STORMWISE: INTEGRATING ARBORICULTURE AND SILVICULTURE TO CREATE STORM-RESILIENT ROADSIDE FORESTS

Jeffrey S. Ward, Thomas E. Worthley, Thomas J. Degnan, and Joseph P. Barsky[1]

Abstract.—The band of trees within 30 m of roads (i.e., roadside forests) is often left unmanaged during traditional forest management activities because of liability concerns about inadvertently causing a vehicular accident or damaging utility lines during harvests. The trees in these same neglected forests often cause extensive utility outages and road blockages during extreme weather. Building on the prescriptions developed in Connecticut , the authors, utility companies, state foresters, highway departments, and forest landowners initiated a collaborative project—Stormwise—that is developing and testing practical, cost-effective, and proactive protocols that integrate silvicultural and arboricultural practices. The goals are to reduce the risk of damage during extreme storms, increase habitat diversity, recover underused volume, and maintain aesthetic appeal. Immediately adjacent to utility and road corridors, trees are pruned using ANSI standards, and at-risk trees are removed. To the interior, crop tree management is used to develop trees with wind-firm, open-grown characteristics along with subcanopies of short-stature trees, native shrubs, and herbs. Seven study areas have been established along 2.3 km of roadside forests. Lessons learned about tree selection and coordination from implementation at three areas are being incorporated into treatments scheduled at the remaining sites. Results of treatments and monitoring will be used to inform communities and stakeholders about the management of roadside forests.

INTRODUCTION

The 30 m of forest adjacent to utility and transportation corridors, hereafter referred to as "roadside forests", is often left unmanaged because of understandable liability concerns about accidently felling a tree onto a power line or across a road in front of a moving vehicle. Management of roadside forests is typically limited to periodic pruning of branches over utility wires or branching extending into the traffic safety zone, removal of saplings and shrubs in those zones, and the occasional removal of hazard trees.

The relative importance of the roadside forest resource is unappreciated. We estimated that approximately 5 percent of Connecticut's forests are within 30 m of a public road, qualifying them as roadside forests (State Vegetation Management Task Force [SVMTF] 2012). This high proportion categorized as roadside forests might seem to be an outlier because of the unique combination of high forest cover (58 percent, Shifley et al. 2012) and high population density (fourth highest in the United States) in Connecticut; however, a recent study reported that 5 percent of forests across the nation were within 42 m of a road (Riitters and Wickham 2003). Road density does not have to be high for a substantial proportion to be considered roadside forest. For example, roadside forests would account for 4.2 percent of forested area in a 260 ha block bounded by an 8 m wide road.

[1] Chief Scientist (JSW) and Agricultural Research Technician (JPB), Connecticut Agricultural Experiment Station, Department of Forestry and Horticulture, 123 Huntington Street, New Haven, CT 06511; Associate Extension Professor (TEW), Cooperative Extension, Haddam, CT; Senior Environmental Scientist (TJD), ES&P, Wallingford, CT. JSW is corresponding author: to contact, call 203-974-8495 or email at jeffrey.ward@ct.gov.

Because the expanse of roadside forests with trees that could affect utility infrastructure and transportation in the region is considerable, a worthwhile goal is moving from their benign neglect with the reactive removal of failed trees affecting public safety to fostering the development and implementation of proactive, cost-effective management practices. The challenges for forest managers are to maintain the aesthetic appeal and ecosystem function (Coffin 2007) of forested byways and mitigate the potential for tree-caused damage to infrastructure during extreme storms. Because the oak-hickory forest does not have a balanced age structure at the regional level (Shifley et al. 2012), and rarely does at the landscape level, creating storm-resistant roadside forests provides an opportunity to increase biodiversity by increasing the diversity of age classes, species, and stand structures.

