October 2019

SOCIO-POLITICAL AND NATURAL-ECOLOGICAL FACTORS INFLUENCING URBAN FOREST MANAGEMENT IN MASSACHUSETTS

Rick W. Harper
University of Massachusetts - Amherst

SOCIO-POLITICAL AND NATURAL-ECOLOGICAL FACTORS INFUENCING URBAN FOREST MANAGEMENT IN MASSACHUSETTS

A Dissertation Presented

By

RICHARD WALLACE HARPER

Submitted to the Graduate School of the

University of Massachusetts Amherst in partial fulfillment

of the requirement for the degree of

DOCTOR OF PHILOSOPHY

SEPTEMBER 2019

Forest Resources and Arboriculture

SOCIO-POLITICAL AND NATURAL-ECOLOGICAL FACTORS INFLUENCING URBAN FOREST MANAGEMENT IN MASSACHUSETTS

A Dissertation Presented

by

RICHARD WALLACE HARPER

Approved as to style and content by:

____
Stephen DeStefano, Co-Chair

____
David V. Bloniarz, Co-Chair

____
Craig R. Nicolson, Member

____
Michael Davidsohn, Outside Member

____
Curtice R. Griffin, Department Head
Department of Environmental Conservation

DEDICATION

This work is dedicated to the memory of my Father who, instilled in me from my first memories, a love for trees and an appreciation for the environment.

ACKNOWLEDGEMENTS

This work would not have been possible without the enthusiastic support, continued guidance and ongoing advice of my committee: Drs. Stephen DeStefano, David Bloniarz, Craig Nicolson, and Michael Davidsohn. Your willingness, expertise, enthusiasm, cooperation and patience made this work a reality. Thank you all.

I am grateful to Dr. Curtice Griffin, Dr. Jody Jellison, Dr. William Miller, Dr. Todd Fuller, Dr. Wes Autio and Dr. Tricia Serio for their ongoing words of encouragement and support here at UMass. I would also like to express my gratitude to Dr. Emily Huff (Michigan State University), Dr. Paul Weston (Charles Sturt University), Dr. Brett Butler (USDA Forest Service), Dr. Nina Bassuk (Cornell University), Dr. Jay Dampier (University of Wisconsin), and Dr. Richard Cowles (CT Agricultural Experiment Station). A special thanks to Eric Griffith and the specialists at the UMass Institute for Social Science Research (ISSR), for consultation on research design, data management and analysis.

The understanding and grace from my loving wife and two young children has been invaluable to the success of this work – thank you Tracy, Trent & Jillian.

ABSTRACT

SOCIO-POLITICAL AND NATURAL-ECOLOGICAL FACTORS INFUENCING URBAN FOREST MANAGEMENT IN MASSACHUSETTS

SEPTEMBER 2019

RICHARD W. HARPER, BES, LAKEHEAD UNIVERSITY

MS, UNIVERSITY OF NEBRASKA

PhD, UNIVERSITY OF MASSACHUSETTS AMHERST

Directed by: Steven DeStefano, PhD, and David V. Bloniarz, PhD

The management of urban forest systems is a complex interaction of social-ecological elements where biophysical factors interact with social aspects including policy decision-makers, managers, and municipal and private-sector employees. In the New England states, tree wardens are the local officials responsible for the preservation, maintenance, and stewardship of the public trees of a municipality. In-person qualitative research interviews were conducted with 50 tree wardens throughout Massachusetts to understand position duties, responsibilities, and professional challenges at the community-level. Qualitative research interviews were also conducted with chairs from 13 volunteer urban tree committees across Massachusetts. The value of employing qualitative methodologies in urban forestry, such as research interviews, as a mechanism to inform Extension professionals of stakeholder needs was also explored and further defined. Clearly emergent themes were identified from interview data and explored through analysis and comparison with existing literature. Tree wardens are typically housed in a municipal department, routinely interact with a number of local organizations, including urban tree committees, and are concerned about emergent plant health issues of importance including Asian longhorned beetle (*Anaplophora glabripennis*), emerald ash borer (*Agrilus planipennis*), and hemlock woolly adelgid (*Adelges tsugae*) (HWA). Since eastern hemlock (*Tsuga canadensis*) is one of only four native coniferous trees of ornamental importance in the Northeast U.S., and

coniferous trees are notoriously underplanted in the urban environment, the ecology and natural history of its native and invasive insect and disease pests were reviewed in detail. These included HWA, elongate hemlock scale (*Fiorinia externa*), and shoestring root rot (*Armillaria* spp.). The use of pest resistant plant material – a strategy known to arborists and urban foresters as employing host plant resistance (HPR) – with applicability of HWA-resistant hemlock trees as potential substitutes for eastern hemlock plantings was explored. It was determined that HWA-resistant Chinese hemlock (*Tsuga chinensis*) would make a suitable surrogate ornamental planting for eastern hemlock in the urban environment.

TABLE OF CONTENTS

Page

LIST OF TABLES

Table Page

LIST OF FIGURES

INTRODUCTION

The origins of the definition of contemporary urban forestry date to the 1960s when Professor Erik Jorgensen, Faculty of Forestry at the University of Toronto developed a new course titled "urban forestry." This course was initiated in response to the serious and ongoing loss of Toronto's urban tree canopy cover due to the onset of Dutch elm disease (*Ophiostoma novo-ulmi*) (DED). Based on a report from Environment Canada (Jorgensen 1974), Jorgensen defined urban forestry as:

> A specialized branch of forestry that has as its objectives the cultivation and management of trees for their present and potential contribution to the physiological, sociological and economic well-being of urban society.

The definition of urban forestry was then expanded upon by Deneke (1993):

> Urban forestry is the sustained planning, planting, protection, maintenance, and care of trees, forests, greenspace and related resources in and around cities and communities for economic, environmental, social, and public health benefits for people. The definition includes retaining trees and forest cover as urban populations expand into surrounding rural areas and restoring critical parts of the urban environment after construction. Expansion at the urban/rural interface raises environmental and public health safety concerns, as well as opportunities to create educational and environmental links between urban people and nature. In addition, urban and community forestry includes the development of citizen involvement and support for investments in long-term on-going tree planting, protection, and care programs.

The reality is, of course, individuals with specialized training, local governing authorities and agencies of the state have been managing plants, forests and greenspace, from the rural to the urban gradient throughout the millennia that have composed human history (Dean 2005, Johnston 2015). The Greek and Roman civilizations, for example, established and cultivated trees, gardens, orchards and plantations. The Romans even titled the individual that cared for these plants an "arborator" – a term that was eventually supplanted by "arborist" in the seventeenth century (Evelyn 1664, Capana 1999, Johnston

2015). Based on a more current review, 'geographic location', 'measurable resource elements' and 'people' were routinely found to consistently emerge as part of a modern definition of urban forestry (Brown 2007). According to Nowak and Greenfield (2018) urban forests themselves may be simply described as "all trees within urban areas."

An understanding of urban forestry and its practice is critical to 21st century society, since as of 2007, over 50% of the world's population, and currently over 80% of America's population, is now classified as "urban" (U.S. Census 2010, U.S. Census 2016). Urban forests are known to supply a plethora of ecosystem services to the citizens living in these urbanized – or built – settings (Nowak et al. 2010, Nowak and Greenfield 2018). In an effort to intrinsically describe the advantages derived from these forests, they are often referred to as "green infrastructure", and increasingly are regarded to be as important to the functionality and well-being of an urban setting as roads, sidewalks, and buildings (Nowak et al. 2010, Clapp et al. 2014, Nowak and Greenfield 2018). Thus, one may rightly conclude that urban forestry is simply the management of trees in the built environment. And this management may be "planned and undertaken at several scales, ranging from the individual tree to the metropolitan landscape and beyond" (Dwyer et al. 2002).

The relationship between urban forestry and the study and experience of the environment is a natural one. Urban settings are often perceived as sites of great "environmental disparity" that feature a low percentage of vegetative canopy cover, offer disproportionally-reduced access to green space and recreational areas, and are characteristically lacking in organismal biodiversity (Reese and Wackernagel 1996, Clapp et al. 2014, US Forest Service 2015, Scharenbroch et al. 2017). Urban forests offer a tangible solution to address these disparities by adding value to living spaces, providing canopy cover to enhance biodiversity and wildlife populations, and augmenting recreational opportunities (McPherson 2007, Nowak and Greenfield 2018). Trees and natural spaces in urban environments are critical to human health and to the quality of life of the individual (van den Berg et al. 2010, Larry 2013, van den Berg et al. 2015).

The management of these urban forest systems in Massachusetts is generally lead by a tree warden – a local official responsible for the preservation, maintenance, and stewardship of the public trees of a municipality (Ricard 2005a, Ricard 2005b, Rines 2010, Rines 2011). These professionals routinely interact with a number of social-ecological elements including policy decision-makers, local associations and volunteer-based organizations, like urban tree committees. They also interact with biophysical factors, including urban infrastructure, plants, and insect and disease pests.

Over time, many invasive insect and disease pest introductions have occurred in the urban and rural forests of eastern North America (Havill and Montgomery 2008, Haack et al. 2010, Dodds and Orwig 2011, Dampier et al. 2018). Some of these invasions have had devastating impacts relative to native tree species populations, including gypsy moth (*Lymantria dispar* Linnaeus), Asian longhorned beetle (*Anaplophora glabripennis* Motschulsky), emerald ash borer (*Agrilus planipennis* Fairmaire), chestnut blight (*Cryphonectria parasitica* (Murrill) Barr) and the aforementioned DED (Elkinton and Liebhold 1996, Schlarbaum et al. 1998, Poland and McCullough 2006, Haack et al. 2010, Childs 2011). Hemlock woolly adelgid (*Adelges tsugae* Annand) (HWA) is also a widely recognized non-native insect pest that has devastated populations of eastern hemlock [(*Tsuga canadensis* (L.) Carrière)] trees throughout the urban and rural forests of eastern

North America (Havill and Montgomery 2008, Weston and Harper 2009, Harper and Cowles 2013, Tobin et al. 2013, Dampier et al. 2015).

The interplay of these complex social and environmental factors that are present in the 21st century urban forest prompted me to conduct the following research for this dissertation: (Chapter1) in-person qualitative research interviews with 50 tree wardens throughout Massachusetts to learn firsthand the position duties, responsibilities, and professional urban forestry-related challenges at the community level; (Chapter 2) qualitative research interviews with chairs from 13 citizen-based urban tree committees across Massachusetts to better understand the characteristics of successful volunteer-involvement in urban forest management at the local level; (Chapter 3) explore the value and application of employing qualitative methodologies in urban forestry, such as research interviews, as a mechanism to inform university-based Extension and continuing education programming audiences about emergent and relevant stakeholder needs; (Chapter 4) review the ecology and natural history of the invasive and indigenous insect and disease pests of one of only four native coniferous trees in the Northeast U.S. to be planted in the urban environment – the eastern hemlock (*Tsuga canadensis*); (Chapter 5) explore the applicability of invasive pest-resistant hemlock trees as potential substitutes for eastern hemlock plantings.

CHAPTER 1

URBAN FOREST MANAGEMENT IN NEW ENGLAND: TOWARDS A CONTEMPORARY UNDERSTANDING OF TREE WARDENS IN MASSACHUSETTS COMMUNITIES

1.1 Abstract

In the New England states, tree wardens are local officials responsible for the preservation, maintenance, and stewardship of municipal public trees. I explored the emerging professional challenges, duties, and responsibilities of tree wardens, from the subject's point of view, by conducting in-person, semi-structured qualitative research interviews with 50 tree wardens throughout Massachusetts. Many of my findings corroborate previous literature, including that tree wardens are typically housed in a municipal department (often public works or highway), that tree wardens routinely interact with a wide variety of local organizations (representatives from other municipal departments, community volunteer associations) and that as community size increases, tree wardens typically have access to a greater pool of resources to carry out urban forest management. A newer finding is that the subject of urban forest health arose as a topic of great importance for tree wardens, as nearly all interviewees (n=49) indicated that they monitor for urban forest pests and that they would like further continuing education concerning this, and other important subjects.

1.2 Introduction

The early Greek civilization pioneered practices related to plant care that included the installation of trees and gardens. It was the Romans, however, who are largely credited with formalizing early "arboriculture" (Johnston 2015). They performed large-scale pruning, felling, and clearing of trees to create space for public infrastructure, and to utilize wood resources for large-scale construction projects. They also carried out widespread planting and transplanting, as they installed trees and plants around their homes and urban landscapes, and established orchards for commercial-scale fruit production. They titled the individual responsible for the care of trees, an "arborator" (Capana 1999). This term continued to be widely used until the 17^{th} century, where it was eventually supplanted with "arborist" (Evelyn 1664).

Through the industrial revolution and beyond, cities and towns grew rapidly in size and population. This expansion meant that interaction between the urban environment and the rural, often wooded, landscape was more likely (Miller and Bates 2015). It was out of this relationship between the "built" and the "natural" ecosystem that the concept of the "urban forest", arose and with it the more defined practice of "urban forestry". An early, but comprehensive, understanding of urban forestry (according to Moeller 1977), was as follows:

> The *urban forest* is a flexible concept that encompasses rows of street trees and clusters of trees in city parks, green belts between cities, and eventually forests that are more remote from the inner city. The urban forest occupies that part of the urban ecosystem made up of vegetation and related natural resources found in urban, suburban and adjacent lands, regardless of ownership. As we move across the urban-rural gradient, the mix of benefits provided by the urban forest changes. The limits of the urban forest cannot be defined by a line on a map. More importantly, the *urban forest* provides a conceptual framework within which to organize a research program to maximize the benefits that forests can contribute to improving urban environments.

Though this definition was outlined over 4 decades ago, its application is still relevant today.

In recent decades, the size and scope of towns and cities of Massachusetts has expanded rapidly. At a rate of 5.0% growth from 1990 to 2000, Massachusetts ranked 4^{th} nationwide among states that experienced the greatest increase in urban growth (Shifley et al. 2012). Massachusetts also ranked 2nd (behind New Jersey), as one of the nation's most urbanized states, with a population increase of 5.5% since 1990 (Shifley et al. 2012). In addition to housing 91% of the state's 6.7 million residents, these same urban settings also feature significant urban tree canopy cover (i.e., Boston 29%, Worcester 37%, Springfield 33%), with plans to increase this cover through local urban tree planting initiatives (Schwarz et al. 2015).

Since the environmental, economic, and social importance of community trees planted in residential settings has been well-documented (McPherson et al. 2007), urban tree planting with the objective to increase tree canopy cover is positive news. Benefits derived from trees include annual air pollution removal equating to 711,000 metric tons nationwide, an estimated value of $3.8 billion USD (Nowak et al. 2006), and reduction of stress and improvement of physical and mental well-being of local citizenry (van den Berg et al. 2010, van den Berg et al. 2015). Urban forests are also credited with increasing values of local properties and the reduction of stormwater runoff through rainfall interception (McPherson et al. 2007, Nowak and Greenfield 2018). Furthermore, citizens themselves also tend to feel very passionately about access to community green space and urban trees, believing that these resources add beauty and value to towns, cities, and neighborhoods (Hull 1992, Shroeder et al. 2006).

Urban trees are, however, presented with very challenging growing conditions (Jutras et al. 2010, Scharenbroch et al. 2017), and limited understanding and empirical data exist regarding their growth response in the built environment (Roman 2014). What is known, however, is that though trees thrive in natural forested habitats for many centuries, those same species of trees located in urban environments often only live for as little as 10 years to perhaps nearly 30 years (Moll 1989, Roman and Scatena 2011). This reduced lifespan is associated with a number of factors including construction injury, invasive pests (Nowak and Greenfield 2012), pollutants, temperature extremes (Jutras et al. 2010), and lack of available growing space (Day et al. 2010, Watson 2014). One of the main concerns related to the greatly-reduced life-expectancy of urban trees, however, is that if they are not provided with the essential conditions to survive (Roman 2014) and they fail to reach their optimal mature stature, many of the aforementioned environmental benefits may not be fully realized.

The urban environments that have been constructed over the centuries have been widely criticized as being notoriously lacking in organismic bio-diversity – from pollinators, to birds, to other wildlife. This is also the case for urban trees. Of the nearly 1.2 million street trees in Massachusetts, nearly half (49%) are in the genus *Acer*. On a higher taxonomic level, 65% of street trees belong to either the Aceraceae or Fagaceae (Cumming et al. 2006). This uniformity may mean that our urban forests lack core resiliency (Kimmins 1997), and that they are susceptible to losses of large numbers of trees from any single disturbance, such as an invasive pest or a weather-related event (Clapp et al. 2014).

These challenges – individually, let alone cumulatively – put urban forest managers in a difficult position as they face the important task of managing urban natural resources with a limited scientific knowledge base from which to draw. To add to this information deficit, urban foresters are routinely faced with important resource (i.e., budget) constraints that directly impact – and even limit – urban tree management efforts (Stobbart and Johnston 2012).

The United States Department of Agriculture - Forest Service (USDA FS) is the main federal agency responsible for administering the national urban and community forestry (UCF) assistance program (Hauer and Johnson 2008). USDA FS involvement in state-wide urban and community forestry formally commenced with the 1978 Cooperative Forestry Assistance Act. The Federal Farm Bill of 1990 substantively increased federal support for the UCF program, at the state level (Hauer and Johnson 2008), to the point where these federal resources have now become a critical component of urban forest management in the U.S. In 2011, the UCF program provided technical and financial support to 7,171 communities throughout each of the 50 states, the District of Columbia, U.S. Territories and affiliated Pacific Island nations, reaching over 194 million residents (USDA FS n.d.). To receive this federal funding, states must address four critical components as a basis for successful urban forest management, including (i) staffing an urban and community forestry program coordinator (ii) coordinating volunteers/partner participants (iii) establishing an urban and community forestry council (iv) creating a 5-year strategic urban forestry plan (Hauer and Johnson 2008).

In Massachusetts, the Department of Conservation and Recreation (DCR) administers the urban and community forestry program (Rines et al. 2010). The state urban forestry coordinator and staff work in direct cooperation with municipal tree wardens (Doherty et al. 2000). The position of "tree warden" was first established in the U.S. by the Massachusetts legislature in 1896 (Ricard and Dreyer 2005, Ricard and Bloniarz 2006), where it was mandated that every town in Massachusetts must employ a tree warden (Rines et al. 2010). To this day, this position remains unique to the six states – Rhode Island, Connecticut, Massachusetts, Vermont, New Hampshire, Maine – that comprise the New England region of the U.S. (Ricard and Bloniarz 2006). Tree wardens are most appropriately identified as the local individuals with the "greatest responsibility" for the preservation and stewardship of public trees in municipalities (Ricard 2005a) of Massachusetts, and other New England states (Ricard 2005b). According to Ricard and Dreyer (2005) the

> "…municipal tree warden is arguably the most important human component of a city or town's community forestry program." A municipality "cannot conduct an effective community forestry program without the participation, perhaps even the leadership, of a well-qualified, active tree warden."

Since 2000, several research efforts have gathered information from, and about, Massachusetts tree wardens (Doherty et al. 2000, Rines et al. 2010, Rines et al. 2011), as well as tree wardens in neighbouring New England states (Ricard 2005a, Ricard 2005b, Ricard and Bloniarz 2006). Pioneering and insightful, these studies helped to establish an important baseline understanding related to the overall challenges and critical issues related to the position of tree warden. What previous studies have not attempted, however, is to "understand the world" from the tree warden's "point of view" using in-person, qualitative research interviews (Brinkmann and Kvale 2015).

Interviews are employed in many sectors, including the social sciences, to supply detailed knowledge from individuals that are usually recognized experts in their field, concerning a specific topic (Elmendorf and Luloff 2006). Interviewing may be regarded as a distinctive procedure that incorporates technique and skill, aimed at generating knowledge through the context of a social practice (Brinkmann and Kvale 2015). Interviews that take place in a face-to-face setting may facilitate extended dialogue, spontaneity, and the discovery of underlying thoughts and emotions that may not otherwise be uncovered (Holloway and Galvin 2017). Interview methodologies may range from being highly structured with detailed questions and topics to be covered, to being open and unstructured. Between these extremes is the semi-structured interview that according to Brinkmann and Kvale (2015),

> "seeks to obtain descriptions of the life world of the interviewee with respect to interpreting the meaning of the described phenomena; it has a sequence of themes to be covered as well as some suggested questions. Yet at the same time there is openness to change of sequence and forms of questions in order to follow up on the specific answers given and the stories told by subjects."

Journals regularly featuring urban forestry-related content (Arboriculture & Urban Forestry, Urban Forestry & Urban Greening, Journal of Forestry, Northern Journal of Applied Forestry) were searched for published studies concerning Massachusetts tree wardens and tree wardens in New England states. Due to the specificity of the topic-matter, 6 studies were closely examined (Doherty et al. 2000, Ricard 2005a, Ricard 2005b, Ricard & Bloniarz 2006, Rines et al. 2010, Rines et al. 2011) for direct, local comparison to findings in this study. Other manuscripts were referenced for purposes of broader contrast and discussion.

I 1) explored the responsibilities and emergent challenges of Massachusetts tree wardens in a naturalistic (i.e., in-person, in situ) manner (Gillham 2005) using a series of closed and open-ended semi-structured interview questions developed around pre-determined themes of interest, with participatory input from urban forestry specialists 2) contrasted these findings with the existing literature to provide comparative contemporary context for the position of tree warden in the Commonwealth of Massachusetts.

1.3 Materials and Methods

I employed a qualitative data collection and analysis approach, utilizing data generated from semi-structured interviews with Massachusetts tree wardens.

During the spring of 2013 an 8-question interview instrument (Table 1.1) was constructed in a participatory manner, with input from academic and agency urban forestry specialists, and beta-tested (Dampier et al. 2015). Interview candidates were selected in a purposive manner (Lemelin et al. 2017), based on the following criteria:

a) They would be able to provide expert knowledge regarding the functions and responsibilities associated with the position of tree warden,
b) They would be in a position to provide expert input concerning the management of urban trees in Massachusetts,
c) They were accessible and responsive to being interviewed and an in-person visitation.

The total number of interviews to be conducted was determined by the point at which "no new analytical insights" were "forthcoming" (Ritche and Lewis 2003), and the point at which a broad-based sampling of tree wardens had been obtained from across Massachusetts. It was determined that these requirements would likely be satisfied after obtaining 50 interviews with tree wardens in their respective communities.

From the autumn of 2013, through the spring of 2016, 50 interviews of active tree wardens were carried out in a naturalistic manner, from select municipalities throughout Massachusetts (Table 1.2). Appointments were scheduled with the respective tree warden, and a single interview typically took 15-30 minutes to complete. On the occasion where the tree warden was not available for a face-to-face meeting, the interview was conducted over the phone. Community visitations typically involved a post-interview tour of the municipality where specific urban trees, parks, and green spaces were explored and discussed.

To obtain a representative sample, tree wardens were purposively selected from larger, more urbanized communities as well as smaller, less densely-populated, rural communities. We adhered to the DCR's urban and community forestry program delineation of central-western Massachusetts (Worcester County west) and eastern Massachusetts (east of Worcester County) (Figure 1.1). Thus, interviews were carried out with tree wardens in communities throughout both regions of the Commonwealth.

Field notes that had been taken during each of the interviews (Brinkmann and Kvale 2015) were reviewed and checked for accuracy before being imported into the Computer Assisted Qualitative Data Analysis Software (CAQDAS), NVivo 11 (2015) (QSR International; Melbourne, AUS). Interview questions were developed around predetermined themes of interest, as described by Gillies et al. (2014), with the participation of agency urban foresters and urban forestry academics who reviewed and commented on the interview instrument before it was utilized. The significance and meaning of the participant responses that related to each of these predetermined themes (i.e., interview questions) was emergent and coded to generate a thematic framework.

Coding was performed in a systematic manner where a nested noding (i.e., initial "parent" nodes, followed by "child" nodes) structure (Dampier et al. 2014) was generated based on interview data, pursuant to the predetermined themes from the interview instrument. New, emergent themes that were attached to the predetermined themes from the interview instrument were corroborated using text search and word frequency counts, and were validated with a second author. Emerging themes were considered potentially valid when they appeared at least three times. If a theme occurred on one occasion (n=1) it may have been an “accident”; a theme that occurred twice (n=2) was considered to have been a “coincidence” (Dampier et al. 2014). To elicit deeper meanings from interview data, a follow-up round of NVivo-based querying (i.e., a matrix coding query) was carried out comparing responses of interviewees to other factors like participant geographical location within the state, or size (i.e., population) of the community. Illustrative quotes were also selected from participants to help clarify or reinforce a potentially emergent theme, and personal communications were also included from pertinent individuals.

