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Training Volunteers to Prune Recently Planted, Small Street Trees

By Ryan Fawcett, Brian Kane, and David V. Bloniarz

Abstract. Background: Trees in towns and cities provide many benefits, but also disservices such as risk and conflicts. Structural pruning of young trees can reduce future conflicts and risk as trees grow larger; it also can reduce future maintenance costs. Volunteers can perform important urban forestry tasks such as planting, watering, and conducting inventories. It was hypothesized that, with training, they could also learn to structurally prune young street trees. Methods: Forty-seven volunteers in three cities in Massachusetts were trained to structurally prune trees. Twenty volunteers trained in a classroom lecture; twenty-seven trained with a hands-on approach. The volunteers' performance was evaluated with a written exam and *in situ* assessments of their ability to specify and explain pruning recommendations and make pruning cuts. Training type and covariates (e.g., volunteers' familiarity with trees, number of branches) influence on volunteers' performance were investigated. Results: On the assessment of volunteers' ability to explain pruning recommendations, volunteers who received hands-on training achieved higher mean scores (79%) than volunteers who received classroom training (74%). All volunteers who received hands-on training did not leave a stub when making a reduction cut, but only 70% of volunteers who received classroom training did not leave a stub. Volunteers who received classroom training achieved higher scores on the exam (93%) than volunteers who received hands-on training (85%). Conclusions: Results suggest that with minimal training volunteers successfully learned structural pruning. This is an encouraging finding that may help municipal arborists accomplish more with limited urban forestry budgets.

Keywords. *Carpinus caroliniana*; *Nyssa sylvatica*; *Ulmus americana* 'Princeton'.

INTRODUCTION

In residential settings, trees provide many benefits and ecosystem services. The amount and value of benefits and ecosystem services generally increase in proportion with leaf area, so it is important for trees in residential settings to grow large and remain healthy (Nowak 2017). However, as trees grow larger, they present greater risk, because failure of large trees can lead to more severe consequences. Larger trees are also more likely to interfere with built infrastructure such as buildings, signs, lights, roads, and sidewalks. Maintaining large trees is also more costly than small trees (Ryder and Moore 2013) because of higher labor, equipment, and debris disposal costs.

Structural pruning of young trees is intended to reduce the odds of future disservices associated with large trees such as failure and conflicts (Lilly et al. 2019). Structural pruning is a long-term approach to creating good tree structure in the future. Good tree structure is presumed to be more resilient because of its greater load-bearing capacity. Defects often associated with failure such as codominant stems and branches, branch unions with included bark, and branches spaced too closely or too far apart on a parent stem are proactively pruned to avoid future problems (Lilly et al. 2019). Two types of cuts are typically used to implement structural pruning: reduction cuts and removal cuts. When making a reduction cut, an arborist prunes the terminal end of a stem back to a higher-order lateral stem that is at least one-third the diameter of the parent stem (Lilly et al. 2019). When making a removal cut, an arborist prunes a higher-order lateral stem at its attachment to the parent stem (Lilly et al. 2019).

Pruning smaller branches reduces the amount of discoloration associated with pruning cuts (Grabosky and Gilman 2007) and subordinating one of a pair of codominant stems retards its growth (Gilman and

Grabosky 2009). Structurally pruning a tree over a longer timeframe can create a strong structure of scaffold branches that are less likely to need future pruning or interfere with nearby structures. Another advantage of structural pruning of young and small trees is that it can be undertaken with minimal equipment and hand tools, making it possible for volunteers to undertake the work. In the United States, an estimated more than 300,000 volunteers annually contribute 1.5 million hours of labor, which accounts for 5% of all public tree care activities (Hauer et al. 2018). Planting and watering public trees are the most common arboricultural activities in which volunteers participate (Hauer et al. 2018). In neighborhoods where volunteers participate in tree planting, the survival rate is between 95% and 99% (Roman et al. 2015). Higher survivorship of newly planted trees reduces costs associated with removing and replacing dead trees. In communities where volunteers helped water trees, tree growth is greater than in communities without community watering support (Mincey and Vogt 2014).

With training, volunteers are also able to conduct tree inventories, accurately measuring species, stem diameter 1.5 m above ground (diameter at breast height [DBH]), crown size, vigor and crown dieback, and management needs (Bloniarz and Ryan 1996; Bancks et al. 2018; Hallett and Hallett 2018). Volunteers can be an essential addition to a municipality's workforce because of the high cost of tree maintenance and what approximately 50% of municipal arborists describe as underfunded management programs (Hauer and Peterson 2016).

Considering (i) the value of public trees to communities and residents, (ii) the importance of structural pruning to reduce future management costs, (iii) limited municipal budgets for tree care, and (iv) volunteers' ability to perform arboricultural activities, our objective was to determine whether volunteers could structurally prune recently planted street trees. We also hypothesized that the type of training volunteers received would influence their competence.

MATERIALS AND METHODS

Study Sites

We conducted the study in 3 cities in the Connecticut River Valley in Massachusetts, USA: Greenfield, Northampton, and Springfield (Figure 1). Greenfield is in United States Department of Agriculture (USDA) Hardiness Zone 5b; Northampton and Springfield are

