Arboriculture & Urban Forestry 2023. 49(2):55–63
https://doi.org/10.48044/jauf.2023.005

Improved Model Estimates of Tree Debris Following Ice Storms

By Richard J. Hauer and Brandon B. Schulz

Abstract. Planning to prepare for storms should involve the estimation of tree debris. This paper tested an improvement of a rapid estimation model of tree debris following ice storms. An initial model found using 30-m resolution National Land Cover Database (NLCD) tree canopy cover (TCC) data did not significantly ($P \approx 0.20$) improve estimation of tree debris within a community right-of-way (ROW) following an ice storm. We tested if finer resolution National Agriculture Imagery Program (NAIP) TCC imagery (2-m resolution or better) could more accurately predict tree debris after an ice storm. Tree canopy cover was estimated with NAIP across the entire community (TCC_{CITY}) and also the area that only covered the ROW plus a 15.24-m (50-foot) buffer on each side (TCC_{ROW}). The TCC_{CITY} ($P = 0.08$) estimate marginally improved tree debris prediction in the overall multiple regression model (R^2 adj = 0.917; $F = 133.8$; df = 3,33), but this was not the case with the TCC_{ROW} ($P = 0.66$) estimate. The TCC_{CITY} estimate was 34.7% (SEM = 2.0) and significantly ($P < 0.001$) 2 times greater than in the 16.2% (SEM = 2.2) TCC estimate from NLCD imagery. We found the TCC_{ROW} was 32.6% (SEM = 1.6) and significantly lower ($P = 0.003$) than in TCC_{CITY}. Results from this study may improve the overall ability to predict tree debris following ice storms from the regional models currently used to a more local estimate for a city. Future investigations are needed to determine if this is the case.
Keywords. Decision Making; Green Spaces; Planning and Management; Tree Canopy; Urban Forestry.

INTRODUCTION

Ice storms occur annually throughout the eastern United States and Canada as well as other places throughout the world (Changnon 2003; Hauer et al. 2006). They vary in intensity from minor ice accumulation of approximately 0.64 cm (0.25 in) that causes little or no damage, to a much greater thickness of precipitation in excess of 5 cm to 10 cm (2 in to 4 in) on surfaces, which can cause remarkable tree damage (Hauer et al. 1993; Hauer et al. 2006; Greene et al. 2007; Klopčič et al. 2020). Monetarily, ice storms result in hundreds of millions of dollars (USD) in annual loss and potentially billions of dollars in losses from property and tree damage during extreme and widespread ice storms (Hauer et al. 2006; Call 2010; Degelia et al. 2016). Damage also occurs to electrical grid systems, roadways, and property from fallen trees and branches, disrupting normal community functions (Call 2010). However, not all trees are severely damaged, as the resistance of tree species to ice accumulation varies (Hauer et al. 1993; Hauer et al. 2006; Coder 2017; Klopčič et al. 2020). Certain characteristics, such as weak branch attachments, indicated by included bark, dead and decaying branches, a broad crown, and fine branching, increase a tree's susceptibility to damage from ice and wind (Hauer et al. 2006; Staudhammer et al. 2009; Coder 2017; Klein et al. 2020).

Following an ice storm, a community often faces the cleanup of tree debris. The debris amounts can be substantial, and a coordinated effort to plan for debris removal is ideal (Escobedo et al. 2009; Schmitt-Harsh and Wiseman 2020; Nowak et al. 2022; Salisbury et al. 2022). The estimation of tree debris following a storm has been calculated using various methods ranging from on-the-ground, airborne laser scanner, aerial imagery, and prediction equations (King et al. 2005; Hauer et al. 2011; Rahman and Rashed 2015; Wu 2019). For example, Wu (2019) used Normalized Difference Vegetation Index (NDVI) values to estimate tree biomass and debris through satellite imagery. Predictive models use a combination of community

©2023 International Society of Arboriculture

attributes (e.g., street distance, community area, housing density) and storm parameters (e.g., ice accumulation, mean wind speed, maximum wind gusts, foliage presence) to estimate debris (Escobedo et al. 2009; Hauer et al. 2011). A field-based system uses inventory plots along the public rights-of-way (ROWs) to assess trees pre-storm in comparison to post-storm damage, which is used to estimate debris throughout the community (Bloniarz et al. 2001; Bond 2005).

Due to the labor and monetary needs required to recover after an ice storm, developing greater ice-storm resistance in tree populations through tree selection and management practices to minimize damage is an ideal forethought for communities (Hauer et al. 2006; Hauer et al. 2011), in addition to predicting potential debris before a storm or conducting a thorough estimation after. Hauer et al. (2011) developed a method by which communities can estimate tree debris following ice storms. They found that total street distance or total community land area and the ice thickness of the storm were significantly related to total debris. Tree canopy cover (TCC) was hypothesized to be a significant predictor (factor) in debris estimation. However, Hauer et al. (2011) found that coarse 30-m resolution National Land Cover Database (NLCD) TCC data did not significantly predict debris. Nowak and Greenfield (2010) found that NLCD imagery significantly underestimates TCC, which possibly explains an issue using NLCD TCC derived data as a debris predictor. Having no trees would result in no tree debris, and it seems logical that as tree density and biomass within an area increase, more potential tree debris is possible after a storm. Thus, TCC is a potential proxy for estimating tree abundance, and finer resolution imagery might improve the ability for this variable to estimate tree debris following an ice storm.