1.4 Results and Discussion

i. Position structure

A majority of the 50 sources, or interviewees (n=26), reported that the position of tree warden was located in, or directly affiliated with, the ‘department of public works (DPW).’ A substantial number of sources (n=8) also indicated that the position of tree warden was associated with the local ‘highway department’. These themes are consistent with Ricard and Bloniarz (2006), who reported that tree wardens in the New England states were commonly housed in DPW (44%) and highway departments (15%). Similarly, Rines et al. (2010) found that 76% of tree wardens in Massachusetts were housed in the DPW, highway department, or another municipal office. Tree wardens interviewed in our study were also often noted associating the terms ‘director’ (n=13) or ‘superintendent’ (n=11) with their position.

ii. Occupational resources

Emergent themes were determined from a majority of the 50 interviewees (n=34) concerning access to 'occupational resources' that facilitated the day-to-day duties of a tree warden. These included 'chipper(s)' (n=21), a 'tree crew' of 2-4 individuals (n=28), and 'trucks' (n=22) of many types including water, dump, bucket and pickup trucks. A matrix coding query comparing community sizes of population 0-10,000, 10,001-20,000 and 20,001-30,000 residents revealed an increase in the number of tree wardens (n=10, n=16, n=18, respectively) who identified that these resources were available, as municipal population levels increased.

This is not surprising, as a direct relationship between increasing community size and available funds for urban forest management is consistent with findings of other studies (Treiman and Gartner 2004, Rines et al. 2010, Stobbart and Johnston 2012, Grado et al. 2013). The direct relationship between resource availability and population size may be due to a combination of factors including an increased tax base (Miller and Bates 1978), increased awareness of the practice of urban forestry among residents (Grado et al. 2013), and the affiliated benefits of urban trees. It may also be associated with a general trend towards greater demand for public services and the level at which they are delivered to residents (Treiman and Gartner 2005) in more populous communities.

iii. Organizational interactions

Emergent themes pertaining to a number of local organizations that tree wardens interacted with was discernible from a clear majority (n=37) of the interview participants. Some of the organizations identified included less formalized 'community organizations' (n=19) comprised of residents like local 'shade tree committees' (n=13), 'garden clubs' (n=6), 'conservation groups' (n=9), or more traditional organizations like 'municipal departments' (n=29), including the 'DPW' (n=7), 'highway department' (n=9), 'water department' (n=8), 'parks department' (n=5), 'planning board' (n=8), and local (i.e., conservation; historical; cemetery; open-space) 'commissions' (n=13). A matrix coding query indicated that tree wardens in the eastern part of the state are more likely to indicate a thematically identifiable 'community organization' or 'municipal department' (n=14, n=19 respectively) than their counterparts in the central-western portion of the state (n= 5, n=10 respectively). This would align with findings from other studies since citizens in larger, more populated communities (which are more common in eastern Massachusetts) tend to be more active and organized around environmental issues like urban green spaces and trees (Treiman and Gartner 2005) and feature a higher occurrence of advocacy groups (Rines et al. 2011).

iv. Monitoring for pests

With the exception of one individual, every tree warden interviewed indicated that 'yes' (n=49), they monitor by at least periodically visually inspecting urban trees for pests. This included *Anaplophora glabripennis* Motschulsky ('ALB', n=31), *Agrilus planipennis* Fairmaire ('EAB', n=29), *Adelges tsugae* Annand ('HWA', n=17), *Operophtera brumata* L. ('winter moth', n=15), *Lymantra dispar* L. ('gypsy moth', n=6), *Ophiostoma novo-ulmi* Brasier ('DED', n=4). According to a matrix coding query, some insect pests were identified in relative equal frequency between tree wardens in eastern Massachusetts and central-western Massachusetts (*A. glabripennis,* n=17 and n= 14, respectively; *A. planipennis,* n=14 and n=15, respectively). However, some pests were referenced to in the eastern part of the state (*L. dispar,* n=6; *O. brumata,* n=15), but not identified at all (n=0) from tree wardens located in the central-western part of

Massachusetts. It is probable that the absence of a pest from entire regions of the state (let alone a local municipality), may lead tree wardens to not concern themselves with it, as they are likely more mindful of real-time pest-related occurrences within their own local jurisdiction. Hence, since *L. dispar* and *O. brumata* have been predominantly located in the eastern part of the state at the time interviews were conducted, tree wardens in more central-western communities do not appear to as readily identify these pests as concerns (Figure 1.2).

The high level of responses from the interview sources affirming that they monitor for urban forest pests is of interest. Though there are numerous other illuminating studies about tree wardens in Massachusetts and the New England region (Doherty et al. 2000, Ricard 2005a, Ricard 2005b, Ricard and Bloniarz 2006, Rines et al. 2010, Rines et al. 2011), there is a dearth of information concerning pest-related activities. According to Raymond Rose, Town of Wrentham tree warden,

> "we used to have a full-time tree crew and a bigger budget when we were dealing with Dutch elm disease in the 1970s."

It would seem that urban forest pest issues affected not only resources ascribed to the community tree budget, but impacted the daily duties of municipal forestry staff, as individuals were presumably dedicated to the full-time removal of large numbers of trees that succumbed to pests like the aforementioned *O. novo-ulmi* in at least some Massachusetts communities. Currently, *Fraxinus* spp. comprise 5% of the urban street tree populations in Massachusetts (Cummins et al. 2006), but with the recent discovery of *A. planipennis*, an abundance of biomass will be locally generated in communities as these trees die. Hence the subject of urban forest health and its impact on tree warden activities is timely and worthy of further examination.

v. Training, educational needs

Interview data in relation to 'training and educational needs' (question 5) of tree wardens was disparate, however, nearly half of the participants (n=24) indicated thematically identifiable subject matter including the desire for more information concerning urban forest 'pests' (n=12), urban forest 'inventories' (n=4), and urban 'tree planting' (n=4). These themes were generally not surprising as the University of Massachusetts Extension Plant Diagnostic Lab "regularly" receives questions about urban forest pest management (Dr. N. Brazee, University of Massachusetts Diagnostic Lab Director, pers. comm.) from urban forest practitioners. The DCR urban and community forestry programme "frequently" receives questions concerning the various perspectives related to urban tree planting, and also "very often" receives inquiries concerning the conducting of an urban forest inventory (M. Freilicher, pers. comm.). Tree wardens also broadly identified the need for more information concerning 'safety' (n=13) with two affiliated sub-themes arising, including 'electrical hazard awareness training' (i.e., EHAP)' (n=3) and 'hazard or risk trees' (n=3). The somewhat lesser frequency regarding the occurrence of these two themes was intriguing. Electrical-related fatalities have been historically responsible for a substantial percentage (around 25% - 30%) of overall fatalities in the tree care industry, though rates have been dropping in recent years (Gerstenberger 2015). Furthermore, the topic of hazard, or risk trees, has received much attention as the issue of public safety and liability has escalated, and since the International Society of Arboriculture (ISA) released its *Tree Risk Assessment Qualification* (TRAQ) in 2011. Additionally, Ricard and Bloniarz (2006) concluded that tree wardens spend "most" of their time on activities like risk tree assessment and removal. The importance of this topic was also determined by Rines et al. (2010), who found that almost “all” tree wardens indicated that “removal of dead and hazard trees” was a “moderate or high” priority issue in their respective community. Our urban forests continue to age and decline, and nationwide the U.S. is losing an estimated 4 000 000 urban trees per year (Nowak and Greenfield 2012), hence the issue of hazard – or risk – trees is likely to continue to be of increasing relevance to tree wardens. It is curious as to why this issue was not identified with more emphasis, and this would indeed be a topic worthy of further research.

vi. Information delivery

Nearly all of the source responses concerning educational ‘information delivery’ mechanism could be thematically categorized (n=46). Over half of tree wardens responded that ‘electronic’ media (n=27) was an acceptable information delivery technique with a substantial number (n=19) specifically indicating that a ‘web-based’ format would be adequate. Over half of the tree wardens (n=31) indicated that ‘in-person’ delivery was also an acceptable mechanism for information exchange, specifically if the interaction was ‘local’ (n=8) and comprised of a ‘meeting’ (n=6) or ‘program’ (n=8). A matrix coding query relating interviewees to geographic location indicated that tree wardens in the eastern part of the state emphasized the need for a mix between ‘electronic’ based materials and ‘in-person’ information exchange (n=21 and n=17, respectively), but that tree wardens in the central-western part of the state indicated more of an emphasis on ‘in-person’ information exchange (n= 14), compared to ‘electronic’ based educational materials (n=6). This may relate to previous statements and findings from other studies, concerning community size and resource availability. Since central-western Massachusetts is composed of smaller, more rural communities and full-time tree wardens tend to be located in larger, more populated communities (Rines et al. 2010), those in the central-western portion of the state are more likely to operate on smaller budgets, respond reactively to tree-related issues and be less likely to have access to the infrastructure and resources that facilitate proactive urban forest management, including the internet (A. Snow, pers. comm.). As Melissa LeVangie, tree warden from the central-western Massachusetts Town of Petersham indicated concerning the transfer of educational information,

> "person-to-person interaction is key…web-based methods should be used to complement any information gaps along the way."

This corroborates Ricard and Bloniarz (2006), who determined that tree wardens find interactions with other tree wardens and in-person attendance at more formal educational seminars to be highly valuable.

vii. Timing (of program delivery)

Tree wardens indicated that 'spring' was the least popular time of the year to engage in educational or training activities (n=2) followed by 'fall' (n=8). On the other hand, 'winter' (n=15) and 'summer' (n=14), were identified as more appropriate times of the year to engage in professional development. This may be due to a number of factors, including the time commitment required by tree wardens that are involved with tasks associated with the commencement and close of the growing season, like spring and/or fall tree planting (D. Lefcourt, pers. comm.).

Since the position of tree warden is not a traditionally-recognized, formal profession, priorities associated with the position may vary considerably from municipality to municipality based on a community's individual urban forest priorities

(Ricard and Bloniarz 2006). Overall, tree wardens expressed that they interact with a wide number of community organizations, and municipal departments on a routine basis. Of further interest in this vein is the relationship between the local tree warden and the local utility (Doherty et al. 2000). Since it is estimated that street trees that are in the vicinity of utility lines are estimated to comprise 50% of the public urban forest (Moll 1988), this is a notable relationship. The interaction between tree wardens and the utility provider was identifiable (n=8) throughout responses in the interview questionnaire. According to Aggie Tuden, tree warden from the City of Medford,

> "…our relationship with the utility company is an important and mutually beneficial one".

Additionally, according to Warren Archey, tree warden in the Town of Lennox,

> "I have enjoyed a close relationship with the utility forester for many years."

Thus, it is apparent that a successful tree warden should have the capacity to effectively communicate with a wide number of individuals and organizations in their respective communities (Rines et al. 2010, Rines et al. 2011), including their utility partners (Doherty et al. 2000). And a successful tree warden should also have the capacity to embrace the dynamic state of their position, being able to balance a number of priorities that are subject to change, based on needs and occurrences in their local jurisdiction.

1.5 Conclusions

Though there is variation within Massachusetts communities, tree wardens are generally housed in a municipal department, like public works or the highway department, often in a senior management capacity. As the size of the community increases, the local tree warden typically has access to a larger pool of available resources; to successfully employ these resources to manage public shade trees, they often need to be able to interact with a wide range of local municipal departments, commissions and citizen volunteer groups. Tree wardens expressed the desire to receive continuing education, either in-person or web-based, preferably in the summer or winter months. Training content may vary widely but should include information pertaining to urban forest pest management, community tree inventories and urban tree planting. Nearly all tree wardens interviewed indicated that they routinely monitor for urban forest pests. Many of these urban forest priorities are worthy of further research, and the dynamic nature of the position of tree warden necessitates routine visitation, to assess training needs and priorities of these individuals who strive to preserve and protect both public trees and public safety throughout the Commonwealth of Massachusetts.

Table 1.1. Interview Questions and Predetermined Themes

Question	Pre-determined Theme
1) What best describes the position of Tree Warden in your community and how long have you occupied this position?	'Position Structure'
2) Highlight the essential resources (staff, technical equipment, etc.) you have to help you do your job?	'Occupational Resources'
3) What sort of groups (i.e. organizations, municipal departments) do you interact with regarding community tree-related issues?	'Organizational Interactions'
4) Are you currently monitoring for pest-related problems?	'Monitoring for Pests'
5) What are three educational/training needs?	
6) How could this information best be disseminated to you?	'Educational Needs'
7) What time of the year is training or programmatic information best made available?	'Information Delivery' 'Timing'
8) Would you be willing to share any of your local success stories with others?	'Sharing Successes'

Table 1.2. Tree wardens from the following Massachusetts municipalities were selected for semi-structured, naturalistic interviews.

Central-Western MA		Eastern MA	
Municipality	'opulation	Municipality	Population
Worcester	183,016	Cambridge	109,694
Springfield	153,991	Fall River	88,712
Chicopee	55,300	Newton	88,287
Amherst	37,819	Brookline	58,732
South Hadley	17,514	Plymouth	58,271
Greenfield	17,456	Medford	57,437
Belchertown	14,649	Barnstable	45,193
Athol	11,584	Everett	44,231
Sturbridge	9,268	Chelsea	38,861
Lenox	5,025	Watertown	34,127
Cheshire	3,235	Andover	33,201
Stockbridge	1,947	Natick	32,786
Ashfield	1,737	Needham	28,888
Granville	1,521	North Andover	28,352
Whately	1,496	Wellesley	27,982
Pelham	1,321	Walpole	24,070
Chester	1,308	Wilmington	22,325
Petersham	1,234	Acton	21,929
Goshen	1,054	Sandwich	20,675
--	--	Newburyport	17,926
--	--	Duxbury	15,059
--	--	Dennis	14,207
--	--	East Bridgewater	13,794
--	--	Bedford	13,320
--	--	Lynnfield	11,596
--	--	Wrentham	10,955
--	--	Dighton	7,086
--	--	Orleans	5,890
--	--	Rochester	5,232
--	--	Avon	4,356
--	--	Plympton	2,820

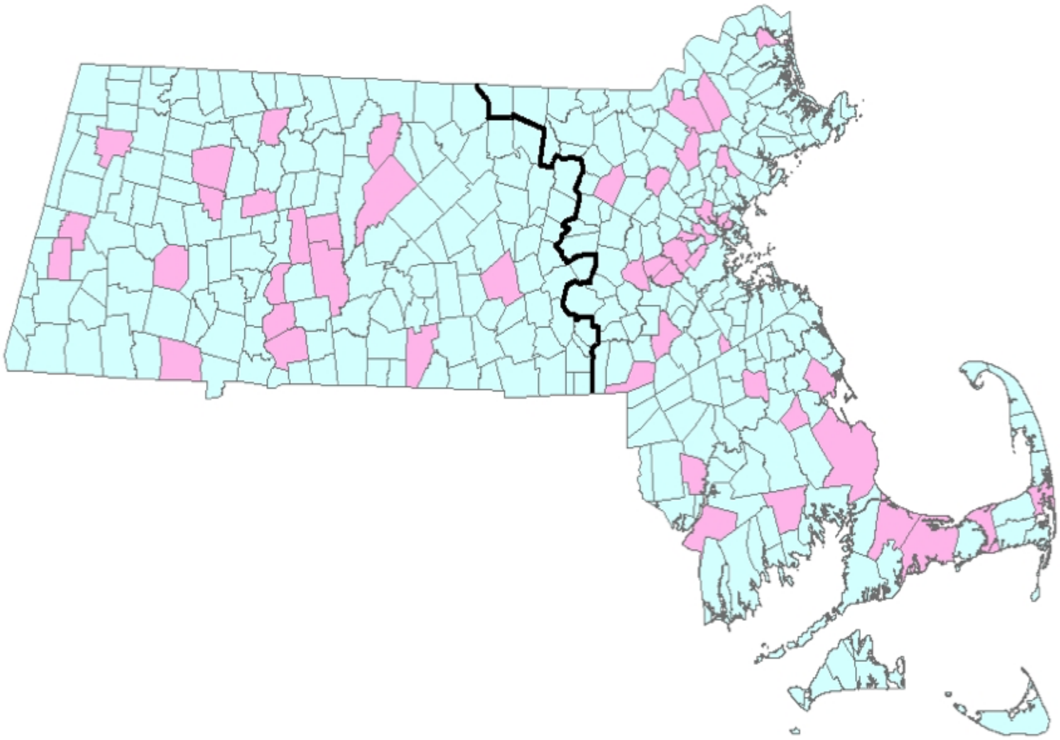

Figure 1.1. Representation of tree warden interviews by town. Note distinct "Western-Central" and "Eastern" regions of the state, as categorized by the Massachusetts Department of Conservation and Recreation's urban and community forestry program.

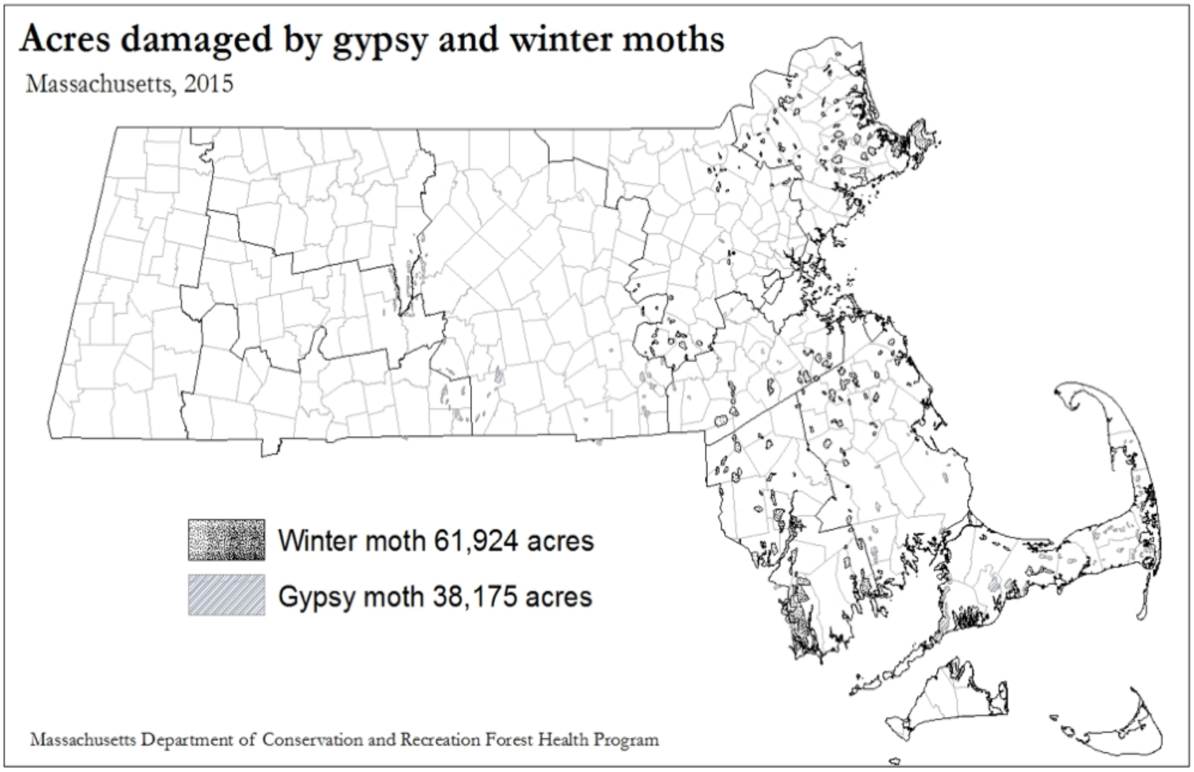

Figure 1.2. *L. dispar* and *O. brumata* in Massachusetts. These insect pests of importance have been typically predominant in eastern MA in 2013 and 2014.

CHAPTER 2

EXPLORING THE CHARACTERISTICS OF SUCCESSFUL VOLUNTEER-LED URBAN FOREST TREE COMMITTEES IN MASSACHUSETTS

2.1 Abstract

Citizen engagement through urban forest tree committee volunteer service may aid in providing essential experience, ideas, and skills that support municipal tree management. Using semi-structured, research interviews with tree committee (TC) representatives from across the Commonwealth of Massachusetts, I endeavored to address current knowledge gaps concerning the general composition, processes, and relationships of volunteer-led urban forest tree committees. My findings indicated that TC representatives are typically motivated, passionate volunteers who generally desire to work cooperatively with the many associations, organizations, and agencies that comprise the local socio-political landscape. Findings also indicated that TC representatives must make a sustained, concerted effort to work collaboratively with their local tree warden to advance the care of their community's urban trees. Municipal managers and decision-makers should attempt to provide TC volunteers with appropriate training opportunities, resources, as well as demonstrate appreciation, to further encourage and solidify volunteer-engagement.

2.2 Introduction

Urbanization and the expansion of the built environment invariably results in the depletion and loss of natural resources including arable land, air and water quality, wildlife habitat, species diversity, and the degradation of natural processes including stormwater abatement, and carbon sequestration (Brown et al. 2005, Nowak et al. 2006, Nowak and Greenfield 2012, Clapp et al. 2014). These processes may be aided and enhanced, however, through the initiation of programs that include the installation of trees and proliferation of urban green spaces. Urban trees may offer a wide number of ecological and economic benefits including carbon sequestration, heat island abatement, air quality improvement, storm water runoff attenuation, wildlife habitat, utility cost savings, and property value enhancement (Nowak and Crane 2002, Nowak et al. 2006, McPherson 2007, Jim and Chen 2009, Bocsi et al. 2018). Urban forests and access to urban green space may also offer an array of health-related benefits for residents including improvement of physical well-being, strengthening of social networks, reduction in obesity, reduction in mental fatigue, as well as the reduction of stress and enhancement of stress recovery (Parsons et al. 1998, Kuo and Sullivan 2001, Westphal 2003, Bell et al. 2008, van den Berg et al. 2015). Social benefits have also been associated with urban vegetation including a greater sense of community, a heightened sense of safety, and greater social interactions (Kuo 2003). Lipkis and Lipkis (1990) summarize these sentiments in stating,

> "Tree planting…fosters community spirit and pride, bringing people together for a meaningful purpose that can build the bridges and promote the understanding that brings the neighborhood together. The initial efforts of the tree planters compound themselves as others find in the trees a deeper appreciation of the community as well as natural beauty."

Citizen involvement in urban greening, including urban forest management, is a concept and practice that has been around for many years. Popular citizen interest may be traced to notable celebrations like the inaugural commemoration of "Arbor Day" in Nebraska, U.S., by J. Sterling Morton in 1872 (Jonnes 2016). A noted agriculturist and lover of trees, Morton served as U.S. Secretary of Agriculture under President Grover

Cleveland where he helped to coordinate and formalize USDA's service to farmers, as well as establish forest preserves. The Arbor Day festivities that he initiated in Nebraska City with the planting of a million trees, would be continued by growing numbers of schools and communities across America and around the world, over the decades to come (Jonnes 2016). Volunteer citizen engagement at the community level also manifested in the late 19th century with the formation of citizen associations, society's, and committees concerning themselves with the well-being and management of local parks, public spaces, and urban trees (Johnston 2015). Among these early groups that formed throughout parts of Europe and the U.S. were the Commons Preservation Society (1865) and the Metropolitan Public Gardens Association (1882) in the U.K. (Johnston 2015), and the Brookline Tree Planting Committee (Massachusetts, U.S.) that was founded in 1886 by notable members like Charles Sprague Sargent and Frederick Law Olmstead, Jr. (N. Geerdts, pers. comm.)

At present, volunteerism in the U.S. is both an important contributor to the American economy, providing an estimated annual value of $172.9 billion USD (McKeever 2015), as well as an important mechanism through which individuals may contribute their time, energy, knowledge and resources to the community around them (Harrison et al. 2017). It is estimated that 62.6 million individuals, or approximately 1 in 4 American adults, is currently engaged in some form of volunteerism (US Bureau of Labor Statistics 2015). Though volunteers may vary relative to their interest-levels, determination, work habits, and skill-set (Harrison et al. 2017), they are often motivated by a strong sense of contribution, and the opportunity to learn new skills and gather information (Domroese and Johnson 2017). Volunteers may also be motivated by a sense of affiliation with other like-minded individuals, recognition for their efforts, achievement and the pursuit of excellence, power and influence, and environmental stewardship (Fazio 2015).