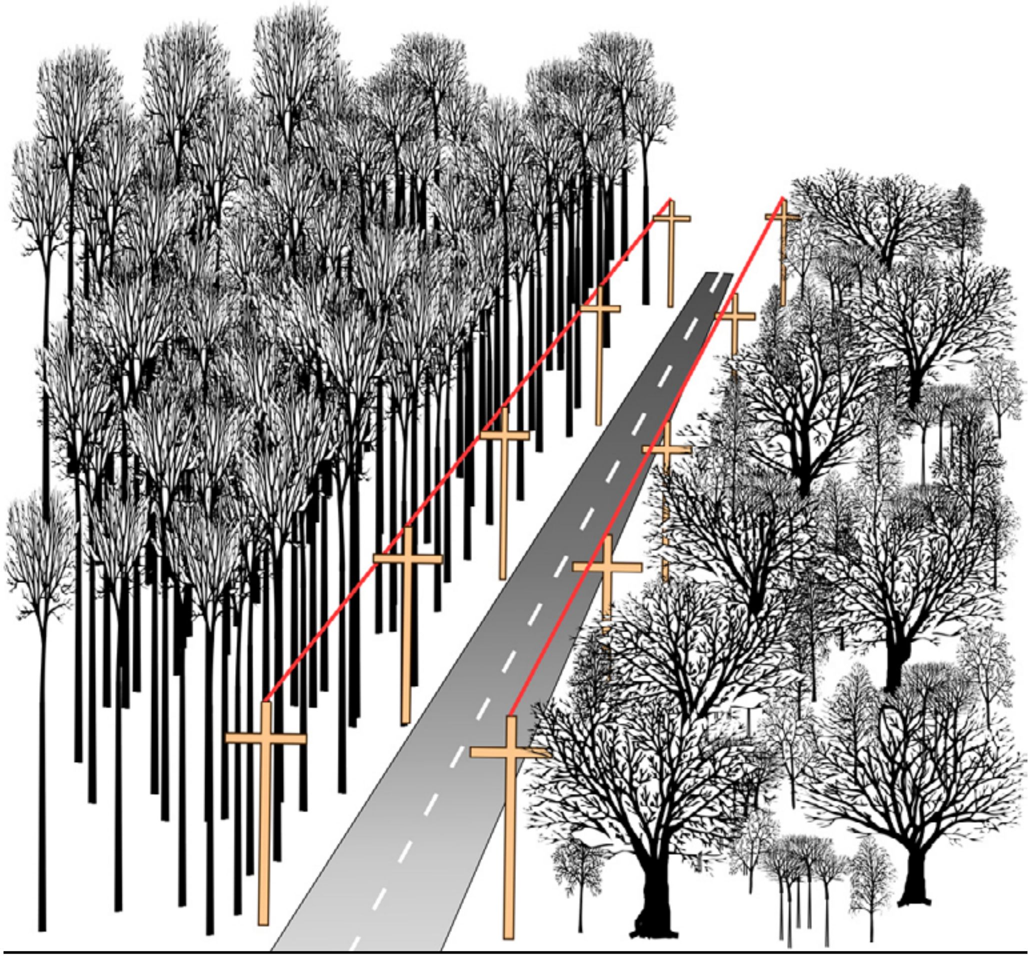
In response to several exceptionally extreme storms in 2011 and 2012, which caused massive tree failure that disrupted utility services and blocked roads for weeks in some areas, a private/public/nongovernmental organization collaborative called Stormwise was formed to characterize and develop management protocols for roadside forests. This partnership includes the private sector (Eversource Energy, United Illuminating, and Connecticut Water Company); public and quasi-public entities (the Connecticut Agricultural Experiment Station, the University of Connecticut, the Connecticut Department of Energy & Environmental Protection, the Connecticut Department of Transportation, the South Central Regional Water Authority, and the Town of Manchester); and nongovernmental organizations (Audubon Connecticut and the White Memorial Foundation).

The proactive approach of Stormwise is to develop healthy, storm-resistant roadside forests by melding arboricultural (individual tree care) and silvicultural (forest management) practices (SVMTF 2012). At the individual tree level, Stormwise vegetation management ideas are based in four very basic concepts:

1. Trees with room or space to grow are healthier trees.
2. Tree branches and twigs will grow and develop toward the sunlight.
3. Trees with the freedom to move in the wind will become more wind firm.
4. The right tree growing in the right place can be given a competitive advantage.

Our vision is to preserve the aesthetic and other benefits of forested roadsides while enhancing their structural and biological diversity. This is achieved by promoting the growth of open-grown trees with crowns that are wide rather than tall, such as those in open fields or orchards, compared to trees in forests, which tend to be tall with narrow crowns. Species with decurrent growth (*Acer*, *Fagus*, *Quercus*) will be favored; those with excurrent growth (*Betula*, *Liriodendron*, *Pinus*, *Populus*) will be discouraged.

Trees growing without dense competition typically display a thigmomorphogenetic (wind) response of stouter buttressed stems and branches and have well-anchored, widespread root systems (Kozlowski and Pallardy 1997). All these characteristics of open-grown trees make them more resistant to wind damage, especially to stem failure or becoming windthrown (Poulos and Camp 2010). Open-grown trees can still provide important aesthetic, hydrologic, and habitat benefits and remain wind firm and of lower risk to power and road infrastructure (Fig. 1). Surrounding these trees and on the immediate roadside edge we envision a matrix of short-stature trees (*Benthamidia*, *Carpinus*, *Ostrya*) and shrubs (*Cornus*, *Hamamelis*, *Viburnum*, *Vaccinium*).



A: Unmanaged roadside forest with tall trees susceptible to storm damage and with few small trees and shrubs.

B: Storm-resistant forest of wind-firm trees that are wide rather than tall and are interspersed with shrubs and small trees. Utility lines are shown on both sides of the street for illustrative purposes.

Figure 1.—Illustration of typical unmanaged roadside forests (A) and roadside forests after full implementation of Stormwise standards (B).

We face a number of challenges to widespread implementation and adoption of Stormwise roadside forest management. On the implementation side, we must develop practical expertise and explore various methods and logistics for implementing a novel vegetation management paradigm. Implementation questions are being examined at our demonstration areas where we are promoting cooperation and coordination of work done by utilities/arborists and foresters/loggers—two groups that are friendly but have not traditionally had the opportunity to work together on projects. Tree crews and forest practitioners will need to use their unique skill sets to develop methods and techniques that are specific to Stormwise roadside forest management.

Acceptance by the public and the arboricultural and forestry communities will be key to widespread adoption of Stormwise roadside forest management. This acceptance will not necessarily hinge only on demonstrating that these practices result in increased utility reliability in extreme weather, but also that the practices create forests that are aesthetically pleasing (Jones 1993, Wolf 2003) and management practices that are cost-effective for utilities, land managers, and landowners. One unique challenge being explored is whether wood produced during roadside forest management activities can be used for products and whether value can be recovered for towns or landowners to offset some of the cost of proactively removing hazard trees.

The proximity of utility lines would present a challenge for implementing these prescriptions if only traditional forest harvesting techniques were available. This challenge is met by partnering with utility tree crews (Eversource Energy and United Illuminating) to fell trees that, should they fail, could land on utility wires or travel corridors. Utility companies immediately benefit from the reduced costs of not having to chip branches (they stay in the woods). Landowners or towns can derive immediate benefits from trees that can be used or sold for higher-value lumber rather than for firewood. The environmental benefits of developing roadside forests with appropriate species include greater biodiversity, increased structural and age diversity, and healthier and more vigorous trees.

