PRUNING CYCLES AND STORM DAMAGE: ARE YOUNG AMERICAN ELMS FAILING PREMATURELY?

Chad P. Giblin and Gary Johnson[1]

Abstract.—The use of Dutch elm disease-resistant elms as a common replacement tree in municipal planting schedules has amassed a large population of these trees in many cities throughout the eastern half of the United States. Reports from practitioners have suggested that this population is vulnerable to catastrophic losses due to severe canopy failures during wind-loading events and that American elm (*Ulmus americana*) selections 'Princeton' and 'Valley Forge' are chronically among the most damaged, which is a combination of poor structure and sheer numbers in the landscape. In this study, tree failures resulting from two storms occurring in 2015 (28 July) and 2016 (05 July) in Saint Paul, Minnesota, were examined. In both cases, young American elms were failing due to excessive canopy damage at a rate of two to three times the failure rates of other tree species in the same landscapes.

Introduction

The increasing popularity of trees like Valley Forge and Princeton American elm (*Ulmus americana* 'Valley Forge' and *U. americana* 'Princeton') and other disease resistant elms have resulted in their widespread planting over the last decade. Since this increase in planting, there have been frequent reports of premature canopy failures, usually resulting from storms and other loading events. Arborists, urban foresters, and city planners and concerned about these reports and have expressed interest in determining if these failures are a result of increasing planting frequency or other factors unique to these species.

Tree Failure Due to Structural Defects

Experienced arboricultural practitioners know that codominant stems with branch inclusions are a recipe for disaster. This is the case for most elms that are larger and faster growing than other species. Codominant stems usually result from the loss of a main leader due to damage or removal. This loss encourages the growth of two or more new leaders that are competing for the same space in the young tree's canopy. Modern nursery production practices favor the removal the top portion of a young leader to encourage more side branching and thus form a more attractive (albeit temporary and artificial) crown. As these branches continue to grow in diameter, their attachment points become compressed, poorly attached, and more prone to failure (Fig. 1). Identification and timely correction of these defects is necessary to avoid catastrophic tree losses, especially during loading events. A study conducted at the Bartlett Tree Labs (Smiley 2003) examined the relative strength of codominant stems harvested from red maple. After harvest, the mechanical force required to separate branch unions with and without inclusions was measured using a dynamometer. Results showed that the presence of a branch inclusion resulted in branch unions that were significantly weaker. One interesting outcome of this research is the discussion of union strength and its relationship to branch size. In this study, smaller diameter branches with included bark were found to be weaker than larger ones. In summary, Smiley suggests that all branch inclusions should be considered weak when compared to those without included bark and should be addressed quickly.

[1] Research Fellow (CPG) and Professor/Extension Professor (GJ), University of Minnesota, 1530 Cleveland Ave. N, 115 Green Hall, Saint Paul, MN 55108. CPG is corresponding author: to contact, call 612-624-2729 or email at gibli002@umn.edu

