Urban Forestry & Urban Greening 15 (2016) 15–21

Contents lists available at ScienceDirect

Urban Forestry & Urban Greening

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

Trends in financial damage related to urban tree failure in the Netherlands

M.A. van Haaften[a,*], M.P.M. Meuwissen[b,*], C. Gardebroek[c], J. Kopinga[d]

[a] Agricultural Economics and Rural Policy (AEP), Wageningen University, PO Box 8130, 6700 EW Wageningen, The Netherlands
[b] Business Economics (BEC), Wageningen University, PO Box 8130, 6700 EW Wageningen, The Netherlands
[c] Agricultural Economics and Rural Policy (AEP), Wageningen University, PO Box 8130, 6700 EW Wageningen, The Netherlands
[d] Alterra Wageningen UR, PO Box 47, 6700 AA Wageningen, The Netherlands

ARTICLE INFO

Article history:
Received 24 March 2015
Received in revised form 18 August 2015
Accepted 1 November 2015
Available online 5 November 2015

Keywords:
Urban forestry
Quantitative tree risk assessment
Risk analysis
Property damage
Financial compensation

ABSTRACT

Risk assessments on trees in urban areas and roadside plantings have become common practice and a large body of information exists on qualitative aspects on the risks of tree failure. Quantitative analysis of financial damage due to tree failure is generally lacking. The objective of this paper is to determine the amount of tree failure related property damage and to derive possible trends in the number of cases and monetary claims and compensations. This paper presents the analysis of 1610 observations on urban tree failure in the Netherlands. The data originate from two different sources, i.e. jurisprudence (4% of the data) and 21 municipalities (96%). The data covers property damage in urban areas between the early sixties and 2010. Within municipalities, paid compensations due to tree failure are found to range from €0 to € 49,296 with an average of €2,244 per paid compensation. Results demonstrate a significant annual increase in tree failure as well as in paid compensations.

Introduction

Advantages of trees have been comprehensively described in the literature, e.g. their effect on air quality, their moderating impact on so-called heat islands, and their effect on cooling or heating costs of buildings (Beckett et al., 2001; Akbari, 2002; Arnfield, 2003; Nowak et al., 2006; Brown and Fisher, 2009; Moore, 2009a,b). The added value of urban trees to the real estate value of surrounding buildings has also been investigated (Anderson and Cordell, 1988; Luttik, 2000; Laverne and Winson-Geideman, 2003; Price, 2003). Other studies describe the calming influence on traffic speed and the increased safety for bicycles and pedestrians of trees planted near roads, road crossings, roundabouts and corners (Ewing and Dumbaugh, 2009; Ewing et al., 2011; Burbridge, 2012). Cost-benefit analyses present the financial advantages of urban trees, but give less attention to the disadvantages (McPherson et al., 2005; Soares et al., 2011). For example, the damage caused by tree roots to pavements, buildings and pipe systems. The literature on these drawbacks is generally qualitative, as e.g. in Kopinga and Meyboom (1995), Arhipova et al. (2007), Morgenroth (2008) and Lucke et al. (2011) who discuss the damage of tree roots to pavements. Only few authors have estimated damage related costs and expenditures (McPherson and Peper, 1996; McPherson, 2000; Randrup et al., 2001). Similarly, the effect of tree roots on crack formations in building walls is discussed (Roberts et al., 2006; Navarro et al., 2009a,b; Satriani et al., 2010), but not substantiated by quantitative data. The interference of tree roots with pipes (sewer pipes, drains, and water works) is discussed by many authors, e.g. Leonard and Townley (1971), Mattheck and Bethge (1999), Randrup et al. (2001), Ridgers et al. (2006) and Östberg et al. (2011), while Rolf and Stal (1994), McPherson and Peper (1996) and Randrup (2000) also provide damage related costs.

Risks of tree failure in urban areas are widely discussed in the literature without quantitative data (Henwood and Pidgeon, 2001; Adams, 2007; Ball, 2007; Ellison, 2007; Wolf and Dixon, 2007; Boddy, 2009; Brown and Fisher, 2009; Forbes-Laird, 2009; Bennett, 2010; Caltrans, 2010; Barrell, 2012). Tree risk assessment methods commonly use a mix of technical and biological approaches to assess the risks of tree failure. These methods are becoming more and more used throughout the world (Wassenaar and Richardson, 2009). Governmental organizations use these methods to develop tree risk management plans to prevent or control tree failure (Pokorny et al., 2003). Some literature addresses the risks of tree failure in quantitative terms, but generally focuses on

* Corresponding authors. Tel.: +31 317483857.
E-mail addresses: marinus.vanhaaften@inholland.nl (M.A. van Haaften), miranda.meuwissen@wur.nl (M.P.M. Meuwissen), koos.gardebroek@wur.nl (C. Gardebroek), jitze.kopinga@wur.nl (J. Kopinga).

http://dx.doi.org/10.1016/j.ufug.2015.11.002
1618-8667/

personal injury damage. Most of the data originate from incidents in the United Kingdom and the United States. Incident frequencies reported by the United States government and in newspaper articles show an increase in registered deaths and injuries during the period from 1965 until 2011 (Johnson, 1981; Schmidlin, 2008; Dunster, 2012). For the United Kingdom, estimates of the ratio of the annual number of deaths due to tree failure per number of inhabitants vary between 1:10,000,000 (Ball and Watt, 2009) and 1:20,000,000 (Fay, 2007). The known annual number of deaths due to tree failure in urban areas in the United Kingdom varies from five to nine during the period 1998–2009 (Adams, 2007; HSE, 2007; Ball and Watt, 2009; Dunster, 2012).