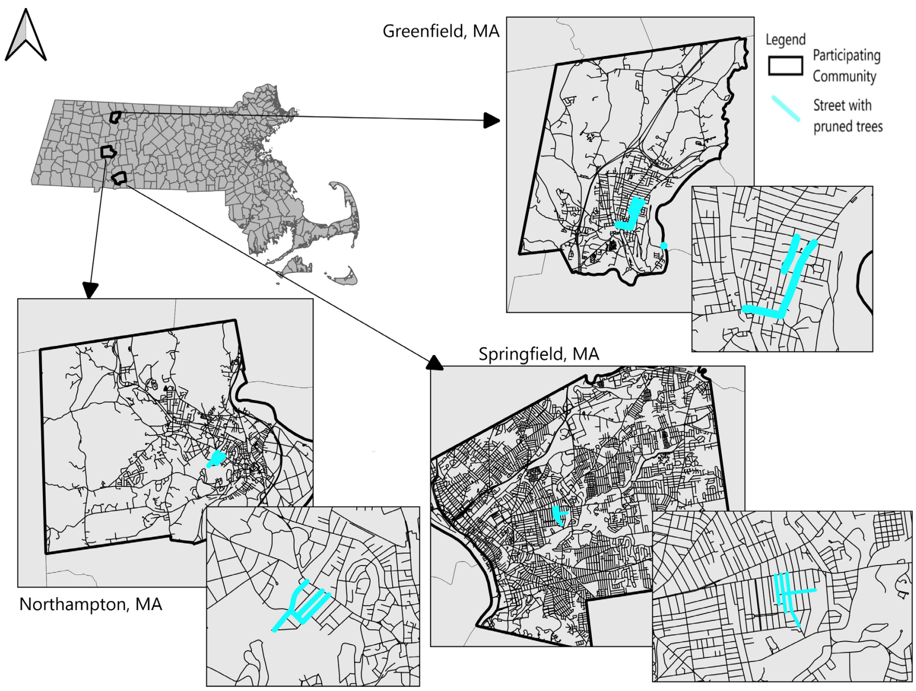

Figure 1. Locations of 3 cities in Massachusetts (upper left) and the specific site at which training and evaluation occurred (insets).

in USDA Hardiness Zone 6a. These cities were selected because each had an active tree committee whose members were interested not only in participating in the study but also in raising awareness of trees and the committee itself. Tree wardens and tree committees throughout the region were previously contacted about community interest in participating in this study.

In each city, the study was conducted on a street with recently planted trees growing in the strip of turfgrass between the street and sidewalk. Selected streets had comparatively low vehicular traffic and street noise and enough trees of the same approximate age, size, and species to accommodate the number of participants who signed up for training. Figure 1 indicates the specific location in each city where we conducted the study. Table 1 includes species and morphological data for trees in each city; Figure 2 shows examples of the trees. We measured the following variables for all trees: species, DBH, height, and number of primary branches.

Curriculum Development

From standard industry texts (Gilman 2011; Lilly et al. 2019) and consultations with arboriculture instructors at 5 vocational high schools in Massachusetts and the University of Massachusetts–Amherst, we developed a curriculum to train participants to structurally prune recently planted small trees. In consultations with arboriculture instructors (7 in total), we asked 2 questions: *What are the most important aspects of pruning instruction to focus on?* and *What are the most effective pedagogical techniques to train students how to prune?* The training curriculum included sections on tree physiology, tree structure, pruning tools, safety, and cutting techniques (included in supplementary material).

Table 1. Morphological data for trees used in the evaluation of suggested pruning actions, including, tree number, stem diameter (cm) 1.5 m above ground (diameter at breast height [DBH]), height (m), and number of branches for each tree used in the pruning prescription assessment in (a) Northampton (American hornbeam, *Carpinus caroliniana*), (b) Springfield (black gum, *Nyssa sylvatica*), and (c) Greenfield (Princeton elm, *Ulmus americana* 'Princeton').

Location	Tree No.	DBH	Height	Number of branches
(a)	1	3.8	3.7	22
	2	3.6	3.1	29
	3	4.6	3.7	20
	4	3.8	3.1	19
	5	3.8	4.3	27
	6	5.1	4.0	33
	7	2.8	3.7	21
Mean (std. dev.)		3.9 (0.7)	3.6 (0.45)	24.4 (5.3)
(b)	1	5.1	3.7	32
	2	8.9	4.0	48
	3	7.2	5.2	40
	4	5.7	5.2	50
	5	4.4	2.4	19
	6	5.1	4.6	27
	7	4.4	3.1	24
Mean (std. dev.)		5.8 (1.6)	4.0 (0.11)	34.3 (12.0)
(c)	1	8.9	4.6	22
	2	8.1	4.3	30
	3	7.4	4.6	25
Mean (std. dev.)		8.1 (0.8)	4.5 (0.18)	25.7 (4.0)

Figure 2. Examples of trees from (A) Northampton (*Carpinus caroliniana*), and (B) Springfield (*Nyssa sylvatica*), Massachusetts.

Training and Evaluation of Participants

Training and evaluation of participants differed in each city because our study was interrupted by the COVID-19 pandemic. The global pandemic also delayed training and evaluation in Greenfield (28 November 2020) and Springfield (19 to 20 February 2021), which occurred after training and evaluation in Northampton (7 to 8 December 2019). The first author, who is an ISA Certified Arborist®, conducted all training sessions. Before the training itself, participants completed a brief survey. They recorded their level of experience with plants on a scale of 1 (no or very little experience) to 5 (extensive experience), what their experience entailed (i.e., gardening, yardwork), and whether they had previously participated in volunteer planting, watering, pruning, or similar activities in their community.

In Northampton, 28 participants were divided randomly into 2 groups of 14 and assigned to 1 of 2 training types. One group (7 December 2019) received indoor classroom training that consisted of 2 consecutive 1-hour PowerPoint lectures on the topics in the curriculum described above (separated by a 10-minute break), followed by 15 minutes for questions. This was considered classroom training. Training for the second group (8 December 2019) covered the same curriculum, but not in a classroom. Instead, the instructor presented the curriculum using trees in the landscape. The trees used to facilitate training were similar to those that participants would prune as part of the evaluation (described below). The presentation lasted 45 minutes; for 90 minutes immediately afterwards, and with guidance from ISA Certified Arborists, participants used hand pruners to practice pruning the trees. Lastly, participants were given 10 minutes for questions. This was considered hands-on training.