The objectives of this paper are to highlight the relative importance of roadside forests, to begin characterization of their composition and structure, and to suggest that roadside forests should be thought of not as an unmanageable liability, nor as a purely aesthetic screen, but as an opportunity to demonstrate proactive forest management. Managing these forests proactively could reduce damage to infrastructure caused by trees during extreme storms; increase age, species, and habitat diversity; recover underused volume; and maintain aesthetic appeal.

STORMWISE FOREST MANAGEMENT

The following paragraphs have been modified from the section "Roadside management in a forested landscape" in the Connecticut vegetation management task force report (SVMTF 2012).

Management Zone

Incorporate the area as large as 30 m on both sides of the infrastructure (e.g., utility lines, roads) passing through forested areas. This includes an infrastructure zone (within 10 m of wires or roads) and a side zone (extending out an additional 20 m) in stands scheduled for forest management (Fig. 2). Mature upper canopy trees are often 20 m tall; some white pine, yellow-poplar, and red oak reach 30 m or taller. Therefore, the management zone should be 30 m wide to include all mature trees that could damage utility infrastructure or block roadways during

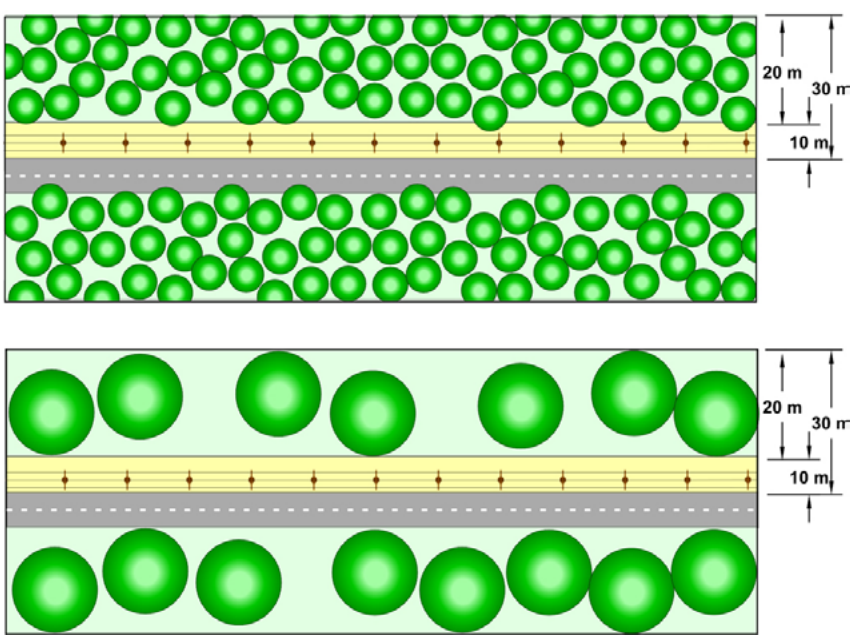


Figure 2.—Bird's-eye view of a typical roadside forest (top) with 1,000+ trees/km on each side of a road compared with a Stormwise forest (bottom) with fewer trees that have crowns that are wide instead of tall. Small trees and shrubs are not shown in either forest, but would occupy gaps between trees.

Tree crowns are shown as green circles and utility poles are illustrated as crossed brown circles connected by brown wires.

an extreme storm. Reducing the visual impact of any cutting operation is imperative because roadside forests by definition are in highly visible locations. Harvesting debris is inevitable; however, care should be taken to reduce the number of high stumps and reduce the height of unmerchantable tops (Jones 1993).

Infrastructure Zone

Combine traditional pruning practices (ANSI A300 Standards) (American National Standard 2005) and an enhanced hazard tree identification process with a long-term, selective tree removal program. Conduct an in-depth review of trees that looks at aboveground and belowground health symptoms and structural risks. This includes reviewing trees that may otherwise be aggressively pruned, to determine if excessive live wood (more than 25 percent) will be removed or the tree will have insufficient leaf area after pruning (typically equivalent to 40 percent of total tree height). Aggressive pruning after a rigid utility line clearance or sight-line standard may leave a tree with long-term structural and health risks that are also visually unappealing. Leaving some structurally sound large trees with well-balanced crowns near wires will improve the aesthetics of the residual stand. Smaller growing trees, shrubs, and grasses should be encouraged to emphasize the "right-tree-right-place" approach. Encourage protection of native species such as dogwood or hophornbeam and shrubs such as mountain laurel, witch hazel, and spicebush. Consider controlling invasive shrubs (e.g., honeysuckle) and vines (e.g., bittersweet). It will be important to consider sight lines when developing a denser understory adjacent to roads.

Side Zone (Young Stands)

Ideally, creation of a storm-resistant forest within the side zone would begin in young stands by releasing 75-100 trees/ha (225-300/curb km, each side of the road) from competition using well-developed crop tree management prescriptions (Miller et al. 2007). Tree selection should be based on growth form (excurrent versus decurrent) and structural integrity and should include a diversity of species. All trees directly competing with selected residual trees should be removed when the canopy begins to close, about every 10-20 years. As trees mature and the crowns of other residual trees close in, the goal should be to reduce the number of residual trees from 75-100 to 30-50 large trees/ha (90-150/curb km) with wide-spreading crowns. These storm-strong trees should be well spaced and managed so that they develop stout trunks and healthy crowns similar to what might be found in an open park. Unlike a park, though, these trees would be surrounded by a diversity of smaller trees, shrubs, and wildflowers.

