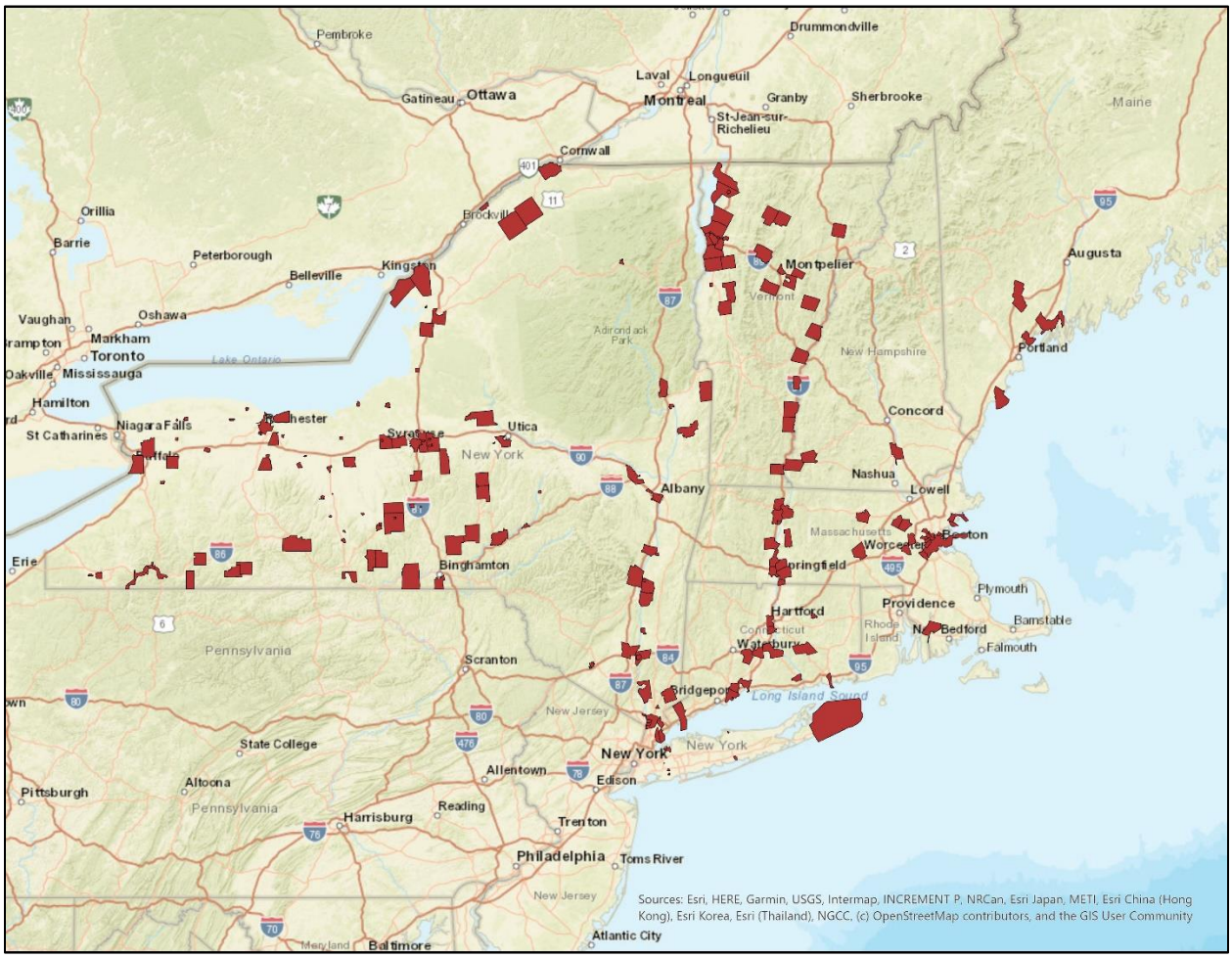
THREATS TO THE URBAN FOREST: THE POTENTIAL ECONOMIC IMPACTS OF INVASIVE FOREST PESTS AND DISEASES IN THE NORTHEAST



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Threats to the Urban Forest: The potential economic impacts of invasive forest pests and diseases in the Northeast

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VERMONT AGENCY OF NATURAL RESOURCES

USDA FOREST SERVICE

The UNIVERSITY of VERMONT

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Executive Summary

We utilized existing public tree inventories from municipalities throughout New England and New York to develop a synthesis of the possible economic impacts of invasive pests and pathogens to enhance municipal planning and management. We collated over 200 tree inventories through collaboration with Mark Ambrose (North Carolina State University), Frank Koch (USDA Forest Service), Fred Cowett (Cornell University), Jeff Ward (Connecticut Agricultural Experiment Station [CAES]) and Elise Schadler (Vermont Urban and Community Forestry).

Through this project we archived 237 municipal tree inventories for 200 municipalities on the FEMC data archive. These inventories range from 1993-2020. Of these, 88 had inventory data that could be used for ecosystem service valuation assessment. We assessed the annual ecosystem service valuation (gross carbon sequestration, avoided runoff, and pollution removal) of measured trees using the USDA Forest Service's i-Tree ECO program. We summed the annual benefits provided by all potential host trees for each of the eight invasive threats we considered – Asian long-horned beetle, brown tail moth, emerald ash borer, gypsy moth, hemlock woolly adelgid, oak wilt, beech leaf disease, and spotted lanternfly – to provide an assessment of the potential economic value put at risk by that pest or pathogen. In addition to the economic loss of benefits, we also provide the cost of replacing equivalent trees (i.e. total structural cost). Together, these metrics can be used to weigh the potential economic risk of a given pest for a municipality. For example, across all 88 municipalities, 688,314 trees were inventoried. Of these, emerald ash borer would impact 17,744 trees (3%) creating a total annual risk value of $140,820 per year, with a replacement cost of $44,335,904.

To present these assessments, we created an online map (https://arcg.is/S0zm9) where users can access information about each municipality's inventory, download a municipality-specific informational flyer aimed at providing planners, decision-makers, and other interested parties access to information related to tree valuation, and access inventory data. This work increases the data available and provides additional resources for managers and technical specialists who advocate for action to address these threats. See https://www.uvm.edu/femc/cooperative/projects/urban_pests for details about this project, to access the map, and to explore inventory data.

Introduction

This project was developed by the Forest Ecosystem Monitoring Cooperative (FEMC) Steering and State Partnership Committees in 2018. Collaborators cited a need to quantify the potential economic impacts of invasive forest pests and pathogens in urban areas and provide tools to communicate these risks in municipal planning and management. As novel invasive threats are identified in the region, or increase in their impact, it is critical for municipalities to have

information on the number of potential host trees that could be impacted as well as their estimated ecosystem service value. Further, it was identified that while there may be many municipal tree inventories in the Northeast, data access and quality issues exist. For example, inventories are often not publicly available, organized in a standard format, or assessed for data errors or incomplete entries. Work done by our collaborators at the Forest Service (Koch et al. 2018) compiled hundreds of inventories from the larger Northeast, Midwest and mid-Atlantic regions for modeling tree distributions in urban areas, and provided the initial foundation for this work. However, these data had not previously been collated into a regional database. The output of this work enhances the available data and resources of managers and technical specialists who engage with the public and policy makers to advocate for action to address these threats.

Specifically, the goals of this project were to:

1) Identify and access all suitable municipal tree inventories in the Northeast;
2) Summarize the economic risks of specific pests and pathogens; and,
3) Develop an interactive online tool for use in outreach and education.