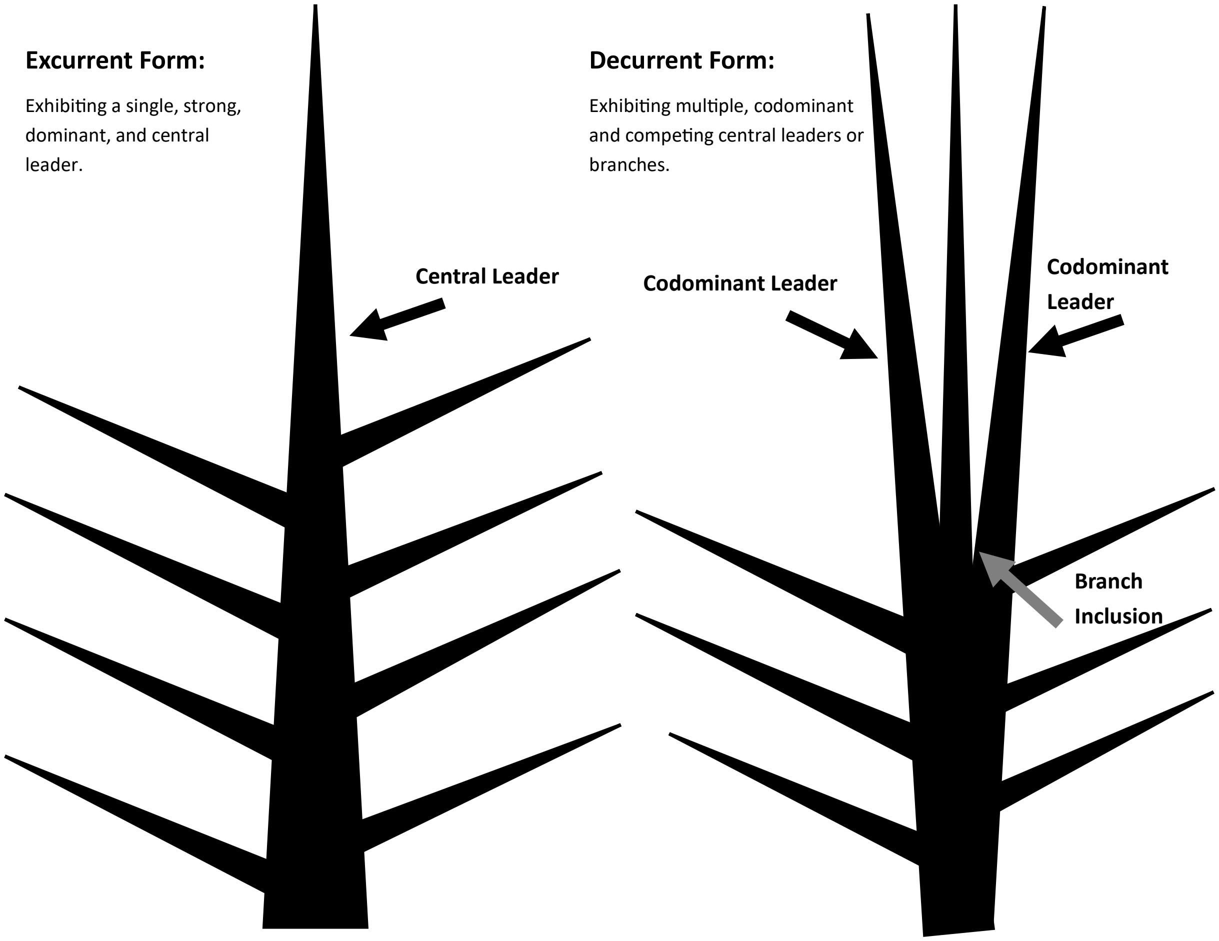

Figure 1.—Diagram of excurrent and decurrent growth forms showing codominant leaders and branch inclusions.

Gilman (2003) published results from a similar study that examined the role of branch-aspect ratio (BAR) in predicting branch union strength. BAR describes the size relationship between the diameter of branches and the diameter of the main stem at the point of attachment. BAR is typically reported with the size of the stem followed by the size of the branch. For example, a 2 cm branch attached to a 4 cm main stem has a BAR of 2:1. Gilman's work found that the amount of force required to break branches increases with BAR, stressing that codominant stems are much more likely to fail than other branches that are smaller in diameter. Gilman et al. (2015) published research that examined how suppression pruning cuts affect trunk strain at the point of branch attachment. Suppression cuts are a type of reduction pruning that removes a distal portion of a branch back to a lateral that is at least one-third but preferably one-half the size of the main branch. This is the first work focused on solving problems observed in the previous work (Gilman 2003). The effect of branch suppression was examined using pairs of codominant branches in live oak that were exposed to artificial wind loading events. To test the effects of reducing strain by pruning, the smaller of the two branches received one of four possible pruning doses that removed 0, 33, 66, and 100 percent of the leaves and branch tissue. They found that strain exerted on the branch attachment was reduced by increasing the pruning dose: more pruning caused a greater reduction in strain. Furthermore, the authors discuss the implications of using reduction pruning (i.e., suppression cuts) to reduce branch aspect ratio and thus increase the strength of the branch union. This allows for removal of multiple codominant branches staged over numerous pruning events, especially important when working with trees that have numerous defects or codominant branches.

Municipal Pruning Cycles: Cost-Benefit Analyses and the Price of Deferred Maintenance

During the last decade, there has been increased focus on developmental pruning of young trees. This practice is focused on guiding newly planted nursery stock from a period of intensive culture and very frequent pruning cycles to a much different maintenance regime in urban and community forests. Frequent pruning events during the first 15 years after planting should focus on the development and maintenance of a strong, central leader. Temporary branches that are located below the height of permanent, structural canopy in a tree should be managed using reduction cuts to suppress their growth to avoid removal at an excessively large size.

An emerging issue in municipal and commercial arboriculture and urban forestry is the cost of deferred maintenance. Miller and Sylvester (1981) examined this issue using Milwaukee, WI, as their subject city. The authors found that delaying maintenance resulted in trees of lower quality and, as a result, lower value. Because more frequent pruning cycles incur greater cost, the authors compared this decrease in value with the increased cost of more frequent maintenance. After statistical analysis, they determined that a pruning cycle between 4 and 5 years results in the best return from maintenance investments. In reference to small trees, the authors found a number of discrepancies in condition class during 1 year of their study and traced this back to a young tree population that needed "extensive corrective pruning...[resulting in] temporarily misshapen crowns, large pruning wounds, and a lower average condition class…". This is very interesting because it draws attention to the fact that these young trees needed major pruning, perhaps for the first time, implying that young trees are more sensitive to longer pruning cycles.

Ryder and Moore (2013) examined both the economic and biological effects of performing pruning on five species of trees. Their work compared the time required to perform developmental pruning on young trees (three times in 7 years) to that required when pruning older trees (one time after 20 years). In the case of eucalyptus, this delay increased the per-tree cost of pruning by 13 to 18 times. When inflation adjustments are made, the increase in time required may cost up to 25 times more than investing in developmental pruning of young trees. Another important point made was noting the decrease in tree defects when they received timely pruning as young trees. This creates an immediate savings in maintenance costs while reducing tree defects and subsequent storm damage linked to those defects. This may, in turn, decrease the overall pruning requirements of maturing trees and create a cost savings structure that lasts the lifetime of the tree.

The above research clearly supports the benefits of performing regular, developmental pruning on young trees. If this pruning is not performed, anecdotal information suggests that young trees—specifically young American elms—will fail at rates higher than other species. To test the hypothesis of exacerbated rates of failure in young elms, two wind loading events occurring in the Saint Paul, MN, area were examined.

Materials and Methods

Storm 1 occurred on 28 July 2015 and Storm 2 occurred on 05 July 2016. Storm damage and tree removal data was collected using Saint Paul tree inventory and work report information via Davey TreeKeeper® version 7 tree management software (Davey Resource Group, Kent, OH). The total number of trees requiring removal was determined for each storm and, in both storms, the rate of young elm failure was determined and compared to the rate of other species in these two storms. Failures were pooled at the genus level. Tree diameter at breast height (d.b.h.) (4.5 feet above the ground) was collected during post-storm surveys to assess damaged trees for removal. The breakdown of species and varieties within the elm genus was examined for both storms.