Side Zone (Mature Stands)

Creating a storm-resistant forest is more challenging in mature roadside forests. Removing all but 30-50 trees/ha in one step would increase the susceptibility of the remaining trees to wind damage for several years until they develop increased stem taper (more wood at the bottom of the tree) and better anchored roots. A more pragmatic approach is to begin with a heavy crown thinning that emphasizes removing trees with obvious structural defects (e.g., cavities or codominant stems with included bark); potential structural defects (e.g., frost cracks, fungal structures, heavy lean, offset crowns); small crowns; perennial diseases; or dieback in the upper crown (Poulos and Camp 2010). The thinning would allow residual trees to become more wind firm by increasing stem taper and developing stronger root systems.

The next step would be to conduct another thinning 10-15 years later, after the trees have become more wind firm. Proceeding immediately to the goal of 30-50 large trees/ha may be possible if sufficient candidate trees with balanced crowns and well-anchored root systems are present. Otherwise, multiple thinnings are recommended to achieve this goal. The thinning process will also encourage growth of native shrubs and small trees that will contribute to the natural look by creating a multilevel canopy reminiscent of an old-growth forest. Currently many, if not most, roadside forests in Connecticut are even-aged stratified mixtures. A more desirable condition would be a low-density, uneven-aged mixture. The specific combination of silvicultural treatments needed to achieve this condition will depend on a number of factors, including initial stand structure. Invasive vines and shrubs may be a problem in some areas after thinnings. Depending on the level of infestation by invasive species, mechanical or chemical control may be required.

The results of this management will be an infrastructure zone that is dominated by shorter right-tree-right-place trees and shrubs, and a side zone with widely spaced large trees in the overstory, younger trees of multiple age and size classes growing in the midstory, and native shrubs in the understory. In the wire zone, long-term pruning costs will be reduced by removing many side zone trees that would otherwise have encroached into the infrastructure zone. This more active, holistic management approach focuses on developing storm-resistant forests along utility line corridors and will reduce damage during the next extreme storm. This approach requires a more expansive vision of the roadside forest and utility line corridor management that looks at reducing immediate risks and at long-term individual-tree care and whole-forest care. For maximum effectiveness, this management regime should be combined with education and outreach to landowners to increase public awareness and achieve a safer, more reliable utility and transportation system.

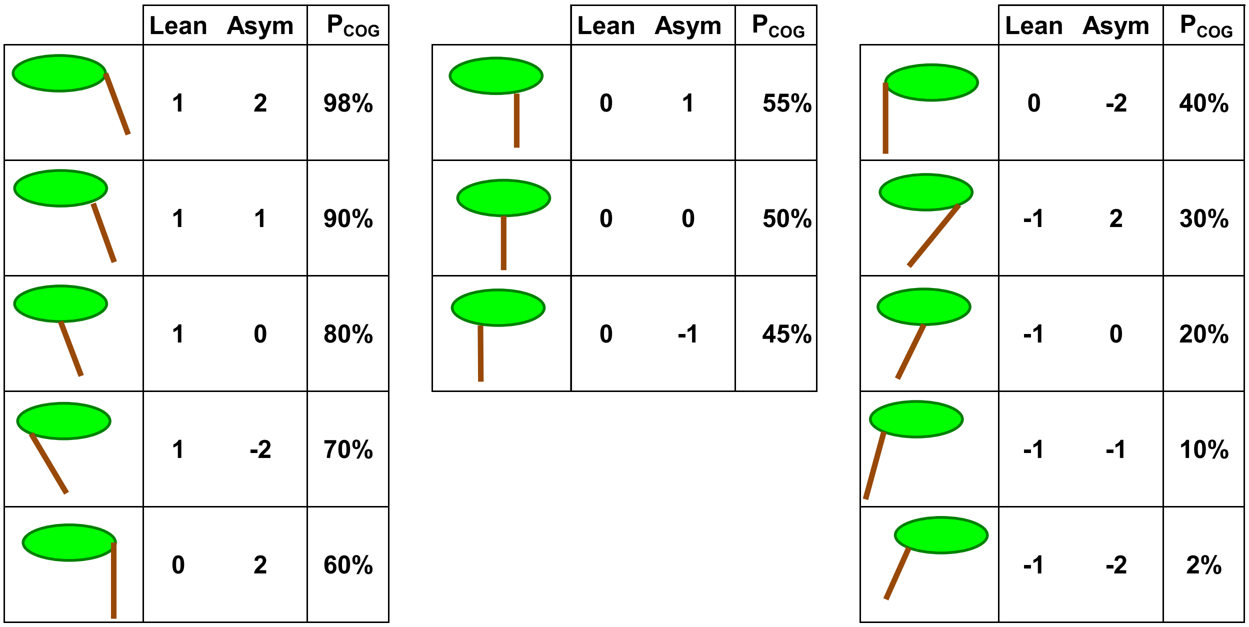
METHODS

Seven study areas were established in Connecticut roadside forests in 2014 and 2015 (Table 1). Once harvesting is completed in 2016, three of the study areas will be part of commercial harvest operations, two areas not scheduled for adjacent-stand management will be harvested to produce lumber in small volumes for the state park system, and one area will be a modification of scheduled highway vegetation management.

