Environmental Horticulture 27:99–104.

Hirano, Y., M. Dannoura, K. Aono, T. Igarashi, M. Ishii, K. Yamase, N. Makita, and Y. Kanazawa. 2009. Limiting factors in the detection of tree roots using ground-penetrating radar. Plant and Soil 319:15–24.

Hook, D.D. and C.L. Brown. 1973. Root adaptations and relative flood tolerance of five hardwood species. Forest Science 19(3):225–229.

Hosner, J.F. 1960. Relative tolerance to complete inundation of fourteen bottomland tree species. Forest Science 6(3):246–251.

Huante, P., E. Rincón, and F.S. Chapin Iii. 1998. Foraging for nutrients, responses to changes in light, and competition in tropical deciduous tree seedlings. Oecologia 117(1):209–216.

Jackson, R.B., L.A. Moore, W.A. Hoffmann, W.T. Pockman, and C.R. Linder. 1999. Ecosystem rooting depth determined with caves and DNA. Proceedings of the National Academy of Science USA 96:11387–11392.

Junqueras, R., A. March i Raurell, J. Chueca, and X. Fabregas i Bargallo. 2000. Respuesta de *Celtis australis* a mejoras en el suelo. Libro de ponencias del IV congreso ISA Europa y V Español de Arboricultura: 299–305.

Kozlowski, T., and S. Pallardy. 1997. Physiology of Woody Plants. 2nd edition. Academic Press, San Diego, CA.

Lyford, W.H., and B.F. Wilson. 1964. Development of the root system of *Acer rubrum* L. Harvard Forest Paper 10 Havard University Petersham, MA 17.

Marrotte, E.L. undated. Fertilization of Trees, Shrubs, Vines and Groundcovers. Vol. 2009. University of Connecticut Cooperative Extension <http://www.hort.uconn.edu/Ipm/homegrnd/htms/41fert.htm>.

Marschner, H. 1996. Mineral Nutrition in Higher Plants. Academic Press, London.

Martin, P.H., and P.L. Marks. 2006. Intact forests provide only weak resistance to shade-tolerant invasive Norway maple (*Acer platanoides* L.). Journal of Ecology 94:1070–1079.

Mattheck, C. 1991. Trees: The Mechanical Design. Springer, Berlin.

McQuilkin, W.E. 1935. Root development of pitch pine, with some comparative observations on shortleaf pine. Journal of Agricultural Engineering Research 51:983–1016.

Mordelet, P., S. Barot, and L. Abbadie. 1996. Root foraging strategies and soil patchiness in a humid savanna. Plant and Soil 182(1):171–176.

Mou, P., R.J. Mitchell, and R.H. Jones. 1997. Root distribution of two tree species under a heterogeneous nutrient environment. Journal of Applied Ecology 34(3):645–656.

Mulatya, J M., J. Wilson, C K. Ong, J.D. Deans, and J.I. Sprent. 2002. Root architecture of provenances, seedlings and cuttings of *Melia volkensii*: implications for crop yield in dryland agroforestry. Agroforestry Systems 56(1):65–72.

Nadezhdina, N., and J. Cermak. 2003. Instrumental methods for studies of structure and function of root systems of large trees. Journal of Experimental Botany 54(387):1511–1521.

Nilsen, E.T., W.M. Jarrell, and R.A. Virginia. 1983. Diurnal and seasonal water relations of the desert phreatotype *Prosopis glandulosa* (honey mesquite) in the Sonoral Desert of California. Ecology 64: 1381–1393.

Patterson, J.C. 1977. Soil compaction: Effects on urban vegetation. Journal of Arboriculture 3(9):161–167.

Perry, T.O. 1982. The ecology of tree roots and the practical significance thereof. Journal of Arboriculture 8(8):197–211.

Pregitzer, K.S. 2002. Fine roots of trees - a new perspective. New Phytologist 154(2):267–273.

Pregitzer, K.S., J.L. DeForest, A.J. Burton, M.F. Allen, R.W. Ruess, and R.L. Hendrick. 2002. Fine root architecture of nine North American trees. Ecological Monographs 72(2):293–309.