The aim of this research was to test if improved TCC estimates based on finer resolution imagery (approximately 1 m to 2 m) would improve the debris estimation models compared to models that use coarser resolution imagery (approximately 30 m). We hypothesized that the finer resolution TCC would be a significant predictor of debris associated with ice storms. We also hypothesized that street distance (or the area of a community) and ice thickness would be significant predictors. We further hypothesized that TCC estimates from finer resolution imagery (approximately 1 m to 2 m) would be higher than coarser resolution imagery (approximately 30 m). Finally, we hypothesized that debris estimates using TCC from within the ROW would be more accurate than a city-wide TCC estimate.

MATERIALS AND METHODS

Site Locations and Data Sources

This study tested the potential improvement of ice storm debris estimation using TCC estimates based on finer resolution imagery. Methods and data from Hauer et al. (2011) for communities in 15 eastern states (USA) were used, with the exception of replacing the TCC estimates. The TCC modification was made by replacing 2001 NLCD 30-m resolution tree canopy imagery with National Agriculture Imagery Program (NAIP) data at an approximate 2-m or better resolution. Figure 1 shows an example difference between NLCD and NAIP imagery and the subsequent ability to estimate tree canopy. In cases where NAIP was not available, National Aerial Photography Program (NAPP) imagery was used, providing data for 5 communities with ice storms before 2001.

Imagery was selected from the nearest date prior to the ice storm for the communities in this study. Most imagery (81%) was within 1 (53%) or 2 (28%) years prior to the ice storm and the remaining within 3 (17%) or 5 (3%) years. The imagery was paired with a municipal boundary shapefile in ArcGIS (ArcMap 10.5.1, Redlands, CA, USA). Image quality (e.g., image resolution) and data sources are found in the Appendix. A total of 1,000 locations as sample points were randomly located within the municipal boundary using the Create Random Points tool, and each was evaluated as landing on tree canopy (1), or not (0), and recorded as such in the ArcGIS attribute table for each location. Percentage TCC was calculated as:

$$\text{TCC (\%)} = (\text{Total Sample Points} - \text{Sample Points Over Tree}) / \text{Total Sample Points}$$

and calculated for the entire city (TCC_{CITY}). Tree canopy cover (TCC_{ROW}) was also estimated by buffering for trees just within the public rights-of-way (ROWs) plus an additional 15.24 m (50 ft) beyond the ROWs on each side. This TCC_{ROW} buffer accounted for trees on public land and for either trees adjoining the ROWs that may become damaged and fall within the ROWs, or tree debris brought into the ROWs by adjoining landowners. The TCC_{ROW} could include debris that was brought to the curb from the resident's private property and mixed with tree debris that fell within the municipal ROWs.

©2023 International Society of Arboriculture

Statistical Approach

Multiple regression models were used to predict tree debris (yd³) as a dependent variable. Ice thickness (in), street miles (mi), and each TCC type (TCC_{CITY} and TCC_{ROW}) were separately used as independent variables to predict tree debris. Results are presented in English with SI equivalent units, as these English parameters are the metrics used by communities in the United States to monitor debris collection. Model parameters used $P < 0.10$ for final inclusion.

RESULTS AND DISCUSSION

Tree Canopy Cover Estimates Based on Two Resolution Types

We found that TCC was 2 times greater ($P < 0.001$, df = 36, $t = 18.480$) using approximately 2-m or better NAIP imagery (34.7%, SEM = 2.0) than 30-m NLCD imagery (16.1%, SEM = 2.0)(Figure 2a). The TCC_{CITY} (37.1%, SEM = 2.5) was greater ($P = 0.003$, df = 34, $t = 3.264$) than in the TCC_{ROW} (32.6%, SEM = 1.6) (Figure 2b). Thus, the NLCD imagery underestimated TCC compared to both NAIP estimates in this study (Figure 3). The NLCD imagery is known to underestimate TCC; as such, our findings were not surprising (Nowak and Greenfield 2010).

Tree Debris Estimation

The NAIP estimate for TCC_{CITY} improved tree debris prediction ($P = 0.08$) in the overall multiple regression model (R^2 adj = 0.917; $F = 133.8$; df = 3,33) in Table 1. Within the studied location, for each percent of TCC_{CITY}, a total of 2,884 yd³ (2,205 m³) of tree debris is expected. Using TCC_{ROW} as a predictor was insignificant in our multiple regression model