In this limited data context, the objective of this paper is to determine the annual number of cases of tree failure related property damage and to derive possible trends in the number of cases and monetary claims and compensations. For this purpose, data from municipalities and jurisprudence have been collected and analyzed.

In the Netherlands the tree owner is responsible in case of damage. As a result of jurisprudence and provisions in the Dutch Civil Code, tree owners are obliged to carry out regular maintenance of trees and checks for imminent failure and visible defects (Jiang et al., 2014). This obligation has the purpose to identify hazardous trees, limit the liability of municipalities and to prevent damage and accidents due to tree failure. This results in the risk assessments of trees by applying the international common visual tree assessment (VTA) method (Mattheck and Breloer, 1994). Based on law, absence or an incorrect performed tree risk assessment leads to a liability of the owner with its obligation to pay damages. Jurisprudence determines that tree owners like municipalities can invoke force majeure if winds of Beaufort force 11 or higher occur. Lower wind speeds are circumstances which municipalities as manager and owner of urban trees should expect and the tree risk assessment program should be adjusted to this risk.

Methods

Collection of data

The analysis focuses on urban areas in the Netherlands. Urban areas in this research are defined as built-up areas where the speed limit is 50 kilometers per hour. With officials of each participating municipality an interview was arranged. In these interviews officials were asked to provide as much detailed information as possible on tree failure and damage caused by tree failure as long as possible back in time. First, officials and municipality workers of the department of public greening were approached. When it turned out that those could not provide information, because of an absence of registration of tree failure in municipal tree inventory databases, officials of the department on claims and insurances were interviewed.

The data used in this study is based on registrations from municipalities, which represent recordings of damage caused by tree failure, without making a distinction between tree or branch failure. Tree or branch failure can be affected by biological causes (e.g. wood decay fungi, increasing age) (Zabel and Morrell, 2012; Schwarze et al., 2013), weather conditions (e.g. strong winds, snow, lightning) (Smiley et al., 2002; Pokorny et al., 2003; Guggenmoos, 2009; Schindler et al., 2012), structural defects (e.g. forks, long branches, bark included junctions) (James, 2003; Smiley et al., 2007; Slater and Ennos, 2015) or loss of roots (e.g. mechanical or due to decay) (Genet et al., 2005; Tello et al., 2005). These possible causes of tree failure are included in the data subject to the following limitations. Tree failure as a result of these causes is registered by municipalities, to fulfill their duty of care for inhabitants as owner of the trees.

In the databases of the department of claims and insurances, biological specifications of the trees involved in tree failure were not recorded (e.g. species, age, diameter at breast height). Regardless of whether there was damage, tree failure as a result of inappropriate pruning or felling activities was not listed in the municipal databases. Also there appeared to be no registration on civil maintenance activities, which made a possible link between root damage and tree failure difficult to determine. Likewise did these databases not display data which represented damage to trees (e.g. car collisions, road maintenance or digging activities), not even if this right away caused damage afterwards (indirect causal relation).

Sample description municipalities

A selection of Dutch municipalities was made. The sample size within this research is large enough to draw reasonable conclusions, it contains 3,227,444 Dutch people living in urban areas. With a confidence interval of 95% we need 3,125,601 or more inhabitants to represent the total current Dutch population of 16.77 million people, living in rural and urban areas. All municipalities with more than 100,000 inhabitants (31) and all municipalities within the province of Utrecht (26) were enquired to provide data from 2012 back as far as possible. Thirteen of the 31 municipalities with more than 100,000 inhabitants responded within the time span of this study (2012–2014). Also, five of the 26 municipalities within the province of Utrecht responded. Each municipality provided multiple observations over a reported period. Additionally, three municipalities voluntarily provided data on tree failure. An overview of the average number of inhabitants and trees for the reporting period for each municipality is shown in Table 1.

Municipalities provided data on the frequency (number of cases per year) of tree failure causing damage or not. And in case of damage, municipalities provided information on the frequency and amount of claimed and paid compensations. The figures from municipalities are used to analyze if there is (absence of) a possible trend in tree failure and a possible trend in the

Table 1
Municipalities ($n = 21$) included in analysis, period covered, and number of inhabitants per municipality.

