Urban Forestry & Urban Greening 14 (2015) 1054–1058

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.com/locate/ufug

Conflicts between landscape trees and lawn maintenance equipment – The first look at an urban epidemic

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ARTICLE INFO

Article history:
Received 21 June 2015
Received in revised form
11 September 2015
Accepted 2 October 2015
Available online 9 October 2015

Keywords:
Arboriculture
Landscape design
Lawnmower blight
Mechanical wounding
Park
Sheffield blight
Tree mortality
Tree stress
Urban ecology
Urban forestry

ABSTRACT

Urban forests are expected to provide numerous ecosystem benefits in challenging conditions that include environmental and anthropogenic stresses. Cities challenge the growth and survival of trees due to restricted growing space, highly modified soils, extreme soil moisture conditions, and climate that often differs from surrounding undeveloped areas. Compounding these stresses are the human factors, like vandalism – both intentional and accidental. Mechanical wounding of exposed surface roots and the lower stem by lawn maintenance equipment falls into the latter category. Anecdotally, lawn maintenance related mechanical damage is a major stressor to landscape trees, compromising their ability to thrive and thus, to provide ecosystem services. Unfortunately, no previous studies have formally quantified the incidence and extent of the problem. Here, we survey mechanical damage for 1018 trees across 308 randomly stratified plots in parks, nature reserves, cemeteries, educational institutions, and roadside grass verges in Christchurch, New Zealand. At least one wound was found on 62.9% of all surveyed trees. This was mainly driven by trees with exposed surface roots, of which 93.6% had at least one wound. This is in contrast to only 43.9% of trees without surface roots exhibiting wounds. Surveyed trees were subjected to repeat wounding with 17.8% of trees having more than 10 wounds. Maintenance activities (i.e. mulch, physical or chemical removal of grass from around the stem) reduced the incidence of mechanical wounding. In the absence of maintenance activities, 67.1% of trees were wounded, while this was reduced to 46.2%, 43.5%, and 64.2% for each of the three aforementioned maintenance activities respectively. While the reductions in mechanical wounding associated with maintenance practices are promising, alternative solutions are necessary to further reduce mechanical wounding, so that the ecosystem benefits derived from urban forests are not undermined by this blight on tree health and survival.

1. Introduction

This ‘disease’ allegedly affects huge numbers of urban trees. Governments (USDA Forest Service, 1974) and university departments (e.g. Whitehouse, 2006) warn about its consequences. It is not a pest like emerald ash borer, nor a fungal disease like Dutch elm disease – it is ‘lawnmower blight’ (USA), ‘Sheffield blight’ (UK) or mechanical wounding. Mechanical wounding is damage to the roots or stem of trees caused by lawnmowers or line trimmers. Allegedly widespread (Cotrone, 2012; Hartman and Eshenaur, 2004), few studies have formally surveyed the incidence of mechanical wounding on urban trees.

Mechanical wounding is potentially problematic as it affects the physiology (Arbellay et al., 2012) and growth of urban trees (Smith, 2006). The consequence for cities and citizens is a reduction in ecosystem services provided by urban forests (Nowak et al., 2013). It is unknown whether mechanical wounding really is a problem that affects urban forests as a whole, or just a few individual trees. If mechanical wounding were monitored like any other pest or disease, its prevalence would have been quantified or mapped, as is the case for Emerald Ash Borer (Kovacs et al., 2010). But despite its apparent severity, no steps have been taken to formally survey the number of trees that are affected.

Here we address this gap in knowledge with the first formal urban tree survey designed to quantify mechanical wounding caused by lawn maintenance equipment. The incidence and frequency of wounding were surveyed for trees across a variety of land use types to determine the severity of mechanical wounding in an urban forest. Factors that predisposed trees to wounding and methods to prevent wounding are also discussed. Finally, based on

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http://dx.doi.org/10.1016/j.ufug.2015.10.002
1618-8667/

the study results, recommendations are made for managing trees in lawn environments.