Immediately following the question-and-answer period of both types of training, participants were given 30 minutes to complete a 15-question multiple-choice exam (included in supplementary material). After a

45-minute break for lunch, all participants completed 2 additional evaluations. In the first, participants used hand pruners to make single reduction and removal cuts on a randomly assigned and recently planted small street tree as an evaluator watched. The first author evaluated participants' pruning cuts in all 3 cities. In the second evaluation, we randomly assigned each participant a recently planted small street tree that had not been previously pruned. We explained that they would perform an initial structural pruning on their tree today, noting that the tree would be on a pruning schedule of 3 to 5 years after the initial pruning. Rather than make pruning cuts, however, participants used high-visibility flagging tape to indicate the branches for which they suggested pruning actions. Then they explained their choices and reasoning to an evaluator. The second author, who is an ISA Certified Arborist, evaluated participants' suggested pruning actions in Northampton and Springfield; the first author evaluated participants' suggested pruning actions in Greenfield.

The multiple-choice exam was graded on a scale of 0% to 100%. Removal cuts were graded as acceptable (a score of 1) or unacceptable (a score of 0) based on 3 criteria: (i) whether the cut damaged the branch collar, (ii) whether the cut damaged the branch bark ridge, and (iii) whether the cut left a stub protruding beyond the branch collar. We also graded reduction cuts as acceptable or unacceptable based on 3 criteria: (i) whether the cut was made at too steep an angle (i.e., the angle of the cut was nearly parallel to, but did not damage, the branch bark ridge), (ii) whether the cut damaged the branch bark ridge, and (iii) whether the cut was made at too shallow an angle (i.e., the angle of the cut was nearly perpendicular to the longitudinal axis of the stem being pruned, leaving a stub). If the answer to 2 or more of the 3 criteria was "yes," the cut was graded as unacceptable; otherwise, the cut was graded as acceptable. We also graded each criterion individually as unacceptable if the answer to the criterion was "yes," or acceptable if the answer was "no". The structural pruning scenario was graded as the proportion of a participant's suggested pruning actions (and explanations) that the evaluator disagreed with. As the participant explained their reason(s) for recommending each pruning action, the evaluator judged whether the action would achieve the participant's justification for recommending the action. If the participant's explanation was incorrect or the suggested pruning action would not achieve the participant's objective, the evaluator would record it as a "disagreement". For example, the evaluator considered it a disagreement if a participant chose to remove a branch that could have served as a temporary branch in the structural pruning process, but if the participant acknowledged the possibility of leaving the branch as a temporary branch and reasonably explained their choice for removing it, the evaluator would not consider it a disagreement. The evaluator also recorded a disagreement if the participant failed to suggest a pruning action to remedy an existing structural issue, such as a plainly defective, broken, or dead branch. The evaluator assigned 2 grades to each participant's suggested pruning actions. The first grade was based on the proportion of total suggested pruning actions that the evaluator recorded as disagreements, on a scale of 0% (all disagreements) to 100% (no disagreements). The second grade was the evaluator's judgment of whether the participant's suggested pruning actions, *in toto*, were acceptable (a score of 1) or unacceptable (a score of 0).

To control for possible bias of the evaluator who evaluated participants' suggested pruning actions, 4 other ISA Certified Arborists assessed the randomly assigned trees used for the evaluation in each city and provided recommendations for structural pruning. For all trees, the evaluator's suggested pruning actions were in agreement with those of the other 4 ISA Certified Arborists.

In Greenfield, all 6 participants received the same hands-on training described for participants in Northampton; we did not offer classroom training because of the COVID-19 pandemic.

In Springfield, we randomly assigned 6 participants to classroom training (19 February 2021) and 7 participants to hands-on training (20 February 2021). The classroom and hands-on training in Springfield were the same as described for participants in Northampton, with one exception: the classroom training was held on Zoom rather than in person. Evaluation of participants who received the classroom training on Zoom was also different than in Northampton: in-person evaluation of pruning cuts and suggested pruning actions occurred on 20 February 2021, which was the day after the classroom training itself.

Data Analysis

To determine whether it was appropriate to combine data from the 3 cities, we used correlation analysis with a variance inflation factor (VIF) using the 'corrplot' package in R (Wei et al. 2017). The only response variable that was highly correlated (VIF $\geq$ 0.5) (Craney and Surles 2002) with location was participants' scores on suggested pruning actions, so the scores were analyzed separately for Northampton and Springfield. We did not analyze scores on suggested pruning actions in Greenfield because all participants received hands-on training. We combined data from the 3 cities to analyze the other response variables: written exam score, acceptable reduction cut, acceptable removal cut, no damage to branch bark ridge on removal cut, no damage to branch collar on removal cut, no stub on removal cut, no damage to branch bark ridge on reduction cut, angle of reduction cut not too steep, angle of reduction cut not too shallow (not leaving a stub).

Beta regression (the "betareg" function from the "betareg" package in R)(Cribari-Neto and Zeileis 2010) was used to analyze scores from the written exam and evaluation of suggested pruning actions because it is well suited to analyzing proportions bounded between 0 and 1 (Ferrari and Cribari-Neto 2004). For scores on the written exam and pruning scenario, we used an iterative, model-building procedure including all relevant predictors and their interactions, and selecting the best model as having the lowest Akaike Information Criterion corrected for small sample sizes (AICc) value. Predictors included in the model for written exam scores were training type, city, and level of experience with plants. Predictors included in the model for scores on suggested pruning actions were training type, level of experience with plants, tree height, DBH, and the number of primary branches on the tree.

Fisher's exact test was used to compare the effect of training type (classroom, hands-on) on binary response variables including, acceptable/unacceptable suggested pruning actions, acceptable/unacceptable removal cut, damage/no damage to branch collar on removal cut, damage/no damage to branch bark ridge on removal cut, stub/no stub on removal cut, acceptable/unacceptable reduction cut, angle too steep/correct angle on reduction cut, damage/no damage to branch bark ridge on reduction cut, angle too shallow (stub)/correct angle (no stub) on reduction cut. If Fisher's exact test showed a significant ($P < 0.05$) difference between the performance of participants who received classroom compared to hands-on training, logistic regression was used to model the data. We used an iterative, model-building procedure including predictors (training type, city, level of experience with plants) and their interactions, selecting the best model as having the lowest AICc value.