Municipality	Reported period	No. of inhabitants[1]
>100,000 inhabitants		
Amersfoort	18/1/2007–31/12/2012	143,864
Amsterdam	7/1995–31/12/2012	741,478
Apeldoorn	2008–2012	155,866
Ede	27/10/2002–18/4/2013	107,072
Emmen	2002–2012	108,831
Groningen	26/4/2001–31/12/2012	182,188
Haarlem	25/04/1997–31/12/2012	148,205
Haarlemmermeer	2009–2012	143,037
Maastricht	11/2/2004–31/12/2012	119,821
Nijmegen	9/6/1969–31/12/2012	153,404
Rotterdam	03/04/2000–31/12/2012	595,700
's-Hertogenbosch	25/11/2006–31/08/2012	138,130
Zoetermeer	1997–2012	114,940
Province of utrecht		
Anonymous	2009–2012	28,727
Bunnik	01/01/2010–31/12/2012	14,449
De Bilt	2/8/2006–29/1/2013	42,026
Wijk bij Duurstede	13/3/2012–14/2/2013	23,050
Zeist	20/4/2011–31/12/2012	61,029
Voluntarily participating municipalities		
Alkmaar	27/10/2002–31/12/2012	93,531
Groesbeek	1/7/1988–29/8/2009	18,792
Venlo	01/01/2001–31/12/2012	93,803

[1] The average annual number of inhabitants during the reported period (*source:* CBS).

Table 2
Frequency of tree failure and average paid compensation (€ per case) in 21 Dutch municipalities.

Municipality[1]	Annual frequency	Inhabitant/case	No. of trees[2]/case	Average paid compensation[3]/case of damage (€)	
	(all cases)	(x:1) (all cases)	(x:1) (all cases)	1991–2000	2001–2010
>100,000 inhabitants					
Amersfoort	10	15,286	7,225		1,521 (n = 11)
Amsterdam[4]	1	720,767	349,945		2,101 (n = 4)
Apeldoorn	7	21,063	8,109		861 (n = 9)
Ede	3	35,050	21,278		3,175 (n = 3)
Emmen	14	7,825	7,334		n.a.
Groningen	8	22,162	9,124		798 (n = 48)
Haarlem	4	40,771	15,131		3,268 (n = 5)
Haarlemmermeer	10	15,057	6,665		n.a.
Maastricht	12	9,859	2,880		919 (n = 29)
Nijmegen	4	39,539	14,109	1,659 (n = 9)	4,257 (n = 20)
Rotterdam	33	17,902	4,568	997 (n = 17)	276 (n = 141)
s-Hertogenbosch	8	18,095	9,563		n.a.
Zoetermeer	5	25,902	9,015	1,443 (n = 9)	2,525 (n = 14)
Province of utrecht					
Anonymous	2	12,768	9,334		2,432 (n = 4)
Bunnik	1	21,674	15,000		n.a.
De Bilt	4	11,862	7,057		2,364 (n = 3)
Wijk bij Duurstede	7	3,533	2,146		n.a.
Zeist	10	6,895	3,954		n.a.
Voluntarily participating municipalities					
Alkmaar	3	29,740	14,627		8,044 (n = 5)
Groesbeek	1	14,203	4,913	1,180 (n = 4)	1,844 (n = 2)
Venlo	11	8,792	5,999		1,083 (n = 18)
Mean/year	7.14	18,899	8,902	1,320	2,244
Minimum/year	0	2,571	1,167	0	0
Maximum/year	52	180,729	65,000	14,707	49,296
Standard deviation	9.07	33,302	14,013	4,158	4,665

[1] The period for which each municipality reported incidents of tree failure is shown in Table 1.
[2] The cases/number of trees are not based on an average of the amount of trees over the reported period, but on the amount of trees in the year 2010.
[3] Average paid compensations are corrected for inflation.
[4] Data from Amsterdam are incomplete and therefore not used in the calculation of the overall mean, minimum and maximum.

claimed and paid compensations faced by municipalities. Compensations are expressed in real terms by correcting for inflation using indices obtained from the central bureau of statistics in the Netherlands (CBS, 2014). All municipalities performed preventive visual tree assessments or equivalent safety checks on trees during the reported period, which is required by Dutch law since 1995. Five municipalities registered this information in the same way for more than one decade. Data on the frequency of tree failure and the frequency and extent of claimed and paid compensations for all 21 municipalities were obtained from the department of insurances or the department of legal affairs from each municipality. In case of multiple observations in one year in one municipality, the average paid compensation was used as input for the analysis. The data from municipalities are presented in Table 2. The data from municipalities represent a total of 1,549 cases. From the 60 invited municipalities, 39 municipalities could not respond because they lacked a municipal databank on cases of tree failure or because they did not perform tree risk assessments. The motivation in the latter case was often based on the financial consideration that it was cheaper to pay damages than to perform tree risk assessments, despite the fact that this is unlawful. Judicial coercion is usually the turning point to engage in tree risk assessments.

Sample description jurisprudence

The records from jurisprudence are examined to identify whether they support the (absence of) trends found in the municipality data. Jurisprudence provided data on the occurrence of tree failure in lawsuits and the compensation per case. Again only reports on lawsuits which discussed tree failure as a result of natural processes were collected. The collected reports on lawsuits provide information on the frequency of lawsuits related to tree failure and the amount and frequency of compensations paid. Reports are from urban tree failure randomly across the Netherlands. In case of multiple observations in one year in one place, the average paid compensation was used as input for the analysis.