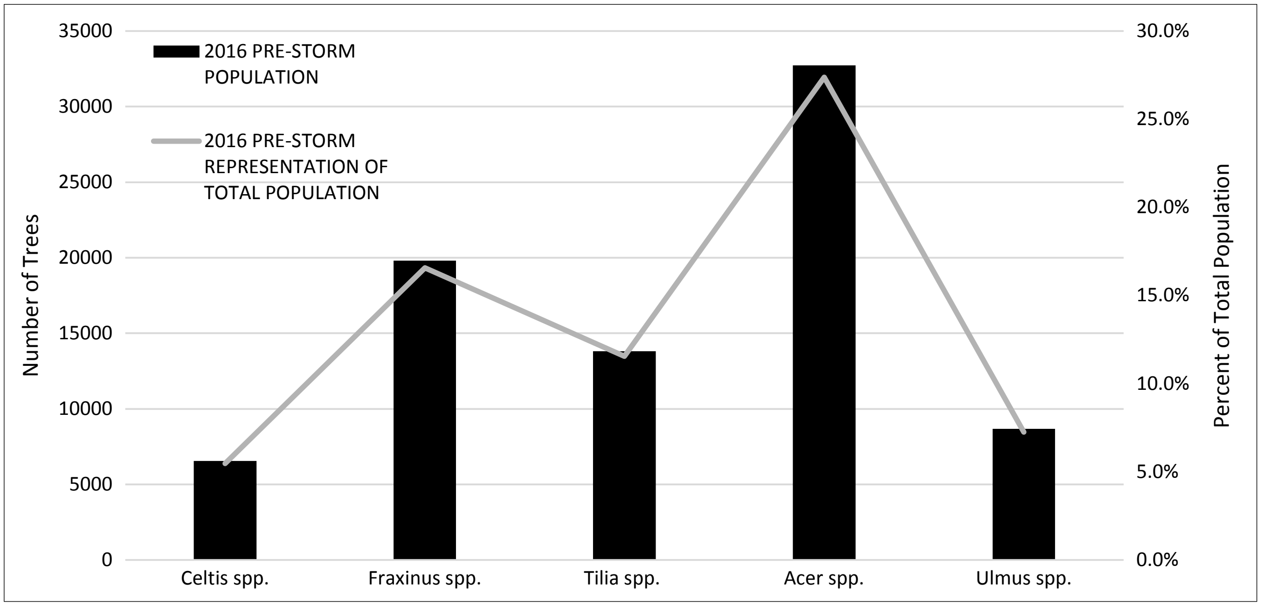

Figure 2.—Number of trees by genus present in Saint Paul, MN, prior to Storm 2 (05 July 2016) and the percentage of the total city tree population of each genus.

Five genera that exhibited storm-related failures at rates higher than other species in both storm events were selected for further study: ash (*Fraxinus* spp.), elm (*Ulmus* spp.), hackberry (*Celtis* spp.), linden (*Tilia* spp.), and maple (*Acer* spp.) This representation of genera is similar to data collected after other wind-loading events in the region (Johnson 2014). Citywide prestorm inventory data was available for Storm 2 in 2016, but not for Storm 1 in 2015. The total population of these five genera and their percent representation of the total population is shown in Figure 2.

Statistical frequency and chi-square tests were conducted to report species percentages, failure rates, and differences between failure rates in different genera and elm cultivars, varieties, and species using IBM SPSS Statistics version 22.0 (IBM 2013).

Results

Local weather data indicates that about 0.5 inches of rain fell during Storm 1 with maximum wind speeds of 25 miles per hour (m.p.h.) and gusts of 33 m.p.h. During Storm 2, about 1.0 inch of rain fell with maximum wind speeds of 38 m.p.h. and gusts of 67 m.p.h. After Storm 1, city staff assessed 181 trees for removal. Damage or failure resulting from Storm 2 required removal of 543 trees. Removal causes included catastrophic failure or irreparable damage to the crown due to codominant and/or included leaders and/or branches; failure due to windthrow; and stem failure.

For Storms 1 and 2, chi-square test procedures were used examine removals at the genus level and to test the null hypothesis that failure rate is equal across all genera. Test results indicate that removal rate was not consistent across all genera for either Storm 1 ($\chi^2(11, N=181) = 298.93, p < 0.01$) or Storm Two ($\chi^2(4, N=543) = 209.155, p < 0.01$). Five genera consistently exhibited storm-related failures at rates higher than other species in both storm events. Ash, elm, hackberry, linden, and maple represented approximately 90 percent of all failures in both storms, while these same five genera comprise just under 70 percent of the overall tree population citywide (Figs. 3 and 4).