To accomplish these goals, we worked with collaborators Mark Ambrose (USDA Forest Service), Frank Koch (USDA Forest Service), and Fred Cowett (Cornell University) to locate inventories and understand their nuances. Additional inventories were provided by Jeff Ward (CAES) and Elise Schadler (Vermont Urban and Community Forestry). Inventories were standardized and then processed in i-Tree ECO (Version 6.1.30) for individual tree-level ecosystem service valuation, which we summed by the cohort of host species for eight different invasive pests and pathogens: Asian long-horned beetle, brown tail moth, emerald ash borer, gypsy moth, hemlock woolly adelgid, oak wilt, beech leaf disease, and spotted lanternfly. We computed annual ecosystem service valuations of gross carbon sequestration, avoided runoff, and pollution removal, and summed them into a total annual value. The total replacement costs of host trees were also computed.

To present this information, we created an online, interactive map (https://arcg.is/S0zm9) where users can see which municipalities have inventory data, download a two-page factsheet summarizing economic ricks, and download inventory data from the FEMC data archive.

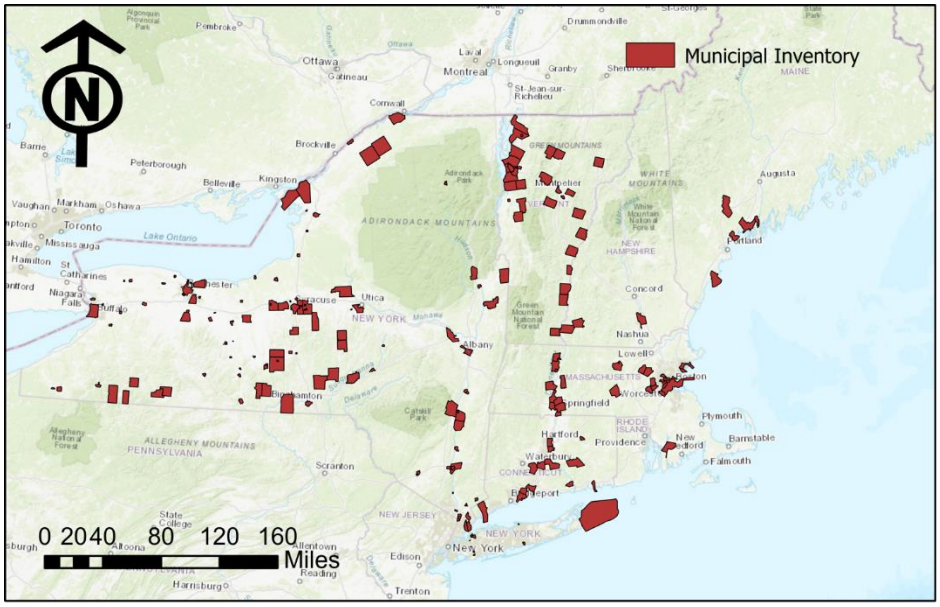

Figure 1. Locations of municipal tree inventory data used in this project.

Methodology

Tree inventories

We compiled public tree inventories from the Northeast (states of Connecticut, Maine, Massachusetts, New Hampshire, New York, Rhode Island, and Vermont) (Figure 1). The majority of the tree inventories were supplied by cooperators Mark Ambrose (USDA Forest Service) and Fred Cowett (Cornell University). Additional inventories were supplied by Jeff Ward (Connecticut Agricultural Experiment Station [CAES]) and Elise Schadler (Vermont Urban and Community Forestry). Each municipality's tree inventory data were added to the FEMC data archive in its native format. A total of 237 inventories from six states were archived (Figure 2). For a complete list of inventories included refer to Table A1 in the Appendix.

Municipal tree inventories came in many forms and all required standardization before they could be evaluated. We used i-Tree ECO V6 (https://www.itreetools.org/) to quantify tree ecosystem service valuation, which requires, at a minimum, tree genus and diameter (typically measured as diameter at breast height [DBH]). We created scripts to reformat each inventory to conform to the i-Tree ECO data structure. The scripts used to process these inventories are available on the FEMC archive (https://www.uvm.edu/femc/data/archive/project/urban_tree_inventories). We formatted all species names using the Integrated Taxonomic Information System (ITIS, http://www.itis.gov/) nomenclature standards using taxonomyCleanr package for R (Smith 2020) and assigned the associated i-Tree ECO species code. In some inventories DBH was

captured in size class. Due to the variability in how size class was defined, we used the maximum value of the size class as the DBH. In cases where the size class was nominal (e.g. 1, 2, 3) and no key or DBH was provided we were unable to use those inventories. In some cases, inventories used common names as species identifiers. These common names were collated into a lookup list of common and scientific names. In other cases, hybrid species and cultivars were recorded and due to the number of discrepancies these were grouped into species. For those that could not be matched, the closest species or genus was assigned. Tree records without a species or genus could not be used in the subsequent valuation assessment. One common issue with a majority of datasets from NY was that species codes did not conform to any accepted nomenclature we could find and therefore these inventories could not be used without additional work.

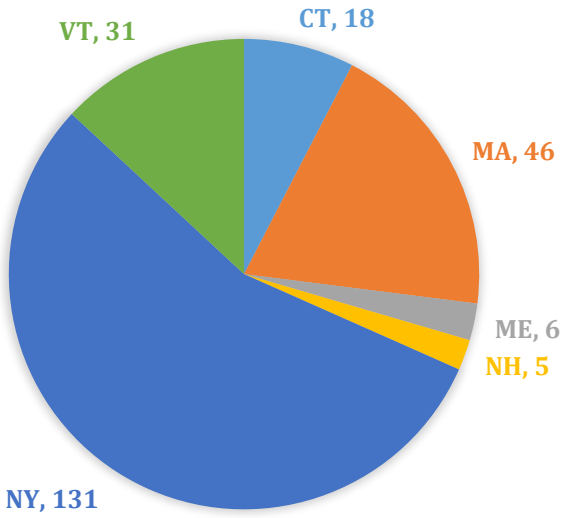

Figure 2. Number of municipal inventories per state collated from cooperators (Total = 237). Note that only 107 of these inventories contained data that conformed to i-Tree ECO requirements.

Of the 24,727 records from Vermont, we found that 2,707 records were not assigned to a municipality. We used tree geographic location information to assign a municipality to each of these trees. We also found that 5,117 tree records did not contain diameter information, however, the majority (3,180) of these were vacant locations. These data were retained in the inventory as records without a diameter, but because i-Tree ECO requires species and diameter, we could not include these records in analysis. For 398 records, the species code assigned was invalid or incomplete. For some of these, the comment field had information on the species that we extracted. Some of the municipal inventories in Vermont used deprecated i-Tree ECO codes for unknown conifers and broadleaf trees. Without information on genus, these trees could not be included in i-Tree for valuation.

In total, we excluded 130 inventories altogether, and 83,755 trees from inventories that we could use overall. 107 inventories, covering 92 municipalities contained data that could be cleaned and processed through i-Tree. Ten of the 92 municipalities contained multiple inventories. For these municipalities we chose the most complete and current inventory for assessment in the following order of preference; complete inventory, complete street tree inventory, partial street tree inventory, parks inventory. This excluded 13 additional inventories. Of the remaining 94 inventories, six were university campus, 4 of which were the only inventory for their municipality. We are primarily interested in municipalities, so these were also excluded. For the final assessments we had 88 municipalities with one inventory representing each.

Invasive pest and pathogens

We assessed economic vulnerability to the invasive tree pests and pathogens listed in Table 1. These species were selected due to their presence in at least one location in the region, their observed negative impacts to trees, and the prevalence of suitable host trees in public (Burke 2020, Ewing et al. 2019, Fite n.d., Havill et al. 2011, Houston 1979, Maine Forest Service n.d., Mosher 1915, O'Brien et al. n.d., Sawyer 2010, Simisky 2019 a, 2019b; Table A 2).

Table 1. List of invasive pests and pathogens selected for inclusion. Not all host trees are listed for each pest. Refer to Table A 2 for complete host list.