Reports on 61 lawsuits from the period 1961 to 2012 were selected from the public national database of jurisprudence and from archives of the only two law offices specialized in tree failure in the Netherlands (1. Mr. B.M. Visser & Partners; 2. Manz Legal). The registration of jurisprudence by the specialized law offices is based on their own interest in drawing up a complete overview of jurisprudence of a certain item, in this case jurisprudence related to trees. All the reported cases of tree failure occurred in urban areas in the Netherlands. Duplicate cases with municipalities were excluded. Beside these cases, there is a large amount of jurisprudence which is not publicly available, possibly related to tree failure. This implies that from the data of jurisprudence only a part of the cases of tree failure with damage can be detected, an unknown part of cases of tree failure with damage remains unknown. Besides, it is impossible to detect cases of tree failure without damage. Hence, the jurisprudence data are inappropriate to derive the frequency of tree failure. Nevertheless, this data underpins the data derived from municipalities. To which extent compensations are paid is not mentioned in reports on lawsuits. The data obtained from jurisprudence is presented in Table 3.

Trend analysis

Regression analysis is used to analyze whether there is a trend in the incidence of tree failure and related compensations in the Netherlands. Data from municipalities are analyzed for tree failures and paid compensations. To establish if the trend is due to an

Table 3
Frequency of tree failure in jurisprudence and compensation per lawsuit.

	1961–1970	1971–1980	1981–1990	1991–2000	2001–2010
Jurisprudence (frequency/year)					
Property[1]	0.60 (n = 6)	1.10 (n = 11)	0.70 (n = 7)	1.70 (n = 17)	1.90 (n = 20)
Paid compensation per lawsuit (in thousand Euros)[2]					
Average	4.45 (n = 3)	2.81 (n = 6)	7.47 (n = 2)	75.09 (n = 7)	101.83 (n = 5)
Minimum	0.15	0.57	3.91	1.98	42.13
Maximum	13.01	5.73	11.04	302.83	196.95

[1] This category shows 60 cases of tree failure, 45 incidents with fallen trees, 15 incidents with falling branches. From the 45 cases of fallen trees, 16 cases concerned property damage and 29 concerned damage on vehicles.
[2] Paid compensations are corrected for inflation.

Table 4
Fixed effects linear regression estimates on annual trends.

	No. of observ.	Trend coefficient	Std. Err.	$P > \|t\|$	Test fixed effects	
					F-value	p-value
All municipalities						
Frequency tree failure	1,549	0.165	0.058	0.005	17.19	0.000
Paid compensation	454	188.104	58.289	0.002	1.17	0.291
Frequency paid compensation	454	−0.007	0.038	0.849	10.45	0.000
Subgroup analyses >10 years[1]						
Frequency tree failure	752	0.146	0.059	0.015	70.52	0.000
Paid compensation	290	229.469	75.139	0.003	2.26	0.071
Frequency paid compensation	290	−0.015	0.051	0.764	25.23	0.000
Jurisprudence						
Paid compensation	61	2861.678	916.411	0.005	–	–
Frequency paid compensation	61	0.002	0.003	0.501	–	–

[1] Five municipalities reported over a period of more than one decade.

increase in reporting in recent years or whether there is a genuine trend, a regression on a subgroup analysis was performed using data from the five municipalities that reported over more than one decade. Given the data structure with multiple observations per municipality, a fixed effects linear regression equation was estimated. The fixed effects estimates are presented in Table 4.

The estimated trend model for all municipalities is defined as: $y_{it} = \alpha_i + \beta_1 t + u_{it}$. In this model y_{it} is the frequency of tree failures in municipality i in year t, α_i denotes the individual intercept for each municipality, β_1 is the trend parameter, t indicates the year of observation and u_{it} is the error term. This model was also estimated for paid compensations and its frequency, in which case y_{it} is the (frequency of) paid compensation per tree failure in municipality i in year t.

Data from jurisprudence are also used for estimating whether there is a trend in the amount of paid compensations as reported in Dutch jurisprudence. However, since we aggregated all jurisprudence of both legal councils and given the limited number of available observations, a standard ordinary least squares was estimated.

Results

The data from municipalities in Table 2 show on average per 19,000 inhabitants one incident of urban tree failure in the Netherlands each year, with each incident possibly involving several inhabitants. The paid compensations due to tree failure are found to range from €0 to €49,296 with an average of €2,244 per paid compensation. Compensation was not paid when municipalities fulfilled their duty of care by performing regular tree risk assessments. The results from the estimated trend model on data from municipalities and jurisprudence substantiated two different trends: a trend in tree failure and a trend in the amount of paid compensations. However, we didn't find a statistically significant trend in the frequency of paid compensations. Despite the more frequent tree failures, the results show not more frequent payments of compensations. The estimation results are presented in Table 4.