Table 2 summarizes the knowledge domains from the training curriculum, the evaluation method(s) used to assess participants' understanding of each domain, the response variable that we analyzed for each evaluation method, and the significance test we used. Table 2 also indicates whether we analyzed data from cities independently or pooled together.

RESULTS

Participants

Table 3 summarizes the type and level of experience that participants reported on the survey. Most participants' experience involved gardening or yardwork at their home; only 2 participants reported no type of experience with plants. Two participants had professional landscaping experience and four had participated in a volunteer tree planting. Participants' self-rated level of experience with plants varied widely, with a plurality of participants indicating "some experience."

Written Exam

The best model to predict participants' scores on the written exam included only the type of training; adding predictors did not improve the model (Table 4). Scores ranged from 53% to 100%; the mean score (93% ± 2.0% standard error) of participants who received classroom training ($n = 20$) was significantly ($P < 0.001$) greater than the mean score (85% ± 1.4%) of participants who received hands-on training ($n = 27$). One participant completed the training and written exam but departed before completing the pruning scenario and pruning cut evaluations.

Suggested Pruning Actions

In Northampton and Springfield, the best models to predict participants' scores on suggested pruning actions included only the type of training (Table 5). In Northampton, scores ranged from 37% to 100%; the mean score (82% ± 1.7%) of participants who received hands-on training ($n = 14$) was significantly ($P = 0.005$)

Table 2. A list of the knowledge domains, evaluation methods, response variables, and significance tests used to analyze data.

Knowledge domain	Evaluation method	Response variable	Significance test
Tree physiology and response to pruning	Written exam	Score (0-100)	Beta regression
Good tree structure	Evaluation of suggested pruning actions*	Score (0-100)	Beta regression
Good tree structure	Evaluation of suggested pruning actions	Acceptable/Unacceptable	Fisher's exact test
Making good pruning cuts	Evaluation of removal cut	Acceptable/Unacceptable	Fisher's exact test
Making good pruning cuts	Removal cut did not damage branch collar	Acceptable/Unacceptable	Fisher's exact test
Making good pruning cuts	Removal cut did not damage branch bark ridge	Acceptable/Unacceptable	Fisher's exact test
Making good pruning cuts	Removal cut did not leave a stub	Acceptable / Unacceptable	Fisher's exact test
Making good pruning cuts	Evaluation of reduction cut	Acceptable/Unacceptable	Fisher's exact test
Making good pruning cuts	Angle of reduction cut not too steep	Acceptable/Unacceptable	Fisher's exact test
Making good pruning cuts	Reduction cut did not damage branch bark ridge	Acceptable/Unacceptable	Fisher's exact test
Making good pruning cuts	Angle of reduction cut not too shallow (did not leave a stub)	Acceptable/Unacceptable	Fisher's exact test

* Data was analyzed separately by city; for other evaluation methods, data was pooled from 3 cities.

Table 3. Participants' (*n* = 47) responses to the survey intended to gauge their experience prior to training.

Type of experience with plants	Count
Conservation	3
Gardening/Yardwork	34
Houseplants	2
Landscaping	2
None	2
Volunteer tree planting	4
Self-rated level of experience with plants	**Count**
None or almost no experience	9
A little experience	8
Some experience	16
A lot of experience	12
Extensive Experience	2

Table 4. The 5 best beta regression models (measured by Akaike's Information Criterion corrected for small sample sizes [AICc]) to predict a participant's score on the written exam from independent variables (type of training, city of training, participant's previous experience with plants); models were based on pooled data from three sites. Model parameters include the number of predictors (K), AICc, comparison of model AICc with AICc of the best model (Δ_{AICc}), goodness of fit (ModelLik), and log likelihood (LL).

Model	K	AICc	Δ_{AICc}	ModelLik	LL
Training	3	−121.02	0	1	63.80
Intercept only (null)	2	−118.14	2.88	0.24	61.21
City	4	−115.15	5.87	0.05	62.06
Training + Experience	7	−112.05	8.97	0.01	64.50
Experience	6	−108.72	12.30	0.00	61.44

greater than the mean score (66% ± 3.2%) of participants who received classroom training (n = 14). In Springfield, scores ranged from 75% to 100%; the mean score (92% ± 1.6%) of participants who received hands-on training (n = 6) was significantly (P = 0.021) greater than the mean score (85% ± 2.0%) of participants who received classroom training (n = 6). In Greenfield, scores for 6 participants ranged from 29% to 100% with a mean of 61% (± 6.5%).

Although the mean scores differed between participants who received classroom compared to hands-on training in Northampton and Springfield, the overall evaluation of suggested pruning actions as acceptable or unacceptable did not vary between participants who received different types of training. For the pooled dataset of all 3 cities, only 2 of 46 pruning scenarios were evaluated as unacceptable (Fisher's Exact P = 0.957).

Pruning Cuts

With one exception, the type of training participants received did not affect their ability to make good pruning cuts (Table 6). When making removal cuts, most participants did not damage the branch bark ridge (91%) or branch collar (85%) and did not leave a stub (91%). Most participants (85%) made an acceptable removal cut overall. Similarly, when making reduction cuts, most participants did not make the cut at too steep (91%) or too shallow an angle (did not leave a stub)(87%) and did not damage the branch bark ridge (87%). Most participants (83%) made an acceptable reduction cut overall (83%), but the type of training affected participants' performance with reduction cuts: none of the participants who received hands-on training made the cut at too shallow an angle (leaving a stub), while 30% of participants who received indoor training left a stub—a significant difference (Fisher's Exact P = 0.003). The logistic regression model to explore this relationship indicated that the type of training was the most important predictor (Table 7).