Community members volunteering on tree committees find themselves working at the juncture of interrelated social-ecological systems (SES) where biophysical factors like tree planting and maintenance, interact with other social elements and human interests like policy decision-makers, municipal managers and employees, and property owners (Mincey et al. 2013). Tree committees endeavor to balance the demands of these different groups and to "reflect the will of the community" (Fazio 2015) in an official capacity on issues pertaining to the management of the urban forest. Though tree committees are typically concerned with the care of trees located in urban streets and parks, they may also find themselves concerned with the management of urban trees found growing on private properties. This is an important consideration since trees growing in yards or on privately-owned landscapes may comprise up to 90% of the urban tree canopy cover of a community (Fazio 2015).

Tree committees may arise for a variety of reasons. In some instances, they may be hastily conscripted to address the acute loss of urban tree canopy cover due to a rapidly-invading pest of importance, or in the event of a severe storm that has caused widespread damage or loss to the urban tree canopy cover (Town of Monson 2017). Tree committees may also form, however, out of the need to address more chronic problems that have developed over time, perhaps as a result of a community's aging and declining high-profile tree population (L. Bozzutto, Pers. Comm.). Whatever the reason behind the genesis, the best legal foundation that can support a community tree committee is typically considered to be a local ordinance, defined as legislation enacted by a municipal authority. Fazio (2015) concludes that ordinances are the best way to protect urban trees while balancing the needs of developers and urban planners. A local ordinance that recognizes, empowers, and authorizes a tree committee to carry out its mandate on behalf of urban trees and community residents can be a critical step in engaging residents and citizen volunteers in urban forest management in a positive and constructive manner. In addition to this particular type of local policy formation, tree committee members may be tasked with variety of other functions that range from routine education and advocacy, to management and administration, to advisement and consultation with elected officials and municipal forestry personnel (Fazio 2015).

Though volunteer urban forest tree committees may have substantial influence on urban forest management and provide a productive avenue for community-wide citizen engagement, they are rarely described in the scientific literature. For example, though there is a plethora of formal research concerning volunteer-led organizations and volunteerism in general, almost none of this information has been contextualized for members of urban forest tree committees, the vast majority of whom are volunteering at the municipal level. Furthermore, the local conditions (challenges, opportunities) under which tree committees must function have been given little, if any, consideration in the research literature. Urban forest tree committee members in New England states, for example, will likely interact with local officers known as "tree wardens" (Ricard 2005). Tree wardens are unique to the New England region (i.e., Connecticut, Rhode Island, Massachusetts, Vermont, New Hampshire, Maine) of the U.S. According to Ricard and Dreyer (2005), a tree warden is an important human component of urban and community forestry, and they posit that a municipality may not have an effective program without the leadership of this individual. Little is known about the nature of the relationship between an urban forest tree committee and a tree warden. At present, no studies have been conducted to establish even a baseline understanding of the characteristics of a well-functioning volunteer-led urban forest tree committee and this research seeks to fill that gap. My broad goal was to understand the general composition, processes, and relationships of tree committees. Specifically, I aimed to determine 1) How tree committees are organized and operate, 2) What successes and challenges tree committees have had and; 3) What relationships exist between tree committees and other urban forestry entities. I explored various perspectives regarding the characteristics of what a successful volunteer-led urban forest tree committee looked like in the Commonwealth of Massachusetts, with the hope that findings may offer insights for other urban forest tree committees in other regions of the U.S., as well as internationally.

2.3 Materials and Methods

I employed a qualitative data collection and analysis approach, utilizing data generated from semi-structured interviews with representatives from urban forest tree committees in Massachusetts. Research interviews have been used in many sectors, including the social sciences, to gather detailed knowledge from individuals that are usually recognized experts in their field, concerning a specific topic (Elmendorf and Luloff 2006). This method has enabled credible, in-depth findings on a wide number of topics (Rubin and Rubin 2012), including a better understanding about the human experience and how we as individuals and groups interact with the environment around us (Dampier et al. 2014). Interviewing for the purposes of research may be regarded as a distinctive procedure that incorporates technique and skill, aimed at generating knowledge through the context of a social practice (Brinkmann and Kvale 2015). In-depth interviewing permits the researcher and the interviewee to investigate and discover matters with varying considerations and complexities. This may produce data that is deeply contextualized and facilitate a variety of perspectives (Rubin and Rubin 2012). Interview methodologies may range from being scripted with standardized questions and subject-areas, to being flexible, open-ended and in-depth (Fontana and Frey 2005). Between the extreme of the structured and unstructured interview is the semi-structured interview that according to Brinkmann and Kvale (2015), obtains highly detailed and descriptive data via a sequence of themes and suggested questions along with probing questions for follow up.

During the spring of 2017 a 21-question interview instrument (Table 2.1) was constructed in a participatory manner, with input from academic and agency urban forestry specialists. Interview candidates were selected in a purposive manner (Dampier et al. 2015, Lemelin et al. 2017), with the objective that the research question would be addressed, and based specifically on the following criteria:

i) Participants would be able to provide general information regarding their urban forest tree committee in Massachusetts.
ii) They would be in a position to offer in-depth, first-hand knowledge regarding the operations and functions of their respective urban forest tree committee.
ii) They could provide information about the variety of ways in which their urban forest tree committee would interact with local residents and community stakeholders.

iii) They were accessible and responsive to being interviewed.

The total number of interviews to be conducted was determined by the point at which "no new analytical insights" were "forthcoming" (Ritche and Lewis 2003), and the point at which a suitable sampling of urban forest tree committee representatives had been obtained from across Massachusetts. Based on local data (MA DCR, unpublished) and a further searching of listed contacts and municipal websites, it was broadly estimated that there are perhaps 50 active, volunteer-based urban tree committees in Massachusetts; hence, it was surmised that data saturation requirements would likely be satisfied after obtaining between 10-15 interviews with urban forest tree committee representatives (Table 2.1).

During the summer of 2017, interviews with 13 volunteer representatives from urban forest tree committees across Massachusetts were carried out (Table 2.2). Appointments were scheduled with the respective volunteer, and a single interview took usually 15-30 minutes to complete, over the phone.

Questions posed to participants from the semi-structured interview tool were categorized into three groups: "Introductory" (questions 1-8), "Operational" (questions 9-12), "Community Relationships" (questions 13-21) (Table 2.1). As part of the interview process, interviewer impressions (i.e., notes) were also taken. Interviews were audio-recorded, generating nearly 4.5 hours of recorded data. All 13 interviews were transcribed over a period of 30 hours.

After the initial transcription, interview data was imported into the Computer Assisted Qualitative Data Analysis Software (CAQDAS), NVivo Version 11 (2015) (QSR International; Melbourne, AUS). Interview questions were developed around predetermined themes of interest, as described by Gillies et al. (2014), with the participation of agency urban foresters and urban forestry academics who reviewed and commented on the interview instrument before it was used (Table 2.1). The significance and meaning of the participant responses that related to each of these predetermined themes (i.e., interview questions) was emergent and coded to generate a thematic framework.

Coding was performed in a systematic manner where a nested node (i.e., initial "parent" nodes, followed by "child" nodes) structure (Dampier et al. 2014) was generated based on interview data, pursuant to the predetermined themes from the interview instrument. New, emergent themes that were attached to the predetermined themes from the interview instrument were corroborated to ensure that coding and content analysis was valid and replicable. In accordance with Berg and Lune (2012), emerging themes were considered potentially valid when they appeared at least three times (n=3) among different interviewees. If a theme occurred on one occasion (n=1) it may have been an "accident"; a theme that occurred twice (n=2) was considered to have been a "coincidence" (Berg and Lune 2012). A sub-sample of interview data was tested with 5 social science researchers as an inter-rater reliability test, with a resulting agreement of 89% and a kappa value of 0.79, both considered sufficient to form inter-rater agreement (Fleiss and Cohen 1973).

2.4 Results

2.4.1 Introductory Questions, Pre-determined Themes

Introductory questions 1-8 from the interview tool (Table 2.1), were coded as the following pre-determined themes: (i) 'TC (Tree Committee) Attributes & Volunteer

Involvement', (ii) 'Volunteer Background & Motivations', (iii) 'TC Formation', (iv) 'TC Charter', (v) 'TC Mission', (vi) 'TC Role', (vii) 'Members & Term Length', (viii) 'Membership Ratification'.

The pre-determined theme, 'TC Attributes & Volunteer Involvement', derived from the initial "grand tour" question that was designed to initiate the interview, but was not anticipated to generate data necessarily relevant to the interview question. During this commencement phase of the interview process, interviewees (or sources) introduced themselves by identifying their 'position' (n=10 sources) and/or their 'duration' (n=6) on their urban forest tree committee, and by discussing the local 'history' (n=8) and origins of their tree committee:

> "The tree committee was started by the board of selectmen in 2011. At that time, they were doing a whole renovation on Main street and there were…beautiful, beautiful pear trees planted along Main street. They had gone in around 40 years ago and in May they would be in bloom and they just made the town look quite majestic. But they were old and they were breaking and they were becoming quite a hazard and they were growing into wires. So the board of Selectmen decided to get a resolution to form a tree committee to be advisory…to come up with a new tree design for Main street." (Great Barrington Tree Committee)

Emergent themes relative to volunteer motivations indicated that members served due to a deep 'personal interest in trees and greening' (n=10). The participant from the Amherst Tree Committee summed up this sentiment well, in stating simply:

> "I've loved trees my whole life."

The emergence of 'professional affiliation, interest' was also a prominently associated theme among interviewees (n=5), as many of them indicated their motivation to volunteer was due to the fact that they were formally credentialed and/or professionally experienced in fields related to urban forestry like 'horticulture', 'forestry', 'landscape architecture/design', 'planning' or as a 'naturalist'.

Emergent themes also indicated that the ‘origin’ (n=13) of the local tree committees spanned ranges from ‘0-10 years’ (n=4), ‘11-20 years’ (n=4), ‘21-30 years’ (n=3). Interview data indicated that ‘yes’ nearly all tree committees (n=10) featured a ‘charter’ as well as a ‘mission statement’ (n=10), respectively. According to the chair of the Fall River Street Tree Planting Program,

> “Yes, we do have a mission, to try to plant trees in the Fall River area and to reach out to the public and inform them of the benefit of trees in a community.”

The vast majority of interviewees indicated their urban forest tree committee played an ‘advisory, educational’ (n=11) role and often worked in a cooperative, consulting manner with municipal staff on issues relevant to urban forest management:

> “We’re an advisory committee so we advise the tree warden. We do vote on issues…that come before the committee…there is a committee vote, but it’s always advisory to the tree warden” (Brookline Tree Planting Committee)

> “[We are] advisory…all final decisions are made by the tree warden” (Newburyport Tree Commission)

Interviewees indicated that urban forest tree committees featured a membership size of ‘4-6’ (n=3) or ‘7-9’ (n=3) individuals, who are most likely serving a ‘3-year’ (n=6) term limit, though some committees had ‘undefined’ (n=4) term limits. Emergent themes indicated that successful candidacy for an urban forest tree committee in Massachusetts may be a multi-step process involving some combination where an individual would receive a ‘personal invitation’ (n=3), would be the subject of a screening ‘interview’ (n=3), complete an ‘application’ (n=4), participate in an ‘initial meeting’ (n=3) and then be formally placed onto the committee through an ‘election’ (n=5) by committee members and/or formal ‘appointment’ (n=9) by the municipality.

2.4.2 Operations

Operational questions 9-12 from the interview tool, were coded as the following pre-determined themes: (ix) 'Meeting Frequency', (x) 'Meeting Functions, Evaluation', (xi) 'Operational Guidance', (xii) 'Programs, Initiatives'. The frequency of urban forest tree committee meetings was often on a 'monthly' (n=10) basis. Meetings themselves may be run by a 'chair' (n=3), almost always follow an 'agenda' (n=12), may feature a 'member reports' (n=3) segment, and typically document meeting 'minutes' (n=11). In relation to 'Operational Guidance', interview data identified that a substantive number of the urban forest tree committees indicated "yes" (n=5) they have a municipal budget, while nearly just as many indicated "no" (n=4) they did not. Interview data also indicated that urban forest tree committees may have some form of a 'plan of work' (n=4) guiding their activities.

Interview data revealed a number of prominent themes in relation to specific programs or initiatives that urban forest tree committees might engage the community with, including 'Arbor Day' (n=6) activities:

> "Every year we have an Arbor Day get-together and this year was planting four trees at the children's museum…the mayor actually has to sign the official form and preside over that [ceremony]." (Fall River Street Tree Planting Program)

> "…we have a very nice Arbor Day celebration which we happen to celebrate in May because April in the Berkshires is way too cold. We work with the third-grade class up at the Lanesborough Elementary…they do tree art, they write tree poems, and we go up and have a day of tree education with them" (Lanesborough Tree & Forest Committee).

Urban forest tree committees may also be engaged in assisting with a local 'urban forest inventory' (n=3), 'urban tree planting' (n=7), and/or some form of direct 'outreach, education' (n=6) like staffing an 'events booth, display' (n=3), or generating 'printed media' (n=3):

> "We put out a newsletter, now it's only once a year, we used to do it twice a year, but it's a thing called "Tree Talk" and we include it in the spring tax bill so that we try to reach many homeowners with as much tree information as we can, and there are a lot of people who comment on that quite often that they…like to get that and they learn new things…" (Lynnfield Tree Commission).

Only one committee indicated that they interacted with the public via a blog.

2.4.3 Community Relationships

Questions 13-21 from the interview tool that were categorized broadly under the heading 'Community Relationships', were coded as the following pre-determined themes: (xiii) 'Successful Collaborators', (xiv) 'Unsuccessful Collaborators', (xv) 'Program Evaluation Methods', (xvi) 'Public Interaction', (xvii) 'Volunteer Retention & Recruitment', (xviii) 'TC & Tree Warden Interaction', (xix) 'TC Relationship with Local Officials', (xx) 'TC Interaction with Local Agencies, Organizations', (xxi) 'Policy Development'.

Interview data indicated that there were a variety of important and successful collaborators including the municipal 'DPW' (n=6), and 'town committees, commissions' (n=6) that included the 'conservation commission' (n=3) and the 'town planning board-committee' (n=3). A majority of the urban tree committee representatives also reported that a variety of NGO's (n=8) were important collaborators including local 'garden clubs' (n=3) and 'environmental groups' (n=3).

Overall, the interview data revealed that nearly all of the urban tree committees identified 'unsuccessful collaborators' (n=12), however since a minimum of at least three interview sources didn't identify a single, specific organization, emergent themes were less discernible, with 'neighborhood groups, citizens' (n=2) and the local 'cemetery commission' (n=2) each appearing on two – potentially coincidental – occasions.

Evaluation of urban tree committee programs generated some interesting responses from interviewees, and while a clear theme emerged relative to the fact that 'no' (n=6) members often did not perform a formal program evaluation, 'informal' (n=9) discussion-based evaluation of initiatives did take place:

> "…there's no formal means of evaluating. I mean, because we meet every month, within the committee we evaluate projects as they're going and certainly feedback from the tree warden and the director of the DPW. I would say there's certainly not a lack of resident feedback when we…do something…not formal but a monthly check-in, certainly." (Arlington Tree Committee)

The manners in which urban tree committees carried out public interaction included 'in-person interaction' (n=7) which could include at a 'table or booth' (n=3) display. The theme 'print media' (n=6) was prominently emergent among committees, however, and nearly all interviewees (n=11) indicated they employed some form of 'electronic, social media' to interact with the public.

Emergent themes relative to the recruiting and maintenance of volunteers included that urban tree committees employed 'electronic recruiting' (n=4) that included 'email' (n=2), 'Facebook' (n=1), and a 'website' (n=1). They also indicated that they felt there was an ongoing 'need for volunteers' (n=4) and that they attempted to 'foster camaraderie & interest' (n=5) to maintain the volunteers they have.

In describing the relationship with the community tree warden, urban tree committees reported that they generally had a 'positive relationship' (n=7) and that there was 'regular communication' (n=6) between the two parties.

> "…if any of us have a question, we either email or call him [the tree warden] and he's incredibly responsive and always able to give us an update…" (Brookline Tree Planting Committee)

> "We love him. He's awesome. Engineer from – spent ten years in Cambridge…good guidance there. He has a great attitude…so the relationship has been super positive

> from day one.” (Newburyport Tree Committee)
>
> “I recruited a fellow – another landscaper to become tree warden whom I worked with previously, so he’s now in that position. So, we have a good relationship and we discuss all aspects and all work.” (Marion Tree Committee)

Responses from three other committee’s relative to their relationship to the tree warden, however, were coded as ‘limited interaction, uncertain’.

In regards to the relationship between urban forest tree committees and their local officials, interviewees typically described the relationship as being ‘positive’ (n=10) and indicated that there was ‘regular interaction’ (n=7) between themselves and community decision makers.

Local agencies and organizations that urban forest tree committee representatives identified as being important included local ‘committees, commissions, administration’ (n=4), ‘municipal departments’ (n=7) and ‘NGOs’ (n=5). Among these emerged more detailed sub-themes that included ‘planning department-board’ (n=4), along with less prominent (n=2) mentions of ‘parks and recreation department’, ‘DPW’ and ‘garden clubs’.

In response to the final pre-determined interview theme concerning ‘Policy Development’, some urban forest tree committees reported ‘no’ (n=3), they were not involved in local policy formation. A more prominent theme (n=8) emerged, however, indicating that ‘yes’ urban forest tree committees in Massachusetts are actively involved in policy development related to ‘local tree by-laws’ (n=4) and ‘local tree ordinances’ (n=4).

2.5 Discussion

2.5.1 Introductory Interview Phase

While it was not surprising that individuals regularly indicated that they serve on an urban forest tree committee because they take great personal interest – and are indeed passionate – about matters concerning urban trees, it was noteworthy to see professional interests and backgrounds represented in this volunteer capacity as well. The ability of a committee to leverage professional expertise is an important asset in deepening its capacity to respond to change, as urban forest needs shift in accordance with community priorities. In the event that professional foresters, horticulturists, and/or landscape architects/designers are serving as urban forest tree committee volunteers, they should be able to provide in-house expertise regarding a practice or initiative such as proper tree planting; yet, if the community wished to expand activities and commence a citizen pruners initiative, those same professionals should be able to provide some degree of guidance and training in that capacity as well. It also speaks to the importance of attracting a diversity of individuals that represent that community as a whole, and can communicate successfully within their spheres of influence regarding municipal urban forest management activities and practices (Locke and Grove 2016).

At an initial glance, it may appear that urban forest tree committees are highly structured, with well-placed systems in working order, ready to integrate new members from the community. The inherently disparate nature of volunteer committees, however, is that some groups are high-functioning while others are not (Harrison et al. 2017). So, while many committees featured a step-by-step system where community residents may get involved, others may be less clear in their procedures, as indicated by their ‘undefined’ term lengths for committee members in some towns.

Finally, it was of interest that, with the exception of the Brookline Tree Planting

Committee, all other Massachusetts urban forest tree committees were formed in the last 30-years. Though there are aforementioned examples of volunteer citizen engagement in municipal parks and urban forest management from periods in the late 19th century, this information speaks to the relative recency of urban forestry as a recognized profession, and sector to volunteer in, in Massachusetts.

2.5.2 Operations

It was of interest that urban forest tree committees were essentially split on the issue of municipal budgets with 5 sources indicating they had access to formally allocated funds, while 4 sources indicated they did not. This issue was raised between the Chair of the Newburyport Tree Committee and Newburyport community leaders:

> "When I joined, the tree commission never received any money. And I went to the mayor and I said "why?" And she said "show me a plan and I'll show you the money."

This interaction may be an important one, as it illustrates the impact of a grassroots, volunteer-led initiative that has the capacity to put together a cohesive plan of work, including how municipal dollars would be spent. Though data revealed that urban forest tree committees in Massachusetts may compose some form of a plan of work (n=4), a closer look reveals that in one of these instances it is essentially a legacy work cycle. Hence, it may be possible that strengthening this activity among more urban forest tree committees may result in a more favorable response from local decision-makers relative to providing financial support.

Prominently emerging themes concerning urban forest tree committee activities like participating in Arbor Day festivities and urban tree planting were not surprising. These activities may be well-suited to volunteer-led urban forest tree committees due to the popular nature of both Arbor Day (Jonnes 2016) and tree planting (Harper et al. 2017) efforts.

2.5.3 Community Relationships

That there were a variety of important and successful collaborators identified by interviewees was not a surprise; what was interesting though, was that responses were so disparate when urban tree committee representatives were asked to identify unsuccessful collaborators. According to the Lanesborough tree & forest committee, the fact that a volunteer urban forest tree committee plays a very specific role in the community may decrease the chances of an unsuccessful collaboration:

> "You know, I guess our span of interest is narrow enough that I don't know that I would say there were any unsuccessful collaborations. I'm not trying to say we do everything right. I guess I'm trying to say we haven't pushed the envelope too far."

It is also possible that interviewees consider the divulgence of an unsuccessful collaboration somewhat sensitive, and individuals generally may not be as forthcoming with this sort of information in a research environment (Cartwright 1988).

The fact that so many (n=11) urban forest tree committees indicated they employed some form of 'electronic, social media' to interact with the public was of interest. Upon further exploration of this theme, however, a prominent number of interviewees indicated this method is through 'Facebook', and nearly all sources indicated this form of interaction is through a website – typically a municipally-housed website. In fact, some individuals highlighted the need to engage their community by increasing their urban forest tree committee's capacity in the realm of social media:

> "…we're working – starting to work with social media. We have a Facebook page and a website. And we have a new woman who just joined the committee who is younger and much more cognizant of social media than I am and she's going to take that sort of thing on…" (Amherst Public Shade Tree Committee)

> “We don’t do a website because we don’t have anyone young enough right now to be that savvy. And I am not a web person. That’d be a good reminder that the world does not travel on paper anymore. It travels on websites and Facebook ‘likes’ and we have to figure out how to do that (Lanesborough Tree & Forest Committee)

The fact that the ongoing ‘need for volunteers’ (n=4) was an emergent theme may be concerning for individuals who find themselves on the front lines of volunteering in any sector, including on urban forest tree committees. Across the U.S. and in other developed nations, membership in civic organizations and volunteerism in specific sectors, as well as generally, appears to be on a downward trajectory (Putnam 1996, Grande and Armstrong 2008, Reuter et al. 2013, Green and Haines 2016). Just as volunteerism itself has positive ramifications that extend beyond the individual and impact the economy and viability of organizations, a shrinking volunteer base may impact – and be indicative of – a range of segments of society from graduation rates, to participation in the democratic process (Green and Haines 2016).

Emergent themes relative to relationships between the urban forest tree committee and their local (New England) tree warden were of interest. Though most committees enthusiastically indicated they had a positive relationship (n=7), not all committees (n=3) felt this way. Though details about the workings of this relationship are largely absent from the research literature, according to Harper et al. (2017), the nature of the position of a successful tree warden requires effective communication and interaction with a wide number of groups, including urban forest tree committees. Though Fazio (2015) does not mention tree wardens by name, he does posit that tree boards must work closely with city foresters. For an effective urban forest tree committee, this same sentiment of cooperation and partnership can –and must – be readily extended to other audiences and important stakeholders including local officials, agencies and organizations.

2.6 Conclusions

Volunteer involvement in urban forestry, including service on an urban forest tree committee, may help to provide essential experience, new ideas and perspectives and offer critical skills towards the furtherance of urban tree management at the local level (Westphal and Childs 1994). Volunteers may also enable access to new audiences and advocates through networks and contacts (Nichnadowicz 2000). Urban foresters routinely identify a lack of available resources (i.e., funding) as a key limiting factor (Stobbart and Johnston 2012) in their urban forest management program, hence the potentially-reduced costs associated with garnering volunteer-based support to aid or carry out initiatives, may also be another welcomed benefit in relation to volunteer involvement in urban forestry (Bloniarz and Ryan 1996). Though typically not paid, volunteers and volunteer-based initiatives do require investment, however, including in equipment, training, and care (i.e., food and water, first aid and safety equipment) (Fazio 2015). Volunteer-related expenditures might also include small-scale celebrations after a significant task is carried out (i.e., a larger-scale urban tree planting or urban tree inventory), like an appreciation dinner. This may bolster morale, and if volunteers know they are valued and feel their efforts are acknowledged, they can connect more fully with the organization and each other, resulting in an increased sense of belonging and involvement (Moran and Mallia 2015). This can act as a positive "loop" since increased involvement can motivate volunteers to continue their relationship and deepen their service commitment with the association (Lammers 1991, Moran and Mallia 2015). Another means of strengthening the effectiveness of urban forest tree committees could be to provide members with program evaluation materials and training. Though informal program and meeting evaluation in the form of member discussions often appeared to take place, formal programmatic participant survey tools would aid in the effort of specifying areas where program delivery may be improved upon and strengthened, and also provide a forum to document new program ideas and suggestions for new subject matter.