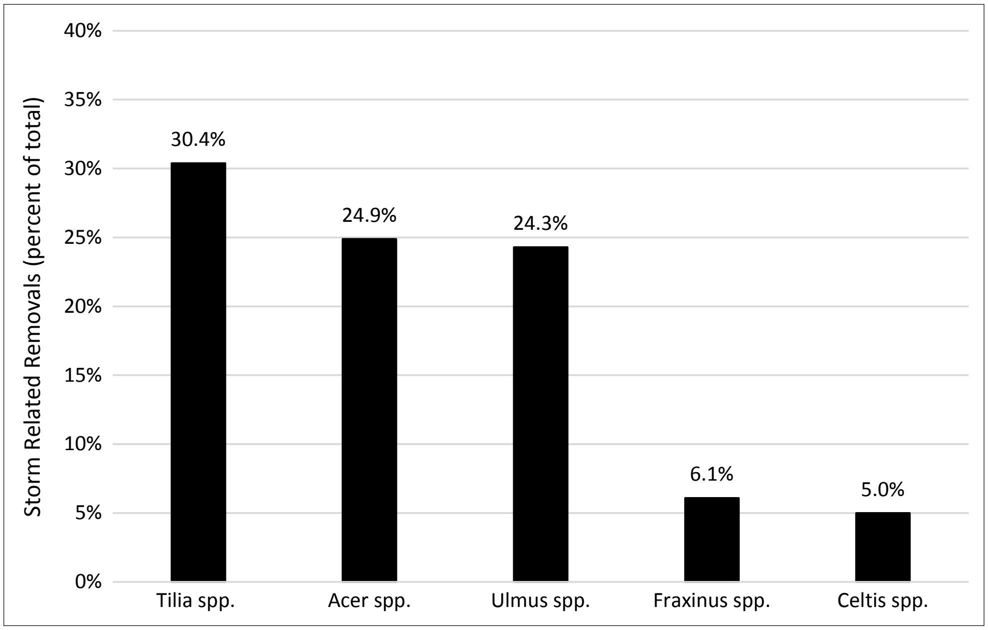

Figure 3.—Percentage of total storm-related removals by genus resulting from Storm 1 (28 July 2015).

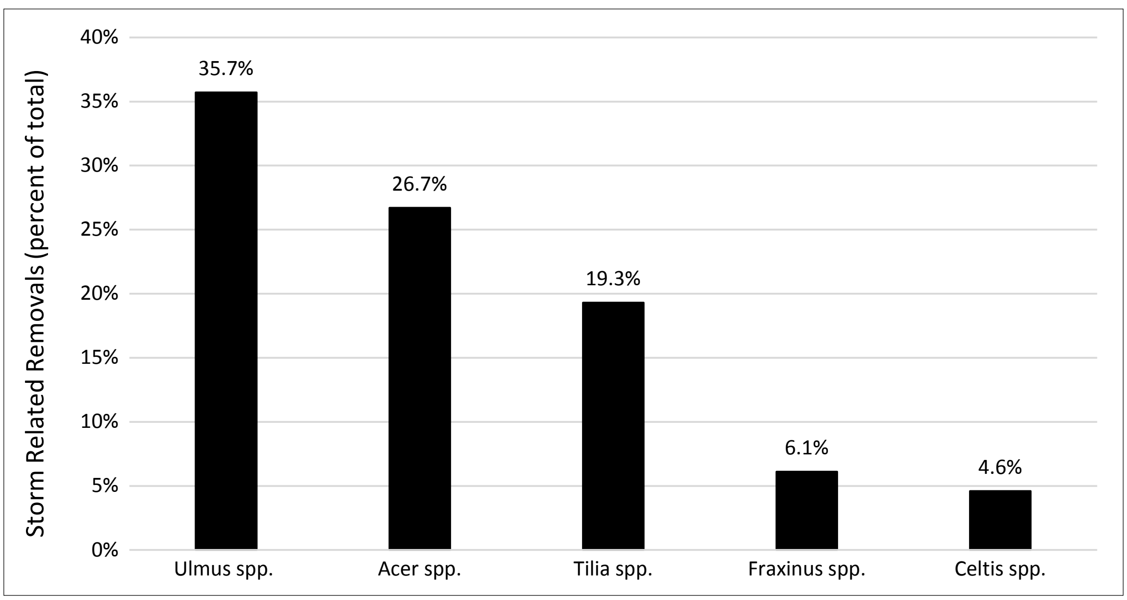

Figure 4.—Percentage of total storm-related removals by genus resulting from Storm 2 (05 July 2016).

In Storm 1, ash were largest trees at the time of failure averaging 19.1 inches d.b.h., followed by linden and maple at 18.2 inches d.b.h. and 15.1 inches d.b.h., respectively. Hackberry and elm were smallest at the time of failure at 13.1 inches d.b.h. and 5.5 inches d.b.h., respectively (Fig. 5). In Storm 2, linden and ash were the largest at the time of failure at 21 inches d.b.h. and 20.8 inches d.b.h., respectively, followed by maple at 16.9 inches d.b.h. Hackberry and elm were the smallest at the time of failure at 13.1 inches d.b.h. and 5.5 inches d.b.h. respectively (Fig. 6). Prestorm inventory data collected in 2016 shows that damage resulting from Storm 2 required the removal of 2.2 percent of the total elm population and less than 1 percent each of hackberry, ash, linden, and maple (Fig. 7). Total prestorm population percentages of these five genera were also calculated. Maple was the most populous at 27.4 percent, followed by ash and linden at 16.6 percent and 11.6 percent, respectively. Elm and hackberry were the least populous of these five genera at 7.3 percent and 5.5 percent, respectively (Fig. 7).

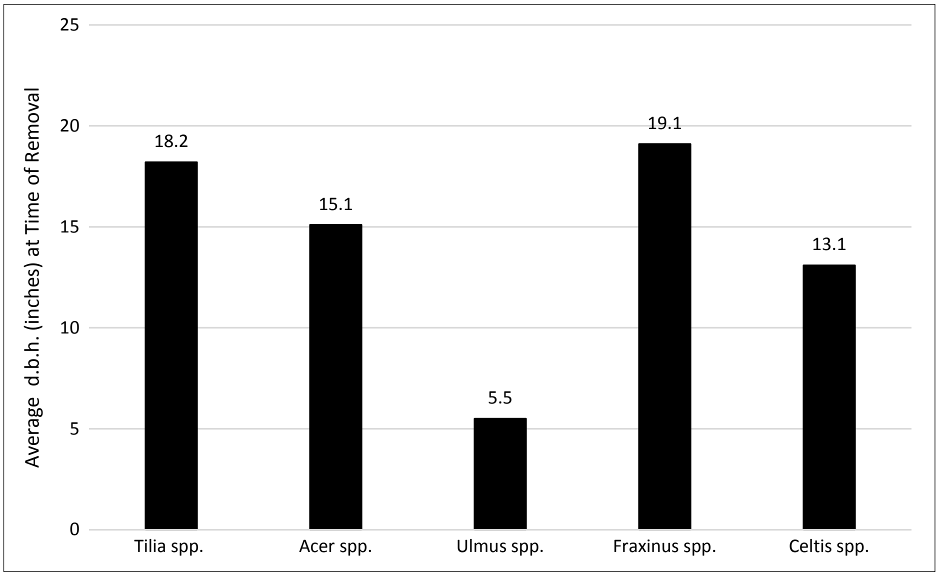

Figure 5.—Average d.b.h. at the time of removal after Storm 1 (28 July 2015).