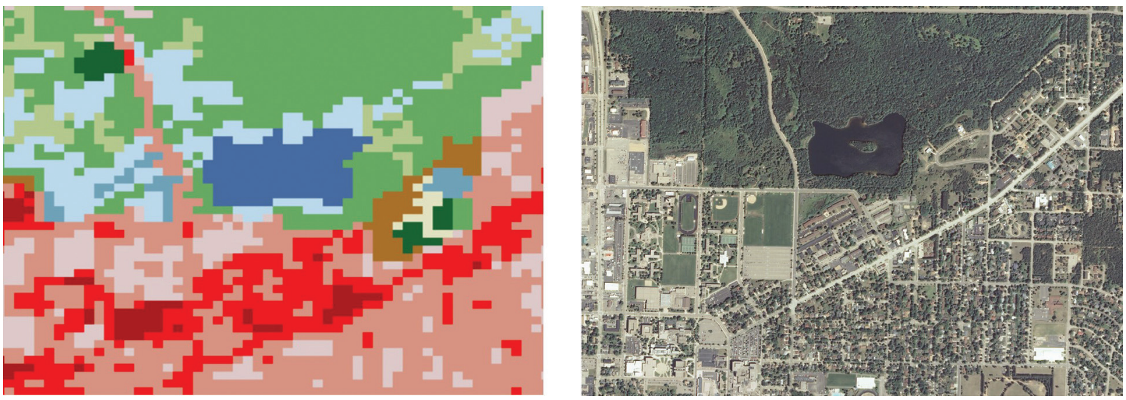

Figure 1. Comparison of 30-m resolution National Land Cover Database (NLCD, left image) and approximately 1-m National Agriculture Imagery Program (NAIP, right image) for Schmeeckle Reserve, Lake Joanis, Stevens Point, WI, USA.

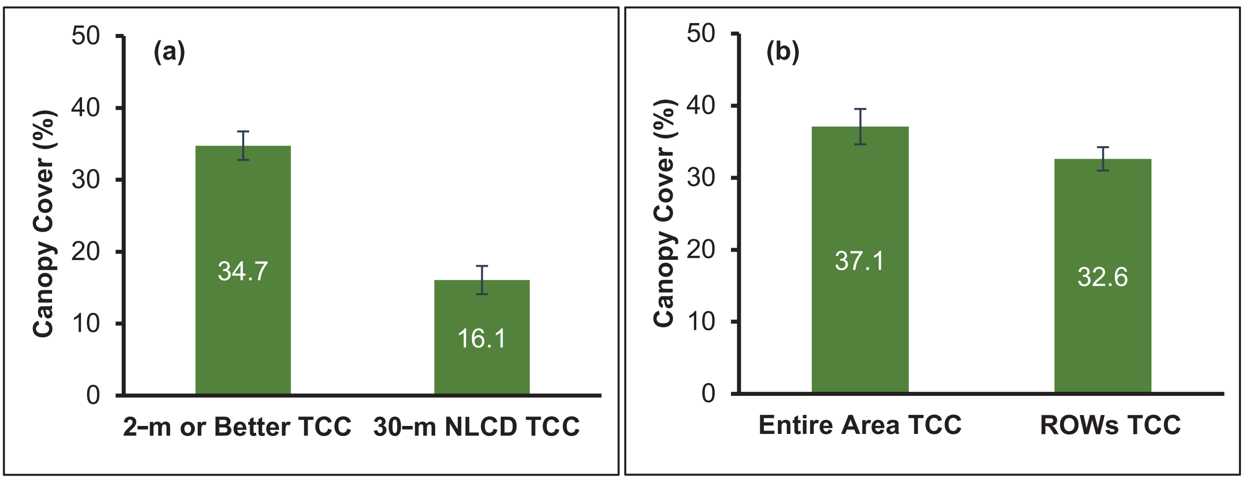

Figure 2. Tree canopy cover (TCC) percentage using 2-m or better imagery (NAIP or NAPP) or 30-m imagery (NLCD) across the entire city (a); percentage TCC across the entire city or only within the rights-of-way (ROWs) using NAIP or NAPP imagery (b).

©2023 International Society of Arboriculture

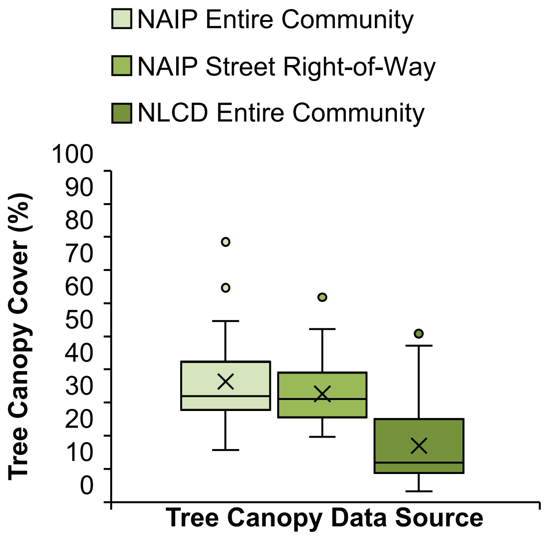

Figure 3. Box plot comparison of tree canopy cover (TCC) using 2-m or better imagery (NAIP or NAPP) or 30-m imagery (NLCD) across the entire community, or within the rights-of-way only (NAIP or NAPP). Box plot parts are: lower box 1st quartile; line median; *X* mean; upper box 3rd quartile. Line ends are minimum and maximum values; circles are outliers.