2. Methods

2.1. Study site

The study was conducted in Christchurch, New Zealand (Lat: 43°31′48″S, Long: 172°37′13″E), a city with a population of 375,000 people. To efficiently survey mechanical wounding for trees in Christchurch, we applied a stratified random sampling design. The city was stratified by land use type and plots (circular, 20 m radius) were randomly distributed (5 plots/hectare) throughout the land uses of interest: parks, nature reserves, cemeteries, education institutions, and roadside grass verges. This initial stratified random sampling design resulted in thousands of potential plots. Surveying all potential plots was unfeasible. Each day, a plot was randomly selected from the potential plots; the randomly selected plot determined which parcel would be surveyed that day. For example, if a plot was randomly selected in "Park X", then all plots in that park were surveyed. The survey was carried out between November 2014 and February 2015 and by its conclusion 1018 trees across 308 plots were measured (Table 1).

2.2. Data collection

At each plot, all trees were assessed for mechanical damage, except for those where less than 50% of the surrounding ground area (crown area projected to the ground) was covered in grass. These trees were excluded from the study so that data collection efforts could focus on trees with the potential to be affected by lawn maintenance equipment. For example, a tree surrounded by pavement would not be included because it is unlikely to be affected by lawn maintenance equipment. For each included tree, the following data were collected: species, DBH, # of wounds, wound status (old, new), wound location (roots, base of stem), as well as the presence or absence of surface roots, mulch, herbicide spray ring (chemical removal of grass around the tree), or grass cutout (physical removal of grass around the tree).

A wound was counted if the mechanical damage exposed or injured the cambium. New wounds were identified by their white wood, which had not darkened over time as old wounds had. Up to 10 wounds were counted per tree, after which # of wounds was defined as >10. Wounds were included if they were observed on surface roots or the stem of a tree up to 30 cm high. It was assumed that all mechanical wounds were caused by lawnmowers or line trimmers, though there was no way to be certain of this.

The area of mulch, herbicide ring, and grass cutout surrounding trees was not measured, though anecdotally it varied considerably. A few large specimen trees surveyed in parks had mulch spread beneath their entire crown, a radius exceeding 5 m. In most cases, mulch, herbicide, and grass cutouts did not exceed a 1 m radius around each tree. The physical removal of grass left no trace of grass surrounding trees, while chemical removal left the dead grass surrounding trees.

2.3. Statistical analysis

Chi-square (χ^2) tests (Pearson's χ^2 test with Yates' continuity correction) were used to determine whether wounding was independent of the presence/absence of land use, surface roots, mulch, herbicide spray rings, or grass cutouts. To account for familywise error rate resulting from multiple comparisons, p values were adjusted using the Hochberg procedure (Hochberg, 1988). An generalized linear model with a pairwise TukeyHSD posthoc test using R package multcomp (Hothorn et al., 2008) was undertaken to determine whether the number of wounds differed across land uses and also across different maintenance options (mulch, herbicide spray, grass cutout). A linear regression tested whether the number of wounds on a tree was independent of its DBH. All analyses were conducted in the R statistical software environment (R Core Team, 2014) and significant effects are reported at the $p < 0.05$ level.

3. Results

3.1. Overall rates of wounding

The surveyed trees ranged from 3 to 253 cm DBH and represented 116 different species. Of the 1018 trees surveyed, 62.9% had at least one wound. A chi-square test showed that the presence of a wound was independent of land use (χ^2 [4 d.f., N = 1018] = 3.7, p = 0.45), despite the varying percentage of wounded trees (Table 1). While not statistically different, mechanical wounding in parks (65.8%) was highest and mechanical wounding in nature reserves (57.1%) was lowest.

Trees with exposed surface roots were significantly more affected by lawn maintenance related mechanical wounding, with 93.6% of 389 trees affected by at least one wound in contrast to 43.9% for trees with no surface roots (χ^2 [1 d.f., N = 1018] = 252.14, $p < 0.0001$).

3.2. Wounding frequency and repetition

The number of wounds on each tree differed across land use types, ranging from an average of 3.18 on trees in roadside grass verges to 4.59 on park trees (Table 1). The number of wounds per tree was significantly greater in parks than in nature reserves (p = 0.012) or on roadside grass verges (p < 0001). Trees in the latter land use also had a lower number of wounds than trees planted in education institutions (p = 0.011).