Trend in tree failure

All 21 participating municipalities were incorporated in one regression, which resulted in a significant annual increase of tree failure of 0.16 cases with a p-value of 0.005. The regression on the subgroup of five municipalities estimated a significant annual increase of the frequency of 0.15 cases with a p-value of 0.015. For both regressions, the significant F-test indicated evidence for differences (unobserved heterogeneity) between municipalities.

The descriptive statistics concerning the amount of lawsuits over time, as reported in Table 3, support these findings. For the decade 1961–1970, the annual frequency of a lawsuit was 0.6, whereas for the period 2001–2010, there were one or two lawsuits with regard to property damage per year.

Trend in paid compensations

Twenty of the responding municipalities provided information on both claimed and paid compensation. The regression analysis on claimed compensations showed similar results as for paid compensations. Therefore the results on claimed compensations are not mentioned in this paper and are available upon request.

The regression showed a significant increase of paid compensations of €188 per case per year with a p-value of 0.002. Despite the increase in amounts of paid compensations, the estimation results did not show any increase in the frequency of paid compensations over time. The regression for the subgroup of five municipalities resulted in a significant increase of €229 paid per case per year with a p-value of 0.003. Also for this sub-group, estimations did not show an increase in the frequency of paid compensations over time. The F-test for the fixed effects indicated absence of heterogeneity within the paid compensations of municipalities. However, the F-test for the frequency of paid compensations did indicate differences (unobserved heterogeneity) between municipalities.

The financial value of the damage was mentioned in the judge's verdict in 36% (22 of 61) of the cases. The paid compensations were on average €45,673.76 per case, varying from a minimum of €152.30 in 1965 and a maximum of €302,829 in 2000. The analyses showed a statistically significant annual increase of paid compensations per lawsuit of €2,862.

Discussion and conclusions

This study combines data on damage caused by urban tree failure from two sources: jurisprudence and 21 municipalities. It provides unique quantitative data on the frequency of incidents of tree failure and the associated compensation for property damage. This study contributes to the literature by quantifying the amount of damage from tree failure causing property damage.

The results of these analyses provided by long-term investigations allow us to quantify the risks of tree failure. Over the past decades, the results show an increase in the annual frequency of tree failure incidents (with and without damage). The results also show an increase in damage and amount of paid compensations for urban tree failure, which implies an increase in the frequency of tree failure with damage. The annual increase in tree failure found in this study seems consistent with the increasing figures in literature from the United States and the United Kingdom. However the number of registered cases by the department of claims and insurances might be an underestimation of the real figures, as it is the department of public greening where tree failures are actually experienced and it is unsure to which extent they always report to the department of claims and insurances. Especially since many Dutch municipalities outsource the clearing of tree failure to contractors. The annual increase in tree failure might therefore be larger as the current figures suggest.

Results also show an increase in the amount of paid compensations and absence of an increase in the frequency of payments. This trend is consistent with findings in research on insurances and lawsuits in the Netherlands, which likewise depict an absence of increase in the frequency of claimed and paid compensations (Eshuis, 2003; Niemeijer and Wijck, 2007). This is also in line with the general principle of good governance founded in Dutch Law that a municipality should strive after equality and consistency. Changes in the number of awarded claims are therefore not to be expected within a short period of time. In addition, also judges and claim assessors will pursue consistency in their judgments, and the claims to be awarded are based in part upon statements they have made in the past in similar cases.

The data provided by the municipalities that participated in this study was obtained from large databases covering incidents of property damage and related compensation. The sample size for the Dutch municipalities was modest. The selected municipalities ranged from a congregation of small villages to large cities with different populations and tree densities. This study was restricted to urban tree failure, and the results are therefore not representative for tree failure in rural areas. A larger survey of both urban and rural municipalities would provide data suitable for quantifying tree risk analyses in all areas of the Netherlands. This is a useful avenue for future research.

From literature several possible explanations can be deducted to explain the increase in annual frequency and amount of damage caused by urban tree failure in the Netherlands. Apart from biological and weather conditions, also social matters (e.g. an increase in public awareness of judicial principles) and management aspects (e.g. increased focus on the costs and decreased focus on the quality of tree maintenance) can play a role. Besides, regulations on the felling of trees have become increasingly restrictive in the last few decades in the Netherlands but also abroad (Singh et al., 1997; Siiskonen, 2007). It is likely that this has led to a gradual increase in the average age of urban trees (Jim and Liu, 1997; Stokes, 1999; Donis et al., 2009). On some possible causes of tree failure municipalities can anticipate by assessing visible defects. In which case the frequency and amount of damage is likely to be higher in situations where no tree risk assessment is conducted (Pokorny et al., 2003; Ellison, 2007). The execution of visual systematic and proactive tree risk assessments is then considered to be appropriate in reducing property damage due to tree failure (Smiley et al., 2007; NTSG, 2011).