Pregitzer, K.S., M.J. Laskowski, A.J. Burton, V.C. Lessard, and D.R. Zak. 1998. Variation in sugar maple root respiration with root diameter and soil depth. Tree Physiology 18(10):665–670.

Rahjardo, H., F.R. Harnas, E.C. Leong, P.Y. Tan, Y.K. Fong, and E.K. Sim. 2009. Tree stability in an improved soil to withstand wind loading. Urban Forestry & Urban Greening *In Press*.

Randrup, T.B., E.G. McPherson, and L.R. Costello. 2001. Tree root intrusion in sewer systems: review of extent and costs. Journal of Infrastructure Systems 7(1):26–31.

Rigg, G.B., and E.S. Harrar. 1931. The root systems of trees growing in sphagnum. American Journal of Botany 18(6):391–397.

Roberts, J. 1976. A study of root distribution and growth in a *Pinus sylvestris* L. (Scots pine) plantation in Thetford Chase, Anglia. Plant and Soil 44:607–621.

Rolf, K. 1991. Soil improvement and increased growth response from subsoil cultivation. Journal of Arboriculture 17(7):200–204.

Schenk, H.J.a.R.B.J. 2002. Rooting depths, lateral root spreads and below-ground/above ground allometries of plants in water-limited ecosystems. Journal of Ecology 90(3):480–494.

Schroeder, K. 2005. Konkurrenz unter Tage [Competition underground]. GruenForum.LA 4:34–38.

Smith, J.H.G. 1964. Root spread can be estimated from crown width of Douglas fir, lodgepole pine, and other British Columbia tree species. The Forestry Chronicle 40(4):456–473.

Smith, W.H. 1976. Character and significance of forest tree root exudates. Ecology 57(2):324–331.

Stokes, A., A.H. Fitter, and M.P. Coutts. 1995. Responses of young trees to wind and shading: Effects on root architecture. Journal of Experimental Botany 46(9):1139–1146.

Stone, E.L., and P.J. Kalisz. 1991. On the maximum extent of tree roots. Forest Ecology and Management 46(1–2):59–102.

Stransky, J.J. 1990. Quercus stellata Wangenh.--post oak. pp. 738–743 In: Silvics of North America: Volume 2. Hardwoods. Vol. Agriculture Handbook 654. R.M. Burns and B.H. Honkala (Ed.) United States Department of Agriculture (USDA), Forest Service.

Strong, W.L., and G.H. LaRoi. 1983. Root system morphology of common boreal forest trees in Alberta. Canadian Journal of Forest Research 13:1160–1173.

Sutton, R.F., and R.W. Tinus. 1983. Root and root system terminology. Forest Science 29(4):supplement (Monograph 24).

Tolle, H. 1967. Durchwurzelungsverhaitnisse mittelalter Kieferbestande [Rooting conditions of mid-age pine stands]. Archiv fuer Forstwesen 16:775–779.

Tubbs, C.H. 1977. Root-crown relations of young sugar maple and yellow birch. Research Note NC-225. USDA Forest Service, North Central Forest Experiment Station.

Wang, Z., D. Guo, X. Wang, J. Gu, and L. Mei. 2006. Fine root architecture, morphology, and biomass of different branch orders of two Chinese temperate tree species. Plant and Soil 288(1):155–171.

Watson, G.W., and E.B. Himelick. 1982. Root distribution of nursery trees and its relationship to transplanting success. Journal of Arboriculture 8(9):225–229.

Wilson, B. F. 1964. Structure and growth of woody roots of *Acer rubrum* L. Harvard Forest Paper 11 Harvard University Petersham, MA 14.

Wong, W., Y. Jio, L. Xu, and Z. Zhong. 1997. Study on the root distribution of *Populus tomentosa*. Journal of the Agricultural University of Hebei Vol. 01.

Yamashita, M., T. Takyu, and T. Sasa. 1997. Gravitropic reaction in the growth of tea roots. Nihon Sakumotsu Gakkai Kiji 66:472–478.