All stems with diameters >12.5 cm within 40 m of infrastructure edge (mowed road shoulder, centerline between utility poles if no road) were sampled along transects 200-600 m long (Fig. 2). Site constraints limited sampling to 25 m from forest edge at the Fairfield County site, which was a 50 m wide forested strip between limited access highway lanes. A number and diameter at breast height (d.b.h.) mark were painted on all trees before mapping to the nearest 0.1 m and recording the species, crown class, and diameter.

Table 1.—Description of roadside study areas established in Connecticut

County	Plot size (m)	Road type	Electric service
Fairfield	600 × 25	Limited access highway	None
Hartford	200 × 40	State highway	Backbone (3-wire)
Litchfield	200 × 40	State highway	Backbone (3-wire)
Middlesex	200 × 40	Town road	Backbone (3-wire)
New Haven	400 × 40	State highway	Backbone (3-wire)
New London	400 × 40	State highway	Backbone (3-wire)
Tolland	250 × 40	Town road	Lateral (1-wire)



Lean	Asym	P_{COG}
1	2	98%
1	1	90%
1	0	80%
1	-2	70%
0	2	60%
0	1	55%
0	0	50%
0	-1	45%
0	-2	40%
-1	2	30%
-1	0	20%
-1	-1	10%
-1	-2	2%

Figure 3.—Center of gravity weighting factor (P_{COG}) estimates using lean—whether a tree bole is leaning toward infrastructure (to left) and asymmetry (asym)—the position of the crown relative to the root collar.

The following data were collected for all trees within 20 m of utility poles and all trees with the potential to fall into the utility corridor: total height; pulpwood height (to 10 cm diameter); degree of root, stem, and crown damage; branch union type; and cracks. Trees were considered to have major defects if they had at least one of the following conditions: roots with advanced decay in or near root collar, a cavity at least one-third of tree diameter, more than one-third of canopy dead, codominant leaders with included bark, or large cracks with decay.

To examine the likelihood that a tree would fall toward the utility wires or road, information was collected about bole lean and crown asymmetry toward or away from the utility wires. Crown asymmetry was assigned one of five classes: all to road, two-thirds to road, centered over bole, one-third to road, or all away from road (Fig. 3). Because approximately 70 percent of a tree's biomass was found in the merchantable saw log (Swank and Reynolds 1986), boles leaning more than 7.5° toward utility poles were considered to have a positive center of gravity (COG). Conversely, those leaning more than 7.5° away from the road were considered to have a negative COG. Trees with neutral bole COGs were considered to have positive COGs if the asymmetry of the crowns was at least two-thirds toward the road.

At all sites, work was planned in coordination with a utility arborist, and trees within reach of the roadside or power line were identified for trimming, removal, or no treatment. Roadside trees (within the wire zone) of commercial size designated for removal were topped by the utility tree crew and the main trunk or bole was left standing. The remaining trees and roadside boles designated for harvesting were dropped using applied directional-felling techniques. Wood removal was by skidder or forwarder at locations where harvesting was under way in the adjacent stand. At locations where only the treatment site was harvested (small area, small volume), scale-appropriate equipment was used for wood removal and value-added operations. Equipment combinations included a rapid transit vehicle with an arch, a small four-wheel drive tractor with a three-point hitch-mounted winch, and a tractor with an arch. A portable band saw mill was incorporated for value-added product recovery at two locations.

ANALYSIS

To examine how density changed with distance from utility poles, we placed distances at 2 m intervals between 0 and 10 m (0-2, 2-4 … and 8-10 m from poles) and 4-m intervals thereafter (10-14, 14-18 …). Density and basal area values were standardized per hectare for ease of comparison.

Repeated measures with analysis of variance for density were used with distance from poles as the "within subject" factors (SYSTAT software, San Jose, CA). Because the number of within subject factors must be less than the number of replicates for repeated measures analysis, we first examined whether density varied 18-40 m from utility poles. Finding no difference (see Results), we examined whether density/basal area varied within 24 m of poles using the 2- to 4-, 6- to 8-, 10- to 14-, 14- to 18-, 18- to 22-, and 22- to 26-m intervals. This kept the number of within subject factors to less than the number of replicates. The 0- to 2-m interval was not used because few had 2 m of pole centers. Reported p-values are those after applying the conservative Greenhouse-Geisser Epsilon correction for deviations from compound symmetry (SYSTAT Software, San Jose, CA; 2009). Differences were considered significant at $p < 0.05$.

Because of limited funding, actual heights were measured on only 2,879 of the 3,743 trees included in the study. Heights were measured on at least 50 trees of each species at each study area or of all trees of a given species if a site had fewer than 50. These data were used to develop local allometric equations, HT = a + ln(d.b.h.), that were used to estimate the total and pulpwood height of the remaining trees.

The probability (P_{infra}) that a tree would strike infrastructure (utility wire, road pavement) if it fell randomly is

$$P_{infra} = \frac{cos^{-1}\left(\frac{D}{H}\right)}{\pi}, \qquad (1)$$

given a tree of height (H) at distance (D) from the infrastructure (derivation in Appendix). Because the smaller branches in the upper canopy are less likely to break utility wires or to impede traffic if they fall on the road, we used the pulpwood height rather than total height for calculating P_{infra}. We also calculated P_{risk} by weighting P_{infra} with a factor (P_{COG}) relative to whether a tree's COG was positive, neutral, or negative (Fig. 3). For simplicity, all calculations assume level terrain and homogeneous soil conditions.

RESULTS

A total of 3,743 trees were included on the seven study areas (Table 2). Stand types included oak (Middlesex, Tolland), oak-red maple (Hartford), red maple (New Haven), sugar maple-black cherry (Litchfield), and pine-oak (New London). All stands were fully stocked with a basal area of 24.5-36.3 m^2/ha. The mean height of measured upper canopy trees was 17.9-25.4 m across stands.