Urban forest tree committee volunteers in Massachusetts are typically passionate, committed individuals who love trees and wish to see this important urban resource managed with care and stewardship in mind. To ensure viability in this sector of volunteerism, committee members should be equipped with resources related to the use of social media as well as strategies to engage and broaden the base of individuals potentially willing to serve on their urban forest tree committee. Successful volunteers serving on an urban forest tree committee must have the ability to work constructively and cooperatively with a wide number of stakeholders, decision makers and audience members, with special attention being given to the community tree warden. Since this individual is pivotal to the urban forest operations in a given municipality (Harper et al. 2017), urban forest tree committee members in Massachusetts – and other states with this position – should make a concerted, sustained effort to foster a cooperative, productive relationship with their tree warden.

As with any exploratory research, this effort has generated many questions worthy of follow-up and further research. The accuracy of information on urban forest tree committee presence and activity across the 351 communities of the Commonwealth of Massachusetts is uncertain. To address this, a census of urban forest tree committees might be performed in cooperation with state agencies and associations. Also, since many urban forest tree committees are actively involved in local policy formation (i.e., tree ordinances, by-laws), research should explore the need and efficacy of legal training for committee volunteers. These, and many other, important questions are worthy of further examination as we strive to better understand the nature of volunteer-led urban forest tree committees.

Table 2.1. Interview Questions and Predetermined Themes. TC = Tree Committee

Question	Pre-determined Theme
1) Briefly tell us about your local TC and your involvement	'TC Attributes & Volunteer Involvement'
2) Briefly outline your background and your motivations for participating on your local TC	'Volunteer Background & Motivations'
3) When was the TC formed?	'TC Formation'
4) Does your TC have a charter?	'TC Charter'
5) Does your TC have a mission?	'TC Mission'
6) Is the TC advisory only, or is there an authority (regulatory) component?	'TC Role'
7) Please outline the number of members on your TC and the typical term length?	'Members & Term Length'
8) How is an individual ratified (formalized) as a TC member?	'Membership Ratification'
9) When does your TC meet?	'Meeting Frequency'
10) How are meetings run and how are they evaluated?	'Meeting Functions, Evaluation'
11) What sort of operational guidance (i.e., annual plan of work, budget) does your TC have?	'Operational Guidance'

12) Briefly identify key programs or initiatives your TC carries out?	'Programs, Initiatives'
13) Briefly identify some key collaborating groups – why have these partnerships been successful?	'Successful Collaborators'
14) Briefly identify some examples of some unsuccessful collaborations. Why?	'Unsuccessful Collaborators'
15) Is there a means of evaluating a program's or an initiative's success?	'Program Evaluation Methods'
16) How does your TC interact with the public (i.e., Facebook page, town meetings, etc.)	'Public Interaction'
17) Identify the steps taken by your TC to maintain volunteers & recruit new participants?	'Volunteer Retention, Recruitment'
18) Briefly describe the nature of your TC's interaction with the local Tree Warden	'TC & Tree Warden Interaction'
19) Briefly describe the nature of your TC's interaction with local municipal officials (i.e., mayor's office, select board, councillors)	'TC Relationship w/ Local Officials'
20) Briefly describe the nature of your TC's interaction with local (municipal) agencies, organizations and/or associations?	'TC Interaction w/ Local Agencies, Organizations'
21) Has your TC helped to develop, shape or implement policy in your community – how?	'Policy Development'

Table 2.2. Urban forest tree committee representatives from the following Massachusetts communities participated in semi-structured interviews.

Municipality	Population
Fall River	88,712
Brookline	58,732
Arlington	42,844
Chelsea	38,861
Amherst	37,819
Saugus	26,628
Greenfield	17,456
Newburyport	17,450
Lynnfield	11,596
Great Barrington	7,104
Mattapoisett	6,045
Marion	4,907
Lanesborough	3,091

CHAPTER 3

EMPLOYING QUALITATIVE RESEARCH INTERVIEWS TO UNDERSTAND URBAN FORESTRY STAKEHOLDER CONTINUING EDUCATION NEEDS

3.1 Abstract

To build deeper knowledge regarding urban forestry issues and familiarity with programming audiences, a multi-year needs assessment was conducted by initiating qualitative stakeholder research interviews with professional urban foresters (i.e., tree wardens) and volunteer urban tree committee chairs. An objective of this exercise was to inform the implementation of relevant university-based continuing education (i.e., Extension) opportunities, that led to the development of online urban forestry programming, and the initiation of an urban tree committee census. Findings indicate that qualitative stakeholder research interviews are a reliable needs assessment methodology and have widespread applicability among education professionals.

3.2 Introduction

For university-based continuing education (i.e., Extension) programming to be relevant, it must meet the needs of the target stakeholder audience. There are a range of ways to assess audience needs from informal conversations, to formal assessments. In recent years, University of Massachusetts Extension faculty and administration concluded that both professional and volunteer urban forestry stakeholder audiences required further engagement in the continuing education program development process. To reliably inform these programming needs, recently-hired Extension faculty needed to acquire a deeper understanding and familiarity of urban forestry issues and audiences, using an approach that would be rigorous, yet not overly technical and unfamiliar to audience members. A review of the literature revealed that continuing education stakeholder audiences prefer face-to-face interaction with a single university Extension professional (Kelsey and Mariger 2002). This was further confirmed in participatory discussions with key faculty, agency specialists, and select members of Massachusetts' urban forestry constituency.

A number of qualitative research approaches (Elmendorf and Luloff 2001, Dodd and Abdalla 2004) were explored and it was decided that our research approach would employ qualitative research interviews (Elmendorf and Luloff 2006, Diehl et al. 2017), with both tree wardens and volunteer urban tree committee chairs. It was believed that this approach would:

i) Foster two-way communication and build rapport (Creswell, 2007, p. 123) between university-based urban forestry Extension personnel and key off-campus urban forestry audiences;

ii) Facilitate the building of knowledge of critical urban forestry issues in Massachusetts (i.e., assess need);

iii) Inform the creation of relevant urban forestry Extension programming opportunities.

Denzin & Lincoln (2005, p. 3) define qualitative researchers as individuals that:

> "…study things in their natural settings, attempting to make sense of, or to interpret, phenomena in terms of the meanings people bring to them."

Creswell (2007, pp. 53–75) identifies five accepted qualitative research approaches:

1) Narrative Study – focused on a single individual.

2) Phenomenological Research – the meaning or experiences of several individuals relative to a concept or phenomenon.
3) Grounded Theory – the generation of an explanation (a theory) of process, action or interaction of typically larger numbers of individuals.
4) Case Study – the study of an issue through the examination of one or more cases.
5) Ethnography – the study of cultures or people groups (i.e., teachers, social workers); strives to answer how a culture or group "works".

Within each of these approaches, a variety of accepted qualitative data collection methods can be employed including participant observation, documentary analysis, narrative analysis, and in-depth qualitative research interviews (Rubin and Rubin 2012). Research interview methodologies may range from being scripted with standardized questions and subject-areas, to being flexible, open-ended and in-depth (Fontana and Frey 2005). Between the extreme of the structured interview and the unstructured interview, is the semi-structured interview, that according to Brinkmann and Kvale (2015), obtains highly detailed and descriptive data via a sequence of themes and suggested questions, along with probing questions for follow up.

I detailed our specific approach of employing qualitative semi-structured stakeholder research interviews with Massachusetts tree wardens and volunteer urban tree committee chairs as a means of fostering audience familiarity, acquiring a deeper understanding of urban forestry issues (i.e., assessing need), and reliably informing university continuing education programming. Additionally, I outlined key interviewer impressions and generalized conclusions applicable to other education professionals who may wish to also employ qualitative stakeholder research interviews.

3.3 Materials and Methods

3.3.1 Interviews with tree wardens

From the autumn of 2013 through the spring of 2016, 50 qualitative research interviews of active Massachusetts tree wardens (Harper et al. 2017) were conducted in their professional (i.e., naturalistic) setting (Lincoln and Guba 1985). This was done with the aid of an 8-question interview instrument (Table 3.1) that had been constructed with input from academic and agency urban forestry specialists, and pre-tested (Dampier et al. 2015).

Interview candidates were selected based on the following criteria:

i) They could provide expert knowledge regarding the functions and responsibilities associated with the position of tree warden,

ii) They could provide expert input concerning the management of urban trees in Massachusetts,

Interviews ranged from 15-30 minutes. If the tree warden was not available in-person, the interview was conducted over the telephone. Community visitations typically involved a post-interview tour of the municipality and its parks, green spaces, and select urban trees. To obtain a representative sample, tree wardens were selected in a stratified, purposive manner from urbanized centers, as well as rural communities (Table 3.2) in both the eastern and western regions of the Commonwealth.

3.3.2 Interviews with chairs of volunteer urban tree committees

During the spring of 2017 a 21-question interview instrument (Table 3.3) was constructed with input from academic and agency urban forestry specialists (Harper et al. 2018). During the summer of 2017, telephone interviews with 13 Chairs representing 13 distinct urban forest tree committees across Massachusetts were conducted (Table 3.4), ranging in duration from 15-30 minutes.

Interview candidates were selected based on the following criteria:

i) Participants could provide general information regarding their urban forest tree committee in Massachusetts,

ii) They could offer in-depth, first-hand knowledge regarding the operations and functions of their respective urban forest tree committee,

iii) They could provide information about the variety of ways in which their urban forest tree committee would interact with local residents and community stakeholders.

Based on local agency data (Massachusetts Department of Conservation and Recreation, unpublished) and a further searching of listed contacts and municipal websites, it was broadly estimated that there are no less than 40 active, volunteer urban tree committees in Massachusetts.

In both interview scenarios, the total number of interviews conducted was determined by the point at which no new analytical insights were forthcoming (Ritchie & Lewis, 2003, p. 336). It was determined that these requirements were satisfied after obtaining interviews with 50 tree wardens and 13 urban tree committee volunteers. All interview candidates were purposively selected (Dampier et al. 2015, Lemelin et al. 2017). Data generated from these interviews were imported into the Computer-Assisted Qualitative Data Analysis Software (CAQDAS) NVivo 11 (2015; QSR International, Melbourne, AUS), and participant responses to questions were coded (Saldana 2013) to generate a thematic framework. A theme was considered legitimately emergent upon its occurrence on three (n=3) different occasions (Berg and Lune 2012). To ensure consistency, codes were checked with collaborating authors. All interviews were conducted by the first author, a university Extension faculty member.

3.4 Results

3.4.1 Interviews with tree wardens

In response to interview questions (Table 3.1), substantive number of the 50 tree wardens reported that their position was located in the ‘department of public works (DPW)’ (n=26) or ‘highway department’ (n=8). They also indicated that their position was often associated with terms like ‘director’ (n=13) or ‘superintendent’ (n=11). Tree wardens indicated that the resources available to carry out their duties included individuals that comprise a ‘tree crew’ (n=28), a variety of water, dump, bucket and pickup ‘trucks’ (n=22), and ‘chipper(s)’ (n=21). Organizations that tree wardens interact with on a regular basis included ‘municipal departments’(DPW; highway; water; parks) (n=29), ‘shade tree committees’ (n=13), ‘commissions’ (historical; cemetery; open-space) (n=13), ‘conservation groups’ (n=9), and ‘garden clubs’ (n=6). Tree wardens indicated that they routinely monitored for urban tree pests like Asian longhorned beetle (‘ALB’, n=31), emerald ash borer (‘EAB’, n=29), ‘winter moth’ (n=15), ‘gypsy moth’ (n=6), and Dutch elm disease (‘DED’, n=4). Training and educational needs for tree wardens included subject-matter related to ‘safety’ (n=13) such as ‘electrical hazard awareness’ (i.e. EHAP, n=3) and ‘hazard or risk trees’ (n=3). Other topics tree wardens identified as requiring further education about included urban forest ‘pests’ (n=12), urban forest ‘inventories’ (n=4), and urban ‘tree planting’ (n=4). Desirable educational delivery mechanisms included ‘in-person’ (n=31) programs or meetings, ‘electronic’ media (n=27), and ‘web-based’ (n=19) methodologies. Tree wardens indicated that ‘winter’ (n=15) and ‘summer’ (n=14) were the most popular times to engage in professional development activities, compared with other less popular times of the year (i.e., spring, autumn).

3.4.2 Interviews with urban tree committee volunteer chairs

Introductory questions (1-8, Table 3.3) with urban tree committee volunteers were designed to acquaint the interviewer with the individual and their respective community. Interviewees identified their committee ‘position’ (n=10) and discussed their ‘duration’ (n=6) as well as points about local ‘history’ (n=8) and tree committee origin. Interviewees indicated that they served in response to a deep ‘personal interest in trees and greening’ (n=10). Individuals also identified themselves as professionals (n=5) in related ‘horticulture’, ‘forestry’, ‘naturalist’, ‘landscape architecture/design’, or ‘planning’ sectors. The ‘origin’ (n=13) of the local tree committees spanned ranges from less than 10 years (n=4) up to 30 years’ (n=3). Nearly all of the 13 tree committees (n=10) represented in the interviews featured a ‘charter’ and ‘mission statement’ and indicated the worked in an ‘advisory, educational’ (n=11) capacity with municipal staff on urban forest issues. Typical committee membership size ranged from ‘4-6’ (n=3) to ‘7-9’ (n=3) individuals, who are most likely serving a ‘3-year’ (n=6) term limit. Successful candidacy for an urban forest tree committee in Massachusetts may be a multi-step process potentially involving a ‘personal invitation’ (n=3), a screening ‘interview’ (n=3), a completed ‘application’ (n=4), participation in an ‘initial meeting’ (n=3) and final placement onto the urban tree committee through an ‘election’ (n=5) by committee members and/or formal ‘appointment’ (n=9) by the municipality.

Operational interview questions (9-12, Table 3.3) related to the mechanical aspects of a functioning urban tree committee. Interviewees identified that meetings were often 'monthly' (n=10), may be run by a 'chair' (n=3), almost always follow an 'agenda' (n=12) and document meeting 'minutes' (n=11). A substantive number of interviewees indicated "yes" (n=5) their urban tree committee has a municipal budget, though nearly just as many indicated "no" (n=4) they did not. Interview data also indicated that urban forest tree committees may have some form of a 'plan of work' (n=4) guiding their activities. Urban forest tree committees might carry out a number of initiatives including 'Arbor Day' (n=6) activities. They may also be engaged in assisting with a local 'urban forest inventory' (n=3), 'urban tree planting' (n=7), and/or some form of direct 'outreach, education' (n=6) like staffing an 'events booth, display' (n=3), or generating 'printed media' (n=3) for handout.

The final segment of the interview (questions 13-21, Table 3.3) related to understanding the urban tree committees and their community relationships. Interview data indicated that there were a variety of critical collaborators including municipal 'DPW' (n=6), and various 'town committees, commissions' (n=6) that included the 'conservation commission' (n=3) and 'town planning board-committee' (n=3). A variety of NGO's (n=8) were identified as important collaborators including local 'garden clubs' (n=3) and 'environmental groups' (n=3). Many urban tree committee representatives indicated that 'no' (n=6) they did not perform a formal program evaluation as part of standard program follow-up. Public interaction took place through 'in-person interaction' (n=7) at a 'table or booth' (n=3) display. Some urban tree committees employed some form of 'electronic recruiting' (n=4) that included 'email' (n=2), 'Facebook' (n=1), and a ‘website’ (n=1) to attract volunteers. Interviewees felt there was an ongoing ‘need for volunteers’ (n=4) and that some committees strove to ‘foster camaraderie & interest’ (n=5) to maintain current volunteer capacity. Urban tree committees reported that they generally had a ‘positive relationship’ (n=7) with their community tree warden and that there was ‘regular communication’ (n=6) between the two parties. Interviewees typically described the relationship with local officials as being ‘positive’ (n=10) and indicated that there was ‘regular interaction’ (n=7) with their community decision makers. Local agencies and organizations of importance that were identified included local ‘municipal departments’ (n=7), ‘committees, commissions, administration’ (n=4), and ‘NGOs’ (n=5). Among these emerged the ‘planning department-board’ (n=4), as well as references to parks and recreation, the department of public works and other garden clubs. Urban forest tree committees indicated ‘yes’ they are often actively involved (n=8) in policy development related to ‘local tree by-laws’ (n=4) and ‘local tree ordinances’ (n=4).

3.5 Discussion and Conclusions

3.5.1 Tree wardens in Massachusetts

Massachusetts tree wardens are generally housed in a municipal department (highway or public works), often in a senior management capacity. To successfully utilize urban forest resources to manage public shade trees, tree wardens typically interact with local municipal departments, commissions, and citizen volunteer groups. Tree wardens expressed the desire to receive continuing education, both in-person and web-based, preferably in the summer or winter months. Training content might include information pertaining to urban forest pest management, safety, tree inventories and urban tree planting. Tree wardens overwhelmingly indicated that they routinely monitor for urban forest pests.

3.5.2 Urban tree committee volunteers in Massachusetts

Urban forest tree committee volunteers in Massachusetts are typically passionate, committed individuals who care deeply about urban trees and their proper management. To ensure viability in this sector of volunteerism, committee members could be equipped with resources related to the use of social media, as well as strategies to engage and broaden the base of individuals potentially willing to serve on their urban forest tree committee. Successful urban tree committee volunteers require the capacity to work constructively and cooperatively with a wide number of stakeholders, decision makers and audience members, with special attention being given to the community tree warden – a position pivotal to the success of urban forest management at the local level in Massachusetts.

In response to qualitative feedback from Massachusetts tree wardens, University of Massachusetts Extension faculty developed the monthly noonhour "Urban Forestry Today" continuing education webcasts. The hundreds of urban foresters and arborists that participate in these monthly webcasts for continuing education credit, view presentations from university researchers and other professionals who discuss the latest science and practice on a variety of urban forestry-related topics, at no cost. The Western Chapter of the Massachusetts Tree Wardens was also founded so that tree wardens in more rural areas of the state could attend more regular, in-person programming.

In accordance with results from interviews with urban tree committee volunteers, a census was initiated to identify and update urban tree committee presence, membership, and activity across the 351 communities of Massachusetts. The creation of an urban tree committee volunteer handbook is also planned, to assist communities with the development and operation of a local urban tree committee. Consideration is also being given to the formation of an urban tree committee association so communities may share resources, exchange information, and develop peer-to-peer volunteer mentorship programs.

3.5.3 The university educator as the interviewer

The qualitative stakeholder research interviews conducted by the university Extension faculty member provided an important experience and opportunity. In this instance, the interaction, documentation, and analysis built knowledge related to the practice of urban forestry in Massachusetts from both urban forestry professional (tree wardens) and volunteer (urban tree committee chairs) viewpoints. It also fostered learning related to the practice of planning, conducting, and formally documenting social science research that could reliably inform future continuing education programming initiatives. This qualitative research exercise both increased the visibility of University of Massachusetts Extension throughout the Commonwealth of Massachusetts and helped to foster camaraderie between university Extension faculty and urban forest stakeholders.

Though qualitative interviews are time-intensive, the organized and systematic manner that this research approach demands provides a much higher likelihood of generating reliable data, compared to informal stakeholder interaction. Qualitative stakeholder research interviews are a reliable needs assessment methodology and have widespread applicability among education professionals that desire to effectively reach audiences with continuing education programming.

Table 3.1. Interview Questions and Predetermined Themes.

Question	Pre-determined Theme
1) What best describes the position of Tree Warden in your community and how long have you occupied this position?	'Position Structure'
2) Highlight the essential resources (staff, technical equipment, etc.) you have to help you do your job?	'Occupational Resources'
3) What sort of groups (i.e. organizations, municipal departments) do you interact with regarding community tree-related issues?	'Organizational Interactions'
4) Are you currently monitoring for pest-related problems?	'Monitoring for Pests'
5) What are three educational/training needs?	
6) How could this information best be disseminated to you?	'Educational Needs'
7) What time of the year is training or programmatic information best made available?	'Information Delivery'
	'Timing'
8) Would you be willing to share any of your local success stories with others?	'Sharing Successes'

Table 3.2. Tree wardens from the following Massachusetts municipalities were selected for semi-structured, naturalistic interviews.

Central-Western MA		Eastern MA	
Municipality	Population	Municipality	Population
Worcester	183,016	Cambridge	109,694
Springfield	153,991	Fall River	88,712
Chicopee	55,300	Newton	88,287
Amherst	37,819	Brookline	58,732
South Hadley	17,514	Plymouth	58,271
Greenfield	17,456	Medford	57,437
Belchertown	14,649	Barnstable	45,193
Athol	11,584	Everett	44,231
Sturbridge	9,268	Chelsea	38,861
Lenox	5,025	Watertown	34,127
Cheshire	3,235	Andover	33,201
Stockbridge	1,947	Natick	32,786
Ashfield	1,737	Needham	28,888
Granville	1,521	North Andover	28,352
Whately	1,496	Wellesley	27,982
Pelham	1,321	Walpole	24,070
Chester	1,308	Wilmington	22,325
Petersham	1,234	Acton	21,929
Goshen	1,054	Sandwich	20,675
--	--	Newburyport	17,926
--	--	Duxbury	15,059
--	--	Dennis	14,207
--	--	East Bridgewater	13,794
--	--	Bedford	13,320
--	--	Lynnfield	11,596
--	--	Wrentham	10,955
--	--	Dighton	7,086
--	--	Orleans	5,890
--	--	Rochester	5,232
--	--	Avon	4,356
--	--	Plympton	2,820

Table 3.3. Interview Questions and Predetermined Themes. TC = Tree Committee

Question	Pre-determined Theme
1) Briefly tell us about your local TC and your involvement	'TC Attributes & Volunteer Involvement'
2) Briefly outline your background and your motivations for participating on your local TC	'Volunteer Background & Motivations'
3) When was the TC formed?	'TC Formation'
4) Does your TC have a charter?	'TC Charter'
5) Does your TC have a mission?	'TC Mission'
6) Is the TC advisory only, or is there an authority (regulatory) component?	'TC Role'
7) Please outline the number of members on your TC and the typical term length?	'Members & Term Length'
8) How is an individual ratified (formalized) as a TC member?	'Membership Ratification'
9) When does your TC meet?	'Meeting Frequency'
10) How are meetings run and how are they evaluated?	'Meeting Functions, Evaluation'
11) What sort of operational guidance (i.e., annual plan of work, budget) does your TC have?	'Operational Guidance'

12) Briefly identify key programs or initiatives your TC carries out?	'Programs, Initiatives'
13) Briefly identify some key collaborating groups – why have these partnerships been successful?	'Successful Collaborators'
14) Briefly identify some examples of some unsuccessful collaborations. Why?	'Unsuccessful Collaborators'
15) Is there a means of evaluating a program's or an initiative's success?	'Program Evaluation Methods'
16) How does your TC interact with the public (i.e., Facebook page, town meetings, etc.)	'Public Interaction'
17) Identify the steps taken by your TC to maintain volunteers & recruit new participants?	'Volunteer Retention, Recruitment'
18) Briefly describe the nature of your TC's interaction with the local Tree Warden	'TC & Tree Warden Interaction'
19) Briefly describe the nature of your TC's interaction with local municipal officials (i.e., mayor's office, select board, councillors)	'TC Relationship w/ Local Officials'
20) Briefly describe the nature of your TC's interaction with local (municipal) agencies, organizations and/or associations?	'TC Interaction w/ Local Agencies, Organizations'
21) Has your TC helped to develop, shape or implement policy in your community – how?	'Policy Development'

Table 3.4. Urban forest tree committee representatives from the following Massachusetts communities participated in semi-structured interviews.