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Résumé. La connaissance de l'étendue et de la distribution du système racinaire d'un arbre est essentielle pour la gestion des arbres dans un environnement construit. En dépit des récentes avancées en matière d'outil de détection des racines, la recherche publiée dans l'architecture des racines d'un arbre en milieu urbain est limitée et a été seulement partiellement synthétisée. Les patrons de croissance des racines d'arbres urbains peuvent considérément différer entre des espèces similaires dans des environnements forestier ou agricole. Dans cet article, nous effectuons une revue de la littérature documentant la croissance des racines chez les arbres en milieu urbain tout comme la littérature qui traite de l'architecture des racines en environnement non urbain et qui pourrait contribuer à notre compréhension des racines d'arbres au sein des environnements construits. Même si les espèces d'arbres peuvent avoir le potentiel génétique pour générer des systèmes racinaires en profondeur (> 2 m), la profondeur des racines en milieux urbains est souvent restreinte par des couches de sols impénétrables ou inhospitalières ou encore par l'infrastructure souterraine. Le développement latéral des racines est généralement restreint par des sols denses sous des surfaces en dur ou par l'absence d'irrigation dans des zones sèches. En combinant les résultats de plusieurs études, nous avons estimé que le rayon d'un système racinaire sans restriction augmentait initialement à un taux de 38 pour 1 comparativement au diamètre du tronc, mais que ce ratio déclinait considérablement avec la maturation de l'arbre. Les racines sont souvent distribuées de manière irrégulière atour de l'arbre et peuvent être influencées par la direction cardinale, le terrain, l'inclinaison de l'arbre ou les obstacles dans un environnement construit. Les racines en contrefort, les pivots racinaires et les autres types de racines font aussi l'objet d'une discussion.

Zusammenfassung. Die Kenntnis über die Ausdehnung und Verteilung eines Baumwurzelsystems ist für die Verwaltung von Bäumen in urbanen Raum notwendig. Unabhängig von jüngsten Fortschritten bei Wurzelfinder-Werkzeugen, ist die bislang publizierte Forschung über Wurzelsysteme von urban wachsenden Bäumen begrenzt und nur teilweise angeglichen. Wurzelwachstumsstrukturen von Stadtbäumen können erheblich von denen in der freien Landschaft oder Wald wachsenden Bäumen abweichen. In dieser Studie geben wir einen Literaturüberblick zur Dokumentation von Wurzelwachstum in der Stadt und auch Literatur über Wurzelarchitektur in freier Landschaft, wie etwas zum allgemeinen Verständnis beitragen kann. Obwohl Baumarten ein genetisches Potential zur Entwicklung eines tiefen Wurzelsystems (>2 m) haben können, ist die Wurzeltiefe in urbanen Räumen gelegentlich begrenzt durch undurchdringbare oder ungastliche, verdichtete Bodenschichten oder durch eine Untergrundbebauung. Die laterale Wurzelausdehnung ist ebenfalls beschränkt durch dichte Böden oder Wassermangel. Wenn die Ergebnisse der zahlreichen Studien zusammengeführt werden, so schätzen wir, daß der Radius eines unbeschränkt wachsenden Wurzelsystems zunimmt mit einer Rate von 38 zu 1, verglichen mit dem Stammdurchmesser, aber dieses Verhältnis nimmt mit zunehmendem Baumalter rapide ab. Wurzeln sind oft unregelmässig um den Baum verteilt und können durch die Hauptrichtung, Gelände, Baumneigung oder Obstruktionen in urbanem Umfeld beeinflusst werden. Stützwurzeln, Saugwurzeln und andere Wurzeltypen werden ebenfalls diskutiert.