Not unexpectedly, density of both poletimber and sawtimber was very low immediately adjacent to the utility corridor because most trees that interfered with wires were removed to maintain service continuity (Fig. 4). For both size classes, but especially for poletimber, there was an apparent peak of density at approximately 10 m from utility pole centers and then a gradual decrease to densities consistent with the surrounding forest.

Table 2.—Summary of stand characteristics of roadside study areas established in Connecticut. N = number of trees in each study area.

			Basal area distribution				
County	N	Oak	Maple	Birch	Other	White pine	m^2/ha
Fairfield	953	43%	19%	18%	13%	7%	26.4
Hartford	336	40%	39%	16%	6%	0%	29.9
Litchfield	382	2%	50%	3%	35%	10%	36.3
Middlesex	269	55%	26%	6%	13%	0%	24.5
New Haven	630	8%	70%	5%	14%	2%	27.3
New London	813	25%	18%	0%	0%	57%	35.7
Tolland	360	72%	19%	4%	5%	1%	25.1
Combined	3,743	31%	34%	7%	11%	16%	26.4

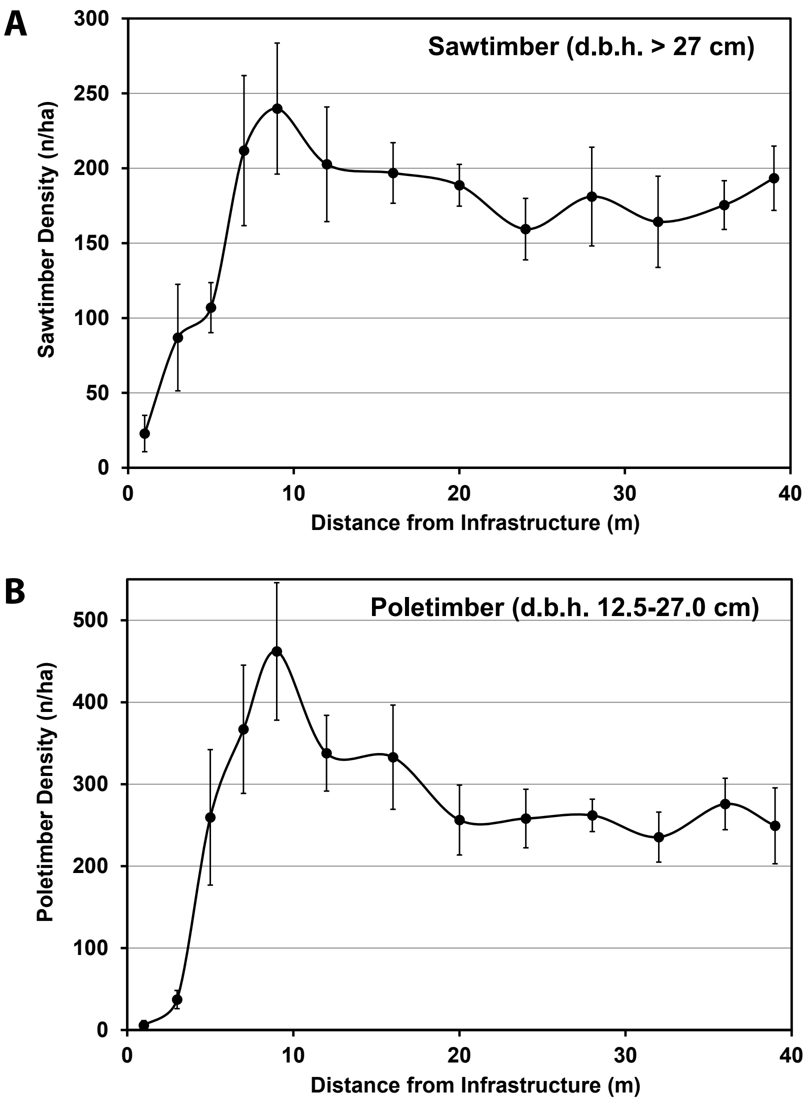


Figure 4.—Density (n/ha) of sawtimber (A) and poletimber (B) trees by distance to infrastructure (e.g., utility wires, roads).

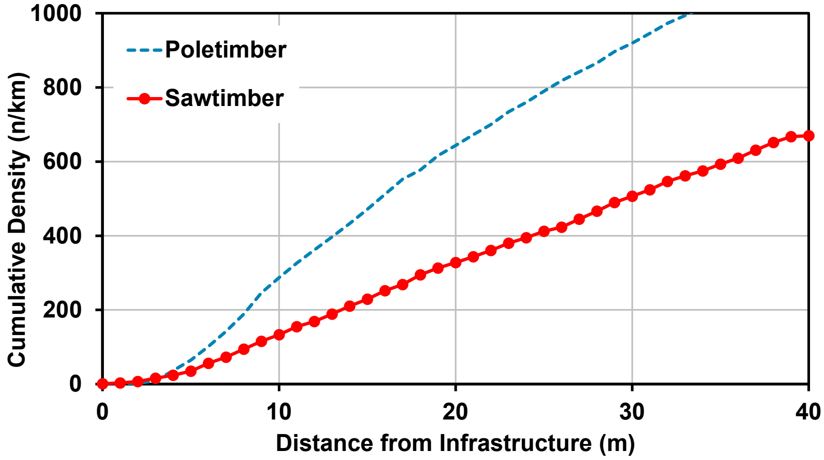


Figure 5.—Cumulative number of trees by size class and distance from infrastructure (e.g., utility wires, roads).