Of the 371 trees with no wounds, 93.3% had no exposed surface roots. For all trees with at least one wound, the proportion of trees with exposed surface roots increased as the number of wounds increased. For example, trees with exposed surface roots comprised 25.7% of trees with 2 wounds, but 47.9% of trees with 5 wounds, 64% of trees with 8 wounds, and 87.3% of trees with more than

Table 1
Summary of surveyed trees including the percentage of wounded trees by land use. Mean and one standard error for the number of wounds on trees across different land uses is also presented. Superscript letters on the mean values identify groups with significantly different means.

Land use	# of Plots	# Trees	% of Wounded Trees	Mean (s.e.) # of Wounds
Park	99	360	65.8	4.59 (0.23)^{a}
Nature reserve	33	161	57.1	3.29 (0.33)^{bc}
Cemetery	29	96	62.5	3.94 (0.44)^{abc}
Education institution	35	118	63.6	4.59 (0.41)^{ab}
Roadside grass verge	112	283	62.2	3.18 (0.21)^{c}
Total	308	1018	62.9	

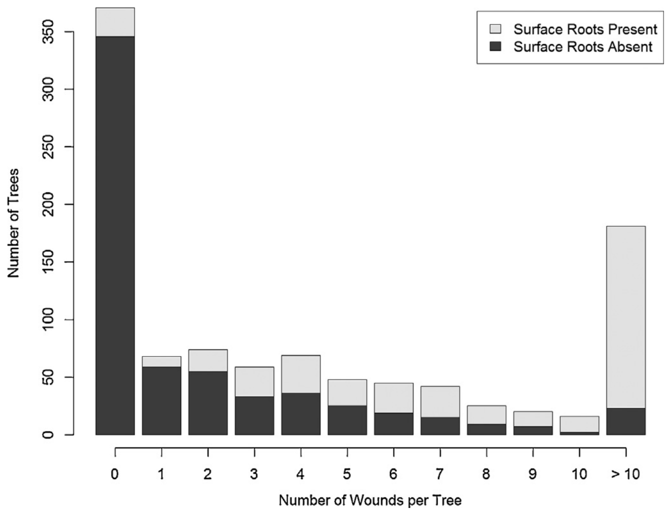

Fig. 1. Frequency distribution showing the number of wounds per tree.

Table 2
Summary showing the mean and one standard error for the number of wounds on trees given different maintenance options. Superscript letters on the mean values identify groups with significantly different means.

Treatment	# of Trees	Mean # of wounds	Standard error
None	370	4.10[a]	0.19
Herbicide spray ring	485	4.24[a]	0.21
Grass cutout	85	1.17[b]	0.29
Mulch	78	2.33[b]	0.54

10 wounds (Fig. 1). Of the 1018 surveyed trees, 17.8% had more than 10 wounds. Trees were also subject to repeated wounding. Of all wounded trees, 40.6% had new wounds on top of wounds. The number of wounds increased with tree DBH ($F(1, 1016) = 176.3$, $p < 0.0001$), but DBH was a poor predictor of the number of wounds (Adjusted $R^2 = 0.15$).

3.3. Impact of maintenance options

370 trees had not been maintained with herbicide spray (chemical removal), grass cutout (physical removal), or mulch; 67.1% of these trees had at least 1 wound resulting from lawn maintenance activities. In contrast, 64.2% of 485 trees where grass had been chemically removed from around the stem were wounded, 43.5% of 85 trees where grass had been physically removed were wounded, and of the 78 trees where mulch was present around the stem, only 46.2% were wounded. The proportion of trees with wounds was significantly greater if none of these maintenance options was undertaken (χ^2 [1 d.f., $N = 1018$] = 6.16, $p = 0.026$).

The number of wounds per tree also differed depending on whether any of the maintenance options were undertaken (Table 2). The mean number of wounds on trees where herbicide spray had been used to remove grass was greater than when trees were surrounded by mulch ($p = 0.015$) or where grass had been physically removed ($p < 0.001$). Both a mulch treatment ($p = 0.026$) and a grass cutout ($p < 0.001$) also resulted in fewer wounds than if no maintenance option had been employed. An herbicide spray ring did not result in any reduction in wounds compared with no maintenance ($p = 0.948$).