Resumen. El conocimiento de la extensión y distribución de los sistemas de raíces es esencial para el manejo de los árboles en el ambiente urbano. A pesar de los avances recientes en herramientas de detección de raíces, las investigaciones publicadas en la arquitectura de las raíces de los árboles en ambientes urbanos han estado limitadas en solamente síntesis parcializadas. Los patrones de crecimiento de las raíces de los árboles urbanos pueden diferir considerablemente de especies similares en ambientes agrícolas o forestales. En este reporte se revisó la literatura documentando el crecimiento de las raíces de los árboles en ambientes urbanos como también la literatura de ambientes no urbanos que pueden contribuir al entendimiento de las raíces de los árboles en ambientes construidos. A pesar de que las raíces de los árboles pueden tener el potencial genético para la generación de sistemas de raíces profundos (> 2 m), el crecimiento en situaciones urbanas está frecuentemente restringido por la impenetrabilidad o inhospitalidad de las capas de suelo o por la infraestructura subterránea. La extensión lateral de las raíces está de alguna manera sujeta a restricción por suelos densos abajo o por la ausencia de riego en áreas secas. Por combinación de resultados de numerosos estudios, se estimó que el radio de un sistema de raíz incrementa inicialmente a la tasa de aproximadamente 38 a 1, comparado al diámetro del tronco, pero esta relación parece declinar considerablemente a medida que el árbol madura. Las raíces están frecuentemente distribuidas irregularmente alrededor del árbol y pueden ser influidas por la dirección cardinal, terreno, inclinación del árbol, u obstáculos en el ambiente construido. Se discuten también las raíces de anclaje, las pivotantes y otros tipos.

APPENDIX

Reports of root system maximum depth and radius and tree height and trunk diameter. Data represent mean measurements of individual trees as reported by the authors. Data analysis is presented in Figure 1 and Figure 2.

Family	Species	Mean Tree Height (m)	Mean Max. Root Depth (m)	Mean Trunk Diameter (cm)	Mean Max. Root Radius (m)	Number of trees measured (N)	Reference
Cupressaceae	*Thuja plicata* Donn.	9			6.4		(Rigg and Harrar 1931)
Pinaceae	*Picea glauca* (Moench) Voss	12	1.4		18.6		(Bannan 1940)
Pinaceae	*Pinus banksiana* Lamb.	14	2.1		8.5	1	(Cheyney 1932)
Pinaceae	*Pinus banksiana* Lamb.	18	2		14	8	(Strong and LaRoi 1983)
Pinaceae	*Pinus contorta* Doug.	2.4			7		(Rigg and Harrar 1931)
Pinaceae	*Pinus flexilis* James.	15	10				R.F. Fisher (personal communication, 1988) as cited in Stone and Kalisz (1991)