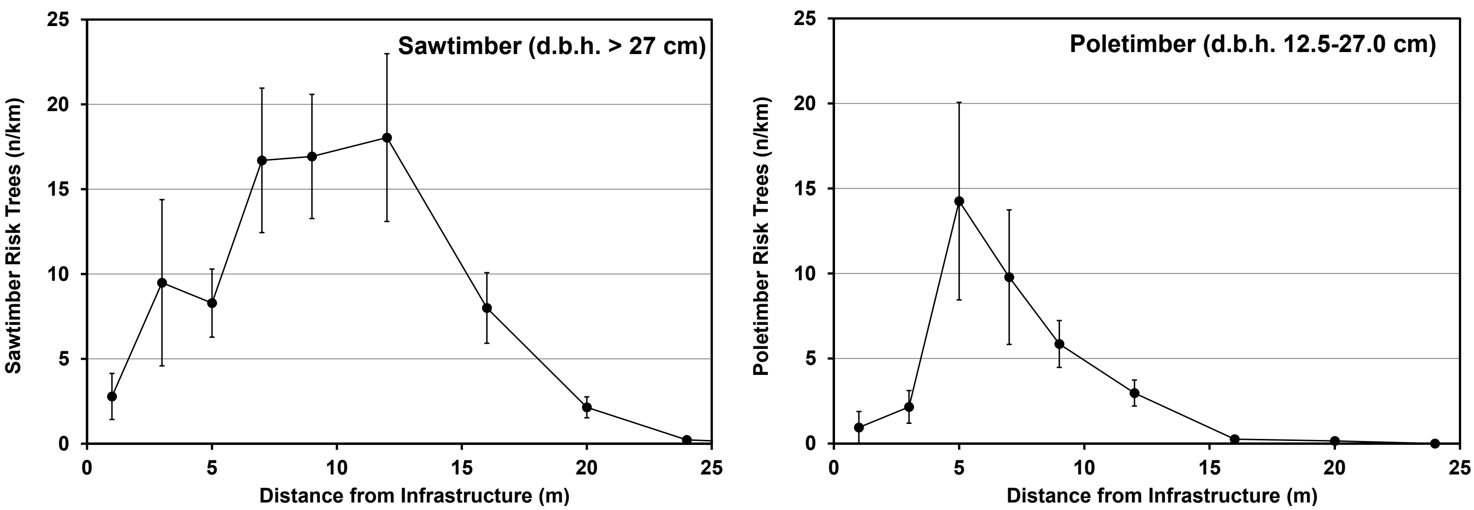


Figure 6.—Estimated number of risk sawtimber trees (left) and poletimber trees (right) that will eventually fall on infrastructure (e.g., on utility wires or across the road). Risk trees are those that will have a branch with a diameter of 10 cm or larger that would strike infrastructure when it falls.

Repeated measures with analysis of variance for density indicated a significant distance effect for poletimber density at distances less than 26 m from utility poles ($F_{5,30}$ = 9.71, P_{GG} = 0.003, where P_{GG} is after Greenhouse-Geisser Epsilon correction), but not for poletimber density in the intervals 18-40 m from utility poles ($F_{4,20}$ = 1.36, P_{GG} = 0.295). For sawtimber density there was only a weak effect at distances less than 26 m from utility poles ($F_{5,30}$ = 2.39, P_{GG} = 0.105) and none for 18-40 m from utility poles ($F_{4,20}$ = 0.53, P_{GG} = 0.612).

From a utility or road maintenance viewpoint, the number of trees per kilometer of forest/corridor interface (Fig. 5) is more pertinent than density per area. There were 313 sawtimber and 616 poletimber trees/km within 20 m of the utility corridors. We estimated that a surprisingly high number of sawtimber (83 ± 17/km) and poletimber (36 ± 12/km) risk trees would fall into the utility or travel corridor if they were windthrown (Fig. 6). Most of these risk trees are outside the utility protection zone and outside zones cleared along travel corridors, except for limited access highways.

DISCUSSION

Utility disruption and road obstruction caused by falling branches or windthrown trees are all too common along forested roadsides during extreme weather events (wind, ice, or snow). Except for removal of trees identified as being very high risk because of advanced decay or severe lean, the traditional reactive approach has been to deal with each tree after it has failed and has fallen onto utility wires or across roads.

Currently tree crews and arborists who work for public utilities in many states are the de facto managers of the roadside forest. In Connecticut, the Public Utility Regulatory Authority limits public utility tree crew activity to a clearly defined utility protection zone. With the concurrence of the abutting property owner, any and all branches may be trimmed within the utility protection zone as high as the equipment can reach. This activity, called *enhanced tree trimming*, addresses the bulk of branch failure issues directly above power lines that might occur during heavy wet snow or ice storms. Our study suggests, however, that potential damage resulting from wind is a broader forest management issue that demands a combination of arboricultural and silvicultural solutions to alter the conditions in roadside stands, as opposed to simply trimming roadside trees.

Although the reactive approach spreads the cost out over time, it often results in power outages, blocked roads limiting emergency access by first responders and the public, and the occasional tragedy when a falling tree strikes a moving vehicle. During the extreme storms that happen every several decades, extended power outages and road blockage caused by falling trees can last for days or weeks and result in economic losses that can reach into the billions of dollars (SVMTF 2012). In addition, because the focus is on removing material to restore power and open travel corridors, the potential economic value of the timber is at best converted to that of firewood.