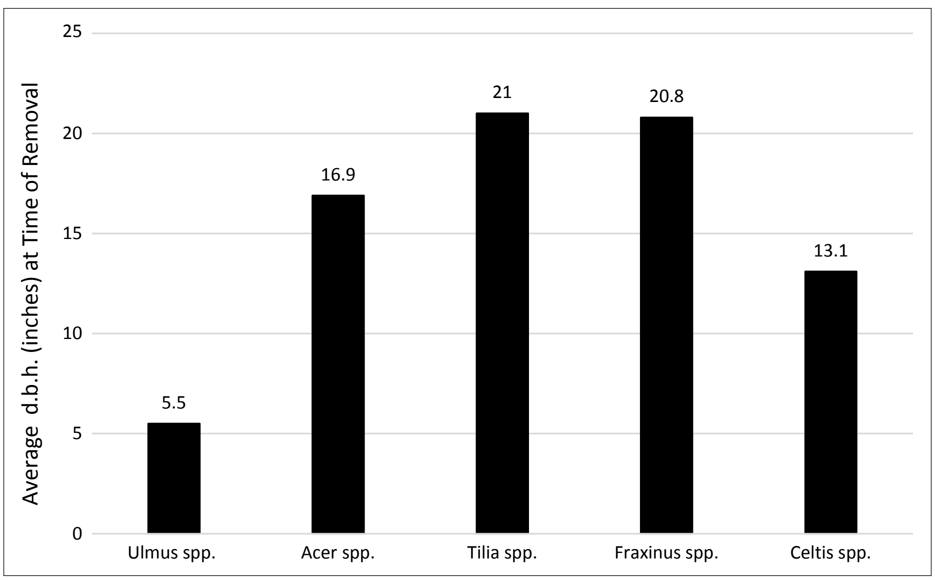

Figure 6.—Average d.b.h. at the time of removal after Storm 2 (05 July 2016).

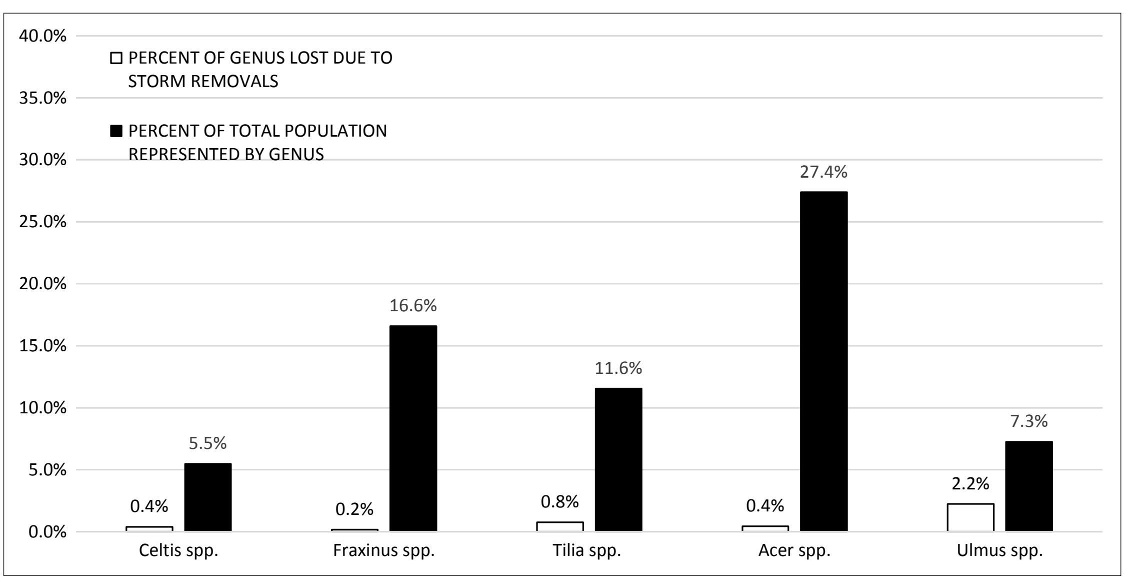

Figure 7.—Percentage of trees by genus lost due to storm removals after Storm 2 (05 July 2016) compared to the percent of the total city tree population of each genus.