Name	Scientific Name	Type	Primary host genera
Emerald ash borer	*Agrilus planipennis*	Insect	Ash, olive, fringetree
Spotted lanternfly	*Lycorma delicatula*	Insect	Tree of heaven, apple, cherry
Asian longhorned beetle	*Anoplophora glabripennis*	Insect	Maple, birch, horsechestnut, elm, willow, sycamore, and others.
Oak wilt	*Bretziella fagacearum*	Fungus	Oak
Browntail moth	*Euproctis chrysorrhoea*	Insect	Apple, plum, crabapple, elm, hawthorn, maple, oak, and others.
Gypsy moth	*Lymantria dispar*	Insect	Oak, alder, apple, poplar, birch, larch, linden, sweetgum, and others.
Hemlock woolly adelgid	*Adelges tsugae*	Insect	Hemlock
Beech leaf disease	*Litylenchus crenatae* subsp. *mccannii*	Insect	Beech

Host tree valuation

The ecosystem services valuation of each municipality's inventoried trees was computed with i-Tree ECO. i-Tree requires certain climatic information, specifically precipitation, for valuation calculations. These data are provided by the weather station closest to the municipality. The selected weather station must have complete precipitation records for the inventory years. If

the inventory year was unknown, we used the year "2020". For those inventories that could be assessed in i-Tree ECO, resulting valuations were summed by pest or pathogen based on host species or genera listed in Table 2.

Informational factsheet

We created a two-page factsheet aimed at providing planners, decision-makers, and other interested parties access to municipality-specific tree valuation information for leading threats. The factsheet (Figure 2) outlines the municipality's assessed annual tree benefits, including gross carbon sequestration, avoided runoff, and pollution removal per pest or pathogen. Benefits provided by all potential host trees for a given pest were summed into a total potential loss per pest/pathogen. In addition to benefits at risk, the cost of replacing trees if they are killed was estimated as the total structural cost. For each municipality with an inventory, four of the eight pests or pathogens of concern (see Table 1) can be displayed in the factsheet. Together, these values can be used to weigh the potential benefit losses and costs that a municipality may incur if the invasive pest or pathogen is not contained. The second page of the factsheet displays summaries of municipal tree inventory data.

Table 2. Tree service and structural valuation computations using i-Tree ECO modeling output.

Variable	Units	i-Tree ECO tables	Computation
Carbon Sequestration	$/yr	IndividualTreeEffects, EcoElementPrices	Sum "GrossCarbonSequestration" by species in IndividualTreeEffects table. Convert from kg to US ton. Multiply by 'Price' under 'Element' CarbonSequestration in EcoElementPrices table.
Avoided Runoff	$/yr	IndividualTreeEffects, EcoElementPrices	Sum "AvoidedRunoff" by species in IndividualTreeEffects table. Multiply by 'Price' under 'Element' InterceptedWater in EcoElementPrices table.
Pollution Removal	$/yr	IndividualTreePollutionEffects	Sum five columns, "CORemovalValue", "O3RemovalValue", "NO2RemovalValue", "PM25RemovalValue", and "SO2RemovalValue", per species in IndividualTreePollutionEffects table.
Structural Value	$	IndividualTreeEffects	Sum "TreeValue" by species (or genus)

Results

Municipal tree inventories

Through this project we archived 237 municipal tree inventories ranging from 1993 – 2020 on the FEMC data archive. For a list of these datasets and more information, see the project page: https://uvm.edu/femc/cooperative/projects/urban_pests . Because many of the inventories were not provided to us from the municipalities themselves, not all datasets were made public. We are in the process of identifying a data contact and requesting permission to make the data public. We have received permission by municipalities to release data and will continue to publish data as more permissions are received.

Further, as explained in the methodology, 130 of the tree inventories were not able to be evaluated in i-Tree ECO because they lacked sufficient information or did not conform to the i-Tree ECO data structure. Only 107 inventories were appropriate for ecosystem service valuation assessment in i-Tree ECO. Formatting these 107 inventories took considerable time and effort; 79 of the remaining inventories could be re-formatted for i-Tree ECO, but species code lists would need to be located or created. As noted previously, only 88 of these 107 inventories were used in the final assessment. Across the 88 inventories that were evaluated in i-Tree ECO, there was a total of 688,314 trees. Maple, oak and basswood were the most common tree species inventoried (Figure 3).

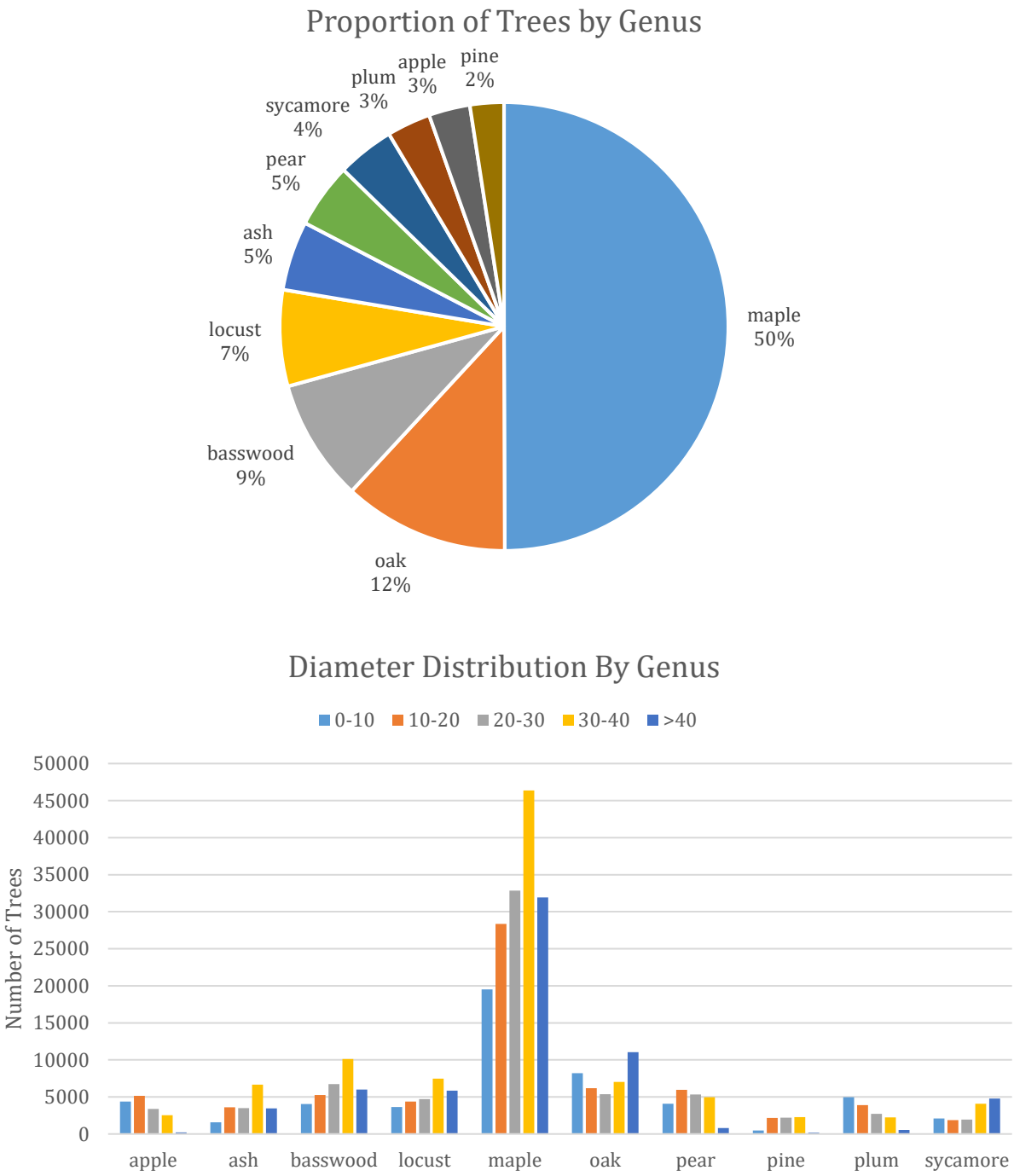

Figure 3. Distribution of species and size classes measured in the 88 inventories processed in i-Tree ECO.