(P = 0.66). This finding was contrary to our hypothesis that it would be a better predictor than TCC_{CITY}. One explanation is that tree debris from city parks would not be captured in the TCC_{ROW} model. Additionally, it is possible that residents also moved tree debris from areas beyond the TCC_{ROW} area, such as from back and side yards, and placed it on the curb for accumulation. The effect of street distance on debris estimation decreased from 655.1 yd^3 (500.9 m^3) of tree debris per street mile (1.61 km) to 638.4 yd^3 (488.1 m^3) in the updated model (Table 2). The ice thickness predictor also increased with each inch (2.54 cm) of ice, accounting for 59,307 yd^3 (45,343 m^3) of tree debris in a community. Tree debris from storms is one component of annual tree biomass in the urban forest (Nowak et al. 2019).

Tree Debris Model Application

The model estimates for debris in this paper predict a volume associated with the near-term collection of tree biomass within public ROWs. Additional woody

Table 1. Estimation of tree debris (yd^3) collected from within public lands and rights-of-way by a community following an ice storm. Modified model based on Hauer et al. (2011). TCC (tree canopy cover); TCC_{CITY} (canopy cover estimate across the entire city).

Variable	Unstandardized coefficients	Standard error of the mean	*t*-statistic	*P*-value
Constant	–257,643	72,644	–3.55	= 0.001
Street distance (mi)	638.4	31.9	20.03	< 0.001
Ice (in)	59,307	19,310	3.07	= 0.004
TCC_{CITY} (%)	2,884	1,603	1.80	= 0.081

Table 2. Comparison of 2 models to estimate tree debris (yd^3) following an ice storm collected by a community using a canopy cover estimate across the entire city (TCC_{CITY}). The NLCD (National Land Cover Database) model variable used 30-m imagery and the NAIP (National Agriculture Imagery Program) and NAPP (National Aerial Photography Program) model variables used approximately 2-m or better imagery. SEM (standard error of the mean); TCC (tree canopy cover).

	NLCD Model Adj R^2 = 0.949		NAIP/NAPP Model Adj R^2 = 0.917	
Variable	Unstandardized coefficients (SEM)	*P*-value	Unstandardized coefficients (SEM)	*P*-value
Constant	–129,677 (72,644)	< 0.001	–257,643 (72,644)	= 0.001
Street distance (mi)	655.1 (31.9)	< 0.001	638.4 (31.9)	< 0.001
Ice (in)	49,426 (19,310)	= 0.003	59,307 (19,310)	= 0.004
TCC_{CITY} (%)	Not Significant	= 0.207	2,884 (1,603)	= 0.081

©2023 International Society of Arboriculture

debris occurs on private property. Tree debris that is collected and reimbursed through United States Federal Emergency Management Agency disaster declaration is restricted to public property (FEMA 2018). The debris estimates from communities used to develop this model were based on debris placed within a public ROW (Hauer et al. 2011). This included debris from trees within the public ROW and debris that was placed in the ROW from private tree debris that either fell or was placed in the public ROW. Additional tree debris occurs on private land that was not accounted for in the model, which a community would normally collect within a few weeks to months following an ice storm.

It is not uncommon for additional tree debris resulting from storms to occur several months or even years later, either from failure initiated by the storm or people's decisions (e.g., people may decide to remove trees due to concern of future failure)(Hauer et al. 2006; Conway and Yip 2016). The model in this paper does not account for this. In addition, trees may become damaged by ice storms and not immediately fail from the storm (Shortle et al. 2003; Luley and Bond 2006; Greene et al. 2007). For example, tree branches may become cracked from ice loading and then, during a later loading event (e.g., wind, ice, foliage), fail and become debris (Zipperer et al. 2004; Greene et al. 2007; Kraemer and Nyland 2010; Coder 2017). While it is important to account for these additional residual sources of debris, the intent of this current model is to rapidly predict potential tree debris volumes during the near-term collection of debris. Thus, the modified model in this paper is intended to make local and regional estimates of debris collected by a municipality soon after ice storms (e.g., weeks to a few months). These estimates could be used then to plan for labor and equipment needs and estimate the potential costs for state and federal recovery funding.

CONCLUSION

Storms are a common urban forest disturbance factor resulting in tree damage and debris. Ice storms are one such common storm in eastern North America. Proactively estimating the volume of debris, or rapidly estimating potential debris soon after a storm, is important for planners. This study used an improved tree canopy estimate within a tree debris estimation model. We found marginal improvement using finer resolution imagery. However, the use of the canopy predictor should make a more local-based estimate for a community from a regional predictive model associated with the original model. Finally, ice storm frequency and severity within the eastern United States necessitates the incorporation of ice storm information into the urban forestry planning process. While we cannot stop ice storms from occurring, we can take steps to reduce the impact of this major forest disturbance on urban forests and the interface between forests, buildings, and infrastructure.