4. Discussion

4.1. Wounding rate

The rate of tree wounding by lawn maintenance equipment in Christchurch, NZ is very high, with 62.9% of trees exhibiting at least one wound. This is likely an underestimate of the proportion of trees affected, as the survey did not account for trees that had been removed due to mortality following mechanical wounding. Considering trees and grass often comprise a large component of urban areas (summarized in (Litvak et al., 2014)), and often share the same greenspaces, perhaps the high rate of mechanical wounding is unsurprising. The data show that the number of wounds increased with increasing tree DBH. Allometric studies have demonstrated that DBH increases with age (Lukaszkiewicz et al., 2005; Peper et al., 2014), so it is possible to infer that more wounds were found on larger trees because they were older and had been exposed to lawn maintenance activities for a longer period of time.

Wounding incidence rates differed across the different land uses, with the highest rate of wounding occurring in park trees and the lowest rate occurring in nature reserve trees; wounding differed by 8.7% between these two land uses. Interviews with Christchurch City Council (CCC) staff following the survey revealed that different land uses are mowed with vastly differing frequencies. Nature reserves are only mowed 4 times per year, whereas parks are mowed between 32 and 38 times per year. This almost certainly accounts for much of the disparity between these two land uses. Unfortunately, mowing frequency data were not available for educational institutions, nor for roadside grass verges, so we could not test this theory on the whole data set.

Formally quantifying the prevalence of lawn-maintenance-related mechanical wounding for the first time is useful as previous research failed to provide a definitive answer. The severity of the problem was described by a survey of municipal arborists and urban foresters from 44 communities in the North Central United States found that lawnmower damage was listed as the third most important environmental stress for street trees behind drought and salt spray (Nielsen et al., 1985). Cumming et al. (2001) came close to quantifying mechanical wounding damage when they reported that 31% of Maryland, USA's street trees showed signs of damage, with the most frequent damage being open wounds. 'Open wounds' included lawn mower scars and 'other' bark damage, but unfortunately, the authors did not specify the percentage of trees affected by open wounds.

The knowledge gained in this survey validates the statements made by university extension departments across the USA. The University of Kentucky suggest that "*One of the most frequent causes of damage to trees [...] comes from lawn equipment*" (Hartman and Eshenaur, 2004), while Cornell University say that "*the trunks of trees and shrubs are easy targets of careless use of [lawnmowers and edge-trimmers]*" (Whitehouse, 2006). The pervasiveness of mechanical wounding from lawn maintenance equipment, previously identified by universities and governments, and now quantified by this research demonstrates the need for appropriate recommendations to avoid the potentially negative consequences of lawn maintenance related mechanical wounding.

4.2. Implications of wounding

But before discussing solutions, it is useful to consider the potential consequences. Previous research has documented the consequences of wounding on trees. Wounds act as vectors for fungal ingress or pathogens, which cause staining and decay (Schwarze et al., 2007; Tsioras and Liamas, 2015). Over time, trees can compartmentalize wounds to isolate injured tissue and prevent the spread of pathogens (Shigo, 1984). But, the trade-off is that energy reserves used for compartmentalization are not available for normal growth (Smith, 2006). Also, since wounding affects the xylem, water transport is temporarily disrupted (Arbellay et al., 2012), further compromising function and growth.

At the scale of an individual tree, mechanical wounding is likely to induce stress (Arbellay et al., 2012) and reduce growth (Smith, 2006). A potential consequence of mechanical wounding is tree removal cost, replacement cost, and associated maintenance contract cost. Depending on the size of tree removed and replanted, this could easily amount to thousands of dollars. But this direct cost may be insignificant when compared to the opportunity cost of lost ecosystem services. Research linking tree structure to ecosystem services has established that healthy, large trees contribute more social, environmental, and economic benefits than small, unhealthy trees (McPherson et al., 1997; Nowak et al., 2013). At the scale of the urban forest, the cumulative consequence of all forgone ecosystem services due to the high incidence of mechanical wounding is particularly concerning.