DISCUSSION

This study was the first to investigate whether novices can learn to acceptably perform structural pruning on recently planted, small street trees; the results were encouraging. Over a period of more than 14 months, in 3 cities, with less than 3 hours of training—and under the extenuating circumstances of a global pandemic—mean scores for the written exam and evaluation of suggested pruning actions exceeded 60%, which is often considered a "passing" academic grade. In addition, 96% of the suggested pruning actions and 84% of pruning cuts were evaluated as acceptable. These findings broadly align with previous studies that inexperienced volunteers can

Table 5. The 5 best beta regression models (measured by Akaike's Information Criterion corrected for small sample sizes [AICc]) to predict a participant's score on the pruning scenario from independent variables (type of training, number of primary branches, tree height); separate models were constructed for (a) Northampton and (b) Springfield. Model parameters include the number of predictors (K), AICc, comparison of model AICc with AICc of the best model (Δ_{AICc}), goodness of fit (ModelLik), and log likelihood (LL).

	Model	K	AICc	Δ_{AICc}	ModelLik	LL
(a)	Training	3	−26.25	0.00	1.00	16.63
	Training + Branches	4	−24.20	2.05	0.36	16.97
	Intercept only (null)	2	−21.53	4.73	0.09	13.00
	Height	3	−19.26	6.99	0.03	13.13
	Branches	3	−19.18	7.08	0.03	13.09
(b)	Training	3	−62.38	0.00	1.00	34.74
	Training + Branches	4	−61.83	0.56	0.76	35.87
	Intercept only (null)	2	−60.03	2.35	0.31	32.28
	Branches	3	−59.82	2.57	0.28	33.45
	Height	3	−57.76	4.62	0.10	32.43

Table 6. Contingency tables for evaluations of removal and reduction cuts, including whether participants who received classroom or hands-on training (a) did not damage the branch bark ridge, (b) did not damage the branch collar on removal cuts or cut at too steep an angle on reduction cuts, (c) did not leave a stub on removal cuts or cut too shallow on reduction cuts, and (d) made a satisfactory cut overall; *P*-values are from Fisher's Exact Test; data are pooled from all 3 cities.

		Removal			Reduction		
	Training	**Acceptable**	**Unacceptable**	**Total**	**Acceptable**	**Unacceptable**	**Total**
(a)	Classroom	19	1	20	18	2	20
	Hands-on	23	3	26	24	2	26
	Total	42	4	46	42	4	46
	P-value			0.435			0.783
(b)	Classroom	15	5	20	16	4	20
	Hands-on	24	2	26	24	2	26
	Total	39	7	46	40	6	46
	P-value			0.105			0.219
(c)	Classroom	17	3	20	14	6	20
	Hands-on	25	1	26	26	0	26
	Total	42	4	46	40	6	46
	P-value			0.183			0.003
(d)	Classroom	16	4	20	15	5	20
	Hands-on	23	3	26	23	3	26
	Total	39	7	46	38	8	46
	P-value			0.428			0.232

accurately understand foundational arboricultural topics and skills like identifying species, measuring tree height and DBH, and assessing condition, after they received training (Bloniarz and Ryan 1996; Roman et al. 2017).

There were several limitations to the study that warrant future study. Including all cities, the number of trees, species, and participants was small in relation to their respective populations. Training and evaluation were conducted in winter, when trees were leafless, perhaps improving participants' ability to visualize crown architecture—both at the time of the study and in the future. We chose trees in view of the study's logistics; in future studies, tree selection should systematically address aspects of crown architecture such as distribution of primary and higher order branches with respect to their parent stem. Another option is to select trees deemed easy or difficult to prune by a panel of certified arborists. The selected species also followed from the study's logistics; intentionally selecting species with consistently excurrent or decurrent form is another line of future investigation. Finally, there are many human factors that might influence how well a participant

Table 7. Logistic regression models to predict whether participants made a reduction cut at the correct angle rather than too shallow (leaving a stub) from independent variables (type of training, participant's previous experience with plants). Models were based on pooled data from 3 cities. Model parameters include the number of predictors (K), Akaike's Information Criterion corrected for small sample sizes (AICc), comparison of model AICc with AICc of the best model (Δ_{AICc}), goodness of fit (ModelLik), and log likelihood (LL).

Model	**K**	**AICc**	Δ_{AICc}	**ModelLik**	**LL**
Training	2	28.71	0.00	1.00	−12.22
Intercept only (null)	1	37.71	9.00	0.01	−17.81
Experience	5	37.97	9.25	0.01	−13.23

understood the training materials. Aside from asking participants to name and rate their experience with plants, we did not collect other presumably relevant parameters (e.g., age, sex, education level and discipline, vocation, and so on). It would also be helpful to pre-test participants to determine their knowledge of pruning before training. A pre-test could be conducted prior to assigning participants to each training method and would presumably be a relevant predictor of participants' performance in assessments. Similarly, administering a post-training survey may have gleaned insights to explain our findings. For example, we speculate that participants in Northampton who received hands-on training, which occurred on a street with noticeable noise from vehicles, may have had difficulty understanding the instructor, who wore a mask to protect against COVID-19.

The type of training influenced participants' performance in largely intuitive ways. While the content of the written exam was the same for participants who received classroom or hands-on training, the higher mean score of participants who received classroom training suggested that it was more appropriate for understanding pruning concepts than the hands-on training. But it is helpful to consider that participants who received classroom training scored, on average, 8 points higher than participants who received hands-on training. The difference was approximately the value of a single question on the exam. Given the limited sample of participants and the challenges for participants who received hands-on training in Northampton to hear the instructor outside while viewing street trees, the difference may be trivial.

In contrast to scores on the written exam, scores on the evaluation of suggested pruning actions were noticeably higher for participants who received hands-on training. This aligned anecdotally with instructors we consulted to develop the curriculum, whose experience suggested that hands-on practice helps students in high-school and college to develop confidence in their ability to prune. It also aligned with studies showing that nursing students who received hands-on and case-based training had better problem-solving and critical-thinking skills than students who received only lecture-based training (Yoo and Park 2015; Gholami et al. 2021). Despite the mean difference in scores on the pruning scenarios for participants who received classroom or hands-on training, however, the number of overall acceptable outcomes was similar for both types of training, which provides confidence that classroom training alone may still be sufficient for volunteers to learn structural pruning.