Host tree valuation

For the 88 municipalities with useable inventory data gypsy moth, spotted lanternfly, browntail moth, and Asian longhorned beetle have the largest potential ecosystem service

valuation losses because each of these pests can impact a large number of tree species (Table A 2) and as a result, affect many inventoried trees (Table 3). This stands in contrast to those estimated for beech leaf disease and hemlock woolly adelgid that only impact a single species or genus. Per municipality, total estimated annual ecosystem service valuations ranged from $130 to $1,634,527. Cities with more trees had a higher valuation, but larger trees also provide greater ecosystem services than a smaller tree of the same species. The structural value indicates the cost of replacement of a similar tree (Table 4). Gypsy moth had the highest estimated structural value cost impacts at $922,466,833, followed by spotted lanternfly and browntail moth.

Table 3. Total estimated annual ecosystem service value of inventoried municipal trees that could be lost due to infestations of the selected invasive pests and pathogens. These data only encompass 88 municipalities in the Northeast. Values were computed with i-Tree ECO and are presented in dollars per year ($/yr).

Invasive pest/pathogen	Avoided runoff ($)	Carbon sequestration ($)	Pollution ($)	Total ($)
Asian longhorned beetle	465,071	516,077	1,472,533	2,453,681
Beech leaf disease	2,261	2,194	5,275	9,731
Browntail moth	482,062	630,035	1,466,197	2,578,294
Emerald ash borer	26,152	27,776	86,893	140,820
Gypsy moth	564,831	696,300	1,687,104	2,948,236
Hemlock woolly adelgid	2,451	1,780	2,839	7,069
Oak wilt	70,085	143,260	191,793	405,138
Spotted lanternfly	504,140	646,548	1,469,116	2,619,804

Table 4. The total number of host trees (N trees) per pest and the estimated total value ($) of replacing those trees.

Invasive pest/pathogen	*N host trees*	*% of total trees inventoried*	*Structural value ($)*
Asian longhorned beetle	229,458	33%	663,619,853
Beech leaf disease	775	0.1%	3,898,622
Browntail moth	281,525	41%	771,912,149
Emerald ash borer	17,744	3%	44,335,904
Gypsy moth	335,317	49%	922,466,833
Hemlock woolly adelgid	1,839	0.3%	3,842,518
Oak wilt	41,357	6%	163,863,467
Spotted lanternfly	287,180	42%	820,966,576

Factsheet

The two-page factsheet we created to display and communicate these data for each municipality is presented in Figure 4. The factsheet summarizes the ecosystem service value of all host trees recorded for a municipality. If a municipality had multiple inventories, a single inventory was selected based on the following order of criteria; complete inventory, complete street tree inventory, partial street tree inventory, parks inventory. Four different pests or pathogens were summarized per municipality. This factsheet is accessible via the project page (https://www.uvm.edu/femc/cooperative/projects/urban_pests) or the online mapping tool described in the next section.

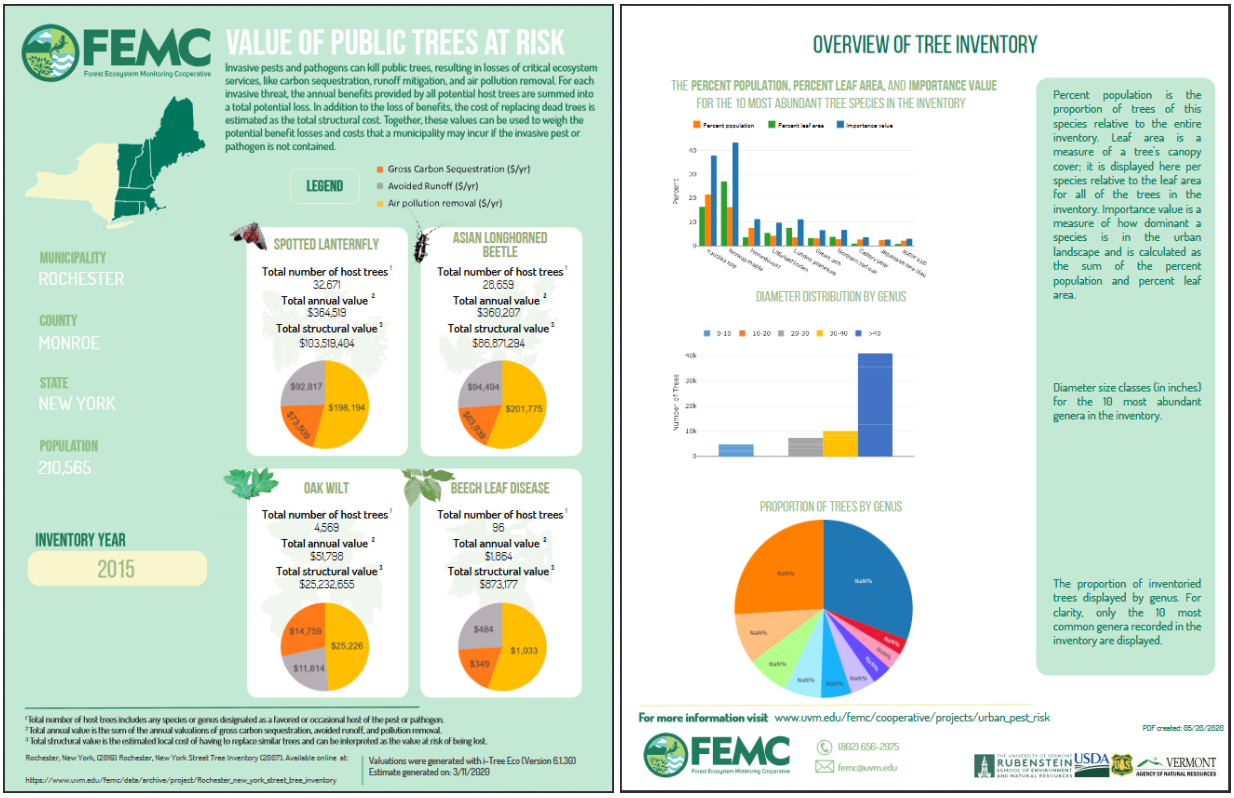

Figure 4. Example of the informational factsheet displaying the ecosystem service valuation for the city of Rochester, NY. Four pests are selected per municipality, here are shown the value of all inventoried host trees for the pests spotted lanternfly, Asian longhorned beetle, oak wilt, and beech leaf disease. On the back of the flyer, we have provided summaries of the inventory data in graphical form.

Online map and catalog

To allow for discovery of this information, we built an online map viewer https://arcg.is/S0zm9 (Figure 5). Municipalities with public inventories are highlighted. A user can select an informational flyer for download. Note that not all inventories included were able to be processed in i-Tree ECO and therefor do not have a factsheet. Additionally, a user can

access the FEMC Data Archive via this tool where individual municipal inventories are archived with associated information. See https://www.uvm.edu/femc/cooperative/projects/urban_pests for details about this project, to access the map, and to explore inventory data.