Wood product volume and value recovery vary dramatically from location to location, and data collection on wood product volume remains incomplete. Two general observations are (1) some wood product volume can be recovered from trees removed at the immediate roadside; however, the value is insufficient to cover the cost of removal by arboricultural tree crews; and (2) at some locations where roadside tree volume has been combined with wood product volume yield from 30-m deep roadside stand management, the implementation cost may be largely offset by the value of products recovered. Much depends on initial timber quality, available markets, harvesting methods used, and opportunities for value-added operations.

Our estimate of nearly 120 risk trees/km (approximately 1 tree/8 m) that could be windthrown into the utility or travel corridor during extreme storms is likely low because it assumes that the trees will not grow taller or form branches with larger diameters. The perception that the number of risk trees is low is likely due to some of these trees dying and breaking apart in situ and because others are removed from wires as they fail over a period of several decades or longer. As Dave Goodson, manager of Vegetation Management at United Illuminating (CT), has repeatedly said, however, "gravity wins" and these many trees will eventually have to be dealt with. The choice the landowners, foresters, utility companies, and highway vegetation managers have to make is whether to deal with the problem and the expense reactively or proactively.

The consequences of neglecting roadside forests will only increase as trees become taller and more massive. This neglect has the potential to affect thousands to millions of people during extreme storms and makes the case that long-term solutions need to go beyond simple utility tree trimming and removal of obvious roadside hazard trees. Addressing this neglect will require adaptive management using innovative combinations of silvicultural and arboricultural techniques. Our study used a variety of operational practices. In some cases, harvesting was accomplished opportunistically as part of a commercial management operation that was already planned. In other cases, the treatment was deliberately planned and executed using small-scale equipment and methods that were appropriate to the small area and volume of potential wood-product material involved. The diverse nature of roadside forest conditions and ownership patterns demands that we examine an assortment of methods, logistics, skill-set combinations, and economic considerations to determine the optimum approaches to roadside forest management implementation. Further study is under way to examine these questions, as well as those associated with community attitudes, landowner opinions, and labor-force requirements. We plan to publish information from these studies in the future.

Like the Firewise program, which encourages local solutions for wildfire safety by involving homeowners, community leaders, planners, and others in an effort to protect people and property from wildfire risk,[2] Stormwise is designed to promote healthy, storm-resistant forests. The proactive Stormwise approach is a collaborative, coordinated effort by landowners, foresters, utility companies, and highway vegetation managers to manage the oft-neglected wooded strip between the point where shoulder mowing and tree pruning stops and the point where logging can be safely accomplished. This forest-road/utility interface is a surprisingly high proportion of the forest resource and is perhaps the most visible canvas of forest management.

We expect that forest owners and utility companies implementing Stormwise strategies will enjoy long-term benefits of fewer trees falling on wires during extreme weather and longer time spans between maintenance and management activities. Ultimately, storm-resistant roadside forests, once established, will require a different type of management and maintenance than the current regime of periodic tree-trimming and fallen tree removal. Rather than a 4- to 5-year trimming cycle, the Stormwise roadside forest will require some management activity every 10-15 years. And rather than being conducted from a bucket truck, much of the management activity would be at the ground level, cutting trees before they grow tall enough to fall on wires and maintaining the appropriate species mixture, density, and age structure in the roadside forest to allow it to remain wind firm.

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[2] See http://www.firewise.org/ for more information.

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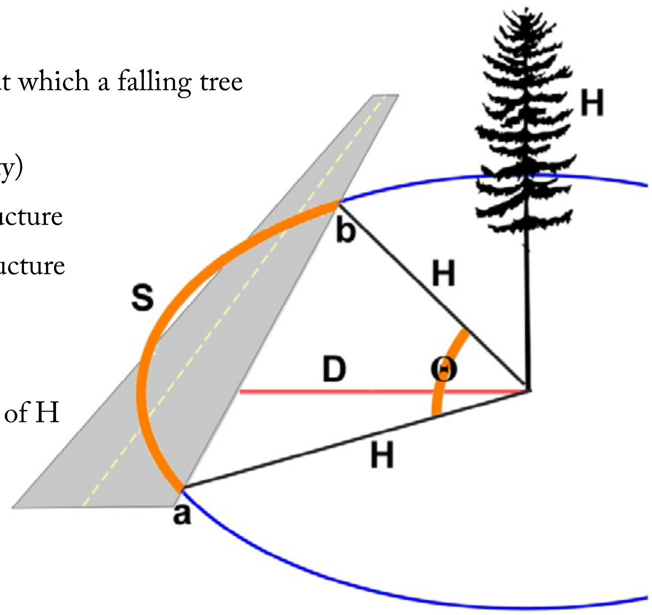
APPENDIX



H = tree height = radius of circle describing limit at which a falling tree damages infrastructure

D = distance of tree to infrastructure (road or utility)

a = point 1 at which falling tree intercepts infrastructure

b = point 2 at which falling tree intercepts infrastructure

S = length of arc ab

θ = angle of arc ab

C = perimeter length of circle with a radius length of H

From mensuration formulas

$C = 2\pi * H$

$S = H * \theta$

$\theta = 2 * \arccos(D/H)$

The probability that the tree falls within area prescribed by arc ab (P_{infra}) is

$P_{infra} = S / C$

$S/C = (H * \theta) / (2\pi * H)$

$= \theta/2\pi$

$= [2 * \arccos(D/H)]/(2\pi)$

$= \arccos(D/H)/\pi$.

The content of this paper reflects the views of the author(s), who are responsible for the facts and accuracy of the information presented herein.