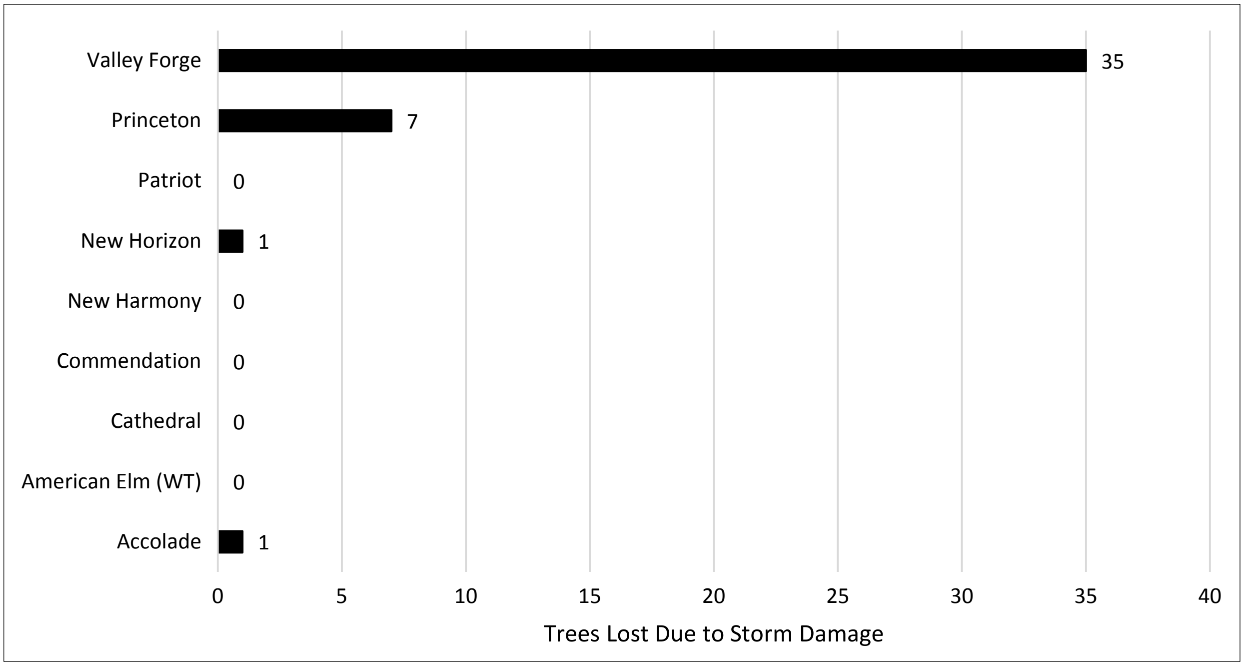

Figure 8.—Number of trees removed by elm species or variety resulting from Storm 1 (28 July 2015). WT refers to wild-type American elm.

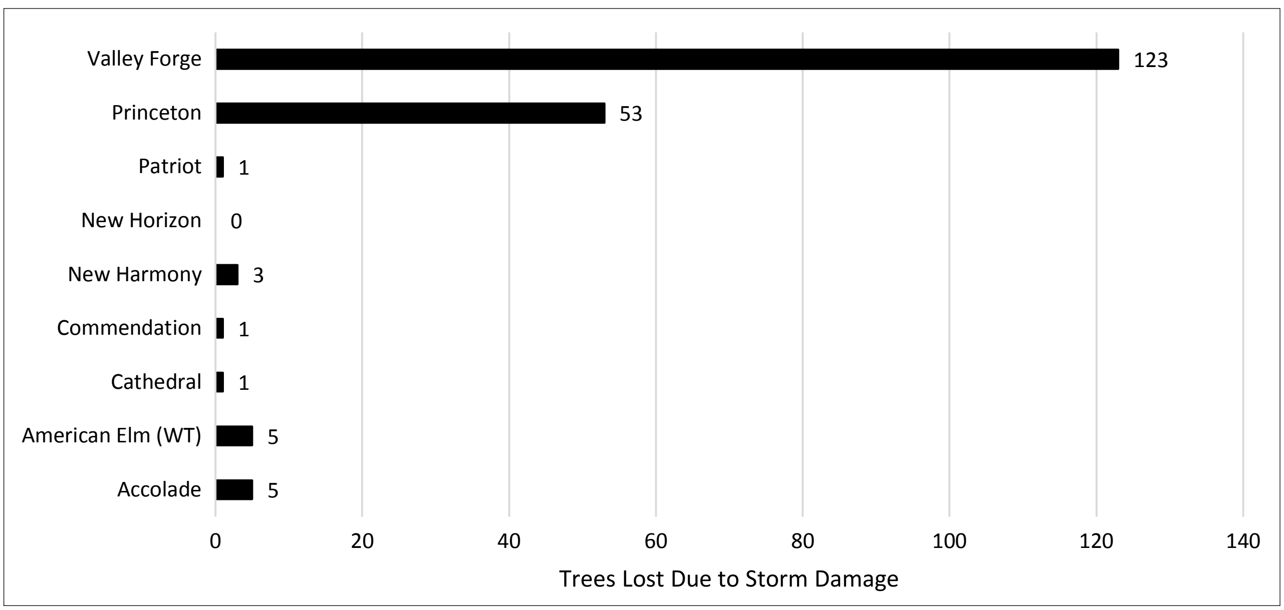

Figure 9.—Number of trees removed by elm species or variety resulting from Storm 2 (05 July 2016). WT refers to wild-type American elm.

In Storm 1, Valley Forge American elm failed more frequently than any other elm variety, cultivar, or species, with 35 removals. This was followed by Princeton American elm at seven removals (Fig. 8). The same trend was observed in Storm 2 with Valley Forge having the highest rate of failure within the elm genus at 123 removals and Princeton at 53 removals (Fig. 9). Varietal failure rates were calculated for Storm 2 only with 17.7 percent of all Valley Forge and 2.7 percent of all Princeton requiring removal after this storm (Figs. 10 and 11).