Pinaceae	*Pinus monticola* Dougl.	11			7		(Rigg and Harrar 1931)
Pinaceae	*Pinus monticola* Dougl.	18			14.2		(Rigg and Harrar 1931)
Pinaceae	*Pinus rigida* Mill.	7	2.7				(McQuilkin 1935) as cited in Stone and Kalisz (1991)
Pinaceae	*Pinus sylvestris* L.	26	2				(Tolle 1967) as cited in Stone and Kalisz (1991)
Pinaceae	*Tsuga heterophylla* (Raf.) Sarg.	6			10		(Rigg and Harrar 1931)
Aceraceae	*Acer rubrum* L.			7.4	2.75	25	(Gilman 1988)
Betulaceae	*Alnus rubra* Bong.	28.35		41.66	4.88	33	(Smith 1964)
Cupressaceae	*Thuja plicata* Donn.	35.05		68.58	5.18	61	(Smith 1964)
Fabaceae	*Acacia bussei* Harms	4			14		(Glover 1952) as cited in Stone and Kalisz (1991)
Fabaceae	*Acacia mellifera* Benth.	4			15		(Adams 1966) as cited in Stone and Kalisz (1991)
Fabaceae	*Acacia seyal* Del.	7	1.2		8		(Adams 1966) as cited in Stone and Kalisz (1991)
Fabaceae	*Dipteryx panamensis* (Pittier) Record	30	5				R.F. Fisher (personal communication, 1988) as cited in Stone and Kalisz (1991)
Fabaceae	*Gleditsia triacanthos* var. *inermis* (L.) C.K. Schneid.			8	2.75	6	(Gilman 1988)
Fabaceae	*Leptadenia pyrotechnica* (Forsk.) Decne.	2	11.5		5		(Betanowny and Wahab 1973) as cited in Stone and Kalisz (1991)
Fabaceae	*Prosopis glandulosa* Torr.	5	6		5		(Nilsen et al. 1983)
Fabaceae	*Prosopis 'juliflora'* (Swartz) DC. (= *P. glandulosa*?)	6	3		19	4	(Cable 1977)
Fagaceae	*Quercus macrocarpa* Michx.	3.6	4.4		3.3	3	(Biswell 1935)
Fagaceae	*Quercus turbinella* Greene	2.4	6.4			1	(Davis and Pase 1977)
Fagaceae	*Quercus virginiana* Mill.			6.5	2.3	25	(Gilman 1988)
Magnoliaceae	*Magnolia grandiflora* L.			7.5	3	25	(Gilman 1988)
Oleaceae	*Fraxinus pennsylvanica* Marsh.			7.5	1.8	6	(Gilman 1988)
Oleaceae	*Syringa reticulata* 'Ivory Silk'	3.67	0.59	6.65	2.79	5	(Gerhold and Johnson 2003)
Oleaceae	*Syringa reticulata* 'Ivory Silk'	4.57	0.5	10.46	4.02	5	(Gerhold and Johnson 2003)
Pinaceae	*Pseudotsuga menziesii* (Mirb)	36.88		58.42	5.49	89	(Smith 1964)
Pinaceae	*Tsuga heterophylla* (Raf.) Sarg.	42.98		66.04	5.49	81	(Smith 1964)
Rosaceae	*Adenostoma fasciculatum* H.&A.	1.5	7.6		3.7	13	(Hellmers et al. 1955)
Rosaceae	*Amelanchier* Autumn Brilliance®	3.83	0.25	3.86	1.98	5	(Gerhold and Johnson 2003)
Rosaceae	*Amelanchier* 'Cumulus'	6.41	0.69	16.08	4.06	6	(Gerhold and Johnson 2003)
Rosaceae	*Amelanchier* 'Snowcloud'	4.03	0.48	4.16	0.896	5	(Gerhold and Johnson 2003)
Rosaceae	*Malus* Harvest Gold®	4.38	0.68	7.11	2.71	5	(Gerhold and Johnson 2003)
Rosaceae	*Malus* 'Professor Sprenger'	3.02	0.35	3.81	2.4	5	(Gerhold and Johnson 2003)
Rosaceae	*Pyrus calleryana* 'Autumn Blaze'	3.57	0.6	4.62	2.23	5	(Gerhold and Johnson 2003)