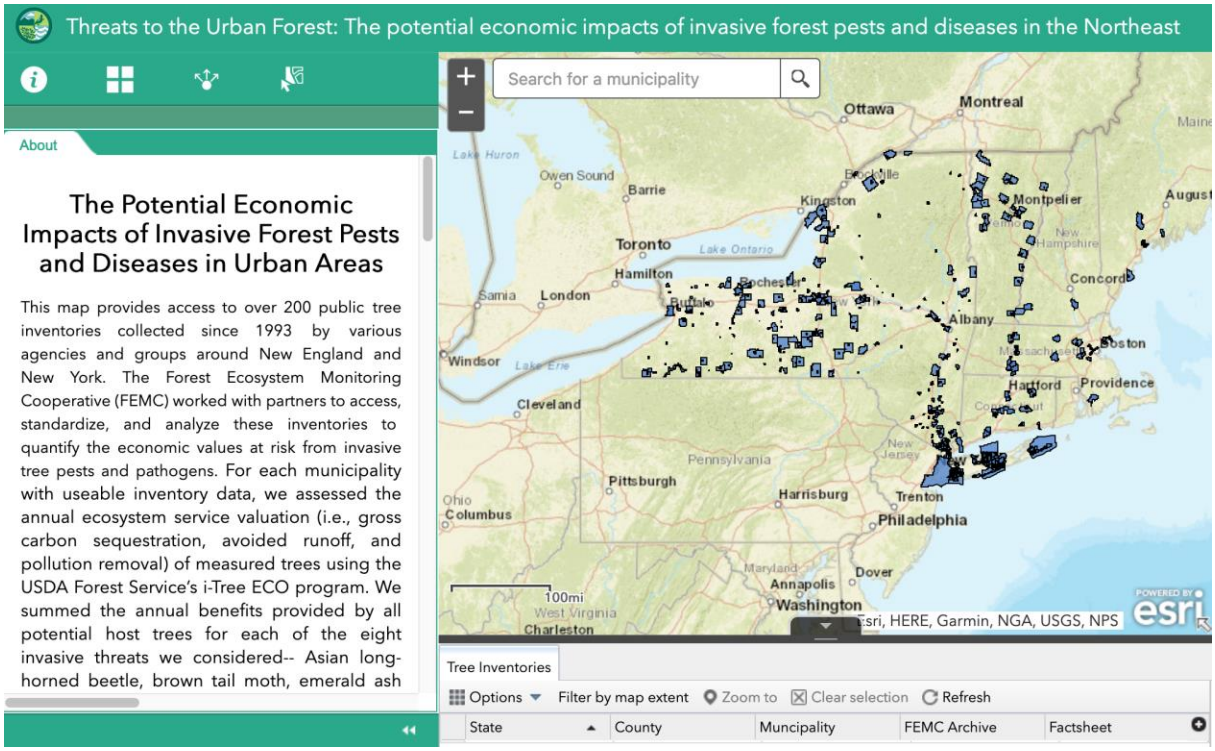

Figure 5. Online interactive map where uses can browse for municipal inventory data, access informational factsheets, and link to the FEMC data archive. Map is available at https://arcg.is/S0zm9.

Future work

A first next step would be to format the other 130 inventories we archived on the FEMC data archive so that they can be evaluated in i-Tree ECO. While 51 of these will not be able to be processed because they are summaries of inventories or are incomplete, 79 have unknown species codes that may be able to be processed with the creation of an appropriate code list.

Second, as new inventories are collected by municipalities or additional inventories are discovered, they can be evaluated via i-Tree ECO, added to the FEMC data archive, and included with the online map.

For municipalities with multiple inventories only one inventory was used for assessment. In some cases, municipalities did separate inventories for parks and streets but for the same year. These raw inventories could be aggregated into a single year dataset and rerun through i-Tree to have a broader assessment of public trees within the municipality. In the cases where a

municipality had multiple inventories across different years, we only used one. Future work could expand the factsheet and map to accommodate presentation of each inventory provided for a municipality and include information about each inventory type, which inventories were most recent and most complete.

References

Burke DJ, Hoke AJ, Koch J. 2020. The emergence of beech leaf disease in Ohio: Probing the plant microbiome in search of the cause. Forest Pathology: e12579.

Ewing CJ, Hausman CE, Pogacnik J, Slot J, Bonello P. 2019. Beech leaf disease: An emerging forest epidemic. Forest Pathology: 49(2).

Fite K. ND. Gypsy moth host preferences. Bartlett Tree Experts. Available at: https://www.bartlett.com/resources/tree-host-preferences-of-gypsy-moth.pdf

Havill NP, Montgomery ME, Keena M. 2011. Hemlock woolly adelgid and its hemlock hosts: a global perspective. In: Onken, B.; Reardon, R. eds. Implementation and status of biological control of the hemlock woolly adelgid. FHTET-2011-04. Morgantown, WV: US Department of Agriculture, Forest Service Forest Health Technology Enterprise Team: 3-14. Chapter 1.. 2011:3-14.

Houston DR. 1979. Classifying forest susceptibility to gypsy moth defoliation. USDA Agric. Handbook No. 542, 23p.

i-Tree ECO. i-Tree Software Suite, version 6.0. Available at: https://www.itreetools.org/

Koch FH, Ambrose MJ, Yemshanov D, Wiseman PE, Cowett FD. 2018. Modeling urban distributions of host trees for invasive forest insects in the eastern and central USA: A three-step approach using field inventory data. Forest Ecology and Management, 417: 222-236

Maine Forest Service. Nd. Browntail Moth. Available at: https://www.maine.gov/dacf/mfs/forest_health/documents/browntail_moth_brochure.pdf

Mosher FH. 1915. Food plants of the gypsy moth in America. USDA Bull. No. 250, 39p.

O'Brien JG, Mielke ME, Starkey D, Juzwik J. nd. Identify, Prevent, and Control Oak Wilt. USDA Forest Service. Available at: https://www.dec.ny.gov/docs/lands_forests_pdf/oakwiltusda.pdf

Sawyer A. 2010. Asian Longhorned Beetle: Annotated Categorization of ALB Host Trees. Available at: https://www.uvm.edu/albeetle/hosts.htm

Simisky T. 2019a. Emerald Ash Borer. Available at: https://ag.umass.edu/landscape/fact-sheets/emerald-ash-borer

Simisky T. 2019b. Spotted Lanternfly Available at: https://ag.umass.edu/landscape/fact-sheets/spotted-lanternfly

Smith C. 2020. EDIorg/taxonomyCleanr (Version 1.3.0). Available at: https://github.com/EDIorg/taxonomyCleanr

Appendix

Table A 1. List of municipal tree inventories included in this project by state, county, and municipality. If applicable, a more specific location is noted. All inventories listed here have been archived on the FEMC Data Archive, but not all were able to

State	County	Municipality	Specific Location	Inventory Year	Inventory Type
CT	New Haven	Cheshire		late 1990s - early 2000s	Street/partial
CT	New London	Colchester		late 1990s - early 2000s	Street/partial
CT	Middlesex	Essex		late 1990s - early 2000s	Street/partial
CT	Hartford	Hartford		2007	UFORE
CT	Hartford	Hartford		late 1990s - early 2000s	Street
CT	New Haven	Meriden		late 1990s - early 2000s	Street/partial
CT	Middlesex	Middletown		Unknown	All trees
CT	New Haven	Milford		late 1990s - early 2000s	Street
CT	New Haven	New Haven		2013	Street
CT	New Haven	New Haven		2018	Street
CT	New Haven	New Haven		late 1990s - early 2000s	Street
CT	New Haven	New Haven		2013	Street
CT	New London	New London	Connecticut College	2016	Campus
CT	New Haven	Orange		late 1990s - early 2000s	Street/partial
CT	Fairfield	Stamford	River Oaks Homeowners Association	2017	HOA
CT	Fairfield	Stamford		late 1990s - early 2000s	Street/partial
CT	Tolland	Storrs	University of Connecticut	2018	Campus
CT	Hartford	Wethersfield		2018	Street/partial
MA	Middlesex	Acton		2015	Street
MA	Hampshire	Amherst		2018	Street
MA	Hampshire	Amherst		2018	Street
MA	Hampshire	Amherst		2018	Street
MA	Hampshire	Amherst	University of Massachusetts	2017	Campus
MA	Middlesex	Arlington		2015	Street
MA	Middlesex	Arlington		2015	Street
MA	Suffolk	Boston	Northeastern University	2017	Campus
MA	Suffolk	Boston	Brighton Towne Estates Homeowners Association	2013	HOA
MA	Norfolk	Brookline		2015	Street
MA	Middlesex	Cambridge		2018	Streets and parks
MA	Middlesex	Cambridge	Massachusetts Institute of Technology	2009	Campus
MA	Suffolk	Chelsea		2017	Street