For both storms, chi-square test procedures were used examine removals at the cultivar, variety, and species level within the elm genus. Test results indicate that removal rate was

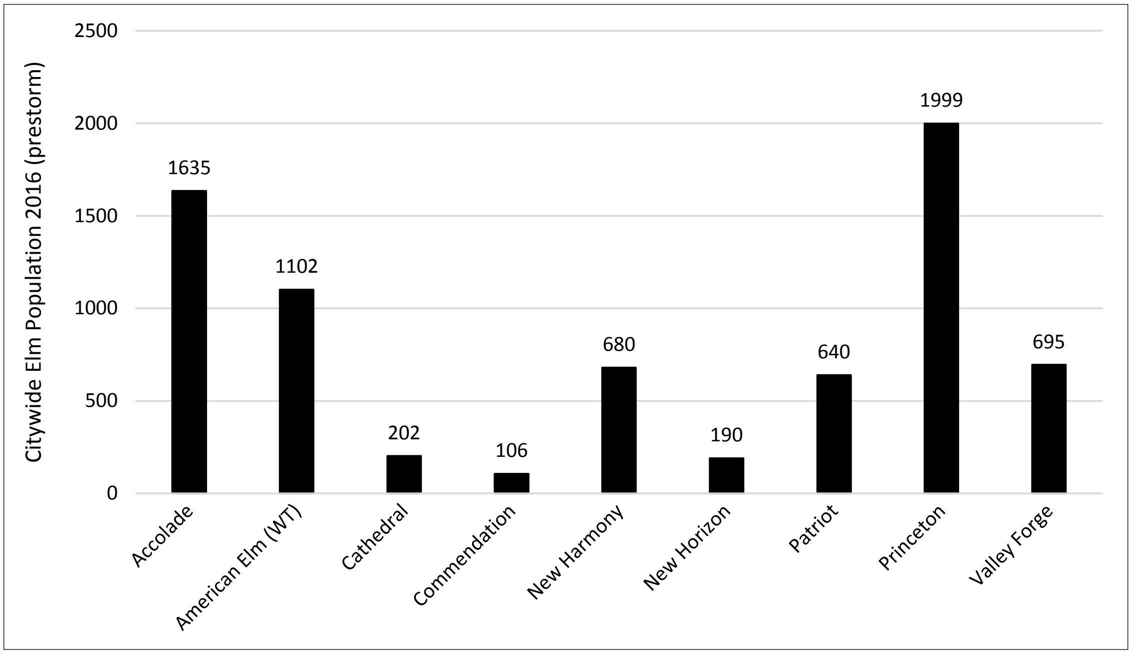

Figure 10.—Total elm population in Saint Paul, MN, by species or variety prior to Storm 2 (05 July 2016). WT refers to wild-type American elm.

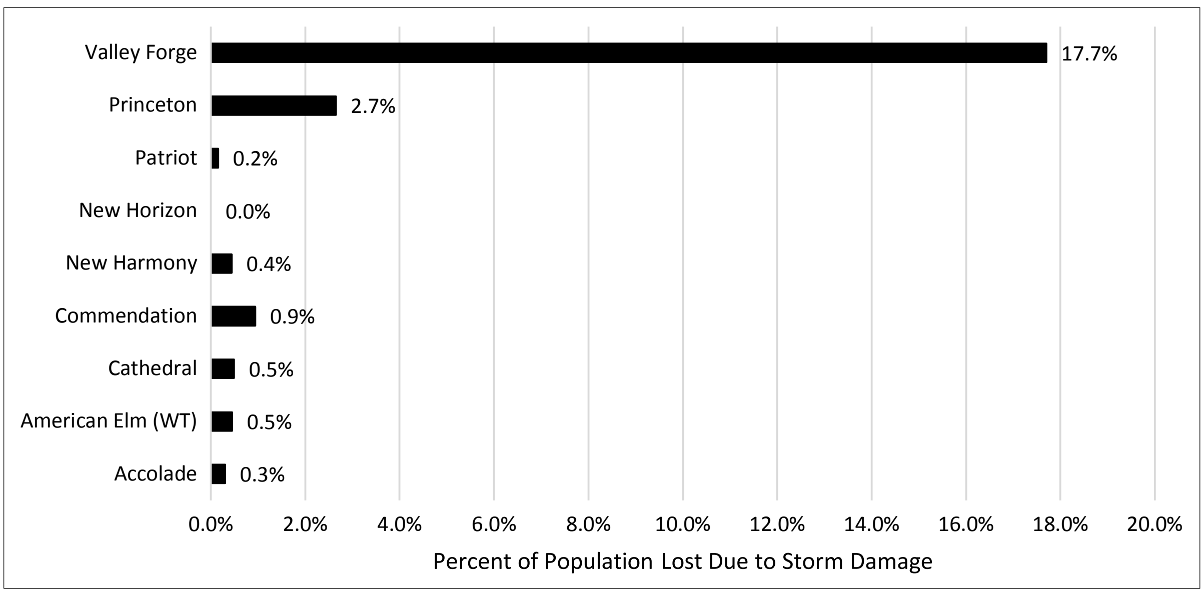

Figure 11.—Percentage of total elms removed by species or variety after Storm 2 (05 July 2016). WT refers to wild-type American elm.

significantly different between Princeton, Valley Forge, New Horizon, and Accolade elm in Storm 1 ($\chi^2(3, N=44) = 72.00, p < 0.01$). In Storm 2 removal rates also differed significantly between New Harmony, Princeton, Valley Forge, wild-type American elm, Accolade, Cathedral, Commendation, and Patriot elms ($\chi^2(9, N=192) = 733.94, p < 0.01$). Chi-square tests procedures were also conducted with adjusted expected removal values for Storm 2. Expected values were adjusted to account for overall representation of a cultivar, variety, or species within the elm genus and removal rate was also found to be significantly different between New Harmony, Princeton, Valley Forge, wild-type American elm, Accolade, Cathedral, Commendation, and Patriot elms ($\chi^2(7, N=192) = 676.04, p < 0.01$). Actual values, expected values, and residuals for elm removals resulting from Storm 2 are were also calculated (Table 1).