APPENDIX continued.

Family	Species	Mean Tree Height (m)	Mean Max. Root Depth (m)	Mean Trunk Diameter (cm)	Mean Max. Root Radius (m)	Number of trees measured (N)	Reference
Rosaceae	*Pyrus calleryana* Chanticleer®	3.83	0.55	5.28	1.56	5	(Gerhold and Johnson 2003)
Rosaceae	*Pyrus communis* L. (H)	3.3	2.7		3		(Ballantyne 1916) as cited in Stone and Kalisz (1991)
Salicaceae	*Populus* × *generosa*			11.9	3.75	6	(Gilman 1988)
Salvadoraceae	*Dobera glabra* A. DC.	2.7	12				(Glover 1952) as cited in Stone and Kalisz (1991)
Tamaricaceae	*Tamarix pentatandra* Pallas	5	3.7		3.3		(Gary 1963) as cited in Stone and Kalisz (1991)
Ulmaceae	*Celtis australis*			19.1	4	35	(Junqueras et al. 2000)

Appendix D – David Spencer Evidence – 1 June 2016 - the STEM scores for the Spruce and Larch trees that are subject to submissions 365 and FS1258

Tree Number	Botanical Name	Common Name	Height (m)	Girth (m)	Crown Spread E/W (m)	Crown Spread N/S (m)	Health	Age Class	Form	Form Score	Occurance	Occurance Score	Vigour	Vigour Score	Function	Function Score	Age	Age Score	Condition Evaluation Total	Stature	Stature Score	Visibilty (km)	Visibility Score	Proximity	Proximity Score	Role	Role Score	Climate	Climate Score	Amenity Evaluation Total	STEM Evaluation Total
275	Larix decidua	Decidous Larch	27.2	2690	9	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	23.8	2950	7.5	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	25.6	3330	8	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	24.2	3620	6	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	20	3060	9	6	Good	Mature	Poor	3	Common	9	Good	15	Useful	9	100+	27	**63**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**120**
275	Larix decidua	Decidous Larch	24.2	3025	7	5.5	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	17.6	3230	10	6	Good	Mature	Poor	3	Common	9	Good	15	Useful	9	100+	27	**63**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**120**
275	Larix decidua	Decidous Larch	23.2	2680	8	6.5	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	26.4	4000	8	8	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	22.4	2920	7	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	25	4200	8	6.5	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Picea breweriana	Brewer's Spruce	27.2	2230	5	5	Good	Mature	Moderate	9	Infrequent	15	Good	15	Useful	9	100+	27	**75**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**132**
275	Larix decidua	Decidous Larch	23.8	3380	8	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	22.6	2940	6	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	26.8	2640	8	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	28.4	3820	8	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	22.6	2910	7	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Picea breweriana	Brewer's Spruce	26.2	1720	4	4	Good	Mature	Good	15	Infrequent	15	Good	15	Useful	9	100+	27	**81**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**138**
275	Larix decidua	Decidous Larch	23	1850	7	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	24.8	2580	6	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	21	3110	6	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Picea breweriana	Brewer's Spruce	24.6	1610	4	4	Good	Mature	Good	15	Infrequent	15	Good	15	Useful	9	100+	27	**81**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**138**
275	Larix decidua	Decidous Larch	19.8	2190	8	6.5	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	21.4	3270	8	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	18.8	2900	7	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Picea breweriana	Brewer's Spruce	27.8	1880	4	4	Good	Mature	Poor	3	Infrequent	15	Some	9	Useful	9	100+	27	**63**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**120**
275	Larix decidua	Decidous Larch	23.6	4320	5	5	Good	Mature	Poor	3	Common	9	Some	9	Useful	9	100+	27	**57**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**114**
275	Larix decidua	Decidous Larch	25	2860	4	5	Good	Mature	Poor	3	Common	9	Some	9	Useful	9	100+	27	**57**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**114**
275	Larix decidua	Decidous Larch	28	2510	4	5	Good	Mature	Moderate	9	Common	9	Some	9	Useful	9	100+	27	**63**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**120**
275	Larix decidua	Decidous Larch	25	2550	5	5	Good	Mature	Moderate	9	Common	9	Some	9	Useful	9	100+	27	**63**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**120**
275	Larix decidua	Decidous Larch	25.8	3830	6	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**