Municipality	Population
Fall River	88,712
Brookline	58,732
Arlington	42,844
Chelsea	38,861
Amherst	37,819
Saugus	26,628
Greenfield	17,456
Newburyport	17,450
Lynnfield	11,596
Great Barrington	7,104
Mattapoisett	6,045
Marion	4,907
Lanesborough	3,091

CHAPTER 4

REVIEWING THE ECOLOGY AND PESTS OF IMPORTANCE OF EASTERN HEMLOCK (*TSUGA CANADENSIS)*

4.1 Abstract

Eastern hemlock *Tsuga canadensis* is a forest tree native to the eastern United States and Canada. In addition to being a species of importance in more rural forested settings, it also occupies a niche as an ornamental conifer in the urbanized landscape, due in part to its shade tolerance and aesthetic appeal. Throughout much of its range, herbivory from numerous pests of importance has been occurring to the point where populations of eastern hemlock are now being extirpated. To better understand the ecology and natural history of invasive and native insect and disease pests, we reviewed and discussed species associated with eastern hemlock. These include non-native insects that have had detrimental impact on populations such as hemlock woolly adelgid *Adelges tsugae* and elongate hemlock scale *Fiorinia externa*, as well as occasional native pests like hemlock borer *Melanophila fulvoguttata* and hemlock loopers *Lambdina* spp. Research efforts should continue to further explore and develop sustainable biological, chemical, and cultural pest-management options, as well as include strategies aimed at maximizing the health of pest-free eastern hemlock.

4.2 Introduction

Eastern hemlock [(*Tsuga canadensis* (L.)) Carrière], is the dominant forest species on 1.17 million ha (2.3 million acres) of forested land in the United States, and can be found growing on an estimated 7.69 million ha (19 million acres) (Schmidt and

McWilliams 1996) ranging from Georgia and Alabama in the south, to Minnesota in the west (Fig. 1). An important constituent of northeastern and Appalachian forests where it may form pure stands, it can also be found growing north into the central-eastern portion of southern Canada and east to the maritime provinces (Farrar 1995). Eastern hemlock has been identified as a forest “foundation species” (Foster 2014) because it can influence the qualities and attributes of an ecosystem beyond what its numbers may suggest. It may also be referred to as an example of ecological legacy, where its presence represents sites that were not previously disturbed through logging or farming (Foster 2014). It is hardy to USDA Zone 3 and is often long lived, with a potential lifespan of over 800 years (Godman and Lancaster 1990).

Eastern hemlock’s shade tolerance is renowned and its understory only requires 5% sunlight, enabling continuous foliar cover through to the forest floor (Godman and Lancaster 1990). This habit creates a unique environment that contributes to vertical, structural, and thermal diversity in a forest stand (Ward et al. 2004). A host of 96 documented avian species have been associated with hemlock-dominated stands in New England, including white-winged crossbill (*Loxia leucoptera*), solitary vireo (*Vireo solitarius*), black-throated green warbler (*Dendroica virens*), and Acadian flycatcher (*Empidonax virescens*) (Yamasaki et al. 2000). Approximately 47 mammalian species have also been documented in association with this forest type, including porcupine (*Erethizon dorsatum*), white-tailed deer (*Odocoileus virginianus*), and moose (*Alces alces*) (Yamasaki et al. 2000, Ward et al. 2004). Also, according to Mathewson (2009), hemlock-dominated stands provide unique and critical habitat for redback salamanders (*Plethodon cinereus*), and the large-scale removal of eastern hemlock trees from a stand may have notable negative impacts on these populations of amphibians (Brooks 2006). Aquatic species like brook trout (*Salvelinus fontinalis*) and several macroinvertebrates have also been found to demonstrate greater diversity and higher population numbers, indicating a direct benefit from hemlock-sheltered streams that are both less likely to dry up and less likely to feature lower summer temperatures (Ward et al. 2004). Water-quality related benefits associated with eastern hemlock are not limited to the regulation of streamflow and moderation of nearby temperatures of bodies of water, as hemlock-dominated stands actually use less water and lose less water:

> "To minimize moisture stress during the warm summer months when soils are dry, hemlock shuts its pores…studies reveal that the maximum rate of water loss is two to four times higher in hardwoods than hemlocks…its overall rate of water lost to the atmosphere is typically half that of nearby forests of oak, red maple and birches" (Foster 2014 p19)

In essence, hemlock trees are not only indicative of moist settings – their biological processes help to ensure that those sites remain that way.

4.2.1 Hemlock and the Urban Landscape

In addition to its importance in the forested environment, eastern hemlock is a valued specimen in the urban environment (Webb et al. 2003, Dampier et al. 2015). Its attractive form, attractive foliage, response to shearing, and shade tolerance make it a landscape niche plant, both as an open-grown tree and as a hedge (Harper and Cowles 2013, Foster 2014). The demand for this species is evidenced in a communication from Dampier et al. (2018):

> "As hemlock woolly adelgid became an increasingly serious problem over the last several decades, the difficulty of suggesting a replacement that would perform the functions that eastern hemlock provides in the [urban] landscape became more and more apparent. Even available species that could partially perform some of these functions lacked the critical aesthetic found only in eastern hemlock." (G.G. Giordano, Cornell University)

There is a dearth of information regarding not only the composition of eastern hemlock trees in the urban environment, but at higher taxonomic levels, the presence of urban conifers (Dolan 2015). Where conifers are present in urban tree inventories, they are often few in number and under-represented (Clapp et al. 2014). According to an assessment of 12 urban street tree inventories from eastern North America, only three genera that are conifers – spruce (*Picea* spp.), pine (*Pinus* spp.), fir (*Abies* spp.) – were listed in the top 32 most common genera (Raupp et al. 2006). Though eastern hemlock was not among this list, it is one of only three native coniferous trees – in addition to white pine (*Pinus strobus* L.) and arborvitae or eastern white-cedar (*Thuja occidentalis* L.) – of commercial ornamental importance in the Northeast U.S.

Whether as a managed hedge or an open-grown specimen in the urban environment, one may reasonably assume that when present as an urban tree, eastern hemlock may offer similar ecological benefits as it would in its forested environment, providing shade and shelter for a variety of wildlife species. According to Weston and Harper (2009), arthropod diversity associated with urban eastern hemlock was demonstrably higher than from among 6 other hemlock species. This corroborates other studies (Trotter and Evans 2010, Mallis and Rieske 2011) that conclude that in naturally-forested settings, there was a higher-degree of arthropod diversity in hemlock-dominated stands than in deciduous forests. Thus, eastern hemlock may also contribute to the diversity of arthropod communities in an urban environment.

Eastern hemlock trees may also serve as representatives of ecological legacy in the urban environment. Since hemlock are not tolerant of root injury (Foster 2014), soil compaction, or dry conditions (Farrar 1995), the presence of healthy urban specimens may represent settings that have been exempt from widespread construction activities often found to be deleterious to plant root and soil health, but that instead feature healthy soil structure, good permeability and ample moisture. Hence, just as urban ecologists may employ the presence or absence of sentinel plants, including weed species, as site indicators of poor drainage, excessive dryness, or soil compaction (Uva et al. 1997), eastern hemlock may be used to identify a relatively moist, but well-drained, undisturbed urban site. Soils on these sites would likely be healthier (Gugino et al. 2009), feature a higher degree of essential gas exchange (Watson et al. 2014), and a higher degree of biological activity. In essence, eastern hemlock may serve as somewhat of an urban foundation species since its presence may represent, and possibly influence, the urban ecosystem on a broader scale, as it does in a traditionally forested setting.

Urban landscapes tend to be defined as ecosystems requiring intense energy and resource inputs, as well as generators of large amounts of waste and pollution (Rees and Wackernagel 1996). With the majority of individuals living in urban settings, urbanization has been argued as being “the most severe and irreversible driver of ecosystem change on the planet” (Douglas et al. 2011, p.xxiii). Plants growing in urban environments are exposed to an array of stress factors including increased temperatures in association with the heat island effect (Kim 1992, Nowak and Dwyer 2000), and compacted soils with little organic matter (% SOM) and limited nutrient availability (Jim 1998a). These conditions may inhibit soil-water movement and uptake and impede root growth (Leibowitz 2012, Savi et al. 2014). Increased herbivory by arthropod pests may also occur as a result of these difficult growing conditions, as has been noted with scale insects – among the most detrimental and challenging urban arthropod pests (Raupp et al.

2010, Dale and Frank 2014b). These increased pest-pressures and difficult overall growing conditions can cause widespread urban tree morbidity and premature mortality (Roman and Scatena 2011, Nowak and Greenfield 2012).

In this manuscript, I consolidate and review the current knowledge on the biology and management of the more common and economically important arthropod pests of eastern hemlock trees encountered in forested and urban landscapes, as well as in their commercial production. A following section devoted to the discussion of the more common disease pests of eastern hemlock will also be included. For each pest, their natural history, life cycle, diagnostic characteristics and plant damage they inflict will be reviewed, synthesized, and highlighted. Management techniques will also be considered including pest identification, scouting and monitoring, as well as control options. The paper concludes with a call for continued research, strategies to encourage host plant health and discussion pertaining to the need to view organismic populations through a long-term perspective.

4.3 Materials and Methods

Primary and secondary sources were consulted regarding the ecology and natural history of hemlock woolly adelgid [*Adelges tsugae* (Annand)], elongate hemlock scale [*Fiorinia externa* (Ferris)], native hemlock scale [*Abgrallaspis ithacae* (Ferris)], non-native circular hemlock scale [*Nuculaspis tsugae* (Marlatt)], spring hemlock looper [*Lambdina athasaria* (Walker)], fall hemlock looper [*Lambdina fiscellaria* (Guenee)], brown hemlock leafminer [*Coleotechnites macleodi* (Freeman)], green hemlock leafminer [*Coleotechnites apicitripunctella* (Clemens)], hemlock borer [*Melanophila fulvoguttata* (Harris)], spruce spider mite [*Oligonychus ununguis* (Jacobi)], hemlock rust mite [(*Nalepella tsugifoliae*)(Keifer)], and shoestring root rot [*Armillaria* spp. (Fr.:Fr.) Staude]. The diagnostic characteristics and signs and symptoms associated with the presence of each of these organisms on eastern hemlock were reviewed. Integrated pest management (IPM) strategies for pests were also outlined, including suggestions for detection (i.e., scouting and monitoring), discussion related to relevant cultural conditions that may foster pest presence and severity, and biological-based and chemical control measures.

4.4 Results

4.4.1 Hemlock woolly adelgid

Hemlock woolly adelgid (HWA) (Family: Adelgidae) is a tiny, detrimental sap-feeding insect from Asia (McClure et al. 2001). It is believed to have arrived in the eastern U.S. on imported plant material bound for a private plant collection in Virginia in the early 1950's (Havill and Montgomery 2008). In North America, this insect completes two generations of wingless parthenogenic females on eastern hemlock, and a winged sexuparae. Generation one is comprised of "sistens/sistentes (sing./pl.)" that hatch in mid-summer, settle at the base of the needles of the new growth, aestivate for up to several months, and commence feeding throughout the cooler autumn-winter seasons (Havill et al. 2016). In late winter-early spring (February in the southern U.S.; March in New England) they each commence deposition of ~300 small (<0.5mm, length and width) amber-colored eggs in a protective white cotton-like waxy ovisac (Limbu et al. 2018). The progrediens/progredientes (sing./pl.) hatch, typically mid-late April in southern New England (personal observation). Unlike sistentes crawlers, progredientes crawlers experience no delay in development and once hatched, they settle near the base of the needle on the previous years' growth. They feed using long stylets that penetrate into xylem ray parenchyma cells (Young et al. 1995), and soon commence deposition of ~100 eggs each (Limbu et al. 2018). Progredientes and sexuparae nymphs hatch simultaneously and though they are initially indistinguishable, the winged sexuparae eventually disperse. HWA crawlers experience four nymphal instars and their dispersal occurs though natural movement (i.e., crawling) by being vectored by other animals (wildlife, birds) or wind. One adelgid alone may initiate a new infestation (Tobin et al. 2013), and airborne adelgids have been captured 600 m from an infestation site. Populations of deer, as well as over 80% of birds trapped near HWA infested-hemlocks, featured eggs and populations of crawlers (McClure 1990). During spring and summer months there may be overlap in life stages, in part due to the long periods of egg laying and hatching (Havill et al. 2016).

HWA is now believed to have successfully infested 50% of the total range of eastern hemlock (Havill et al. 2016) (Fig. 2). It continues its spread north at a rate of 12-20 km/yr. (Evans and Gregoire 2007), functionally extirpating hemlocks from their range. Successful HWA infestation results in reduced tree growth, discoloration of foliage, and premature needle drop resulting in critical weakening of the tree. HWA is capable of killing an untreated, successfully infested hemlock in less than a decade in horticultural settings (Hoover et al. 2009, Harper and Weston 2016), and in some situations less than 5 years (Radville et al. 2011).

Since the white "cottony masses" that are produced by HWA are visible to the eye throughout most of year, scouting for the presence of this insect may involve simply turning eastern hemlock foliage over and performing a visual inspection of the underside of a twig. Populations of potential predators are almost never high enough to reliably control HWA in the landscape (Weston and Harper 2009). If HWA detection has been made at an early stage of infestation, select situations may permit successful management via mechanical removal of infested plant tissue (M. McClure, CT Agricultural Experiment Station, personal communication). This is most likely to include a planting that is entirely accessible by hand (i.e., small tree or hedge), that may be monitored routinely. More likely, however, properly timed applications of contact insecticides like horticultural oil or insecticidal soap may be needed to demonstrably reduce populations to negligible levels (Lamb 2018). Systemic neo-nicotinoid insecticides (i.e. imidacloprid, dinotefuran) may also be applied for the treatment of HWA (Lamb 2018). Treatment of all HWA-infested hemlocks in an area may not be feasible, ensuring that HWA populations will likely re-bound over time. Biological control efforts continue to be ongoing and have involved experimentation with numerous pathogenic organisms (*Beauveria bassiana*, *Metarhizium anisopliae*) and insect predators (*Laricobius* spp., *Scymnus* spp.), often producing mixed results (Havill et al. 2016).

4.4.2 Elongate hemlock scale

Elongate hemlock scale (Family: Diaspididae) (EHS) was initially confirmed in the U.S. in 1908 in Queens, NY (Sasscer 1912), and it was first described as a new species in 1942 (Johnson and Lyon 1991). EHS now occurs in at least 10 states throughout southern, northern, and western portions of the range of eastern hemlock (Kosztarab 1996) (Fig. 3). In some locales it is considered to be the primary herbivorous insect pest of eastern hemlock, of even greater significance than HWA. A generalist, EHS is known to infest 43 tree species from a wide number of genera including spruce (*Picea* spp.), pine (*Pinus* spp.), fir (*Abies* spp.), and hemlock (*Tsuga* spp.) (McClure 2002).

As with HWA, EHS may be vectored by wind and birds, and once situated on a suitable host, the crawlers settle under the waxy cuticle of the newest foliage. They commence feeding by inserting their stylet far into the needle in a manner parallel to the leaf surface. EHS mouthparts may be extensive – as much as 3-4x the length of their body (Johnson and Lyon 1991). As crawlers actively feed and develop they secrete a waxy, protective covering (i.e. a "test"). Females may live for over a year in this environment. Males experience 5 stages of development, pupate under their test and emerge as delicate, winged adults, while females transition to a third adult feeding stage. After mating, the male dies and 6-8 weeks later, the fertilized female commences laying approximately 20 eggs over an extended period of time (McClure 2002). After about a month, crawlers hatch from the eggs and exit through the posterior of the test (Johnson and Lyon 1991). It is only in this stage that dispersal may occur. Overwintering generally occurs in either the egg stage or as the fertilized adult female.

As populations build and feeding continues, needles turn chlorotic and begin to fall. This is followed by branch loss and finally plant death, typically within a decade of the infestation (McClure 2002). Trees in good health may live considerably longer, but may be aesthetically compromised and more susceptible to secondary pests.

Because EHS are usually visible to the eye throughout the year, scouting for the presence of this insect involves simply turning foliage over on a suspected host plant and performing a visual inspection of the underside, at virtually any time. Close inspection of the female test during late spring (Mid-May in southern New England) may reveal the presence of egg hatch and peak crawler emergence (personal observation). Because of the asynchronous manner related to egg hatch/crawler activity, follow-up scouting should take place throughout the growing season (Johnson and Lyon 1991). Though natural enemies like the micro-hymenopteran *Aspidiotiphagus citrinus* and lady beetle (*Chilocorus stigma*) have been demonstrated to successfully eliminate individual scale insects, populations of EHS are rarely controlled at acceptable levels in the landscape. Leaf loss and branch dieback may occur with as few as 10 individuals per needle, and though populations tend to build over time, this may occur at a substantially greater rate on specimens that are already stressed (McClure 2002).

Overpopulation by EHS can diminish host plant nutrient availability causing a population reduction in the field. The substantial overlap of life stages of this insect can make management difficult, even with the use of insecticides. Repeated use of contact products may offer demonstrated efficacy, as well as treatments that include the use of newer-generation systemic materials (i.e. dinotefuran) that readily translocate to locations on the plant with recently-settled crawlers (Lamb et al., 2018).

4.4.3 Other scale insect pests

The native hemlock scale and non-native circular hemlock scale (Family: Diaspididae) have been found to be pests of eastern hemlock. Both insects are armored scales and feed on the underside of the needles. They feature two generations per year, with egg production first occurring the early half of the growing season (May-June) and again later in the summer (i.e., August – September) in association with the second generation (Johnson and Lyon 1991). Though little formal study has been conducted relative to these insects, non-native circular hemlock scale was first confirmed in 1910 on shipments of *T. diversifolia* and *T. sieboldii* originating from Japan (Johnson and Lyon 1991).

Even modest infestations can cause chlorosis, which may be viewed from the upper portion of the leaf, and needle loss on host evergreen conifers (McClure 2002). As with EHS, naturally occurring predators may reduce populations, however as numbers build, it may be necessary to institute an insecticide regime employing contact or systemic products (Lamb 2018), for consistent population management.

4.4.4 Hemlock loopers

Spring hemlock looper (SHL) and fall hemlock looper (FHL), are known to defoliate eastern hemlock in the eastern U.S. (Maier et al, 2004). Similar in appearance (Family: Geometridae), both caterpillars feature a brownish-grayish body, are present in the mid-latter half of the growing season. Fall hemlock looper may also be known commonly as eastern hemlock looper. Spring hemlock looper overwinter in the soil as pupae, but FHL overwinter as an egg on the above-ground portions of the plant (i.e., foliage) with adults actively mating and laying eggs in September and October in the Northeast (Johnson and Lyon 1991, Maier et al. 2004). Loopers tend to be notoriously messy feeders, eating only portions of the foliage, and moving from newer growth to older growth as they age (Johnson and Lyon 1991). Though not usually problematic on a substantial scale, population outbreaks of these insects are cyclical and may be locally serious, occurring every 3-4 decades with SHL, but more frequently with FHL (Maier et al. 2004). Scouting may involve simple visual inspection/monitoring of susceptible plants throughout the growing season, commencing in July when caterpillars of FHL become evident. Loopers move in a characteristic manner where they repeatedly pull their prolegs located at the end of the abdomen, forward toward their thoracic legs, followed by a stretching motion where the thoracic legs are then moved away from the prolegs. Both specimens may be found on the same tree simultaneously, however, SHL larvae are consistently smaller (Maier et al. 2004).

Natural enemies may include a complex of parasites and microbes, and a number of biologicals including *Bacillus thuringiensis* subsp. *kurstaki* and *aizawai*. A number of other insecticides, including synthetic pyrethroids, anthranilic diamides and spinosad may also be employed for control of these insects (Lamb et al., 2018), on the occasion that populations reach intolerable levels.

4.4.5 Hemlock leafminers

Eastern hemlock is a primary host to two closely related (Family: Gelechiidae) native insects known as the brown hemlock leafminer and the green hemlock leafminer. Though outbreaks may be infrequent, they may occur at local levels in the Northeastern U.S. (Johnson and Lyon 1991). The immature caterpillars of these species enter and feed on the succulent internal tissue of needles, tying them together with silk. After overwintering, feeding continues throughout May and June, where an even larger "nest" is constructed among the silken-bound needles for shelter during pupation (Maier et al. 2004). Ranging in length from 6-8 mm, these insects share a very similar life cycle, with immatures being distinguishable by their brown or green larval coloration (Johnson and Lyon 1991). A number of biologicals including *Bacillus thuringiensis* subsp. *kurstaki* and *aizawai*, as well as and other synthetic insecticidal products (i.e., pyrethroids, anthranilic diamides) would no doubt reduce populations, but the need for treatment would be extremely rare.

4.4.6 Hemlock borer

The hemlock borer is a native flatheaded borer (Family: Buprestidae) of occasional importance. Characteristic of buprestids, it is typically present on a susceptible host plant (eastern hemlock or Carolina hemlock) that has experienced substantial stress from other primary factors like climate (i.e., drought), or herbivory from another insect of importance (i.e., HWA or EHS) (Kelley and Evans 2000). Hemlock borer may infest a number of coniferous trees including larch (*Larix laracina*), white pine (*Pinus strobus*) and many native spruce (*Picea* spp.) trees. In rural, forested settings it often infests trees that have been recently downed through natural occurrences, like wind (Hussain and Shenefelt 1959).

The hemlock borer is typically bivoltine, requiring two years to complete the cycle from egg to adult. At approximately 10 mm in length, Adult beetles are flattened, black-metallic in appearance, featuring up to 6 yellow spots on their back (Kelley and Evans 2000). They are present throughout the summer months in the Northeast U.S., with peak emergence in July. After emergence, adults only persist for about 2 weeks, during which time they mate. The fertilized female will then lay approximately 150 white eggs, about 0.8 mm in length, in bark crevices of sun-exposed sides of declining trees (Hussain and Shenefelt 1959). Egg hatch occurs in about a week and the characteristically white larvae feed under the bark until they reach their maximum length of approximately 2.5 cm (Kelley and Evans 2000). Larvae overwinter in a pre-pupal chamber in the phloem and mature throughout the second summer. Larvae molt a total of four times (Hussain and Shenefelt 1959). They then overwinter in the outer bark and pupate the following spring, where the adult will then emerge during the growing season though 3 mm diameter holes.

As hemlock borer larvae tunnel beneath the bark, they may be readily consumed by foraging woodpeckers. In addition to lowering local populations of borers in individual trees, noting this behavior may facilitate early detection. Other naturally occurring insects that may reduce populations of hemlock borer, include parasitic wasps and ant populations (Hussain and Shenefelt 1959). A proactive management program should include steps to prevent borer infestation designed to maximize plant health through supplemental watering and management of other insects of importance that may initiate plant stress. Though rarely implemented in the case of HB, bark treatments with synthetic pyrethroids (i.e., permethrin) and soil drenches with neo-nicotinoids (i.e., imidacloprid) may be implemented to prevent borer infestation (Lamb 2018).

4.4.7 Spruce Spider Mite

The spruce spider mite (Family: Tetranychidae) (SSM) is a widely-known pest of coniferous plants, and has been referred to as "the most destructive" mite in the world (Boyne and Hain 1983). It is known to feed on a variety of junipers, spruce, arborvitae, pine, fir, larch and hemlock trees, and though present in naturally forested settings, it is usually of greatest concern on more urbanized landscape plantings (Johnson and Lyon 1991).

Overwintering in the egg stage under protected sites (i.e., bark crevices, bud scales, etc.), hatch typically occurs in April or May in New England. Development of the larvae requires approx. 3 days and development of the nymph requires about 6 days (Johnson and Lyon 1991). The immature mites are born with 3 pairs of legs and develop a fourth pair upon entering the 2nd instar stage. Generations of SSM develop at intervals of 2 – 3 weeks, with at least 3 (Johnson and Lyon 1991), but reportedly 10 or more generations (G. Hoover, Penn State University, personal communication) occurring, depending on seasonal conditions. SSM produce webbing around buds and needles that is notable with the naked eye. SSM feed with piercing-sucking mouthparts in the chlorophyll-bearing cells of predominantly older needles, causing stippling that may appear chlorotic, bronze, or greyish in coloration and may be confused with an abiotic condition like pollution injury. Eventually, injured leaves may turn brown and drop from the host plant.