MA	Hampden	Chicopee		2018	Street
MA	Middlesex	Concord		2017	Public
MA	Norfolk	Dedham		2017	Public (mostly street)
MA	Norfolk	Dedham		2016	Parks
MA	Franklin	Deerfield		2016	Street
MA	Bristol	Fall River		2011-2012	Street
MA	Bristol	Fall River		2012	Street
MA	Franklin	Greenfield Town		2013	Street
MA	Hampden	Holyoke		2013	Street
MA	Worcester	Leominster		Unknown	Street
MA	Hampden	Longmeadow		2018	Public
MA	Middlesex	Natick		2015	Public
MA	Suffolk	Boston	Boston College	2015	Campus
MA	Hampshire	Northampton		2009	Public
MA	Hampshire	Northampton		2009	Public
MA	Franklin	Deerfield		2017	Street
MA	Essex	Salem		2016-2017	Street
MA	Essex	Salem		2016	Street
MA	Middlesex	Somerville		2018	Streets and parks
MA	Middlesex	Somerville		Unknown	Not provided
MA	Middlesex	Somerville		2009	Streets and parks
MA	Franklin	South Deerfield		2016-2017	Street
MA	Hampden	Springfield		2014-2018	Street, park, and campus
MA	Hampden	Springfield		2014-2019	Not provided
MA	Hampden	Springfield		2014-2020	Not provided
MA	Hampden	Springfield		2004-2019	Street trees
MA	Essex	Swampscott		2016-2017	Street
MA	Franklin	Turners Falls		2015	Public
MA	Middlesex	Watertown Town		2014	Street
MA	Norfolk	Wellesley		2004-2019	Public
MA	Hampden	West Springfield Town		2015-2016	Public
MA	Middlesex	Weston		2017	Street
MA	Worcester	Worcester		2008	Street
ME	Androscoggin	Auburn		2016	Street
ME	Androscoggin	Auburn		2016-2018	Street
ME	Sagadahoc	Bath		1993-2014	Public
ME	Cumberland	Brunswick	Bowdoin College	Unknown	Campus
ME	York	Kennebunkport		1998-2008	Public
ME	Cumberland	Yarmouth		2018	Street

NH	Cheshire	Chesterfield		2018	Public
NH	Cheshire	Keene		2013	City-owned trees
NH	Cheshire	Keene		2015	City-owned trees
NH	Cheshire	Keene	Keene State College	2015	Campus
NH	Hillsborough	Manchester		2018	Street
NY	Jefferson	Adams		2013	SWAT Street
NY	Albany	Albany		2015	street
NY	Erie	Alden		2018	Street trees
NY	Cattaraugus	Allegany		2009	SWAT Street
NY	Allegany	Andover		2015-2018	street
NY	Greene	Athens		2015	Street
NY	Genesee	Batavia		2014	Streets and parks
NY	Steuben	Bath		2018	street
NY	Dutchess	Beacon		2017	SWAT Street and park
NY	Dutchess	Beacon		2013	SWAT Street
NY	Westchester	Bedford		2015	Public
NY	Nassau	Bellerose		2018	street
NY	Broome	Binghamton		2015-2018	Public
NY	Monroe	Brockport		2016	Street
NY	Erie	Buffalo		2016-2017	Public (mostly street)
NY	Schuyler	Burdett		2008	street
NY	Onondaga	Camillus		2009	SWAT Street
NY	Ontario	Canandaigua		2006	street
NY	St. Lawrence	Canton		1999	Not provided
NY	Jefferson	Cape Vincent		2010	SWAT Street
NY	Tompkins	Cayuga Heights		2015	Not provided
NY	Madison	Cazenovia		2018	SWAT Street
NY	Jefferson	Clayton		2014	Streets and parks
NY	Oneida	Clinton		2018	street
NY	Wayne	Clyde		2017	SWAT Street
NY	Otswego	Cooperstown		2013	Public
NY	Cortland	Cortland		2018	Public
NY	Allegany	Cuba		2009	SWAT Street
NY	Onondaga	De witt		2015-2018	SWAT Street
NY	Onondaga	De witt		2016	SWAT Street
NY	Jefferson	Dexter		2017	SWAT Street
NY	Westchester	Dobbs Ferry		2015-2016	Not provided
NY	Yates	Dresden		2018	street
NY	Tompkins	Dryden		2016-2017	street

NY	Yates	Dundee		2003-2008	street
NY		Earlville		2010	street
NY	Erie	East Aurora		2001	Not provided
NY	Suffolk	East Hampton		2003-2006	street
NY	Nassau	East Rockaway		2004	SWAT Street
NY	Onondaga	East Syracuse		2010	street
NY	Onondaga	Elbridge		2008	SWAT Street
NY	Chemung	Elmira		2010	SWAT Street
NY	Cayuga	Fair Haven		2009	street
NY	Monroe	Fairport		2003	street
NY	Onondaga	Fayetteville		2004-2005	SWAT Street
NY	Dutchess	Fishkill		2008	SWAT Street
NY	Tompkins	Freeville		2008	street
NY	Oswego	Fulton		2005-2006	SWAT Street
NY	Ontario	Geneva		2007	STRATUM
NY	Ontario	Geneva		Unknown	street
NY	Warren	Glens Falls		2006-2009	street
NY	Washington	Granville		2005	SWAT Street
NY	Nassau	Great Neck Plaza		2011	street
NY	Chenango	Greene		2011	Street
NY	Washington	Greenwich		Unknown	street
NY	Tompkins	Groton		2008	street
NY	Madison	Hamilton		2000	street
NY	Westchester	Hastings-on-Hudson		2012	Street
NY	Monroe	Hilton		Unknown	street
NY	Monroe	Honeoye Falls		2006	street
NY	Columbia	Hudson		Unknown	street
NY	Westchester	Irvington		2018	SWAT Street
NY	Tompkins	Ithaca	Cornell University	2018	Campus
NY	Chautauqua	Jamestown		2014	street
NY	Onondaga	Jordan		2018	SWAT Street
NY	Warren	Lake George		2013	street
NY	Chautauqua	Lakewood		2015	Unknown
NY	Livingston	Lima		2018	street
NY	Onondaga	Liverpool		2009	SWAT Street
NY	Nassau	Malverne		2015-2018	Not provided
NY	Nassau	Malverne		2016	street
NY	Westchester	Mamaroneck		2017	SWAT Street
NY	Onondaga	Manlius		2015-2016	SWAT Street
NY	St. Lawrence	Massena		2018	street