To support the trends in tree failure with statistical evidence, it is necessary to record data on the possible causes from trees which were subject to tree failure. Tree management databases of municipalities provide accurate information on (biological) properties of existing trees (e.g. age, species, DBH) and visible structural defects. Data on non-existing trees is often automatically erased from the database. The lack of historic data in municipal databases on a tree-specific level, hampers a thorough analyses on the possible causes explaining observed trends. The observed trends in this paper reported data from 1960, which means that in some municipalities one or two generations of trees deceased. Since we know that there is a trend, it is definitely useful to investigate which municipality can provide information on specific explanatory variables. Information on biological aspects (e.g. planting date and species) and management aspects (e.g. costs of tree maintenance, frequency of tree assessments) can possibly be detected from administrative archives. It is also useful to see whether backups from municipal databases can provide information on the expiration date and on the possible appearance of structural defects, wood decay fungi and insects. The findings in this paper show that it would be beneficial to perform further research into the possible causes of trends in tree failure. Adding data from administrative and historical records to the current literature will enable us to test hypotheses about how structural defects, biological and climatological aspects influence tree failure over time. This information could greatly assist urban land managers by showing them where to put the focus when performing regular tree risk assessments.

Climatological records are listed by the Royal Netherlands Meteorological Institute, which has 37 weather stations distributed over the Netherlands. Some of these weather stations exist for a few years and some for more than a century. A further analyses on the weather conditions at the time tree failure occurs, seems useful to investigate possible correlations or associations.

The literature on quantitative aspects of damage caused by tree failure merely focuses on personal injury damage with barely any quantitative data on the frequency and amount of property damage (Johnson, 1981; Adams, 2007; HSE, 2007; Schmidlin, 2008; Ball and Watt, 2009; Dunster, 2012). The collection of data on personal damage in Dutch municipalities might be biased due to the absence of a uniform registration system in which personal damage due to tree failure can be recorded. Further research is necessary to formulate absolute statements on personal damage.

The upward trend of tree failure implies that municipalities are increasingly held accountable for the correctness of their policy and accuracy of their tree maintenance in the future. It also indicates an increasing number of property damage at risk. The increasing trend in amounts of paid and claimed compensations implies an increasing relevance of preventive tree risk assessments. Particularly because regularly checks and maintenance are one of the corner stones in limiting the tree owner's liability.

Acknowledgments

We would like to thank the two anonymous reviewers for their help in improving this manuscript.

References

Adams, J., 2007. Dangerous trees? Arboric. J. 30, 95–103 (The International Journal of Urban Forestry).

Akbari, H., 2002. Shade trees reduce building energy use and CO_2 emissions from power plants. Environ. Pollut. 116, S119–S126.

Anderson, L.M., Cordell, H.K., 1988. Influence of trees on residential property values in Athens, Georgia (U.S.A.): a survey based on actual sales prices. Landscape Urban Plann. 15, 153–164.

Arhipova, L., Spijker, J.H., Kopinga, J., 2007. Ecology of tree roots in substances of the Hague. In: Research Report Alterra Report 1590. Alterra, Wageningen (ISSN 1566-7197).

Arnfield, J.A., 2003. Two decades of urban climate research: a review of turbulence, exchanges of energy and water, and the urban heat island. Int. J. Climatol. 23, 1–26.

Ball, D.J., 2007. The evolution of risk assessment and risk management: a background to the development of risk philosophy. Arboric. J. 30, 105–112 (The International Journal of Urban Forestry).

Ball, D.J., Watt, J., 2009. Report for the National Tree Safety Group—Trees and the Risk of Harm. Centre for Decision Analysis and Risk Management, Middlesex University.

Barrell, J., 2012. Balancing tree benefits against tree security: the duty holder's dilemma. Arboric. J. 34, 29–44.

Beckett, K.P., Freer-Smith, P.H., Taylor, G., 2001. Particulate pollution capture by urban trees: effect of species and windspeed. Global Change Biol. 6, 995–1003.

Bennett, L., 2010. Trees and public liability—who really decides what is reasonably safe? Arboric. J. 33, 141–164.

Boddy, M., 2009. British standards and arboriculture. Arboric. J. 32, 5–17.

Brown, N., Fisher, R., 2009. Trees Outside Woods: a Report to Woodland Trust. University of Oxford, Oxford, UK.

Burbridge, S.K., 2012. Identifying characteristics of high-risk intersections for pedestrians and cyclists: a case study from Salt Lake Country. In: UT-12.13.

Caltrans, 2010. Trees and highway safety. In: Preliminary investigation—Executive Summary. CTC & Associates LLC.

CBS, 2014. Central Bureau of Statistics in the Netherlands. CBS, Den Haag, statline.cbs.nl.

Dixon, K.K., Wolf, K.L.,2007. Benefits and Risks of Urban Roadside Landscape: Finding a Livable, Balanced Response. In: Proceedings of the 3rd Urban Street Symposium (June 24–27, 2007; Seattle, WA). Transportation Research Board of the National Academies of Science, Washington, DC.

Donis, J., Rokpelnis, M., Snepsts, G., Zarins, J.,2009. Extreme wind speeds as a natural disturbance agent in spruce forests in Latvia. In: Proceedings of the 2nd International Conference Wind Effects on Trees. Albert-Ludwigs-University of Freiburg, Germany, Freiburg, pp. 163–168.