LITERATURE CITED

Bloniarz DV, Ryan HDP III, Luley CJ, Bond J, Hawkins DC. 2001. An initial storm damage assessment protocol for urban and community forests. Amherst (MA, USA): USDA Forest Service, Northeast Center for Urban and Community Forestry, University of Massachusetts, Amherst; Naples (NY, USA): Davey Resource Group. [Accessed 2022 October 9]. 35 p. www.umass.edu/urbantree/icestorm/pages/StormAssessProtocol.doc

Bond J. 2005. Final report: 2003 storm damage protocol implementation (OH-03-346). Naples (NY, USA): Davey Resource Group. [Accessed 2022 October 9]. 20 p. www.itreetools.org/storm/resources/2003%20SDAP%20Implementation.pdf

Call DA. 2010. Changes in ice storm impacts over time: 1886–2000. *Weather, Climate, and Society*. 2(1):23-35. https://doi.org/10.1175/2009WCAS1013.1

Changnon SA. 2003. Characteristics of ice storms in the United States. *Journal of Applied Meteorology and Climatology*. 42(5):630-639. https://doi.org/10.1175/1520-0450(2003)042<0630:COISIT>2.0.CO;2

Coder KD. 2017. Tree damage from major ice storms. *Arborist News*. 26(1):20-23.

Conway TM, Yip V. 2016. Assessing residents' reactions to urban forest disservices: A case study of a major storm event. *Landscape and Urban Planning*. 153:1-10. https://doi.org/10.1016/j.landurbplan.2016.04.016

Degelia SK, Christian JI, Basara JB, Mitchell TJ, Gardner DF, Jackson SE, Ragland JC, Mahan HR. 2016. An overview of ice storms and their impact in the United States. *International Journal of Climatology*. 36(8):2811-2822. https://doi.org/10.1002/joc.4525

Escobedo FJ, Luley CJ, Bond J, Staudhammer C, Bartel C. 2009. Hurricane debris and damage assessment for Florida urban forests. *Arboriculture & Urban Forestry*. 35(2):100-106. https://doi.org/10.48044/jauf.2009.018

FEMA. 2018. Fact sheet: Navigating your recovery: Debris removal. Hyattsville (MD, USA): Federal Emergency Management Agency. R4 DR-4400-GA FS 001. [Accessed 2022 October 9]. 2 p. https://www.fema.gov/press-release/20210318/fact-sheet-navigating-your-recovery-debris-removal

Greene DF, Jones KF, Proulx OJ. 2007. The effect of icing events on the death and regeneration of North American trees. In: Johnson EA, Miyanishi K. *Plant disturbance ecology: The process and the response*. Cambridge (MA, USA): Academic Press. p. 181-213. https://doi.org/10.1016/B978-012088778-1/50008-X

Hauer RJ, Dawson JO, Werner LP. 2006. Trees and ice storms: The development of ice storm–resistant urban tree populations. 2nd Ed. Joint Publication 06-1. Wausau (WI, USA): College

©2023 International Society of Arboriculture

of Natural Resources, University of Wisconsin–Stevens Point; Urbana (IL, USA): Department of Natural Resources and Environmental Sciences and the Office of Continuing Education, University of Illinois at Urbana-Champaign. 20 p. https://digitalcommons.unl.edu/usdafsfacpub/295

Hauer RJ, Hauer AJ, Hartel DR, Johnson JR. 2011. Rapid assessment of tree debris following urban forest ice storms. *Arboriculture & Urban Forestry*. 37(5):236-246. https://doi.org/10.48044/jauf.2011.031

Hauer RJ, Wang W, Dawson JO. 1993. Ice storm damage to urban trees. *Journal of Arboriculture*. 19(4):187-194. https://doi.org/10.48044/jauf.1993.031

King DJ, Olthof I, Pellikka PKE, Seed ED, Butson C. 2005. Modeling and mapping damage to forests from an ice storm using remote sensing and environmental data. *Natural Hazards*. 35:321-342. https://doi.org/10.1007/s11069-004-1795-4

Klein RW, Koeser AK, Kane B, Landry SM, Shields H, Lloyd S, Hansen G. 2020. Evaluating the likelihood of tree failure in Naples, Florida (United States) following Hurricane Irma. *Forests*. 11(5):485. https://doi.org/10.3390/f11050485

Klopčič M, Poljanec A, Dolinar M, Kastelec D, Bončina A. 2020. Ice-storm damage to trees in mixed Central European forests: Damage patterns, predictors and susceptibility of tree species. *Forestry: An International Journal of Forest Research*. 93(3): 430-443. https://doi.org/10.1093/forestry/cpz068

Kraemer MJ, Nyland RD. 2010. Hardwood crown injuries and rebuilding following ice storms: A literature review. Newtown Square (PA, USA): U.S. Department of Agriculture, Forest Service, Northern Research Station. General Technical Report NRS-60. 29 p. https://www.nrs.fs.usda.gov/pubs/34892

Luley CJ, Bond J. 2006. Evaluation of the fate of ice storm–damaged urban maple (*Acer*) trees. *Arboriculture & Urban Forestry*. 32(5):214-220. https://doi.org/10.48044/jauf.2006.027

Nowak DJ, Greenfield EJ. 2010. Evaluating the National Land Cover Database tree canopy and impervious cover estimates across the conterminous United States: A comparison with photo-interpreted estimates. *Environmental Management*. 46:378-390. https://doi.org/10.1007/s00267-010-9536-9