Tree Number	Botanical Name	Common Name	Height (m)	Girth (m)	Crown Spread E/W (m)	Crown Spread N/S (m)	Health	Age Class	Form	Form Score	Occurance	Occurance Score	Vigour	Vigour Score	Function	Function Score	Age	Age Score	Condition Evaluation Total	Stature	Stature Score	Visibilty (km)	Visibility Score	Proximity	Proximity Score	Role	Role Score	Climate	Climate Score	Amenity Evaluation Total	STEM Evaluation Total
275	Larix decidua	Decidous Larch	27.2	3600	6	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	22	2890	6	6	Good	Mature	Poor	3	Common	9	Some	9	Useful	9	100+	27	**57**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**114**
275	Larix decidua	Decidous Larch	27	3380	6	6	Fair	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	24.2	4270	6	6	Fair	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	26	4270	6	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Picea breweriana	Brewer's Spruce	28	2190	4	6	Fair	Mature	Poor	3	Infrequent	15	Some	9	Useful	9	100+	27	**63**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**120**
275	Picea breweriana	Brewer's Spruce	27.8	1970	3	3	Fair	Mature	Moderate	9	Infrequent	15	Good	15	Useful	9	100+	27	**75**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**132**
275	Picea breweriana	Brewer's Spruce	23.6	2070	4	3	Fair	Mature	Poor	3	Infrequent	15	Some	9	Useful	9	100+	27	**63**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**120**
275	Larix decidua	Decidous Larch	23.4	2990	4	3	Fair	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Picea breweriana	Brewer's Spruce	30.6	2340	4	5	Fair	Mature	Moderate	9	Infrequent	15	Good	15	Useful	9	100+	27	**75**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**132**
275	Picea breweriana	Brewer's Spruce	28.8	1990	4	5	Fair	Mature	Moderate	9	Infrequent	15	Good	15	Useful	9	100+	27	**75**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**132**
275	Picea breweriana	Brewer's Spruce	27	2170	4	5	Fair	Mature	Moderate	9	Infrequent	15	Some	9	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	24.5	2770	4	4	Fair	Mature	Moderate	9	Common	9	Some	9	Useful	9	100+	27	**63**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**120**
275	Picea breweriana	Brewer's Spruce	30	1390	4	4	Fair	Mature	Moderate	9	Common	9	Some	9	Useful	9	100+	27	**63**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**120**
275	Picea breweriana	Brewer's Spruce	32	2540	4	5	Fair	Mature	Moderate	9	Common	9	Some	9	Useful	9	100+	27	**63**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**120**
275	Picea breweriana	Brewer's Spruce	33.2	2710	4	4	Fair	Mature	Moderate	9	Infrequent	15	Some	9	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Picea breweriana	Brewer's Spruce	27	2290	4	8	Good	Mature	Moderate	9	Infrequent	15	Good	15	Useful	9	100+	27	**75**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**132**
275	Picea breweriana	Brewer's Spruce	26	2160	5	5	Good	Mature	Moderate	9	Infrequent	15	Good	15	Useful	9	100+	27	**75**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**132**
275	Larix decidua	Decidous Larch	20	2450	6	6	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	3 - 8	3	1	9	Group 10+	15	Important	15	Minor	3	**45**	**114**
275	Larix decidua	Decidous Larch	18	2490	7	5	Good	Mature	Poor	3	Common	9	Good	15	Useful	9	100+	27	**63**	9 - 14	9	1	9	Group 10+	15	Important	15	Minor	3	**51**	**114**
275	Picea breweriana	Brewer's Spruce	19	2510	5	5	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Picea breweriana	Brewer's Spruce	27	1550	4.5	4	Good	Mature	Moderate	9	Infrequent	15	Good	15	Useful	9	100+	27	**75**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**132**
275	Picea breweriana	Brewer's Spruce	20	1880	4.5	4	Good	Mature	Moderate	9	Infrequent	15	Good	15	Useful	9	100+	27	**75**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**132**
275	Picea breweriana	Brewer's Spruce	18	1380	4	3	Good	Mature	Moderate	9	Infrequent	15	Good	15	Useful	9	100+	27	**75**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**132**
275	Larix decidua	Decidous Larch	24	3670	8	8	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Picea breweriana	Brewer's Spruce	29	3040	8	8	Good	Mature	Moderate	9	Infrequent	15	Good	15	Useful	9	100+	27	**75**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**132**
275	Picea breweriana	Brewer's Spruce	22	2030	5	4.5	Good	Mature	Moderate	9	Infrequent	15	Good	15	Useful	9	100+	27	**75**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**132**
275	Larix decidua	Decidous Larch	23	2910	8	8	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	23	3150	8	8	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Larix decidua	Decidous Larch	20	3600	8	8	Good	Mature	Moderate	9	Common	9	Good	15	Useful	9	100+	27	**69**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**126**
275	Picea breweriana	Brewer's Spruce	27	2320	6	6	Good	Mature	Moderate	9	Infrequent	15	Good	15	Useful	9	100+	27	**75**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**132**
275	Picea breweriana	Brewer's Spruce	27	2180	6	6	Good	Mature	Moderate	9	Infrequent	15	Good	15	Useful	9	100+	27	**75**	15 - 20	15	1	9	Group 10+	15	Important	15	Minor	3	**57**	**132**