Dunster, J.A., 2012. Are trees really risky? A review of tree-caused fatalities and injuries in the general public. In: D. A. E. C. Ltd (Ed.), 2012 Annual Conference, Portland, Oregon. International Society of Arboriculture. J.A. Dunster 4621 Cliffwood Place, Victoria, B.C. Canada. V8Y 1B6, Portland, Oregon, p. 4.

Ellison, M., 2007. Moving the focus from tree defects to rational risk management—a paradigm shift for tree managers. Arboric. J. 30, 137–142.

Eshuis, R.J.J., 2003. Claims bij de rechtbank. Wetenschappelijk Onderzoek en Documentatie Centrum, Den Haag.

Ewing, R., Dumbaugh, E., 2009. The built environment and traffic safety: a review of empirical evidence. J. Plann. 23, 347–367.

Ewing, R., Meakins, G., Bjarnson, G., Hilton, H., 2011. Transportation and Land Use. Making Healthy Places. Island Press/Center for Research Economics, pp. 149–169.

Fay, N., 2007. Towards reasonable tree risk decision making? Arboric. J. 30, 143–161.

Forbes-Laird, J., 2009. Liability for death or injury caused by falling trees or branches: a review of the present position under English law in relation to tree safety inspection. Arboric. J. 32, 233–241.

Genet, M., Stokes, A., Salin, F., Mickovski, S.B., Fourcaud, T., Dumail, J.-F., van Beek, R., 2005. The influence of cellulose content on tensile strength in tree roots. Plant Soil 278, 1–9.

Guggenmoos, S., 2009. Managing tree-caused electric service interruptions. UAA Q. (Special Edition:4–9).

Henwood, K., Pidgeon, N., 2001. Talk about woods and trees: threat of urbanization, stability, and biodiversity. J. Environ. Psychol. 21, 125–147.

HSE, 2007. In: A. F. s. A. S. Section (Ed.), Health and Safety Executive—Management of the Risk from Falling Trees—SIM 01/2007/05. Health and Safety Executive.

James, K., 2003. Dynamic loading of trees. J. Arboriculture 29, 165–171.

Jiang, B., Chang, C.-Y., Sullivan, W.C., 2014. A dose of nature: tree cover, stress reduction, and gender differences. Landscape Urban Plann. 132, 26–36.

Jim, C.Y., Liu, H.H.T., 1997. Storm damage on urban trees in Guangzhou, China. Landscape Urban Plann. 38, 45–59.

Johnson, D.W., 1981. Tree hazards: recognition and reduction in recreation Sites. In: U. S. D. o. Agriculture (Ed.), USDA, Forest Service. Forest Pest Management, State and Private Forestry, Rocky Mountain Region, Denver, CO.

Kopinga, J., Meyboom, P., 1995. Dwarsscheuren in asfaltverhardingen door boomwortels. Groen Instituut voor Bos- en Natuuronderzoek, Wageningen, pp. 34–36.

Laverne, R.J., Winson-Geideman, K., 2003. The influence of trees and landscaping on rental rates at office buildings. J. Arboriculture 29, 281–290.

Leonard, O.A., Townley, N.R., 1971. Control of tree roots in sewers and drains. Calif. Agric. 25, 13–15.

Lucke, T., Johnson, T., Beecham, S., Cameron, D., Moore, G.M., 2011. Using permeable pavements to promote street tree health, to minimize pavement damage and to reduce stormwater flows. In: 12th International Conference on Urban Drainage, 11–16 September 2011, Porto Alegre/Brazil, pp. 1–8.

Luttik, J., 2000. The value of trees, water and open space as reflected by house prices in the Netherlands. Landscape Urban Plann. 48, 161–167.

Mattheck, C., Bethge, K., 1999. Biomechanical study on the interactions of roots with gas and water pipelines for the evaluation of tree sites. Arboric. J. 23, 343–371.

Mattheck, C., Breloer, H., 1994. Field guide for Visual Tree Assessment (VTA). Arboric. J. 18, 1–23.

McPherson, E.G., 2000. Expenditures associated with conflicts between street tree root growth and hardscape in California, United States. J. Arboriculture 26, 289–297.

McPherson, E.G., Peper, P.P., 1996. Costs of street tree damage to infrastructure. Arboric. J. 20, 143–160.

McPherson, E.G., Simpson, J.R., Peper, P.J., Maco, S.E., Xiao, Q., 2005. Municipal forest benefits and costs in five US cities. J. For. 103, 411–416.

Moore, G.M., 2009a. People, trees, landscapes and climate change. In: Sykes, M. (Ed.), Climate Change: on for Young & Old. Future Leaders, Melbourne, pp. 132–149.

Moore, G.M.,2009b. Urban trees: worth more than they cost. In: Proceedings of the Tenth National Street Symposium. University of Adelaide/Waite Arboretum Adelaide.

Morgenroth, J., 2008. A review of root barrier research. Arboriculture & Urban For. 34, 84–88.

Navarro, V., Candel, M., Yustres, A., Alonso, J., García, B., 2009a. Trees, lateral shrinkage and building damage. Eng. Geol. 108, 189–198.