NY	Cortland	McGraw	2016-2017	street
NY		Medina	2003	SWAT Street
NY		Middleport	Unknown	Not provided
NY	Orange	Middletown	Unknown	Public
NY	Onondaga	Minoa	2000	street
NY		Montour Falls	Unknown	street
NY	Oneida	New Hartford	2007	SWAT Street
NY	Westchester	New Rochelle	2010	Not provided
NY	Orange	Newburgh	2015	Public
NY		North Syracuse	2008	SWAT Street
NY	St. Lawrence	Ogdensburg	1999	street
NY	Otsego	Oneonta	2011	SWAT Street
NY	Tioga	Owego	2009	SWAT Street
NY	Chenango	Oxford	Unknown	street
NY	Suffolk	Patchogue	2008	All trees
NY		Penn Yan	2010	SWAT Street
NY	Monroe	Pittsford	2004-2017	Street
NY	Monroe	Pittsford	2004	street
NY	Westchester	Pleasantville	1998	street
NY	Suffolk	Poquott	2016	Public
NY	Nassau	Port Washington	Unknown	street
NY	Cattaraugus	Portville	2009	Public
NY	St. Lawrence	Potsdam	2018	street
NY	Dutchess	Poughkeepsie	2014	street
NY	Oswego	Pulaski	2017	street
NY	Dutchess	Red Hook	2015	SWAT Street
NY	Dutchess	Rhinebeck	2018	SWAT Street
NY	Monroe	Rochester	2015	Streets and Parks
NY	Monroe	Rochester	2018	Street tree inventory
NY	Oneida	Rome	2014	Streets and parks
NY	Schenectady	Rotterdam	2018	Public
NY	Cattaraugus	Salamanca	2017	Street
NY		Saranac Lake	2013	street
NY	Ulster	Saugerties	2015	Street
NY	Seneca	Seneca Falls	2016	SWAT Street
NY	Chenango	Sherburne	2017	SWAT Street
NY	Ontario	Shortsville	2015-2016	street
NY	Rockland	South Nyack	2018	SWAT Street
NY	Tioga	Spencer	2016-2017	street
NY	Onondaga	Syracuse	2010-2018	Public

NY	Onondaga	Syracuse		2004	UFORE
NY	Dutchess	Tivoli		2006	SWAT Street
NY	Erie	Tonawanda		2015-2016	Streets and Parks
NY	Erie	Tonawanda		2008	street
NY	Tompkins	Trumansburg		2008	street
NY	Onondaga	Tully		2009	SWAT Street
NY	Otsego	Unadilla		2011	street
NY	Chemung	Van Etten		2008	Not provided
NY	Westchester	Verplanck		2006	Street
NY	Westchester	Verplanck		2006	Street
NY	Jefferson	Watertown		2017-2018	Public
NY	Jefferson	Watertown		1998-2008	street
NY	Monroe	Webster		2018	Street tree
NY	Allegany	Wellsville		2014	street
NY	Westchester	White Plains		2018	street
NY		Williamsville		2017	Public
NY		Williamsville		2017	Public
VT	Washington	Barre City		2015	Public
VT	Windham	Brattleboro		2015	Public
VT	Addison	Bristol		2014	Public
VT	Chittenden	South Burlington		2015	Street tree
VT	Chittenden	Burlington	University of Vermont	2014	Campus
VT	Chittenden	Charlotte		2016	Public
VT	Chittenden	Colchester		2000	Street
VT	Orange	Corinth		2005	Public
VT	Chittenden	Essex Junction		2014-2016	Public
VT	Windsor	Hartford		Unknown	Street, public green space, and school
VT	Chittenden	Hinesburg		2015	Public
VT	Lamoille	Hyde Park		2017	Street, cemetery, facilities
VT	Lamoille	Johnson		2014	Green space and street tree
VT	Caledonia	Lyndon		2015	Green space and street tree
VT	Addison	Middlebury		2014	Streets and parks
VT	Addison	Middlebury	Middlebury College	2011	Campus
VT	Chittenden	Milton		2015	Green space and street tree
VT	Washington	Montpelier		2018	Green space and street tree
VT	Washington	Northfield		2014	Green space and street tree
VT	Washington	Plainfield		2015	Green space and street tree

VT	Windham	Rockingham	2015	Green space and street tree
VT	Chittenden	Shelburne	2014	Green space and street tree
VT	Windsor	Springfield	2015	Green space and street tree
VT	Franklin	St. Albans city	2015	Green space and street tree
VT	Franklin	St. Albans town	2015	Green space and street tree
VT	Franklin	Swanton	2014	Green space and street tree
VT	Orange	Thetford	2018	Green space and street tree
VT	Addison	Vergennes	2014	Street tree and green space inventory
VT	Washington	Waterbury	2016	Street tree
VT	Windsor	Windsor	2016	Public
VT	Chittenden	Winooski	2018	Street tree inventory

Table A 2. List of host tree species for the eight invasive pests and pathogens listed in Table 1.

Host name	Scientific name	Pest/pathogen	Pest preference	Source
Alder	*Alnus* spp.	Gypsy moth	Very good	Mosher (1915)
Apen, bigtooth	*Populus grandidentata*	Spotted lanternfly	Good	Simisky (2019b)
Apple	*Malus* spp.	Gypsy moth	Very good	Mosher (1915)
		Browntail moth	Very good	Maine Forest Service (nd)
		Spotted lanternfly	Very good	Simisky (2019b)
Ash	*Fraxinus* spp.	Emerald ash borer	Very good	Simisky (2019a)
Ash, green	*Fraxinus pennsylvanica*	Asian longhorned beetle	Occasional	Sawyer (2010)
Ash, white	*Fraxinus americana*	Spotted lanternfly	Good	Simisky (2019b)
Aspen, bigtooth	*Populus grandidenta*	Gypsy moth	Very good	Mosher (1915)
Aspen, quaking	*Populus tremuloides*	Gypsy moth	Very good	Mosher (1915)
		Asian longhorned beetle	Occasional	Sawyer (2010)
Beech	*Fagus* spp.	Beech leaf disease	Very good	Ewing et al. (2019)
Beech, American	*Fagus grandifolia*	Gypsy moth	Very good	Mosher (1915)
		Spotted lanternfly	Good	Simisky (2019b)
Birch, black	*Betula lenta*	Gypsy moth	Occasional	Mosher (1915)
		Spotted lanternfly	Good	Simisky (2019b)
Birch, gray	*Betula populifera*	Gypsy moth	Very good	Mosher (1915)
Birch, paper	*Betula papyrifera*	Gypsy moth	Very good	Mosher (1915)

		Spotted lanternfly	Good	Simisky (2019b)
Birch, river	*Betula nigra*	Gypsy moth	Very good	Mosher (1915)
Birch, yellow	*Betula alleghaniensis*	Gypsy moth	Occasional	Mosher (1915)
Birches	*Betula* spp.	Asian longhorned beetle	Good	Sawyer (2010)
Boxelder	*Acer negundo*	Gypsy moth	Very good	Mosher (1915)
Buckeye	*Aesculus* spp.	Gypsy moth	Occasional	Mosher (1915)
Butternut	*Juglans cinera*	Gypsy moth	Occasional	Mosher (1915)
Cherry	*Prunus* spp.	Browntail moth	Very good	Maine Forest Service (nd)
	Prunus spp.	Spotted lanternfly	Very good	Simisky (2019b)
Cherry, black	*Prunus serotina*	Gypsy moth	Occasional	Mosher (1915)
		Spotted lanternfly	Good	Simisky (2019b)
Cherry, choke	*Prunus virginiana*	Gypsy moth	Occasional	Mosher (1915)
Cherry, pin	*Prunus pennsylvanica*	Gypsy moth	Occasional	Mosher (1915)
Cherry, sweet	*Prunus avium*	Gypsy moth	Occasional	Mosher (1915)
Chestnut, American	*Castanea dentata*	Gypsy moth	Occasional	Mosher (1915)
Chinkapin	*Castanea pumila*	Gypsy moth	Occasional	Mosher (1915)
Cottonwood, eastern	*Populus deltoides*	Gypsy moth	Occasional	Mosher (1915)
		Asian longhorned beetle	Occasional	Sawyer (2010)
Crabapple	*Malus* spp.	Gypsy moth	Very good	Mosher (1915)
		Browntail moth	Very good	Maine Forest Service (nd)
Cucumbertree	*Magnolia acuminata*	Gypsy moth	Occasional	Mosher (1915)
Dogwood	*Cornus spp.*	Spotted lanternfly	Good	Simisky (2019b)
Dogwood, flowering	*Cornus florida*	Gypsy moth	Occasional	Mosher (1915)
Elm	*Ulmus spp.*	Browntail moth	Very good	Maine Forest Service (nd)
		Asian longhorned beetle	Very good	Sawyer (2010)
Elm, American	*Ulmus americana*	Gypsy moth	Occasional	Mosher (1915)
Elm, English	*Ulmus procera*	Gypsy moth	Occasional	Mosher (1915)
Elm, slippery	*Ulmus rubra*	Gypsy moth	Occasional	Mosher (1915)
		Spotted lanternfly	Good	Simisky (2019b)
Gum, black	*Nyssa sylvatica*	Gypsy moth	Occasional	Mosher (1915)
		Spotted lanternfly	Good	Simisky (2019b)
Hackberry	*Celtis occidentalis*	Gypsy moth	Occasional	Mosher (1915)
		Asian longhorned beetle	Occasional	Sawyer (2010)
Hawthorn	*Crategus* spp.	Gypsy moth	Very good	Mosher (1915)
		Browntail moth	Very good	Maine Forest Service (nd)
Hazelnut	*Corylus* spp.	Gypsy moth	Very good	Mosher (1915)