Although we expected that participants who received hands-on training, which included practicing making cuts with the guidance of a certified arborist, would be more likely to make better pruning cuts, the type of training did not affect the proportion of acceptable reduction or removal cuts. We speculate that making pruning cuts requires less judgment than choosing branches for suggested pruning actions. Instead, participants only needed to identify the relevant parts of the branch union (branch collar and branch bark ridge). Images on the PowerPoint slides seen by participants who received classroom training presumably were clear enough that participants could visualize where to make cuts in relation to the branch collar and branch bark ridge. However, the finding that participants who received classroom training were more likely to leave a stub when making a reduction cut does not support our speculation. Perhaps participants who received classroom training had more difficulty with leaving a stub on reduction cuts because the absence of a branch collar and branch bark ridge on the parent stem does not provide clear guidelines for where to make the cut.

The type of training was the only independent variable that plainly influenced participants' performance. This presumably reflected the limited samples of trees and participants, but it may be that training alone will be enough to prepare future volunteers for structural pruning. Investigating the effect of crown architecture and participants' background in addition to training is important. There is also merit in exploring whether lecture material delivered in-person or remotely affects participants' understanding and retention of the material. Presenting the lecture material remotely in Springfield did not appear to have negatively influenced participants' scores on suggested pruning actions. The disparity in scores between participants who received hands-on compared to classroom training was less than in Northampton, where participants received classroom training in person. If future studies find similar outcomes, training volunteers could be expedited by providing some of the lecture material in an online format, supplemented by an abbreviated hands-on training session that follows.

Although our findings indicate that most participants in the study understood the basic tree physiology underlying good pruning technique and demonstrated the ability to choose appropriate branches to prune and make good pruning cuts, one final limitation is essential for future study. It is unlikely that a single training session—whether in a classroom, online, hands-on, or in combination—is sufficient for long-term retention of the training material, and our study did not include a follow-up assessment of participants' retention of knowledge and skills. Without regular practice, "skill decay" is a well-documented phenomenon (Arthur et al. 1998) and investigating how quickly it occurs following training in structural pruning, and what factors influence the timeframe is essential. Understanding the rate of skill decay following training in structural pruning will provide a clearer picture of the benefits and costs of training because the investment in training must be compared to the number of trees a trained volunteer can structurally prune. If volunteers need frequent retraining, the presumed cost savings of having volunteers structurally prune trees may not be realized. It will also be helpful to explore whether a particular type of training is more effective for a longer time, and whether the rate of skill decay differs among different aspects of pruning (e.g., knowledge of tree physiology, ability to select appropriate branches to prune, making good pruning cuts).

CONCLUSIONS

Participants who received comparatively limited training in structural pruning were largely successful in understanding and applying the knowledge and skills from the training—whether it was in a classroom setting or hands-on in the field. This finding is encouraging for municipal arborists who would benefit from community volunteers to help structurally prune recently planted, small street trees. The long-term benefit-cost ratio of trees in a community can be increased if structural pruning costs are reduced.

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Ryan Fawcett
Department of Environmental Conservation
University of Massachusetts–Amherst
Amherst, MA, USA

Brian Kane (corresponding author)
Massachusetts Arborists Association Professor
Department of Environmental Conservation
University of Massachusetts–Amherst
160 Holdsworth Way
Amherst, MA, USA
+1-413-545-6637
bkane@umass.edu

David V. Bloniarz
Adjunct Professor
Department of Environmental Conservation
University of Massachusetts–Amherst
USDA Forest Service
Amherst, MA, USA

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Résumé. Contexte: Les arbres dans les villes et les communautés offrent de nombreux bénéfices, mais génèrent également des inconvénients tels que le risque de dommages et les interférences. L'élagage structural des jeunes arbres peut réduire les interférences aériennes et les risques éventuels de dommages à mesure que les arbres grandissent ; il peut également réduire les coûts d'entretien ultérieurs. Les bénévoles peuvent effectuer d'importantes tâches liées à la foresterie urbaine, telles que la plantation, l'arrosage et la conduite d'inventaires. Une hypothèse a été émise à l'effet qu'avec une formation préalable minimale, ils pourraient également apprendre à élaguer structurellement les jeunes arbres en bordure des rues. Méthodes: Quarante-sept volontaires de trois villes du Massachusetts ont été formés à l'élagage structural. Vingt volontaires ont été formés dans le cadre d'un cours magistral et vingt-sept autres dans le cadre d'une approche pratique. La performance des volontaires fut évaluée avec un examen écrit et une évaluations *in situ* portant sur leur aptitude à spécifier et à expliquer les recommandations de taille et à effectuer des coupes. Le type de formation reçue et les covariables (par exemple, la familiarité des volontaires avec les arbres, le nombre de branches à tailler) ont été étudiés afin de déterminer leur influence sur les performances des volontaires. Résultats: Lors de l'évaluation de la capacité des volontaires à expliquer les recommandations de taille, les volontaires ayant reçu une formation pratique ont obtenu des notes moyennes plus élevées (79%) que les volontaires ayant reçu une formation en classe (74%). Aucun des volontaires ayant reçu une formation pratique n'a laissé de chicot en effectuant une coupe de réduction, mais seuls 70 % des volontaires ayant reçu une formation en classe n'ont laissé aucun chicot. Les volontaires ayant reçu une formation en classe ont obtenu de meilleurs résultats à l'examen (93%) que ceux ayant reçu une formation pratique (85%). Conclusions: Les résultats démontrent qu'avec une formation minimale, des volontaires ont réussi à comprendre l'élagage structurel. Il s'agit d'un résultat encourageant pouvant aider les arboriculteurs municipaux à accomplir davantage avec des budgets limités en matière de foresterie urbaine.