SSM is considered to be a "cool-season" mite, where feeding and population build-up occurs in the early and latter months of the growing season, but slows drastically in the hot, dry summer months (Johnson and Lyon 1991), when temperatures exceed 26° Celsius (Boyne and Hain 1983). While chlorotic-greyish stippling injury may be noted from the upper portion of the needles, feeding associated with SSM occurs on the underside of eastern hemlock needles.

Scouting may be performed by shaking needles above white paper to dislodge active SSM's, followed by the use of a hand lens to view and count individuals. Pesticides that may be applied for the management of SSM populations include suffocants like horticultural oil or contact materials like insecticidal soap. Strategic timing of applications can be important to minimize impacts to naturally-occurring enemies of SSM, including early in the growing season (April – May) and late in the growing season (August – September) (Lamb 2018). Commercial miticides with a variety of modes of action, including those that impact mite neurological systems, may also be applied for the control of SSM (Lamb et al., 2018). When managing SSM, rotation of pesticide options should be encouraged to help prevent resistance.

4.4.8 Hemlock rust mite

Hemlock rust mite (HRM) is a native arthropod pest of eastern hemlock. Much about eriophyid mites (Family: Eriophyidae) is unknown, though HRM can be observed openly feeding in spring on needles of hemlock and other conifers (Johnson and Lyon 1991). Adult HRM have only four legs at maturity (compared to SSM which has 8 legs). Their appearance may vary from nearly clear to tan-orange in coloration (Sidebottom 2019). This mite has become increasingly problematic in nurseries and Christmas tree farms from the mid-Atlantic states to Long Island (Johnson and Lyon 1991). As populations diminish with the onset of summer, reddish-chlorotic feeding injury may become more apparent on infested needles. Though feeding injury may sometimes be confused with nutrient deficiency, it may also feature a somewhat distinct "dusty" appearance, with small scratch-like marks visible under a hand lens. Host plants may drop foliage if damage is severe enough, and mite populations may proliferate very quickly – from a few in number to over 50 on a single needle in as little as 2-weeks (Sidebottom 2019). Routine scouting is critical, noting that environmental conditions may predispose an area to higher HRM populations. Outbreaks have been noted in association with a warm fall, followed by long dry spring. Weekly scouting may commence early in the growing season on sites with a history of HRM, bearing in mind that populations are often higher on the southeast side of the tree. Scouting both upper and lower needle surfaces and on new and previous year's growth is important. Careful note should be taken of burgeoning populations and treatment with horticultural oil or commercial miticides may occur when 80% of shoots inspected have mites on them, and/or 8 mites are present on a single needle (Sidebottom 2019).

4.4.9 Shoestring root rot

Though eastern hemlock is known to be resistant to stem decay, it has been associated with a root decay pathogen known as shoestring root rot (Family: Marasmiaceae). This fungal pathogen is also known by other common names including armillaria and honey mushrooms, in association with the color of its above-ground fruiting bodies. Shoestring root rot consists of a genus of 40 basidiomycetes that are cosmopolitan in distribution, ranging from primary plant killers to opportunists that only damage plants in association with other pests (Sinclair and Lyon 2005). Most species of shoestring root rot are generalists, having numerous hosts. They are known to most frequently spread via the vegetative state (i.e., rhizomorphs) and actively decompose tree stumps and roots throughout forested and urbanized landscapes. Shoestring root rot is known to cause widespread mortality in coniferous forests of western U.S. and Canada, and to be problematic in relation to reforestation efforts. After a harvest, the pathogen can aggressively exploit existing stumps as a foodsource to sustain itself, while infecting newly planted trees directly, which only become increasingly less susceptible to infection after a number (10-15) of years. Secondary infections that spread from tree-to-tree may also occur. Mortality may be especially high on sites that were once frequented with oaks, but have been replanted with coniferous seedlings (Williams et al., 1986). In landscapes across the U.S., tree mortality in association with shoestring root rot may be particularly severe after substantial defoliation from leaf-feeding insect pests like gypsy moth (*Lymantria dispar*) (Sinclair and Lyon 2005).

According to Hagle (2010), shoestring root rot may be classified as a "disease of the site" where once its mycelia are entrenched in a specific location, they should be considered permanent. Hagle (2010) describes four patterns of disease development:

1) Distinct, large, root disease patches with single or few host species.
2) Merging of multiple clones, forming continuous site coverage over large area (s), featuring grouped and dispersed host plant mortality.
3) Infection from stumps from previous generation, resulting in clusters of residual mortality of saplings, that will decrease in virulence.
4) Roots lesions, butt rott from primary inoculum from dead trees and stumps of previous generation. Little mortality and low impact until environmental conditions trigger root lesion extension.

Once established, mycelia may expand outward as long as there is sufficient substrate. The expansion of this disease may occur at rates that vary from up to 1m/yr., or even more. Upon the successful infestation of a tree root, the cambium is killed, and dead root tissues are decayed, with the mycelium eventually continuing upwards to colonize the root collar and girdle the tree. Infection may also be established in heartwood of roots and lower stem (buttress region) where a cavity of decay may be formed, typically within the first three feet of the ground, though higher under select circumstances. Depending on tree species, health and other factors, the tree may persist for many decades before death in association with this pathogen occurs (Hagle 2010). The role of spores from shoestring root rot is not well understood, yet hundreds of pounds of honey-colored mushrooms may be produced at the base of infected trees during the summer-autumn months, perhaps in an effort to establish initial infection on nearby wood debris (Hagle 2010).

The impacts of this pathogen on the health of eastern hemlock is somewhat in question. According to the literature (Hepting 1971, Wargo and Fagan 2000, Brazee and Wick 2011) it has been documented as being frequently associated with populations of forested eastern hemlock, but has not been known to cause decay or host plant mortality. In more urbanized settings, shoestring root rot can be commonly observed in association with eastern hemlock mortality (pers. obs.).

Shoestring root rot may be scouted for by removing bark at the lower portion of the stem/root collar, or by exposing tree roots themselves. Black rhizomorphs – aggregations of hyphae covered by dark cortex of protective cells – and/or the white-colored mycelial fan may be readily noted with the naked eye, indicating the presence of the disease. Since no chemical methodologies may be employed to treat an infected host plant, the single most appropriate management strategy is to rogue out an infected host removing as much of the root tissue as possible, and replant with a more resistant tree species (Hagle 2010). Where the disease may be less vigorous, infection rates may be reduced by taking steps to maximize plant health, such as treating a primary insect pest infestation and maintaining appropriate levels of hydration (Lamb 2018).

4.4.10 Other disease pests

Other diseases of eastern hemlock are usually incidental, with no control strategies typically being recommended. These include cytospora spp. (*Cytospora* spp.), fabrella needle blight (*Fabrella tsugae*), and rusts of cones/twigs (*Melampsora farlowii*) and needles (*Melampsora abietiscanadensis* and *Pucciniastrum sp.*) (Moorman 2016).

4.5 Discussion and Conclusions

Massachusetts tree wardens readily identified hemlock woolly adelgid among the many pests of concern that they scout for or manage on urban trees (Chapter 1). Since the existence of eastern hemlock indeed spans the urban-rural gradient, plant care and pest management strategies should be especially adaptable and multi-pronged. A continuation of progress in the research and development of biological, chemical, and cultural pest-management methodologies is critical to maintaining this long-lived climax tree that does not respond favorably to change or stress. Urban settings are, after-all, notoriously challenging, making growth, development and subsistence of urban plants difficult. Pathogens that are not typically problematic in traditional, forested settings may become serious threats to the well-being of eastern hemlock, as we at least observe in the case of shoestring root rot. This is likely due to the heightened levels of stress that this tree is already experiencing from factors like compacted soils, limited space, air pollutants and road salt.

Biological and other innovative pest management strategies continue to generate interest regarding large-scale, long-term population management. Yet, beneficial entomopathogenic fungi often have very specific environmental requirements that may limit their use on a commercial scale. Challenges related to the rearing, release, and efficacy of beneficial predatory insects may limit their applicability as well. Chemical interventions that may be efficacious, usually offer only a short-term reduction of pest populations, and expense and controversy may be associated with their use (Harper et al. 2016b). A plethora of unintended consequences pertaining to environmental contamination and unforeseeable impacts on other organismic populations have been observed over time with the use of pesticides. The desirable attributes of neo-nicotinoids, for example, have made them a relatively less-toxic, more popular alternative compared to other traditional insecticide formulations, yet concerns have arisen about their ability to potentially reduce beneficial predatory insects, reduce specific plant defense mechanisms, and directly exacerbate populations of pest organisms like SSM (Raupp &

Szczepaniec 2015). Even more widespread are concerns associated with their potential to detrimentally impact the health of beneficial pollinators (Cowles 2015). Hence, though many of the populations of the insect pests on eastern hemlock that were previously discussed may be managed through chemical means, the risks – or at least risk perceptions – of insecticides may substantially reduce the feasibility of their widespread use on a long-term basis.

In the urban environment, maintenance and care of individual trees and small numbers of plantings may occur on a very localized level. As a consequence, urban environments may aid in the preservation, migration and even proliferation of numerous uncommon tree species on streets, parks and private properties. Tree species like Kentucky coffee-tree, Osage-orange and honey-locust are believed to persist on mere fragments of their original range, after the mammalian megafauna responsible for feeding on their fruits and dispersal of their seed became extinct approximately 10,000 years ago. Despite this natural migratory limitation, these trees – known as anachronisms – have been the beneficiary of urban tree planting campaigns that have proceeded to proliferate their numbers across the U.S. (Janzen and Martin 1982, Barlow 2000). In similar manner, perhaps the urban forest will ensure the certainty of other tree species that require individualized care, including eastern hemlock.

In the case of eastern hemlock, the temporal nature of its natural history is an important factor worthy of further consideration. Though it has been present on the broader landscape of the eastern U.S. from 6,000 – 3,000 B.C., its populations did experience a drastic, range-wide decline from 3,500 – 1,500 B.C. This phenomena has been studied extensively, yet conclusions behind its near-extinction range from climate change, to the invasion or outbreak of a disease or insect pest like hemlock looper. Though populations rebounded since that time, they have never fully recovered (Foster 2014), and the modern-day complex of both native and non-native pests found to infest eastern hemlock remains ever challenging and numerous. Eastern North America has had a well-documented history of the accidental introduction of invasive insects that have had devastating impacts on native tree species (Dodds and Orwig 2011), and with ever-increasing international trade these pressures are not likely to abate. Thus, in accordance with Gleason's individualistic concept of ecology where plant species response occurs in what is largely an independent manner (McIntosh 1995), we should perhaps be prepared for new and unanticipated combinations of plants in the future, as species populations – including numbers of eastern hemlock – fluctuate over time.

CHAPTER 5

HOST PLANT RESISTANCE AND ALTERNATIVE *TSUGA* SPP AS REPLACEMENT FOR *T. CANADENSIS* IN THE URBAN LANDSCAPE

5.1 Abstract

Seven species of hemlock (*Tsuga* spp.) — four from North America and three from Asia —were evaluated in replicated plots in Katonah, NY (USDA Plant Hardiness Zone 6b) as potential replacements for eastern hemlock (*Tsuga canadensis*), which is gradually being extirpated from landscapes in the eastern U.S. by the invasive hemlock woolly adelgid (*Adelges tsugae*). Chinese hemlock (*T. chinensis*) showed the greatest potential as a replacement for *T. canadensis* as mortality was very low, overall plant health was exceptional, and tolerance to *A. tsugae* was robust. Early indicators suggest that *T. chinensis* may also be readily propagated from hardwood cuttings under appropriate greenhouse conditions. These characteristics suggest that *T. chinensis* may indeed become a viable replacement for *T. canadensis* and a valuable addition to urban landscapes in the eastern U.S.

5.2 Introduction

The use of pest-resistant host plants has long been accepted as an important part of a comprehensive integrated pest management (IPM) program (Larsson 2002, Dreistadt 2004). Trees that show potential resistance to a pest of importance, however, must be able to tolerate the climatic conditions in their newly planted locations. An important urban landscape tree that has been the focus of research seeking to find resistant accessions is eastern hemlock [*Tsuga canadensis* (L.) Carrière]. While *T. canadensis* has been an important component of managed and natural landscapes in the northeastern United

States because of its size and stately presence, not to mention its importance in moderating temperature and retaining soil and unique assemblages of organisms in native habitats (Black and Mack 1976, Lapin 1994, Quimby 1995), it is gradually being extirpated by a small invasive sap-feeding insect from Asia, the hemlock woolly adelgid [*Adelges tsugae* (Annand)] (HWA). *Tsuga* spp. of Asian origin might be expected to possess resistance to *A. tsugae* because of prolonged exposure to the pest, owing to their broader common geographic origin (Bryant et al. 1994); Chinese hemlock [*T. chinensis* (Franch) E. Pritz] has indeed been reported as being highly resistant to *A. tsugae* (Del Tredici and Kitajima 2004, Hoover et al. 2009, Montgomery et al. 2009, Weston & Harper 2009).

Studies have examined the survivability and adaptability of hemlock (*Tsuga* spp.) in different parts of the U.S. but the research has been limited to a few species (Bentz et al. 2002). Although growth response and survivorship of some species of Asian hemlock, such as *T. chinensis,* existing outside their indigenous territories have been published (Del Tredici and Kitajima 2004), formal data are limited regarding other *Tsuga* spp. Additionally, published information regarding other factors including susceptibility of *Tsuga* spp. that are not native to the northeastern U.S. to pests of economic importance such as HWA (Montgomery et al. 2009, Weston and Harper 2009), elongate hemlock scale (*Fiorinia externa* Ferris) (EHS) (Hoover et al. 2009, Harper and Cowles 2013) and spruce spider mite (*Oligonychus ununguis* Jacobi) (SSM) (Del Tredici and Kitajima 2004) may be limited or unavailable. Furthermore, when a specimen of *Tsuga* spp. has demonstrated resistance to a pest of importance like HWA (Bentz et al. 2002, Havill and Montgomery 2008), resistance mechanisms, though perhaps suspected to be mechanical or chemical in nature (Oten et al. 2010), may not actually be known (Bentz et al. 2002). Propagation techniques for *Tsuga* spp., especially *T. canadensis*, have been published (Del Tredici 1985, Jetton 2008), but little research has focused on the propagation of *T. chinensis*.

I sought to better understand the longer term survivability and growth performance of seven species of *Tsuga* originating from western North America and Asia in the northeastern U.S., nearly nine years after they were initially planted in research plots in Westchester County, NY. I also aimed to document the ability of *T. chinensis* to be propagated from hardwood cuttings in the early stage of vegetative propagation.

5.3 Materials and Methods

Located in Katonah, NY (USDA Hardiness Zone 6b), Lasdon Park and Arboretum is a 94 ha (234 acre) public park that hosts a variety of horticulture research and teaching interests (Anonymous 2013). On 30 September 2003, three experimental plots composed of a variety of *Tsuga* spp. were established within the deer-fenced portion of the property, designated Front Gate, Magnolia Garden and Hemlock Hedge plots.

Tsuga selection consisted of the following seven species based on commercial availability:

Tsuga canadensis (L.) Carrière (Canadian/eastern hemlock) – Though a highly valued ornamental tree in the Northeast U.S., its range extends south to Georgia and Alabama and west to Minnesota. Hardy to USDA Zone 3, it is also found growing at its northern range that extends into the central-eastern portion of southern Canada. Its response to shearing and tolerance to shade have made it an ideal hedge species, however, its graceful form and size – the national champion is 47.5 m (156 ft) in height – also make this tree valued as an individual specimen tree or grouped planting (Farrar 1995, Dirr 2011). As HWA has reduced the salability of *T. canadensis* and its numerous cultivars throughout significant portions of the infestation range, horticulture specialists have continued to answer questions from arborists and other horticulture professionals as well as the general public about suitable woody ornamentals that may supplant the landscape niche that this tree has successfully occupied. Specifically, this includes the natural screening benefits from a maintained *T. canadensis* hedge, serving to divide shaded suburban properties (G. Giordano, pers. comm.). Numerous published reports have affirmed host susceptibility to HWA (Table 5.1.) and 28 of the original 36 research specimens have persisted at Lasdon Arboretum (Table 5.2.).

Tsuga caroliniana Engelm. (Carolina hemlock) – Though not common in the horticulture trade with no formally recognized subspecies, forms or varieties, several references to the ornamental application and value of this tree have been made (Dirr 2011). *Tsuga caroliniana* can be found in a limited range that includes southern Virginia, North Carolina, South Carolina, and Georgia. Its limited growing range often includes elevations between 640 m – 1220 m (2100' – 4000') (Anonymous 2008), which seems to have limited both its exploitation as a significant contributor to either the forest products or ornamental horticulture industries (Coladonato 1993). Though it has been noted successfully growing well outside its range of origin as far north as Amherst, MA (pers. obs.), concerns related to climatic challenges from more northerly sites do not appear to have yet been formally researched; this information would be important as only one of the 18 research specimens have persisted at Lasdon Arboretum (Table 5.2.). Still, this tree is shade tolerant, may grow to a height of up to 21m (70 ft) and may offer some degree of promise in the horticulture trade (Coladonato 1993, Dirr 2011) though its susceptibility to HWA and EHS may inevitably be limiting. Numerous manuscripts detail host susceptibility to HWA (Table 5.1.).

Tsuga heterophylla (Raf.) Sarg. (western hemlock) – Reputed as an elegant giant, reaching heights in excess of 60 m (200 ft), western hemlock is known as a versatile tree that can be found growing throughout moist/humid coastal regions of the Pacific Northwest as well as inland among the various mountain ranges into Canada and as far north as Alaska (Packee 1990). Its graceful appearance and tolerance to shearing and shade have endeared *T. heterophylla* as a landscape planting typically within its host range, and a number of varieties (cultivars) are commercially available (Anonymous 2014). It is described as being hardy to USDA Zone 6, and only four of the original 11 research specimens have survived at Lasdon Arboretum (Table 5.2.). Numerous manuscripts affirm host susceptibility to HWA (Table 5.1.).

Tsuga mertensiana (Bong.) Carrière (mountain hemlock) – A significantly smaller tree than its native western counterpart (max. ht. about 30 m/100 ft), *T. mertensiana* is rarely found growing in close association with *T. heterophylla* as it typically occupies the less temperate, more elevated mountainous sites of the Pacific Northwest, Canada and Alaska (Means 1990). Several varieties of this tree are available commercially (Anonymous 2014), presumably for landscape purposes. Though it is described as being hardy to USDA Zone 5, and though numerous manuscripts describe host resistance to HWA (Table 5.1.), only two of the original 18 research specimens have persisted at Lasdon Arboretum (Table 5.2.).

Tsuga chinensis (Franch.) E. Pritz (Chinese hemlock) – Described as attaining heights in excess of 30 m (100 ft.) in China (Dirr 2011), *T. chinensis* has been growing successfully in Jamaica Plain, MA (USDA Zone 6b) since a specimen was established at the Arnold Arboretum in 1910 by E.H. Wilson (Havill and Montgomery 2008). Thirty-eight *T. chinensis* seedlings that had been planted in 1999 were inventoried 09 March 2004, identifying no post-winter mortality though exposure to a low of -22.5°C (-8.5°F) had occurred on January 16, 2004 (Del Tredici and Kitajima 2004). Dirr (2011) describes *T. chinensis* hardiness to Zone 5, and 17 of the 18 specimens at Lasdon Arboretum have persisted (Table 5.2.).

Tsuga diversifolia (Maximowicz) Masters (northern Japanese hemlock) – Occurring in northern Japan at higher elevations, records indicate this tree to have been in commercial cultivation and trade since 1861 (Anonymous 2014). Though only three of the original 18 research specimens still persist at Lasdon Arboretum (Table 5.2.), Dirr (2011) describes survivorship of this tree as far north as Maine (Zone 4) and reports observing specimens at heights of over 12 m (40 ft) in Congreve Gardens, Ireland. Though many manuscripts report host resistance to HWA (Table 5.1.), findings among all references are not entirely consistent.

Tsuga sieboldii Carrière (Japanese hemlock) – Found naturally growing in southern Japan at lower elevations, records indicate this tree to have successfully been in cultivation and trade since 1914 (Havill and Montgomery 2008). One of the original 18 research specimens remains living at Lasdon Arboretum (Table 5.2.).

Tsuga canadensis, T. chinensis and *T. heterophylla* were sourced from Eby Nursery, Wilsonville OR and *T. caroliniana, T. diversifolia, T. mertensiana, T. sieboldii* were obtained from Forestfarm Nursery, Williams OR.

Research plots were approximately 12 m x 14 m (40 ft x 45 ft), each including six rows of the research trees spaced at approximately 2 m (6 ft) intervals. Species were planted in each row in random order and were intended to include at least one of each of the aforementioned seven *Tsuga* species as well as a second representative of *T. canadensis* per row. Because seven specimens of *T. heterophylla* and one *T. caroliniana* perished before time of planting (30 September 2003), some rows were lacking a complete complement of trees (the remaining specimens of *T. heterophylla* were distributed as evenly as possible among plots, Table 2). Daylight penetration on the plots ranged from full-partial sun throughout the day (Front Gate and Magnolia Garden Plots), to nearly full shade provided by deciduous trees (Hemlock Hedge Plot). Plots had been mulched annually commencing in autumn 2006 with 5–10 cm (2-4”) depth of whole-tree mulch (i.e. assorted wood chips) from a municipal composting facility for the purposes of weed management, moisture retention, and soil temperature regulation. Prior to annual mulching, the area between the trees was mowed as needed during the summer to reduce vegetative competition from grasses and weeds. Soil samples within the plots were submitted to the University of Massachusetts (UMass) Soil Diagnostic Laboratory on 31 May 2013. Soil compaction readings were also taken in each plot at 12 random locations with a Dickey John soil penetrometer (i.e. compaction tester) on 29 May 2013.

Trees were assessed for performance and pest occurrence on 19 and 24 July 2012. The height of trees was measured to the nearest 0.03m (1/10’) using a Jameson telescopic measuring rod (Jameson, LLC; Clover, SC), and overall health was assessed visually, where each tree was assigned a rating from 0 (dead) to 5 (lush, dark green needles). The presence or absence of HWA and EHS was noted after inspecting several branches from each tree using a simple binary (presence/absence) classification.

Hardwood cuttings averaging 12.5-15 cm (4-6") in length from the most recent years' growth were taken from *T.chinensis* growing in the research plots on 20 January 2014. Cuttings were kept in closed plastic bags, transported to the UMass College of Natural Sciences greenhouse, and potted on 22 January 2014. The cut ends were dipped in Dip 'N Grow (Dip 'N Grow, Inc.; Clackamas, OR) at a concentration of 5,000 ppm IBA and 2,500 ppm NAA before potting in sand:perlite (1:1) in standard 50-plug, 25.4 cm x 50.8 cm (10" x 20") grow trays. Two growing conditions were compared: 1) under a polyethylene moisture ("poly") tent with bottom heat (21°C/70°F) and 2) on a mist bench with no bottom heat (air temperature 24°C/75°F). Four flats of 50 cuttings each (200 cuttings total) were reared in the poly tent and six flats (300 cuttings total) were reared on the mist bench. Rooting could not be verified until cuttings remained for a "3-4 month" period under the aforementioned conditions (J. Alexander, pers. comm.). Establishment and vigor were assessed at various times over the following ten months. Vigor was assessed visually on a whole-tray basis using a 0-5 visual rating system where 0=100% mortality of grow tray specimens and 5 = 100% viability and lush, green needles, similar to the vigor rating used to assess tree health in the field.

Height data from mature trees growing in the research plots were analyzed using randomized complete block analysis of variance (ANOVA) and tree vigor was analyzed with Kruskal-Wallis one-way non-parametric ANOVA because the data did not meet the assumptions of randomized complete block ANOVA. Because of the low number of trees surviving for many of the test species, these analyses were performed only for *T. canadensis* and *T. chinensis*. Survivorship was analyzed for all species using χ^2 for the total number of each of the test species surviving, regardless of plot (replicate), and propagation results were analyzed with a two-sample *t* test. Analyses were performed with Statistix 9 (Analytical Software, Tallahassee, FL).