Nowak DJ, Greenfield EJ, Ash RM. 2019. Annual biomass loss and potential value of urban tree waste in the United States. *Urban Forestry & Urban Greening*. 46:126469. https://doi.org/10.1016/j.ufug.2019.126469

Nowak DJ, Greenfield EJ, Ellis A. 2022. Assessing urban forest threats across the conterminous United States. *Journal of Forestry*. 120(6):676-692. https://doi.org/10.1093/jofore/fvac019

Rahman MT, Rashed T. 2015. Urban tree damage estimation using airborne laser scanner data and geographic information systems: An example from 2007 Oklahoma ice storm. *Urban Forestry & Urban Greening*. 14(3):562-572. https://doi.org/10.1016/j.ufug.2015.05.008

Salisbury AB, Koeser AK, Hauer RJ, Hilbert DR, Abd-Elrahman AH, Andreu MG, Britt K, Landry SM, Lusk MG, Miesbauer JW, Thorn H. 2022. The legacy of hurricanes, historic land cover, and municipal ordinances on urban tree canopy in Florida (United States). *Frontiers in Forest and Global Change*. 5:742157. https://doi.org/10.3389/ffgc.2022.742157

Schmitt-Harsh ML, Wiseman E. 2020. Household perceptions and practices of recycling tree debris from residential properties. *Sustainability*. 12(16):6476. https://doi.org/10.3390/su12166476

Shortle WC, Smith KT, Dudzik KR. 2003. Tree survival and growth following ice storm injury. Newtown Square (PA, USA): U.S. Department of Agriculture, Forest Service, Northeastern Research Station. Research Paper NE-723. 4 p. https://doi.org/10.2737/NE-RP-723

Staudhammer CL, Escobedo F, Luley C, Bond J. 2009. Technical note: Patterns of urban forest debris from the 2004 and 2005 Florida hurricane seasons. *Southern Journal of Applied Forestry*. 33(4):193-196. https://doi.org/10.1093/sjaf/33.4.193

Wu J. 2019. Developing general equations for urban tree biomass estimation with high-resolution satellite imagery. *Sustainability*. 11(16):4347. https://doi.org/10.3390/su11164347

Zipperer WC, Sisinni SM, Bond J, Luley C, Pleninger AG. 2004. An assessment of management history of damaged and undamaged trees 8 years after the ice storm in Rochester, New York, U.S. *Journal of Arboriculture*. 30(2):92-100. https://doi.org/10.48044/jauf.2004.011

ACKNOWLEDGMENTS

This research was supported through funding and cooperation from the USDA Forest Service Southern Region, the University of Wisconsin–Stevens Point, the USDA Forest Service Midwest Center for Urban and Community Forestry, and the USDA National Institute of Food and Agriculture, McIntire-Stennis project 1021277.

Richard J. Hauer (corresponding author)
Professor of Urban and Community Forestry
University of Wisconsin–Stevens Point
College of Natural Resources
Stevens Point, WI, USA
Director of Urban Forestry
CN Utility Services
West Des Moines, IA, USA
rhauer@cnutility.com

Brandon B. Schulz
Undergraduate Research Assistant
University of Wisconsin–Stevens Point
College of Natural Resources
Stevens Point, WI, USA

Conflicts of Interest:
The authors reported no conflicts of interest.

Résumé. La planification des mesures de préparation en vue des tempêtes devrait inclure l'estimation des débris d'arbres qui seront générés. Cette étude a testée l'amélioration d'un modèle d'estimation rapides des débris d'arbres suite à des épisodes de verglas. Un premier modèle trouvé, utilisant les données de la couverture de la canopée arborescente (TCC) de la National Land Cover Database (NLCD) à résolution de 30 m, n'a pas amélioré de manière significative ($P \approx 0{,}20$) l'estimation des débris d'arbres dans une servitude de passage communautaire après un épisode de verglas. Nous avons testé si l'imagerie TCC plus fine du National Agriculture Imagery Program (NAIP)(résolution de 2 m ou supérieure) pouvait prédire avec plus de précision les débris d'arbres après un verglas. La couverture de la canopée des

©2023 International Society of Arboriculture

arbres a été estimée avec le NAIP sur l'ensemble de la communauté (TCC_{CITY}) et également sur la zone qui ne couvrait que la servitude de passage et une zone tampon de 15,24 m (50 pieds) de chaque côté de (TCC_{ROW}). L'estimation TCC_{CITY} (P = 0,08) a légèrement amélioré la prédiction des débris d'arbres dans le modèle de régression multiple global (R^2 adj = 0,917; F = 133,8; df = 3,33), mais ce n'était pas le cas avec l'estimation TCC_{ROW} (P = 0,66). L'estimation de la TCC_{CITY} était de 34,7% (SEM = 2,0) et significativement (P < 0,001) deux fois supérieure à l'estimation de la TCC de 16,2% (SEM = 2,2) provenant de l'imagerie NLCD. Nous avons constaté que le TCC_{ROW} était de 32,6% (SEM = 1,6) et significativement plus faible (P = 0,003) que le TCC_{CITY}. Les résultats de cette étude peuvent améliorer la capacité globale d'estimation des débris d'arbres générés lors des verglas, en comparaison des modèles régionaux actuellement utilisés, pour une évaluation plus locale par une ville. Des investigations futures seront nécessaires pour déterminer si c'est le cas.