Navarro, V., Candel, M., Yustres, A., Sánchez, J., Alonso, J., 2009b. Trees, soil moisture and foundation movements. Comput. Geotech. 36, 810–818.

Niemeijer, E., Wijck, v.P., 2007. Met recht risico's reduceren. Beleid en Maatschappij 34, 168–179.

Nowak, D.J., Crane, D.E., Stevens, J.C., 2006. Air pollution removal by urban trees and shrubs in the United States. Urban For.Urban Greening 4, 115–123.

NTSG, 2011. Common Sense Risk Management of Trees: Guidance on Trees and Public Safety in the UK for Owners, Managers and Advisers. Forestry Commission Edinburgh.

Östberg, J., Martinsson, M., Stål, Ö., Fransson, A.-M., 2011. Risk of root intrusion by tree and shrub species into sewer pipes in Swedish urban areas. Urban For. Urban Greening 11, 65–71.

Pokorny, J.D., McGuinness, B., O'Brien, J.G., Hauer, R.J., Johnson, G.R., Albers, J.S., MacKenzie, M., Dunlap, T.T., Spears, B.J., Bedker, P.J., Mielke, M.E., 2003. In: F. S. U.S. Department of Agriculture, Northeastern Area (Ed.), Urban Tree Risk Management: A Community Guide to Program Design and Implemetation. U.S. Department of Agriculture, St. Paul.

Price, C., 2003. Quantifying the aesthetic benefits of urban forestry. Urban For. Urban Greening 1, 123–133.

Randrup, T., 2000. Occurrence of tree roots in Danish municipal sewer systems. Arboric. J. 24, 283–306.

Randrup, T.B., McPherson, E.G., Costello, L.R., 2001. A review of tree root conflicts with sidewalks, curbs and roads. Urban Ecosyst. 5, 209–225.

Ridgers, D., Rolf, K., Stål, Ö., 2006. Management and planning solutions to lack of resistance to root penetration by modern PVC and concrete sewer pipes. Arboric. J. 29, 269–290.

Roberts, J., Jackson, N., Smith, M., 2006. Tree root damage on buildings, tree root damage to pavement and low-rise structures, tree root damage to sewers, drains and pipes. In: D.f.C.a.L. Government (Ed.), Tree Roots in the Built Environment. The Stationary Office, Norwich, UK, Chapters 10–12.

Rolf, K., Stal, O., 1994. Tree roots in sewer systems im Malmo, Sweden. J. Arboriculture 20, 329–335.

Satriani, A., Loperte, A., Proto, M., Bavusi, M., 2010. Building damage caused by tree roots: laboratory experiments of GPR and ERT surveys. Adv. Geosci. 24, 133–137.

Schindler, D., Bauhus, J., Mayer, H., 2012. Wind effects on trees. Eur. J. For. Res. 131, 159–163.

Schmidlin, T.W., 2008. Deaths from wind-related tree failures. In: Tree Care Industry Magazine. Tree Care Industry Association, Kent, OH, pp. 8–12.

Schwarze, F.W.M.R., Engels, J., Mattheck, C., 2013. Fungal Strategies of Wood Decay in Trees. Springer Science & Business Media, Berlin, Heidelberg, Germany.

Siiskonen, H., 2007. The conflict between traditional and scientific forest management in 20th century Finland. For. Ecolog. Manage. 249, 125–133.

Singh, S.P., Rawat, Y.S., Garkoti, S.C., 1997. Failure of brown oak (*Quercus semecarpifolia*) to regenerate in central Himalaya: a case of environmental semisurprise. Curr. Sci. 73, 371–374.

Slater, D., Ennos, R., 2015. The level of occlusion of included bark affects the strength of Bifurcations in Hazel. Arboricultur Urban For. 41, 194–207.

Smiley, E.T., Fraedrich, B.R., Fengler, P., 2007. Hazard tree inspection, evaluation, and management. In: Kuser, J.E. (Ed.), Urban Community Forestry in the Northeast. Springer, New York, NY, pp. 227–294.

Smiley, E.T., Graham, W., Cullen, S., 2002. Best Management Practice for Tree Lightning Protection. International Society of Arboriculture, Champaign, IL.

Soares, A.L., Rego, F.C., McPherson, E.G., Simpson, J.R., Peper, P.J., Xiao, Q., 2011. Benefits and costs of street trees in Lisbon, Portugal. Urban For. Urban Greening 10, 69–78.

Stokes, A., 1999. Strain distribution during anchorage failure of *Pinus pinaster Ait.* at different ages and tree growth response to wind-induced root movement. Plant Soil 217, 17–27.
Tello, M.L., Tomalak, M., Siwecki, R., Gáper, J., Motta, E., Mateo-Sagasta, E., 2005. Biotic Urban Growing Conditions—Threats, Pests and Diseases. Urban Forests and Trees Springer, pp. 325–365.
Wassenaar, P.v., Richardson, M., 2009. A review of tree risk assessment using minimally invasive technologies and two case studies. Arboric. J. 32, 275–292.
Zabel, R.A., Morrell, J.J., 2012. Wood Microbiology: Decay and its Prevention. Academic Press, London.