Hemlock, eastern	*Tsuga canadensis*	Gypsy moth	Occasional	Mosher (1915)
Hemlock	*Tsuga spp.*	Hemlock woolly adelgid	Very good	Havill et al. (2011)
Hickory, bitternut	*Carya cordiformis*	Gypsy moth	Occasional	Mosher (1915)
Hickory, mockernut	*Carya tomentosa*	Gypsy moth	Occasional	Mosher (1915)
Hickory, pignut	*Carya glabra*	Gypsy moth	Occasional	Mosher (1915)
		Spotted lanternfly	Good	Simisky (2019b)
Hickory, shagbark	*Carya ovata*	Gypsy moth	Occasional	Mosher (1915)
Hophornbeam	*Ostrya virginiana*	Gypsy moth	Occasional	Mosher (1915)
Hornbeam	*Carpinus caroliniana*	Gypsy moth	Occasional	Mosher (1915)
Horsechestnut	*Aesculus* spp.	Asian longhorned beetle	Very good	Sawyer (2010)
Katsura	*Cercidiphyllum spp.*	Asian longhorned beetle	Occasional	Sawyer (2010)
Larch	*Larix* spp.	Gypsy moth	Very good	Mosher (1915)
Liden, American	*Tilia americana*	Spotted lanternfly	Good	Simisky (2019b)
Linden	*Tilia* spp.	Gypsy moth	Very good	Mosher (1915)
Maple	*Acer* spp.	Asian longhorned beetle	Very good	Sawyer (2010)
		Spotted lanternfly	Good	Simisky (2019b)
		Gypsy moth	Occasional	Mosher (1915)
		Browntail moth	Very good	Maine Forest Service (nd)
Mimosa, silk tree	*Alizia* spp.	Asian longhorned beetle	Occasional	Sawyer (2010)
Mountain Ash	*Sorbus* spp.	Gypsy moth	Very good	Mosher (1915)
		Asian longhorned beetle	Occasional	Sawyer (2010)
Oak	*Quercus* spp.	Oak wilt	Very good	O'Brien et al. (nd)
		Browntail moth	Very good	Maine Forest Service (nd)
		Spotted lanternfly	Good	Simisky (2019b)
Oak, black	*Quercus velutina*	Gypsy moth	Very good	Mosher (1915)
Oak, blackjack	*Quercus marilandica*	Gypsy moth	Very good	Mosher (1915)
Oak, bur	*Quercus macrocarpa*	Gypsy moth	Very good	Mosher (1915)
Oak, chestnut	*Quercus prinus, Quercus montana*	Gypsy moth	Very good	Mosher (1915)
Oak, chinkapin	*Quercus muehlenbergii*	Gypsy moth	Very good	Mosher (1915)
Oak, pin	*Quercus palustris*	Gypsy moth	Very good	Mosher (1915)
Oak, post	*Quercus stellata*	Gypsy moth	Very good	Mosher (1915)
Oak, red	*Quercus rubra*	Gypsy moth	Very good	Mosher (1915)
Oak, scarlet	*Quercus coccinea*	Gypsy moth	Very good	Mosher (1915)
Oak, shingle	*Quercus imbricaria*	Gypsy moth	Very good	Mosher (1915)
Oak, swamp white	*Quercus bicolor*	Gypsy moth	Very good	Mosher (1915)
Oak, white	*Quercus alba*	Gypsy moth	Very good	Mosher (1915)

Oak, willow	*Quercus phellos*	Gypsy moth	Very good	Mosher (1915)
Olive	*Olea europaea*	Emerald ash borer	Good	Simisky (2019a)
Paw Paw	*Asimina triloba*	Gypsy moth	Occasional	Mosher (1915)
Pear	*Pyrus* spp.	Gypsy moth	Occasional	Mosher (1915)
		Browntail moth	Very good	Maine Forest Service (nd)
Persimmon	*Diospyros virginiana*	Gypsy moth	Occasional	Mosher (1915)
Pine	*Pinus* spp.	Gypsy moth	Occasional	Mosher (1915)
		Spotted lanternfly	Very good	Simisky (2019b)
Plum	*Prunus* spp.	Gypsy moth	Occasional	Mosher (1915)
Poplar, Balm of Gilead	*Populus balsamifera*	Gypsy moth	Very good	Mosher (1915)
Poplar, Lombardy	*Populus nigra var. italica*	Gypsy moth	Very good	Mosher (1915)
Poplar, white	*Populusalba*	Gypsy moth	Occasional	Mosher (1915)
Redbud	*Cercis canadensis*	Gypsy moth	Occasional	Mosher (1915)
Sassafras	*Sassafras albidum*	Gypsy moth	Occasional	Mosher (1915)
		Spotted lanternfly	Good	Simisky (2019b)
Serviceberry	*Amelanchier* spp.	Browntail moth	Very good	Maine Forest Service (nd)
		Gypsy moth	Very good	Mosher (1915)
		Spotted lanternfly	Good	Simisky (2019b)
Snowbell, Japanese	*Styrax japonicus*	Spotted lanternfly	Good	Simisky (2019b)
Sourwood	*Oxydendrum arboreum*	Gypsy moth	Occasional	Mosher (1915)
Spruce	*Picea* spp.	Gypsy moth	Occasional	Mosher (1915)
Sweetgum	*Liquidambar styraciflua*	Gypsy moth	Very good	Mosher (1915)
Sycamore	*Platanus* spp.	Asian longhorned beetle	Good	Sawyer (2010)
Sycamore, American	*Platanus occidentalis*	Spotted lanternfly	Good	Simisky (2019b)
Tree of heaven	*Ailanthus altissima*	Spotted lanternfly	Very good	Simisky (2019b)
Tulip poplar	*Liriodendron tulipifera*	Spotted lanternfly	Good	Simisky (2019b)
Walnut, black	*Juglans nigra*	Spotted lanternfly	Good	Simisky (2019b)
White fringe tree	*Chionanthus virginicus*	Emerald ash borer	Good	Simisky (2019a)
Willow	*Salix* spp.	Gypsy moth	Very good	Mosher (1915)
		Browntail moth	Very good	Maine Forest Service (nd)
		Asian longhorned beetle	Very good	Sawyer (2010)
		Spotted lanternfly	Good	Simisky (2019b)
Witch hazel	*Hamamelis virginiana*	Gypsy moth	Very good	Mosher (1915)

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