Zusammenfassung. Hintergrund: Bäume in Städten und Gemeinden bieten viele Vorteile, aber auch Nachteile wie Risiken und Konflikte. Der strukturelle Rückschnitt junger Bäume kann künftige Konflikte und Risiken verringern, wenn die Bäume größer werden; er kann auch künftige Instandhaltungskosten senken. Freiwillige Helfer können wichtige Aufgaben in der städtischen Forstwirtschaft übernehmen, z. B. das Pflanzen, Bewässern und die Durchführung von Bestandsaufnahmen. Es wurde die Hypothese aufgestellt, dass sie mit einer entsprechenden Schulung auch lernen könnten, junge Straßenbäume strukturell zu beschneiden. Methoden: Siebenundvierzig Freiwillige in drei Städten in Massachusetts wurden im strukturellen Beschneiden von Bäumen geschult. Zwanzig Freiwillige wurden in einer Vorlesung im Klassenzimmer geschult, siebenundzwanzig in einem praktischen Ansatz. Die Leistung der Freiwilligen wurde anhand einer schriftlichen Prüfung und einer Vor-Ort-Beurteilung ihrer Fähigkeit, Beschneidungsempfehlungen zu spezifizieren und zu erklären sowie Schnitte durchzuführen, bewertet. Es wurde untersucht, welchen Einfluss die Art des Trainings und Kovariaten (z.B. Vertrautheit der Probanden mit Bäumen, Anzahl der Äste) auf die Leistung der Probanden haben. Ergebnisse: Bei der Beurteilung der Fähigkeit der Freiwilligen, Schnittempfehlungen zu erklären, erreichten Freiwillige, die eine praktische Schulung erhielten, höhere Durchschnittswerte (79%) als Freiwillige, die eine Schulung im Klassenzimmer erhielten (74%). Alle Freiwilligen, die an einer praktischen Schulung teilgenommen haben, haben bei einem Reduktionsschnitt keinen Stummel hinterlassen, aber nur 70% der Freiwilligen, die an einer Schulung im Klassenzimmer teilgenommen haben, haben keinen Stummel hinterlassen. Freiwillige, die an einer Präsenzschulung teilgenommen haben, erzielten bei der Prüfung eine höhere Punktzahl (93%) als Freiwillige, die an einer praktischen Schulung teilgenommen haben (85%). Schlussfolgerungen: Die Ergebnisse deuten darauf hin, dass die Freiwilligen mit minimaler Schulung erfolgreich das strukturelle Beschneiden erlernten. Dies ist ein ermutigendes Ergebnis, das den kommunalen Baumpflegern helfen könnte, mit begrenzten Budgets für die städtische Forstwirtschaft mehr zu erreichen.

Resumen. Antecedentes: Los árboles de los pueblos y ciudades proporcionan muchos beneficios, pero también perjuicios como el riesgo y los conflictos. La poda estructural de árboles jóvenes puede reducir futuros conflictos y riesgos a medida que los árboles crecen; también puede reducir los costos de mantenimiento futuros. Los voluntarios pueden realizar importantes tareas de silvicultura urbana, como plantar, regar y realizar inventarios. Se planteó la hipótesis de que, con entrenamiento, también podrían aprender a podar estructuralmente los árboles jóvenes de las calles. Métodos: Cuarenta y siete voluntarios en tres ciudades de Massachusetts fueron entrenados para podar árboles estructuralmente. Veinte voluntarios se formaron en una clase magistral; veintisiete se capacitaron con un enfoque práctico. El desempeño de los voluntarios se evaluó con un examen escrito y evaluaciones *in situ* de su capacidad para especificar y explicar las recomendaciones de poda y realizar cortes de poda. Se investigó la influencia del tipo de entrenamiento y las covariables (p. ej., familiaridad de los voluntarios con los árboles, número de ramas) en el rendimiento de los voluntarios. Resultados: En la evaluación de la capacidad de los voluntarios para explicar las recomendaciones de poda, los voluntarios que recibieron capacitación práctica lograron puntajes medios más altos (79%) que los voluntarios que recibieron capacitación en el aula (74%). Todos los voluntarios que recibieron capacitación práctica no dejaron un muñón al hacer un corte de reducción, pero solo el 70% de los voluntarios que recibieron capacitación en el aula no dejaron un muñón. Los voluntarios que recibieron capacitación en el aula obtuvieron puntajes más altos en el examen (93%) que los voluntarios que recibieron capacitación práctica (85%). Conclusiones: Los resultados sugieren que con un mínimo entrenamiento los voluntarios aprendieron con éxito la poda estructural. Este es un hallazgo alentador que puede ayudar a los arboricultores municipales a lograr más con presupuestos limitados de silvicultura urbana.

Appendix.

Volunteer Pruning Curriculum

- To satisfactorily prune a young tree, what should someone know?
  - Safety
    - ◊ PPE
      - * Helmet
      - * Safety glasses
      - * Hi-vis clothing
      - * Hearing protection
    - ◊ Site inspection
      - * Hazards—Things that could harm you as you work
      - * Obstacles—Things that could be harmed by you as you work
    - ◊ Setting up a work site
      - * Signs, cones
      - * Awareness of hazards and obstacles
      - * Keep sidewalks and roads clear of persons and pruned branches
  - Tools
    - ◊ Handsaw
    - ◊ Pole saw
    - ◊ Hand pruners
    - ◊ Pole pruners
  - Tree physiology
    - ◊ Tree parts and their functions
      - * Roots
      - * Trunk
      - * Branches
      - * Leaves
      - * Buds
      - * Xylem
      - * Phloem
      - * Cambium
      - * Branch bark ridge
      - * Branch collar
    - ◊ Tree growth
      - * Primary
      - * Secondary
      - * Response to pruning
        - CODIT
        - Woundwood and wound occlusion
        - Regrowth