Table 1.—Total elm population in Saint Paul, MN, by species or variety prior to Storm 2 (05 July 2016). Actual losses resulting from storm-related removals and the predicted losses based on weighted frequencies and residuals determined by the overall representation of each species or variety within the elm (*Ulmus* spp.) genus. WT refers to wild-type American elm.

Elm Variety or Cultivar	Total Population 2016	Actual N	% of Population	Predicted N
Accolade	1635	5	22.6%	43
American elm (WT)	1102	5	15.2%	29
Cathedral	202	1	2.8%	5
Commendation	106	1	1.5%	3
New Harmony	680	3	9.4%	18
Patriot	640	1	8.8%	17
Princeton	1999	53	27.6%	53
Valley Forge	695	123	9.6%	18
	7059	192		187

Elm Variety or Cultivar	Total Population 2016	Actual (N)	Predicted (N)	Residual (N)
Accolade	1635	5	43	-39
American elm (WT)	1102	5	29	-25
Cathedral	202	1	5	-4
Commendation	106	1	3	-2
New Harmony	680	3	18	-16
Patriot	640	1	17	-17
Princeton	1999	53	53	-2
Valley Forge	695	123	18	104
TOTAL	7249	192		

Discussion

This initial examination of failure from two recent storms in Saint Paul, MN, indicates that elms, particularly young American elms, are suffering damage and subsequently, removal, at a rate that is disproportionate to their representation in the overall urban tree population of this city. These storm failures and removals that are observed in young American elms also are occurring much earlier in their lives than any other tree species. This trend is troubling when communities like Saint Paul are devoting so much effort to pruning young elms and other small trees. Saint Paul currently prunes young elms a minimum of three times during the first 10 years after planting. This pruning cycle is generally more frequent than other, similar communities and well-aligned with recommended pruning cycle frequencies reported in a recent review of literature (Vogt et al. 2015).

Additionally, there are two trends observed when elm failures are compared with other species that suffered damage and failures. First, elms are failing at a rate that is two or three times greater than other species when compared to their representative population, citywide. In Storm 2, elms lost 2.2 percent of their population while maples lost just 0.4 percent. A second trend observed in elms is their size at the time of failure. In both the 2015 and 2016 storms, the average d.b.h. at the time of failure for all elms was about 5.5 inches d.b.h., this even includes the handful of larger, mature elms that also failed. In contrast, all other species were much larger at the time of failure, ranging from 13 inches d.b.h. in hackberry to nearly 20 inches d.b.h. in ash and linden. The other species typically failed due to wood decay at the time of failure while elm failures occur at weak branch or leader attachments in otherwise healthy, nondecayed wood tissue (Johnson, unpublished data). The observed form and exceptional growth rate of both Valley Forge and Princeton American elm may play a role in their exacerbated rate of storm damage and catastrophic failure. Both of these selections have an alarming tendency to form weak branch attachments at much more acute angles than other elm varieties—especially those of Asian origin. Additionally, American elms, in general, are less likely to exhibit an excurrent growth habit (i.e., a growth form with a strong, dominant central leader) (Fig. 1). Asian elms such as Accolade may possess inherent growth habits that are structurally superior to others.

The rate of failure observed in both Valley Forge and Princeton American elm indicates that more research is required to accurately determine optimum pruning cycles for these and other, similarly structured young trees in the municipal setting and to make recommendations for species that are properly aligned with expectations and municipal budgets allocated for young tree maintenance. Juvenile form of young elms is very plastic and can be greatly influenced—positively and negatively—in the production nursery setting. To avoid the release of elm cultivars that exhibit poor branch structure thus increasing likelihood of failure and damage during wind-loading events, researchers should conduct long-term growth habit assessments alongside Dutch elm disease resistance screening trials, preferably in cooperation with arboricultural researchers or arborists skilled in assessing juvenile form and pruning schedules. Also, because juvenile growth rates and forms of elm are so different than their mature counterparts, assessment of mature tree branch architecture (e.g., branch angle measurement and incidence of dysfunction) does not present itself as a technique useful for screening.

Acknowledgments

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Literature Cited

Gilman, E.F. 2003. **Branch-to-stem diameter ratio affects strength of attachment.** Journal of Arboriculture. 29(5): 291-294.

Gilman, E.F.; Miesbauer, J.W.; Masters, F.J. 2015. **Structural pruning effects on stem and trunk strain in wind.** Arboriculture & Urban Forestry. 41(1): 3-10.

IBM Corp. 2013. **IBM SPSS statistics for Windows, version 22.0.** Armonk, NY: IBM Corp.

Johnson, G.R. 2014. **When winds and trees collide: The influence of sidewalk repair, trunk flare, and wind-loading events on boulevard tree failures.** Arborist News. December 2014: 50-53.

Miller, R.W.; Sylvester, W.A. 1981. **An economic evaluation of the pruning cycle.** Journal of Arboriculture. 7(4): 109-112.

Ryder, C.M.; Moore, G.M. 2013. **The arboricultural and economic benefits of formative pruning street trees.** Arboriculture & Urban Forestry. 39(1): 17-24.

Smiley, E.T. 2003. **Does included bark reduce the strength of codominant stems?** Journal of Arboriculture. 29(2): 104-106.

Vogt, J.; Hauer, R.J.; Fischer, B.C. 2015. **The costs of maintaining and not maintaining the urban forest: A review of the urban forestry and arboriculture literature.** Arboriculture & Urban Forestry. 41(6): 293-323.