Zusammenfassung. Zur Sturmvorbereitung gehört auch die Abschätzung des Ausmaßes der Baumverluste. In dieser Arbeit wurde eine Verbesserung eines Modells zur schnellen Schätzung von Baumverschmutzungen nach Eisstürmen getestet. Ein erstes Modell, bei dem Daten der National Land Cover Database (NLCD) mit einer Auflösung von 30 m für die Baumkronenbedeckung (TCC) verwendet wurden, führte nicht zu einer signifikanten Verbesserung (P ≈ 0,20) der Schätzung des Baumschutts innerhalb eines kommunalen Wegerechts (ROW) nach einem Eissturm. Wir testeten, ob feiner aufgelöste TCC-Bilder des National Agriculture Imagery Program (NAIP)(2 m Auflösung oder besser) eine genauere Vorhersage des Baumschutts nach einem Eissturm ermöglichen. Die Baumkronenbedeckung wurde mit NAIP für die gesamte Gemeinde (TCC_{CITY}) und auch für den Bereich geschätzt, der nur die Fahrbahn und einen 15,24 m langen Puffer auf jeder Seite der Fahrbahn abdeckte (TCC_{ROW}). Die TCC_{CITY}-Schätzung (P = 0,08) verbesserte die Vorhersage des Baumschadens im gesamten multiplen Regressionsmodell geringfügig (R^2 adj = 0,917; F = 133,8; df = 3,33), aber dies war nicht der Fall bei der TCC_{ROW}-Schätzung (P = 0,66). Die TCC_{CITY}-Schätzung betrug 34,7 % (SEM = 2,0) und war signifikant (P < 0,001) doppelt so hoch wie die TCC-Schätzung von 16,2 % (SEM = 2,2) aus den NLCD-Bildern. Wir fanden heraus, dass die TCC_{ROW} 32,6 % (SEM = 1,6) betrug und signifikant niedriger (P = 0,003) war als die TCC_{CITY}. Die Ergebnisse dieser Studie könnten die allgemeine Fähigkeit zur Vorhersage von Baumverlusten nach Eisstürmen verbessern, indem die derzeit verwendeten regionalen Modelle durch eine lokalere Schätzung für eine Stadt ersetzt werden. Zukünftige Untersuchungen sind erforderlich, um festzustellen, ob dies der Fall ist.

Resumen. La planificación de preparación para las tormentas debe implicar la estimación de los restos de árboles. Este documento probó una mejora de un modelo de estimación rápida de escombros de árboles después de tormentas de hielo. Un modelo inicial encontrado utilizando datos de cobertura de dosel arbóreo (TCC) de la Base de Datos Nacional de Cobertura del Suelo (NLCD) de 30 m de resolución no mejoró significativamente (P ≈ 0,20) la estimación de los desechos arbóreos dentro de un derecho de paso comunitario (ROW) después de una tormenta de hielo. Probamos si las imágenes TCC del Programa Nacional de Imágenes Agrícolas (NAIP) de resolución más fina (resolución de 2 m o mejor) podrían predecir con mayor precisión los escombros de árboles después de una tormenta de hielo. La cobertura del dosel de los árboles se estimó con NAIP en toda la comunidad (TCC_{CITY}) y también el área que solo cubría la ROW más un amortiguador de 15,24 m (50 pies) a cada lado de (TCC_{ROW}). La estimación de TCC_{CITY} (P = 0,08) mejoró marginalmente la predicción de escombros arbóreos en el modelo general de regresión múltiple (R^2 adj = 0,917; F = 133,8; df = 3,33), pero este no fue el caso con la estimación de TCC_{ROW} (P = 0,66). La estimación de TCC_{CITY} fue de 34,7% (SEM = 2,0) y significativamente (P < 0,001) dos veces mayor que en la estimación de TCC de 16,2% (SEM = 2,2) de imágenes NLCD. Encontramos que el TCC_{ROW} fue del 32,6% (SEM = 1,6) y significativamente menor (P = 0,003) que en TCC_{CITY}. Los resultados de este estudio pueden mejorar la capacidad general para predecir los escombros de árboles después de las tormentas de hielo de los modelos regionales utilizados actualmente a una estimación más local para una ciudad. Se necesitan investigaciones futuras para determinar si este es el caso.

Arboriculture & Urban Forestry Quiz Questions

To complete this quiz, go to the ISA website, log into your MyISA account, and make your way to the page for *Arboriculture & Urban Forestry* CEU Quizzes (www.isa-arbor.com/store/ceuquizzes/113).

Add the quiz to your cart, proceed through checkout, and look for the content to appear on your personal dashboard under the header, "My Quizzes." If you need a username and password, send us an e-mail (isa@isa-arbor.com).