5.4 Results and Discussion

Soil analysis. Texture-by-feel evaluation revealed a loam soil comprising the growing media in all three of the experimental plots in which the *Tsuga* spp. were growing. Bulk density (Db) readings were 0.96 g/cc (Front Gate), 0.98g/cc (Magnolia Garden), 0.81g/cc (Hemlock Hedge). Bulk density may be one significant factor useful in identifying compacted soils; these values indicate that from a structural standpoint, the soil in the research plots was well below levels considered restrictive to root growth (i.e. 1.40-1.65g/cc) (Alberty et al. 1984). This was further corroborated by data from the penetrometer readings, which revealed root penetration to a depth of 18-23 cm (7-9") throughout the three plots: 19.2 cm (7.54") (Front Gate), 17.9 cm (7.04") (Magnolia Garden), and 21.3 cm (8.38") (Hemlock Hedge). A significant layer of organic matter had accumulated on the three plots, which is likely responsible for the soil organic matter (SOM) reading of 10.4% in the Front Gate Plot, though SOM readings for the other two plots were more within normal levels of nearly 5% (4.7% Magnolia Garden; 3.8% Hemlock Hedge) (Harris et al. 2004). The pH readings from the soil test report indicated the following values: Front Gate Plot, 5.4; Magnolia Garden, 5.4; and Hemlock Hedge, 5.2. Since *T. canadensis* is found growing on soils that range from "very acidic" to "nearly neutral" (Godman & Lancaster 1990), these values should not be limiting factors.

The pattern of tree growth observed between 2004 and 2008 (Weston & Harper 2009) largely continued between 2008 and 2012. Specimens of *T. canadensis* continued to measure the tallest of the seven species, but *T. heterophylla* was now similar in height to *T. canadensis* (Figure 5.1). Specimens of *T. chinensis* were nearly as tall as the tallest two species, but were significantly shorter than *T. canadensis* ($P < 0.01$), although the actual difference was relatively small. Specimens of *T. diversifolia* were numerically less than half as tall as the tallest trees, and the remaining species were minuscule in comparison (these differences were not statistically testable). Obtaining an accurate estimate of the height of the smallest was compromised because very few specimens of each of these species survived through 2012 (Table 5.2.).

Substantial differences existed in the ability of the seven species to survive the conditions in the research plots in the northeastern U.S. The differences in survivorship among the species observed in 2008 (Weston & Harper 2009) were accentuated in 2012; the four species with the lowest survivorship in 2008 (*T. caroliniana*, *T. mertensiana*, *T. diversifolia*, *and T. sieboldii*) displayed even lower survivorship in 2012 (Table 5.2), ranging between 5 and 17%. *Tsuga canadensis* and *T. chinensis* continued to display the highest survivorship, with values of 72.2 and 94.4%, respectively. The biggest change from 2008 was *T. heterophylla*, which dropped from 75 to 36% survivorship, apparently suffering substantial winter mortality as evidenced by the consistent brown-chlorotic appearance of the foliage after each winter season. Specific information pertaining to the provenance of these *Tsuga* spp. was unavailable and it is important to note that the particular area of origin of a species (and specimen) may influence factors like plant hardiness.

Another measure of performance of the test trees was the vigor rating. Vigor ratings for *T. canadensis* and *T. chinensis* were identical in 2008 at 4.2 + 0.4 (mean ±

standard deviation), but dropped to 3.7 ± 0.8 for *T. canadensis* by 2012. On the other hand, the vigor rating of *T. chinensis* increased to 5.0 ± 0.0 in 2012. This difference in vigor rating was statistically significant ($F = 60.0$, df = 1, 42, $P < 0.001$).

In 2008, populations of EHS were found on 73 and 35% of the specimens of *T. canadensis* and *T. chinensis*, respectively (Weston and Harper 2009). Data collection during July 2012 revealed HWA to be present on none of the 17 surviving specimens of *T. chinensis*, while EHS was present on all of the *T. chinensis* specimens (though no negative effects appeared to be associated with the presence of this insect on these trees). HWA was found to be present on 27 of the 28 surviving *T. canadensis* specimens (96.43%) while EHS was found to be present on all *T. canadensis* trees in the study plots. In fact, all of the remaining specimens of *Tsuga* spp. were positively infested with EHS, regardless of species. These results would indicate that further study concerning this insect and its effect on various *Tsuga* spp. would be in order.

The *T. chinensis* cuttings that were potted as part of the exploratory propagation proof-of-concept were evaluated approximately 6 weeks after potting (28 February) and appeared to have started well; all of the 200 cuttings that were potted and placed under the poly tent with bottom heat had maintained their needles and were lush/green with buds flushing new growth. The cuttings under the mist heads also appeared to be getting a good start, with 296 of the 300 having maintained needles, a lush/green appearance and new growth flushing from buds. The mean early-stage survival of the cuttings from the two methods was not significantly different ($t = -2.05$, df = 8, $P > 0.05$). The early-stage survival rate observed for *T. chinensis* may be higher than that observed for hardwood cuttings of *T. canadensis* reported by Doran (1952) (65-71%) and perhaps substantially higher than that reported for softwood cuttings of *T. canadensis* by Jetton et al. (2005) (22%). A second assessment of transplant success and root establishment was conducted on 14 July 2014, approximately six months after transplantation. Of the cuttings housed under the poly tent, 141 (70.5%) demonstrated successful root formation; 186 (62.0%) of the cuttings housed under mist heads demonstrated successful initial root formation. Bi-weekly evaluations taken between 14 July and 20 October 2014 revealed a steady decline in survivorship of cuttings under both cultivation methods; survivorship of cuttings under the poly tent had declined to 56.5 $\pm$ 12.5% at the end of this period compared to 40.3 + 12.0% for cuttings under the mist heads. Although this difference was not statistically different, it suggests that cultivation under the poly tent will result in greater transplant establishment, which is supported by the higher visual rating for these cuttings (3.8 $\pm$ 0.5) compared with 3.1 $\pm$ 0.6 for cuttings held under the mist heads. This differential vigor of cuttings under the two cultivation methods is likely explained by the warmer, slightly drier rooting conditions associated with the heating pad and generally drier foliage in the poly tent (J. Kinchla, pers. comm.). Further evaluation will be required to determine if the plants may be successfully lined-out. Exploration of transplantation using softwood cuttings may also prove beneficial and be worthy of formal study.

These results on balance suggest that *T. chinensis* is worthy of serious consideration as a replacement for *T. canadensis* in landscapes in the northeastern U.S. The growth form of *T. chinensis* shares similarities to that of *T. canadensis* as evidenced by the fact that 28% of study participants comparing the aesthetic properties of *T. chinensis* to *T. canadensis* could not distinguish between the two species (Dampier et al. 2015). Also, the subtle differences between the species (i.e. the larger and deeper green, glossier needles of *T. chinensis*) do not make the plant less attractive as a landscape selection than *T. canadensis* when comparing consumer purchase preferences (Dampier et al. 2015). The ability of *T*. *chinensis* to resist HWA and demonstrate no deleterious effects associated with the presence of EHS is an even more compelling reason to consider *T. chinensis* as a replacement for *T. canadensis*. Though further research questions should be addressed concerning this species (i.e. How does it respond to shearing? Is it resistant to deer herbivory? How does it respond to transplantation?), the added benefit of the potential ease of propagating *T. chinensis* from hardwood cuttings, which are often more difficult to establish than softwood cuttings, bodes well for propagators wishing to establish trade in *T. chinensis*.

Table 5.1. Summary of *Tsuga* susceptibility to hemlock woolly adelgid (*Adelges tsugae*). Ratings are: S = susceptible, T = tolerant, R = resistant, ? = questionable.

	Species[a]						
Author(s)/Year	can	car	het	mer	div	sie	chi
McClure/1992	S	S	T	T	S	S	---
del Tredici & Kitajima/2004	S	S	?	---	R	?	R
Montgomery & Lagalante/2008	S	S	?	R	R	S	R
Montgomery et al./2009	S	S	---	---	---	S	R
Weston & Harper/2009	S	S	S	R	R	R	R
Harper & Weston (current study)	S	S	S	R	S	R	R

[a]Species abbreviations as follows: can = *T. canadensis*, car = *T. caroliniana*, het = *T. heterophylla*, mer = *T. mertensiana*, chi = *T. chinensis*, div = *T. diversifolia*, sie = *T. sieboldii*. Dashes (---) indicate species that were not evaluated in certain studies.

Table 5.2. Survival of seven species of *Tsuga* evaluated in test plots at Lasdon Park Arboretum. The number of trees in each of the plots planted in 2003 and remaining alive in 2012 is shown, along with percent survivorship for each plot and averaged across plots.

Species	Year	Plot[a]			Average[b]
		1	2	3	
T. canadensis	2003	12	12	12	
	2012	6	8	12	
	% survival	50.0	66.7	100.0	72.2
T. caroliniana	2003	6	6	6	
	2012	0	1	0	
	% survival	0.0	16.7	0.0	5.6**
T. chinensis	2003	6	6	6	
	2012	6	5	6	
	% survival	100.0	83.3	100.0	94.4
T. diversifolia	2003	6	6	6	
	2012	1	2	0	
	% survival	16.7	33.3	0.0	16.7**
T. heterophylla	2003	4	4	3	
	2012	3	1	0	
	% survival	75.0	25.0	0.0	33.3*
T. mertensiana	2003	6	6	6	
	2012	1	1	0	
	% survival	16.7	16.7	0.0	11.1**
T. sieboldii	2003	6	6	6	
	2012	0	1	0	
	% survival	0.0	16.7	0.0	5.6**

[a] Plot numbers are as follows: 1 – Front Gate, 2 – Magnolia Garden, 3 – Hemlock Hedge.

[b] Asterisks indicate significant mortality as determined by χ^2 test; * = significant at $P < 0.05$, ** = significant at $P < 0.01$.

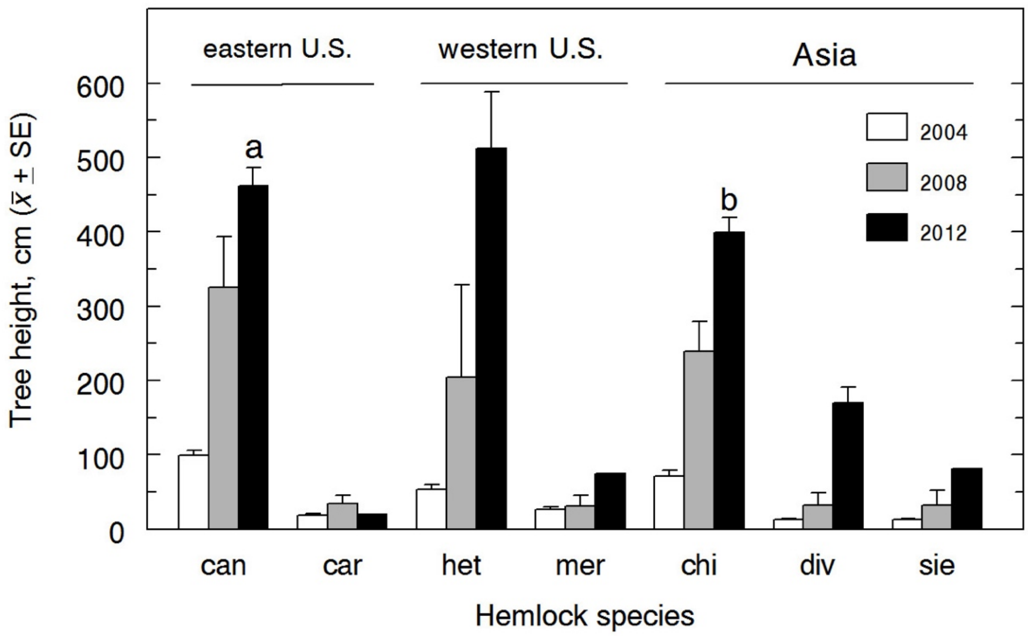

Figure 5.1. Height of *Tsuga* spp. in the research plots at Lasdon Park. Bars for 2012 accompanied by the same letter are not significantly different as determined by ANOVA followed by mean comparisons using LSD at $P = 0.05$ (only *T. canadensis* and *T. chinensis* could be tested; see text for details). Species abbreviations as follows: can = *T. canadensis*, car = *T. caroliniana*, het = *T. heterophylla*, mer = *T. mertensiana*, chi = *T. chinensis*, div = *T. diversifolia*, sie = *T. sieboldii*.

CONCLUSIONS

Data derived from in-person qualitative research interviews that were conducted with 50 tree wardens (Chapter 1). throughout Massachusetts from 2013 – 2016 availed that tree wardens are typically housed in a municipal department (like the Department of Public Works, or Highway Department), and that a direct relationship exists between community population size and access to resources and infrastructure to carry out urban forest management at the local level. Nearly all interviewees indicated that they are concerned about and monitor for, invasive urban forest pests like HWA, and that they would like further continuing education concerning this and other emergent subjects of importance. These include performing urban forest inventories and urban tree planting. Information delivery preferences included online and electronic formats, as well as in-person programming. Data also revealed that tree wardens interact with a number of agencies, associations, and volunteer-based organizations such as urban tree committees.

Data derived from qualitative research interviews with 13 chairs of volunteer-based urban tree committees (TC) (Chapter 2) indicated that these individuals are typically motivated, passionate volunteers who generally desire to work cooperatively with the many associations, organizations and agencies that comprise the local socio-political landscape. TC representatives and their membership should make a sustained, concerted effort to work collaboratively with their local tree warden to cooperatively and successfully advance urban forest management at the local level. Municipal managers and decision-makers should attempt to provide TC volunteers with appropriate training opportunities, resources, and demonstrate appreciation and gratitude to further encourage and solidify urban forestry volunteer-engagement in their community.

Qualitative approaches, including research interviews with key stakeholders, were explored and identified as an important and useful means to generate data to inform Extension programming activities in the urban forestry sector (Chapter 3). Though other means exist to derive this data, including mail-based surveys and informal conversations, the formality and familiarity associated with a recognized methodology like a research interview can help ensure both reliability of data and facilitate the establishment of a professional relationship between Extension professionals and their programming audiences

Since eastern hemlock (*Tsuga canadensis*) is one of only four native coniferous trees of ornamental importance in the Northeast U.S., and coniferous trees are notoriously underplanted in the urban environment, the ecology and natural history of its native and invasive insect and disease pests were reviewed in detail (Chapter 4). These included hemlock woolly adelgid [*Adelges tsugae* (Annand)], elongate hemlock scale [*Fiorinia externa* (Ferris)], spruce spider mite [*Oligonychus ununguis* (Jacobi)], and shoestring root rot [*Armillaria* spp. (Fr.:Fr.) Staude]. Though challenges remain, biological and other innovative pest management strategies continue to generate ongoing interest regarding large-scale, long-term population management. Efforts related to research and development on this front should continue. Other pest management strategies that will be employed in an effort to manage pest populations on a short-term basis include chemical-based approaches, and the use of pest-resistant plant materials – an approach known as the exploitation of host plant resistance. The investigation of a number of host plant resistant *Tsuga* spp in relation to their susceptibility to invasive pests (Chapter 5), indicate that *T. chinensis* may indeed be a viable replacement for *T. canadensis* and a valuable addition to urban landscapes in the eastern U.S.

The management of urban forest systems is a complex interaction of social-ecological elements where biophysical factors like infrastructure, plants, insect and disease pests, interact with social aspects including policy decision-makers, managers, and municipal and private-sector employees. Cooperation and coordination of these factors at differing levels of interaction is critical in moving the practice of urban forest management forward in a sustainable manner, in the 21st century.

BIBLIOGRAPHY

Alberty, C.A., H.M. Pellet and D.H. Taylor. 1984. Characterization of soil compaction at construction sites and woody plant response. Journal of Environmental Horticulture 2: 48-53.

Anonymous. 2008. Carolina hemlock (*Tsuga caroliniana*). Virginia Natural Heritage Fact Sheet. Online: www.dcr.virginia.gov/natural_heritage/documents/fstcaroliniana.pdf Accessed: 27 January 2015.

Anonymous. 2013. Lasdon Park, Arboretum and Veterans Museum. Online: http://lasdonpark.org Accessed: 10 December 2013.

Anonymous. 2014. Landscape Plants: Images, Identification and Information. Vol.3. Oregon State University. Online: http://oregonstate.edu/dept/ldplants/3plants.htm#tsuga Accessed: 31 October 2014.

Barlow, 2000. The ghosts of evolution: Nonsensical fruit, missing partners and other ecological anachronisms. Basic Books. New York, NY. 302 pp.

Bell, J.F., J.S. Wilson and G.C. Liu. 2008. Neighborhood greenness and 2-year changes in body mass index of children and youth. American Journal of Preventative Medicine 35: 547-553.

Bentz, S.E., L.G.H. Riedel, M.R. Pooler and A.M. Townsend. 2002. Hybridization and self-compatibility in controlled pollinations of eastern North American and Asian hemlock (*Tsuga*) species. Journal of Arboriculture 28: 200–205.

Berg, B.L. and H. Lune. 2012. Qualitative research methods for the social sciences. 8th ed. Pearson, Upper Saddle River, N.J. 432 pp.

Bergold, J. 2007. Participatory strategies in community psychology research—a short survey. *In* Bergold, J. and S. Thomas. 2012. Participatory research methods: a methodological approach. Forum: qualitative social research 13(1). Online: http://www.qualitative-research.net/index.php/fqs/article/view/1801/3334 Accessed: 15 August 2015.

Bergold, J. and S. Thomas. 2012. Participatory research methods: a methodological approach. Forum: qualitative social research 13(1). Online: http://www.qualitative-research.net/index.php/fqs/article/view/1801/3334 Accessed: 15 August 2015.

Black, R. A. and R.N. Mack. 1976. *Tsuga canadensis* in Ohio: Synecological and phytogeographical relationships. Vegetatio 32: 11-19.

Bloniarz, D.V. and H.D.P. Ryan. 1996. The use of volunteer initiatives in conducting urban forest resource inventories. Journal of Arboriculture 22: 75-82.

Bocsi, T., P.S. Warren, R.W. Harper and S. DeStefano. 2018. Wildlife habitat management on college and university campuses. Cities and the Environment (CATE) 11: Article 1. https://digitalcommons.lmu.edu/cate/vol11/iss1/1

Boyne, J.V. and F.P. Hain. 1983. Effects of constant temperature, relative humidity, and simulated rainfall on development and survival of the spruce spider mite (*Oligonychus ununguis*). Canadian Entomologist 115: 93-105.

Brazee, N.J. and R.L. Wick. 2011. Armillaria spp distribution and site relationships in *Pinus*- and *Tsuga*-dominated forests in Massachusetts. Canadian Journal of Forest Research 41: 1477-1490.

Brinkmann, S. and S. Kvale. 2015. Interviews: Learning the craft of qualitative research interviewing. 3rd ed. SAGE Publications. London, U.K. 405 pp.

Brooks, R.T. 2001. Effects of the removal of overstory hemlock from hemlock dominated forests on eastern redback salamanders. Forest Ecology and Management 149: 197-204.

Brown, D.G., K.M. Johnson, T.R. Loveland and D.M. Theobald. 2005. Rural land-use trends in the conterminous United States, 1950-2000. Ecological Society of America 15: 1851-1863.

Brown, I. 2007. Wisconsin statewide urban forest assessment: Development and implementation. MS Thesis, University of Wisconsin-Stevens Point *In* Miller, R.W., R.J. Hauer and L.P. Werner. 2015. Urban forestry: Planning and managing urban greenspaces. Waveland Press. Long Grove, IL.

Bryant, J.P., R.K. Swihart, P.B. Reichardt and L. Newton. 1994. Biogeography of woody plant chemical defense against snowshoe hare browsing: comparison of Alaska and eastern North America. Oikos 70: 385-395.

Capana, R.J. 1999. Arboriculture: History and development in North America. East Lansing, MI: Michigan State University Press. 443 pp.

Cartwright, A. 1988. Interview or postal questionnaires? Comparisons of data about women's experiences with maternity services. The Milbank Quarterly 66: 172-189.

Clapp, J.C., H.D.P. Ryan, R.W. Harper and D.V. Bloniarz. 2014. Rationale for the increased use of conifers as functional green infrastructure. Arboricultural Journal 36: 161-178.

Coladonato, M. 1993. *Tsuga caroliniana*. *In* Fire Effects Information System. U.S. Department of Agriculture, Forest Service. Rocky Mountain Research Station, Fire Sciences Laboratory. Online: http://www.fs.fed.us/database/feis/ Accessed: 30 October 2014.

Cowles, R. 2015. Systemic insecticide impacts on the environment and bee pollinators. Tree care industry 26: 38-46.

Creswell, J.W. 2007. Qualitative inquiry & research design: Choosing among 5 approaches. 2nd ed. SAGE Publications, Inc. Thousand Oaks, CA. 395 pp.

Cumming, A.B., D.B. Twardus and W.D. Smith. 2006. Maryland and Massachusetts street tree monitoring pilot projects. NA-FR-01-06. USDA Forest Service, Northeastern Area State and Private Forestry. Newtown Square, PA. 24 pp.

Dale, A.G., and S.D. Frank. 2014b. Urban warming trumps natural enemy regulation of herbivorous pests. Ecological Applications 24:1596–1607.

Dampier, J.E., R.W. Harper, A. McElhinney and E. Biltonen. 2018. Modeling benefit-cost analysis of hemlock woolly adelgid host plant resistance with emphasis on least-toxic chemical treatment alternatives. HortTechnology 28: 624-628.

Dampier, J.E.E., R.W. Harper, L. Schwartzberg and R.H. Lemelin. 2015. Comparison of Arborists' and Horticulturists' preferences of *Tsuga chinensis* to *T. canadensis* in the urban landscape. Arboriculture & Urban Forestry 41: 41-48.

Dampier, J.E., R.H. Lemelin, C. Shahi and N. Luckai. 2014. Small town identity and history's contribution to a response in policy change: A case study of transition from coal to biomass energy conversion. Energy, Sustainability and Society 4: 1-14.

Day, S.D., P.E. Wiseman, S.B. Dickinson and J.R. Harris. 2010. Tree root ecology in the urban environment and implications for a sustainable rhizosphere. Arboriculture and Urban Forestry 36: 193-205.

Dean, J. 2005. Said tree is a veritable nuisance. Ottawa's street trees 1869-1939. Urban History Review 34: 46-57.

Del Tredici, P. 1985. Propagation of *Tsuga canadensis* cultivars: Hardwood versus softwood cuttings. Proceedings of the International Plant Propagation Society 35: 565-569.

Del Tredici, P. and A. Kitajima. 2004. Introduction and cultivation of Chinese hemlock (*Tsuga chinensis*) and its resistance to hemlock woolly adelgid (*Adelges tsugae*). Journal of Arboriculture 20: 282–287.

Deneke, F. 1993. Urban Forestry in North America: Towards a global ecosystem perspective. pp 4-8. *In* G. Blouin & R. Comeau [Eds.], Proceedings of the First Canadian Urban Forests Conference 30 May-2 June 1993. Winnipeg, MB. 151 pp.

Diehl, N.W., N.L. Sloan, E.P. Garcia, S. Galindo-Gonzalez, D.R. Dourte and C.W. Fraisse. 2017. Climate-related risks and management issues facing agriculture in the southeast: Interviews with Extension professionals. Journal of Extension 55: Article 1FEA2. Online: https://www.joe.org/joe/2017february/a2.php Accessed: 21 July 2018.

Dirr, M.A. 2011. Encyclopedia of trees and shrubs**.** Timber Press, Inc. Portland, OR. 951 pp.

Dodd, A. and C. Abdalla. 2004. Strengthening environmental policy education through qualitative research: Experience with Pennsylvania's nutrient management regulatory review. Journal of Extension 42: Article 5FEA2. Online: https://www.joe.org/joe/2004october/a2.php Accessed: 23 July 2018.

Dodds, K.J. and D.A. Orwig. 2011. An invasive urban forest pest invades natural environments – Asian longhorned beetle in northeastern US hardwood forests. Canadian Journal of Forest Research 41: 1729-1742.

Doherty, K.D., H.D.P. Ryan and D.V. Bloniarz. 2000. Tree wardens and utility arborists: a management team working for street trees in Massachusetts. Journal of Arboriculture 26: 38–47.

Dolan, R. 2015. Two hundred years of forest change: Effects of urbanization on tree species composition and structure. Arboriculture & Urban Forestry 41: 136–145.

Domroese, M.C. and E.A. Johnson. 2017. Why watch bees? Motivations of citizen science volunteers in the great pollinator project. Biological Conservation 208: 40-47.

Doran, W.L. 1952. The vegetative propagation of hemlock. Journal of Forestry 50: 126-129.

Douglas, I., D. Goode, M. Houck and R. Wang. 2011. The routledge handbook of urban ecology. Routledge. Oxon, U.K. 654 pp.