It is important to appreciate that a single wound may not have serious effects on tree growth and condition; after all, trees are resilient. But the results show that trees were subject to numerous wounds, 6.7% of trees had exactly one wound, while 56.9% had more than one wound. Worse still, 17.8% of trees had more than 10 wounds and 40.6% of all wounded trees had new wounds over old wounds. It is the frequency and repetition of wounding that may be responsible for tree decline and the associated loss of ecosystem benefits.

4.3. Recommendation to reduce mechanical wounding

The results justify the use of tree maintenance practices that keep grass away from the stem. While mulch, herbicide spray, and grass cutouts all reduced the incidence of mechanical wounding, it is likely that observed reductions were underestimated. These practices have only been applied for the last couple of decades, so for older trees wounding would already have been present when the maintenance practice was applied. Of the three practices, mulch and grass cutouts performed equally and better than herbicide spray rings. With respect to the number of wounds per tree, only grass cutouts and mulch made significant reductions. In Christchurch, herbicide is applied early in the growing season, so weeds were observed growing inside the herbicide application area late in the growing season. Also, previously sprayed dead grass is left standing next to the tree. It is assumed that lawn maintenance staff would remove dead grass and weeds with lawnmowers or line trimmers, thereby limiting the efficacy of the herbicide technique for preventing mechanical wounding. Mulch presents a physical barrier between the lawn maintenance equipment and the tree and has the additional benefits of soil improvement and moisture retention (Scharenbroch, 2009). Of the three options surveyed in this study, mulch is almost certainly the best maintenance technique for providing soil-related benefits to the tree while preventing mechanical wounding.

Trees maintained with mulch, herbicide, or grass cutouts were still wounded between 43 and 64%, so it is clear that they are not a complete solution. These solutions are most likely to be successful if grass and other vegetation is kept away from trunk flare and surface roots. As such, the solution would need to be applied to an area proportional to the size of the tree. Scharenbroch et al. (2014) recommend a mulch application radius of at least three times the diameter of the trunk. This mulching guideline could reasonably be extended to physical and chemical grass removal if mechanical wounding is to be minimized.

A complementary solution may include policy to hold lawn maintenance staff accountable; this could be via a combination of incentives and/or penalties. Such a solution would require audits or monitoring of fresh wounding following lawn maintenance operations. Numerous tree protection bylaws and ordnances already penalize parties who damage or remove trees, so perhaps these could be expanded to include injury from lawn maintenance. Another potential solution could employ targeted education, training, certification, or accreditation. A precedent exists in the arboriculture industry (e.g. certified arborist) and the standard of tree care has improved markedly. In all likelihood, a combination of these potential solutions will be required to combat a problem as pervasive as mechanical wounding.

5. Conclusions

Mechanical wounding caused by lawn maintenance activities was widespread in Christchurch, affecting 62.9% of 1018 surveyed trees. Wounds at multiple locations on the same tree (17.8% of trees had more than 10 wounds) and also repeated wounding at the same location on a tree (40.6% of wounded trees) compounded the problem. Surface roots were a major predisposing factor to mechanical wounding. At least one wound was found on 93.6% of trees with surface roots and 87.3% of all trees with more than 10 wounds had surface roots. Solutions to this widespread problem should include mulch and/or physical removal of vegetation from around the base of trees; herbicide spray rings had limited benefit. Solutions must also incorporate policy, education, or certification. This study may not be representative of lawncare-related mechanical wounding in other cities or countries. Comparable surveys should be conducted elsewhere to validate these results. A major assumption of the study was that all wounds were caused by lawn maintenance equipment. As such, our results may overestimate the incidence of mechanical wounding. Future work could improve upon this result by real-time observation of lawn maintenance activities and associated wounding. Despite these limitations, this study succeeds in advancing the knowledge of threats to urban trees, by being the first to quantify lawncare-related mechanical wounding.

Acknowledgements

This research was funded by University of Canterbury Summer Scholarship scheme with co-funding generously provided by New Zealand Arboriculture Association and NZ Recreation Association Member Councils: Wellington City Council (CC), Hutt CC, Invercargill CC, Marlborough District Council (DC), Tasman DC, Gore DC, Timaru DC, and South Waikato DC. Helpful contributions were made by Christchurch City Council staff Dieter Steinegg, Shane Moohan and Christchurch Botanic Gardens Curator John Clemens.