Appendix. Continued

- ○ How to make pruning cuts
  - ◊ Reduction cut
  - ◊ Thinning or removal cut (collar cut)
  - ◊ Small branches (1 cut)
  - ◊ Larger branches (3 cuts)
- ○ Structural pruning
  - ◊ What is it?
  - ◊ Why is it necessary?
    - * Identify branches with weak unions
    - * Refer to CODIT and explain why it is better to make smaller cuts on younger trees than larger cuts on mature trees
    - * Why branch axial and circumferential branch spacing is important
  - ◊ Timeframe—How long can a volunteer reasonably and safely complete structural pruning?
  - ◊ How to perform
    - * Identify dead, dying, crossing, rubbing, interfering
    - * Identify lowest permanent branch (LPB)
      - • Understand how LPB might change for different locations
    - * Identify scaffold branches
    - * Identify current or future weak unions
    - * Understand maximum percent foliage or percent crown to remove in each year
    - * Understand how to subordinate branches to slow growth
      - • Subordinate at present to remove in the future
      - • Subordinate to decrease ratio of trunk to branch diameter
      - • Understand when to use reduction or thinning cuts
    - * What do you do in each year post-transplant?

- ● To determine whether the type and amount of training affects a trainee's competence, how should you vary the type and amount of training?
  - ○ Exclusively indoor training
    - ◊ PowerPoint slides with images (maybe videos) as appropriate to illustrate concepts (e.g., tree parts) and actions (e.g., how to make cuts)
    - ◊ Show examples of PPE and pruning tools, but participants do not use
  - ○ Indoor and outdoor training
    - ◊ Indoors
      - * PowerPoint slides with images (maybe videos) as appropriate to illustrate concepts (e.g., tree parts) and actions (e.g., how to make cuts)
      - * Show examples of PPE and pruning tools
    - ◊ Outdoors
      - * Instructor demonstrates and participants complete
        - • Site inspection
        - • Work zone set up
        - • Assessment of which branches to prune

        - Making pruning cuts
          - Choosing the appropriate tool
        - Location of branch bark ridge, branch collar, wound occlusion
  - ○ Evaluation methods
    - ◊ Outdoor
      - * Participant completes site assessment
      - * Participant sets up work zone
      - * Which branches to prune (will need to pick a "year after transplant")
        - Participant places labels on tree
          - LPB, scaffold branches, which to subordinate, which have weak unions, dead/dying/diseased/crossing/etc.
        - Participant makes cuts
          - Removal or thinning
          - Reduction
          - Choose appropriate tool
            - Include a range of branch sizes so participants must use all four tools
    - ◊ Written test
      - * Tree parts
      - * Response to pruning
      - * Set up work zone
      - * Site assessment
      - * Label branches to prune
        - LPB, scaffold branches, which to subordinate, which have weak unions, dead/dying/diseased/crossing/etc.
      - * Illustrate how to make cuts
        - Thinning or removal
        - Reduction
        - Choose appropriate pruning tool

Multiple Choice Exam

Volunteer ID: /15

1. Which of the following is NOT a main objective of structural pruning?
   a. Develop a dominant leader
   b. Set the lowest permanent branch
   c. Space branches around the trunk
   d. Thin the crown
2. The dominant-leader structure important for large-maturing trees is less important on small-maturing trees because small-maturing trees:
   a. are less likely to cause injury or property damage if they fail
   b. usually do not have included bark
   c. cannot be grown with a dominant leader
   d. grow slower than large-maturing trees
3. Permanent branches on a tree are called:
   a. scaffold branches
   b. twigs
   c. major branches
   d. codominant branches
4. Scaffold limbs on large-maturing shade trees should be:
   a. chosen at the nursery
   b. spaced evenly around the trunk of the tree to the top of the crown
   c. chosen so they will droop down
   d. the prettiest looking ones

Appendix. Continued

5. What is the best way to prevent formation of codominant stems?
   a. Reduce or remove branches that might compete with the leading stem
   b. Remove lateral branches so the codominant stem will die
   c. Trim other branches to let more light into the crown
   d. Remove roots on the side with the competing stem
6. When removing a 2-inch- (5-cm-)thick branch at shoulder height the tool you use to make the cut should be?
   a. Hand pruners
   b. Axe
   c. Chainsaw
   d. Hand saw
7. It is important to structurally prune trees when they are young so that:
   a. they can grow to be strong mature trees
   b. we spend less money pruning them later
   c. pruning cuts leave small wounds
   d. All the above
8. When removing a branch, the best place to make a cut is:
   a. through the branch bark ridge
   b. just outside the branch collar
   c. 5 inches (12.7 cm) from the trunk
   d. flush with the trunk
9. If you are pruning a large branch with a hand or pole saw, the best way to make a cut is:
   a. make an under cut on the branch, then remove a large portion of the branch above it, then finally remove the remaining portion of the branch at the branch collar
   b. make a single cut at the branch collar
   c. pull the branch until it snaps, then cut at the snap
   d. cut so that the wound will be even with the bark, making it easier for the wound to heal
10. What is the highest percentage of the canopy that should be pruned in one cycle?
    a. 5%
    b. 25%
    c. 50%
    d. 75%
11. What part of the tree prevents the spread of decay and disease after a branch has been pruned?
    a. The branch protection zone
    b. The bark
    c. Apical bud
    d. Branch collar
12. Decay is most likely to occur if:
    a. a small branch is removed
    b. a dead branch is removed
    c. a large codominant stem is removed
    d. None of the answers is correct
13. The steps of the pre-cut method are:
    a. cut straight through the branch
    b. make an undercut one foot out from the trunk or parent branch, make a second cut on top of the undercut, make a third cut to remove the stub
    c. cut through the top of the branch one foot out from the trunk or parent branch, make a cut to remove the stub
    d. None of the answers is correct
14. Included bark usually:
    a. grows in U-shaped unions
    b. forms on broken branches
    c. indicates a weak union
    d. should be left alone
15. Newly planted trees should be pruned:
    a. heavily to make sure they have the right structure
    b. so that they have equal amounts of roots and branches
    c. very little to keep them healthy
    d. to reduce the amount of wind they catch