A passing score for this quiz requires sixteen correct answers. Quiz results will display immediately upon quiz completion. CEU(s) are processed immediately. You may take the quiz as often as is necessary to pass.

Appendix on next page

©2023 International Society of Arboriculture

Appendix.

Table S1. Imagery sources and quality used in this study to estimate tree canopy cover (TCC). NLCD (National Land Cover Database); NAIP (National Agriculture Imagery Program); NAPP (National Aerial Photography Program); ND (no data).

City	State	Ice storm year	Imagery date	Spectral bands[a]	Image source	Approximate resolution (m)	NLCD TCC (%) entire community	NAIP/NAPP TCC (%) entire community	NAIP/NAPP TCC (%) street rights-of-way
Ballwin	MO	2007	2006	Three-Band	NAIP	2	31.5	54.7	37.6
Bath	ME	2008	2007	Three-Band	NAIP	1	47.1	64.8	47.6
Burlington	NC	2002	1995	One-Band	NAPP	2	16.1	30.4	ND
Burlington	NC	2003	1995	One-Band	NAPP	2	16.1	30.4	ND
Decatur	IL	2006	2005	Three-Band	NAIP	2	11.7	40.4	39.0
Ellisville	MO	2006	2005	Three-Band	NAIP	2	ND	53.0	40.4
Euclid	OH	1996	1994	One-Band	NAIP	3.5	9.0	28.1	ND
Evansville	IN	2009	2008	Four-Band	NAIP	1	10.2	27.1	24.1
Exeter	MO	2007	2005	Three-Band	NAIP	2	3.3	27.7	27.0
Fayetteville	AR	2009	2006	Three-Band	NAIP	2	26.1	42.3	28.9
Forsyth	IL	2007	2005	Three-Band	NAIP	2	6.2	29.0	19.9
Gladstone	MO	2002	1997	One-Band	NAPP	2	11.6	30.3	ND
Greenville	SC	2005	2005	Three-Band	NAIP	1	40.2	50.7	48.3
Harrison	AR	2009	2006	Three-Band	NAIP	2	13.1	37.2	31.8
Henderson	KY	2009	2008	Three-Band	NAIP	1	11.9	28.9	23.3
Henderson-ville	NC	2010	2009	Four-Band	NAIP	1	25.7	35.0	42.2
Holden	MA	2008	2006	Three-Band	NAIP	2	ND	78.5	61.8
Jackson	MO	2007	2007	Three-Band	NAIP	1	14.7	31.9	23.2
Jefferson City	MO	2007	2005	Three-Band	NAIP	2	26.3	44.4	31.0
Jonesboro	AR	2009	2006	Three-Band	NAIP	2	24.9	31.6	24.4
Leesburg	VA	2007	2006	Three-Band	NAIP	2	11.3	31.0	30.3
Leominster	MA	2008	2006	Three-Band	NAIP	2	50.8	64.6	52.2
Lincoln	IL	2006	2005	One-Band	NAIP	2	4.0	35.6	39.2
Litchfield	CT	2001	1998	One-Band	NAPP	3.9	51.2	ND	ND

©2023 International Society of Arboriculture

Table S1. continued

City	State	Ice storm year	Imagery date	Spectral bands[a]	Image source	Approximate resolution (m)	NLCD TCC (%) entire community	NAIP/NAPP TCC (%) entire community	NAIP/NAPP TCC (%) street rights-of-way
Maryville	MO	2007	2005	Three-Band	NAIP	2	4.2	21.0	23.6
Mayfield	KY	2009	2008	Three-Band	NAIP	1	9.8	30.8	26.4
Mountain Home	AR	2009	2006	Three-Band	NAIP	2	19.7	42.0	27.6
Owensboro	KY	2009	2008	Three-Band	NAIP	1	7.0	21.0	19.7
Paducah	KY	2009	2008	Three-Band	NAIP	1	14.1	36.1	31.2
Raleigh	NC	2002	1999	Three-Band	NAPP	0.5	32.8	53.4	39.4
Richmond Heights	OH	2006	2005	Three-Band	NAIP	2	18.6	49.3	38.5
Savannah	MO	2007	2006	Three-Band	NAIP	2	5.1	27.8	29.9
Sidney	OH	2005	2004	Three-Band	NAIP	1	13.7	27.2	25.5
Sikeston	MO	2008	2007	Three-Band	NAIP	1	4.3	15.6	25.5
Sikeston	MO	2009	2007	Three-Band	NAIP	1	4.3	15.6	25.5
Springfield	MO	2007	2005	Three-Band	NAIP	2	11.7	39.9	36.3
St. Louis	MO	2006	2005	Three-Band	NAIP	2	7.9	16.0	31.5
St. Peters	MO	2007	2005	Three-Band	NAIP	2	10.0	26.9	24.5
Tulsa	OK	2007	2006	Three-Band	NAIP	2	10.1	33.9	32.5
Winchester	VA	2007	2006	Three-Band	NAIP	2	9.1	33.0	31.7

[a]Four-Band (Natural Color/Color Infrared); Three-Band (Color); One-Band (Black and White)

©2023 International Society of Arboriculture