References

Arbellay, E., Fonti, P., Stoffel, M., 2012. Duration and extension of anatomical changes in wood structure after cambial injury. J. Exp. Bot. 63, 3271–3277.
Cotrone, V., 2012. Protect Your Trees and Shrubs From Lawnmower Blight. Penn State – College of Agricultural Sciences.
Cumming, A.B., Galvin, M.F., Rabaglia, R.J., Cumming, J.R., Twardus, D.B., 2001. Forest health monitoring protocol applied to roadside trees in Maryland. J. Arboricult. 27, 126–138.
Hartman, J., Eshenaur, B., 2004. Wounds and Wood Decay of Trees Fact Sheet # PPFS-OR-W-01. University of Kentucky – College of Agriculture.
Hochberg, Y., 1988. A sharper Bonferroni procedure for multiple tests of significance. Biometrika 75, 800–802.
Hothorn, T., Bretz, F., Westfall, P., 2008. Simultaneous inference in general parametric models. Biom. J. 50, 346–363.
Kovacs, K.F., Haight, R.G., McCullough, D.G., Mercader, R.J., Siegert, N.W., Liebhold, A.M., 2010. Cost of potential emerald ash borer damage in U.S. communities. Ecol. Econ. 69, 569–578, 2009–2019.
Litvak, E., Bijoor, N.S., Pataki, D.E., 2014. Adding trees to irrigated turfgrass lawns may be a water-saving measure in semi-arid environments. Ecohydrology 7, 1314–1330.
Lukaszkiewicz, J., Kosmala, M., Chrapka, M., Borowski, J., 2005. Determining the age of streetside Tilia cordata trees with a DBH-based model. J. Arboricult. 31, 280–283.
McPherson, E.G., Nowak, D., Heisler, G., Grimmond, S., Souch, C., Grant, R., Rowntree, R., 1997. Quantifying urban forest structure, function, and value: the Chicago Urban Forest Climate Project. Urban Ecosyst. 1, 49–61.
Nielsen, D.G., Hart, E.R., Dix, M.E., Linit, M.J., Appleby, J.E., Ascerno, M., Mahr, D.L., Potter, D.A., Jones, J.A., 1985. Common street trees and their pest problems in the North Central United States. J. Arboricult. 11, 225–232.

Nowak, D.J., Hoehn, R.E., Bodine, A.R., Greenfield, E.J., O'Neil-Dunne, J., 2013. Urban forest structure, ecosystem services and change in Syracuse, NY. Urban Ecosyst., 1–23.
Peper, P.J., Alzate, C.P., McNeil, J.W., Hashemi, J., 2014. Allometric equations for urban ash trees (fraxinus spp.) in oakville, southern ontario, Canada. Urban For. Urban Green. 13, 175–183.
R Core Team, 2014. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria.
Scharenbroch, B.C., 2009. A meta-analysis of studies published in Arboriculture & Urban Forestry relating to organic materials and impacts on soil, tree, and environmental properties. Arboricult. Urban For. 35, 221–231.
Scharenbroch, B.C., Smiley, E.T., Kocher, W., 2014. Soil Management for Urban Trees. International Society of Arboriculture, Champaign, IL, USA.
Schwarze, F.W.M.R., Grüner, J., Schubert, M., Fink, S., 2007. Defence reactions and fungal colonisation in fraxinus excelsior and Tilia platyphyllos after stem wounding. Arboricult. J. 30, 61–82.
Shigo, A.L., 1984. Compartmentalization: a conceptual framework for understanding how trees grow and defend themselves. Annu. Rev. Phytopathol. 22, 189–214.
Smith, K.T., 2006. Compartmentalization today. Arboricult. J. 29, 173–184.
Tsioras, P.A., Liamas, D.K., 2015. Residual tree damage along skidding trails in beech stands in Greece. J. For. Res.
USDA Forest Service, 1974. Your Tree's trouble may be you! In: U.S.D.o. (Ed.), Agriculture.
Whitehouse, S.E., 2006. Common Cultural Problems of Landscape Trees & Shrubs. Cornell University.