Dreistadt, S.H. 2004. Pests of landscape trees and shrubs: An integrated pest management guide. 2nd ed. Integrated Pest Management Program, University of California Division of Agriculture and Natural Resources. 210 pp.

Elkinton, J.S. and A.M. Liebhold. 1996. Population dynamics of gypsy moth in North America. Annual Review of Entomology 35: 571-96.

Elmendorf, W.F. and A.E. Luloff. 2006. Using key informant interviews to understand open space conservation in a developing watershed. Arboriculture & Urban Forestry 32: 54-61.

Elmendorf, W.F. and A.E. Luloff. 2001. Using qualitative data collection methods when planning for community forests. Journal of Arboriculture 27: 139-151.

Evans A. and T. Gregoire. 2007. A geographically variable model of hemlock woolly adelgid spread. Biological Invasions 9: 369-382.

Evelyn, J. 1664. Slyva or a discourse of forest trees and the propagation of timber in His Majesties dominions (p. 287). London: J. Martyn and J. Allestry. Online: https://archive.org/stream/sylvaordiscourse02evelrich#page/286/mode/2up/search/arborist Accessed: 17 April 2017.

Farrar, J.L. 1995. Trees of the Northern United States and Canada. Iowa State University Press. Ames, Iowa. 502 pp.

Fazio, J.R. No Date. How to work with volunteers effectively. Tree City USA Bulletin No. 36. Arbor Day Foundation. Lincoln, NE.

Fazio, J.R. No Date. Tree protection ordinances. Tree City USA Bulletin No. 31. Arbor Day Foundation. Lincoln, NE.

Fazio, J.R. 2015. Tree board handbook. Arbor Day Foundation. Lincoln, NE.

Fleiss, J.L. and J. Cohen. 1973. The equivalence of weighted kappa and the intraclass correlation coefficient as measures of reliability. Educational and Psychological Measurement 33: 613-619.

Fontana, A. J.H. Frey. 2005. The interview: From neutral stance to political involvement. *In* Denzin, N.K., Lincoln, Y.S. [Eds.], The sage handbook of qualitative research, 3rd ed. Sage Publications, Inc., Thousand Oaks, CA.

Foster, D. R. [Ed.], 2014. Hemlock: a forest giant on the edge. Yale University Press. New Haven, CT. 336 pp.

Grande, D. and K. Armstrong. 2008. Community volunteerism of U.S. physicians. Journal of General Internal Medicine 12: 1987-1991.

Gerstenberger, P. 2015. Occupational accidents. Tree Care Industry Association. 4 pp.

Gillham, B. 2005. Research interviewing: the range of techniques. McGraw-Hill Education. Berkshire, England. 173 pp.

Gillies, K., Z.C. Skea and M.K. Campbell. 2014. Decision aids for randomized controlled trials: a qualitative exploration of stakeholders' views. BMJ Open 4: 1-13.

Grado, S.C., M.K. Measells and D.L. Grebner. 2013. Revisiting the status, needs and knowledge levels of Mississippi's Governmental Entities relative to urban forestry. Arboriculture and Urban Forestry 39: 149-156.

Godman, R. M. and K. Lancaster. 1990. *Tsuga canadensis*. *In* R.M. Burns and B.H. Honkala [Eds.], Silvics of North America: Volume 1. Agricultural Handbook 654. USDA, Forest Service, Washington, D.C.

Gugino, B.K., O.J. Idowu, R.R. Schindelbeck, H.M. van Es, D.W. Wolfe, B.N. Moebius-Clune, J.E. Thies, and G.S. Abawi. 2009. Cornell soil health assessment training manual. 2nd ed. Cornell University, Geneva, NY. Online: http://soilhealth.cals.cornell.edu/extension/manual/manual.pdf Accessed: 02 August 2015.

Farrar, J.L. 1995. Trees of the Northern United States and Canada. Iowa State University Press. Ames, Iowa. 502 pp.

Haack, R.A., F. Hérard, J. Sun and J.J. Turgeon. 2010. Managing invasive populations of Asian longhorned beetle and citrus longhorned beetle: A worldwide perspective. Annual Review of Entomology 55: 521-546.

Hagle, S.K. 2010. Management guide for Armillaria root disease. USDA Forest Service, Forest Health Protection and State Forestry Organizations. 23 pp.

Harper, R.W., E.S. Huff, D.V. Bloniarz, S. DeStefano and C.R. Nicolson. 2018. Exploring the characteristics of successful volunteer-led urban forest tree committees in Massachusetts. Urban Forestry & Urban Greening 34: 311-317.

Harper, R.W., D.V. Bloniarz, S. DeStefano and C.R. Nicolson. 2017. Urban forest management in New England: Towards a contemporary understanding of tree wardens in Massachusetts communities. Arboricultural Journal 39: 1-17.

Harper, R.W. and P.A. Weston. 2016. Potential of alternative *Tsuga* spp. as landscape replacements from western North America and Asia as replacements for *T. canadensis*: longer-term evaluation and propagation of *T. canadensis*. Arboriculture & Urban Forestry 42: 346-354.

Harper, R.W., W.R. Autio, J.T. Finn and F.S. Rossi. 2016b. Tree wardens and public grounds management in North America: Overseeding athletic fields with perennial ryegrass to promote safe playing surface. Arboricultural Journal 40: 1–13.

Harper, R.W. and R.S. Cowles. 2013. Susceptibility of Chinese hemlock (*Tsuga chinensis*) to injury from autumn horticultural oil applications. Arboriculture & Urban Forestry 39: 6-10.

Harris, R.W., J.R. Clark and N.P. Matheny. 2004. Arboriculture: Integrated management of landscape trees, shrubs, and vines. 4th ed. Prentice Hall. 592 pp.

Harrison, V.S., A. Xiao, H.K. Ott and D. Bortree. 2017. Calling all volunteers: The role of stewardship and involvement in volunteer-organization relationships. Public Relations Review 43: 872-881.

Hauer, R. and G. Johnson. 2008. Approaches within the 50 United States to meeting federal requirements for urban and community forestry assistance programs. Arboriculture & Urban Forestry 34: 74-83.

Havill, N.P., L.G. Vieira, and S.M. Salom. 2016. Hemlock woolly adelgid. USDA Forest Service FHTET-2014-05. Morgantown, WV. 21 pp.

Havill, N.P. and M.E. Montgomery. 2008. The role of arboreta in studying the evolution of host resistance to the hemlock woolly adelgid. Arnoldia 65: 2–9.

Hepting, G.H. 1971. Diseases of forest and shade trees of the United States. United States Department of Agriculture Handbook 1669. 658 pp.

Holloway, I. and K. Galvin. 2017. Qualitative research in nursing and healthcare, 4th ed. Wiley Blackwell. West Sussex, U.K. 359 pp.

Hull, R. B. 1992. How the public values urban forests. Journal of Arboriculture 18: 98-101.

Hussain, A., and R.D. Shenefelt. 1959. The hemlock borer. Wisconsin Conservation Department, Technical Bulletin #19. Madison, WI.

Hoover, B.K., R.M. Bates, J.C. Sellmer and G.A. Hoover. 2009. Challenging Chinese hemlock (*Tsuga chinensis*) with hemlock woolly adelgid (*Adelges tsugae*) ovisacs. Arboriculture & Urban Forestry 35: 1-4.

Janzen, D.H. and P.S. Martin. 1982. The fruits the gomphotheres ate. Science 215: 19-27.

Jetton, R. M., J. Frampton and F. P. Hain. 2005. Vegetative propagation of mature eastern and Carolina hemlocks by softwood cuttings. HortScience 40: 1469-1473.

Jim, C.Y. 1998a. Physical and chemical properties of a Hong Kong roadside soil in relation to urban tree growth. Urban Ecosystems 2: 171–181.

Jim, C.Y. and W. Chen. 2009. Ecosystem services and valuation of urban forests in China. Urban Forestry & Urban Greening 26: 187-194.

Johnston, M. 2015. Trees in towns and cities: A history of British urban arboriculture. Oxbow Books. Oxford, U.K. 270 pp.

Johnson, W.T. and H.H. Lyon. 1991. Insects that feed on trees and shrubs. 2nd ed. Cornell University Press. Ithaca, NY. 560 pp.

Jonnes, J. 2016. Urban forests: A natural history of trees and people in the American cityscape. Viking. New York, NY. 394 pp.

Jorgensen, E. 1974. Towards an urban forestry concept. Environment Canada. 14pp.

Jutras, P., S.O. Prasher and G.R. Mehuys. 2010. Appraisal of key abiotic parameters affecting street tree growth. Arboriculture & Urban Forestry 36: 1-10.

Kelsey, K.D. and S.C. Mariger. 2002. A case study of stakeholder needs for extension education. Journal of Extension, 40: Article 2RIB2. Online: https://www.joe.org/joe/2002april/rb2.php Accessed: 25 July 2018

Kelley, R. and R. Evans. 2000. Hemlock Borer. United States Department of Agriculture Forest Service Pest Alert NA-PR-03-00.

Kim, H.H. 1992. Urban heat island. International Journal of Remote Sensing 13: 2319–2336.

Kimmins, J.P. 1997. Biodiversity and its relationship to ecosystem health and integrity. The Forestry Chronicle 73: 229-32.

Kosztarab, M. 1996. Scale insects of northeastern North America: Identification, biology, and distribution. Special Publication Number 3. Virginia Museum of Natural History, Martinsville, VA.

Kuo, F.E. 2003. The role of arboriculture in a healthy social ecology. Journal of Arboriculture 29: 148–155.

Kuo, F.E. and W. Sullivan. 2001. Environment and crime in the inner city: Does vegetation reduce crime? Environmental Behavior 33: 343-367.

Lamb, E.M. [Ed.]. 2018 Cornell pest management guide for commercial production and maintenance of trees and shrubs. Pesticide Management and Education Program. Cornell University, Ithaca NY.

Lammers, J.C. 1991. Attitudes, motives and demographic predictors of volunteer commitment and service duration. Journal of Social Service Research 14: 125-140.

Lapin, B. 1994. The impact of hemlock woolly adelgid on resources in the Lower Connecticut River Valley. Report for the NE Center for Forest Health Research. Hamden, Conn. USDA Forest Service. 45 pp.

Larry, B. 2013. Assessing environmental justice in urban communities. USDA Forest Service. Online: http://www.fs.fed.us/research/docs/urban/environmental-justice-briefing.pdf Accessed: 01 July 2015.

Larsson, L. 2002. Resistance in trees to insects – an overview of mechanisms and interactions. *In* Mechanisms and Deployment of Resistance in Trees to Insects, M.R. Wagner, K.M. Clancy, F. Lieutier, and T.D. Paine, [Eds]. Dordrecht: Kluwer Academic Publishers: 1-30.

Leibowitz, R. 2012. Urban tree growth and longevity: An international meeting and research symposium white paper. Arboriculture & Urban Forestry 38: 237-241

Lemelin, R.H., J.E. Dampier, R.W. Harper, D. Balika and R. Bowles. 2017. Perceptions of insects: a visual analysis. Society & Animals. DOI: 10.1163/15685306-12341469.

Limbu, S., M.A. Keena and M.C. Whitmore. 2018. Hemlock woolly adelgid (Hemiptera: Adelgidae): A non-native pest of hemlocks in eastern North America. Journal of Integrated Pest Management 9: 1-16.

Lincoln, Y.S. and E.G. Guba. 1985. Naturalistic inquiry (Vol. 75). SAGE Publications, Inc. Thousand Oaks, CA. 416 pp.

Lipkis, A. and K. Lipkis. 1990. The simple act of planting a tree: A citizen foresters guide to healing your neighborhood, your city, and your world. Tree People. Los Angeles, CA. 236 pp.

Locke, D.H. and J.M. Grove. 2016. Doing the hard work where it's easiest? Examining the relationships between urban greening programs and social and ecological characteristics. Applied Spatial Analysis & Policy 9: 77-96.

Maier, C.T., C.R. Lemmon, J.M. Fengler, D.F. Schweitzer, and R.C. Reardon. 2004. Caterpillars on the foliage of conifers in the Northeastern United States. Morgantown, WV. USDA Forest Service. Forest Health Technology Enterprise Team FHTET-2004-01. 151 pp.

Mallis, R.E. and L.K. Rieske. 2011. Arboreal spiders in eastern hemlock. Environmental Entomology 40: 1378-1387.

Mathewson, B. 2009. The relative abundance of eastern red-backed salamander populations in eastern hemlock-dominated and mixed deciduous forests at Harvard Forest. Northeast Naturalist 16:1-12.

McClure, M.S. 2002. Elongate hemlock scale. USDA Forest Service Pest Alert NA-PR-01-02. Morgantown, WV.

McClure, M.S., S.M. Salom and K.S. Shields. 2001. Hemlock woolly adelgid. USDA Forest Service FHTET-2001-03. Morgantown, WV. 14 pp.

McClure, M.S. 1990. Role of wind, birds, deer, and humans in the dispersal of hemlock woolly adelgid, *Adelges tsugae* (Homoptera, Adelgidae). Annals of the Entomological Society America 82:50-54.

McIntosh, R.P. 1995. H.A. Gleason's 'individualistic concept' and theory of animal communities: a continuing controversy. Biological Reviews of the Cambridge Philosophical Society 70 (2): 317-57.

McKeever, B. 2015. The nonprofit sector in brief 2015: Public charities, giving, and volunteering. Retrieved from: http://www.urban.org/research/publication/nonprofit-sector-brief-2015-public-charities-giving-and-volunteering

McPherson, E. G., J. R. Simpson, P. J. Peper, S. L. Gardner, K. E. Vargas and Q. Xiao. 2007. Northeast community tree guide: Benefits, costs, and strategic planning. Albany, CA: USDA Forest Service, Pacific Southwest Research Station. 106 pp.

McWilliams, W.H. and T.L. Schmidt. 2000. Composition, structure, and sustainability of hemlock ecosystems in Eastern North America. *In* Ward, J.S., M.E. Montgomery, C.A.S.-J. Cheah, B.P. Onken, and R.S. Cowles. 2004. Eastern hemlock forests: guidelines to minimize the impacts of hemlock woolly adelgid. USDA Forest Service. Morgantown, WV.
Online: http://na.fs.fed.us/pubs/tps/eastern_hemlock/eastern_hemlock.pdf
Accessed: 02 June 2015.

Means, J.E. 1990. *Tsuga mertensiana*. *In* R.M. Burns and B. H. Honkala [Eds.], Silvics of North America: Volume 1. Agricultural Handbook 654. USDA Forest Service, Washington, D.C.

Miller, R.W. and T.R. Bates. 1978. National implications of an urban forestry survey in Wisconsin. Journal of Arboriculture 4: 125-127.

Miller, R.W., R.J. Hauer and L.P. Werner. 2015. Urban forestry: Planning and managing urban greenspaces. Waveland Press. Long Grove, IL. 560 pp.

Mincey, S.K., M. Hutten, B.C. Fischer, T.P. Evans, S.I. Stewart and J.M. Vogt. 2013. Structuring institutional analysis for urban ecosystems: A key to sustainable urban forest management. Urban Ecosystems 16: 553-571.

Moll, G. 1989. The state of our urban forest. American Forests Nov/Dec: 61–64.

Montgomery, M. E. and A.F. Lagalante. 2008. The role of volatile terpenoids in the relationship of the hemlock woolly adelgid and its host-plants. Fourth Symposium on hemlock woolly adelgid in the eastern United States; CT. FHTET 2008-01, 118–123.

Montgomery, M.E., S.E. Bentz, and R.T. Olsen. 2009. Evaluation of hemlock (*Tsuga*) species and hybrids for resistance to *Adelges tsugae* (Hemiptera: Adelgidae) using artificial infestation. Journal of Economic Entomology 102: 1247-1254.

Moorman 2016. Hemlock diseases. Pennsylvania State University. Online: https://extension.psu.edu/hemlock-diseases Accessed: 16 April 2019.

Moran, K. and T. Mallia. 2015. Wholly engaged: Integrating volunteer and donor programs. *In* R. J. Rosenthal [Ed.], Volunteer engagement 2.0: Ideas and insights changing the world. John Wiley & Sons. Hoboken, NJ. 384 pp.

Nichnadowicz, J. 2000. Community involvement in urban forestry programs. *In* J.E. Kuser [Ed.], Handbook of urban and community forestry in the Northeast. Kluwer Academic/Plenum. New York, NY. 487 pp.

Nowak, D.J. and E.J. Greenfield. 2018. U.S. urban forest statistics, values, projections. Journal of Forestry 116: 164-177.

Nowak, D.J. and E.J. Greenfield. 2012. Tree and impervious cover change in U.S. cities. Urban Forestry & Urban Greening 11: 21-30.

Nowak, D.J., S.M. Stein, P.B. Randler, E.J. Greenfield, S.J. Comas, M.A. Carr and R.J. Alig. 2010. Sustaining America's urban trees and forests. USDA Forest Service General Technical Report NRS-62. Online: http://www.fs.fed.us/openspace/fote/reports/nrs-62_sustaining_americas_urban.pdf Accessed: 01 July 2015.

Nowak, D.J., D.E. Crane and J.C. Stevens. 2006. Air pollution removal by urban trees and shrubs in the United States. Urban Forestry & Urban Greening 4: 115-123.

Nowak, D. and D. Crane. 2002. Carbon storage and sequestration by urban trees in the USA. Environmental Pollution 116: 381–389.

Nowak, D.J., and J.F. Dwyer. 2000. Understanding the costs and benefits of urban forest ecosystems. pp. 11–25. In: J.E. Kuser [Ed.]. Handbook of community and urban forestry in the Northeast, Kluwer, NY.

Oten, K.F., A.C. Cohen, J.B. Strider and F. P. Hain. 2010. Investigating host resistance using scanning electron microscopy. Proceedings from the Fifth Symposium on Hemlock Woolly Adelgid in the Eastern United States. United States Forest Service (FHTET-2010-07).

Packee, E.C. 1990. *Tsuga heterophylla*. *In* R.M. Burns and B.H. Honkala [Eds.], Silvics of North America: Volume 1. Agricultural Handbook 654. USDA Forest Service. Washington, D.C.

Parsons, R., L.G. Tassinary, R.S. Ulrich. M.R. Hebl and M. Grossman-Alexander. 1998. The view from the road: Implications for stress recovery and immunization. Journal of Environmental Psychology 18: 113-140.

Poland, T. and D. McCullough. 2006. Emerald ash borer: invasion of the urban forest and the threat to North America's ash resource. Journal of Forestry 104: 118-124.

Putnam, R. 1996. The strange disappearance of civic America. Policy: American Journal of Public Policy & Ideas 12: 3-15.

Quimby, J. W. 1995. Value and importance of hemlock ecosystems in the eastern United States. Proceedings of the first hemlock woolly adelgid review. USDA Forest Service Publication FHTET 96-10.

Radville, L., A. Chaves and E.L. Preisser. 2011. Variation in plant defense against invasive herbivores: evidence for a hypersensitive response in eastern hemlocks (*Tsuga canadensis*). Journal of Chemical Ecology 37: 592-7.

Raupp, M.J., and A. Szczepaniec. 2015. Collatoral effects of neonicotinoid insecticides. Tree care industry 26: 30-34.

Raupp, M.J., P.M. Shrewsbury and D.A. Herms. 2010. Ecology of herbivorous arthropods in urban landscapes. Annual Review of Entomology 55: 19–38.

Raupp, M.J., A.B. Cumming and E.C. Raupp. 2006. Street tree diversity in eastern North America and its potential for tree loss to exotic borers. Arboriculture & Urban Forestry 32: 297-304.

Rees, W. and M. Wackernagel. 1996. Urban ecological footprints: Why cities cannot be sustainable – And why they are a key to sustainability. Environmental Impact Assessment Review 16: 223-248.

Reuter, C., O. Heger and V. Pipek. 2013. Combining real and virtual volunteers through social media. Proceedings of 10th International ISRAM Conference. Baden-Baden, Germany. May 2013.

Ricard, R.M. and G.D. Dreyer. 2005. Greening Connecticut cities and towns: Managing public trees and community forests. University of Connecticut, College of Agriculture and Natural Resources. Storrs, CT. 265 pp.

Ricard, R. M. 2005a. Shade trees and tree wardens: Revising the history of urban forestry. Northern Journal of Forestry 103: 230–233.

Ricard, R. M. 2005b. Connecticut's tree wardens: A survey of current practices, continuing education, and voluntary certification. Northern Journal of Applied Forestry 22: 248–253.

Rines, D. R., B. Kane, D. Kittredge, H.D.P. Ryan and B. Butler. 2011. Measuring urban forestry performance and demographic associations in Massachusetts, USA. Urban Forestry & Urban Greening 10: 113-118.

Rines, D. R., B. Kane, D. Kittredge and H.D.P. Ryan. 2010. Urban forestry priorities of Massachusetts (USA) tree wardens. Urban Forestry & Urban Greening 9: 295-301.

Ritchie, J. and J. Lewis. [Eds.], 2003. Qualitative research practice: A guide for social science students and researchers. SAGE Publications. London, U.K. (p.336).

Roman, L.A. 2014. How many trees are enough? Tree death and the urban canopy. Scenario Journal 5: 1-8.

Roman, L.A. and F.N. Scatena. 2011. Street tree survival rates: Meta-analysis of previous studies and application to a field survey in Philadelphia, PA, USA. Urban Forestry & Urban Greening 10: 269-274.

Rubin, H.J. and I.S. Rubin. 2012. Qualitative interviewing: The art of hearing data. 3rd ed., Sage Publications, Inc. London, U.K. 265 pp.

Saldana, J. 2013. The coding manual for qualitative researchers. 2nd ed. Sage Publications, Inc. London, U.K. 303 pp.

Sasscer, E.R. 1912. The genus Fiorinia in the United States. USDA, Bureau of Entomology Technical Service 16: 75-82.

Savi, T., S. Bertuzzi, S. Branca, M. Tretiach, and A. Nardini. 2014. Drought-induced xylem cavitation and hydraulic deterioration: Risk factors for urban trees under climate change? New Phytologist 205: 1106-1116.

Schroeder, H., J. Flannigan and R. Coles. 2006. Residents' attitudes toward street trees in the UK and US communities. Arboriculture & Urban Forestry 32: 236-246.

Scharenbroch, B.C., D. Carter, M. Bialecki, R. Fahey, L. Scheberl, M. Catania, L.A. Roman, N.L. Bassuk, R.W. Harper, L. Werner, A. Siewert, S. Miller, L. Hutyra and S. Raciti. 2017. A rapid urban site index for assessing the quality of street tree planting sites. Urban Forestry & Urban Greening 27: 279-286.

Schlarbaum, S.E., F. Hebard, P.C. Spaine and J.C. Kamalay. 1998. Three American tragedies: chestnut blight, butternut canker, and Dutch elm disease. *In* Proceedings of the exotic pests of eastern forests conference. USDA Forest Service and Tennessee Exotic Pest Plant Council. Online: http://www.srs.fs.usda.gov/pubs/ja/ja_schlarbaum002.htm Accessed: 02 May 2014.

Schmidt, T.L. and W.H. McWilliams. 1996. Status of eastern hemlock in the northern U.S. *In* Ward, J.S., M.E. Montgomery, C.A.S.-J. Cheah, B.P. Onken, and R.S. Cowles. 2004. Eastern hemlock forests: Guidelines to minimize the impacts of hemlock woolly adelgid. USDA Forest Service. Morgantown, WV. Online: http://na.fs.fed.us/pubs/tps/eastern_hemlock/eastern_hemlock.pdf Accessed: 02 June 2015.

Schwarz, K., M. Fragkias, C.G. Boone, W. Zhou, M. McHale, J.M. Grove, J. O'Neil-Dunne, J.P. McFadden, G.L. Buckley, D. Childers, L. Ogden, S. Pincetl, D. Pataki, A. Whitmer and M.L. Cadenasso. 2015. Trees grow on money: Urban tree canopy cover and environmental justice. PLoS ONE 10(4): e0122051. doi:10.1371/journal.pone.0122051

Shifley, S. R., F.X. Aguilar, N. Song, S.I. Stewart, D.J. Nowak, D.D. Gormanson, K.W. Moser, S. Wormstead and E.J. Greenfield. 2012. Forests of the northern United States. USDA Forest Service, Northern Research Station. 202 pp.

Sidebottom, J. 2019. Rust mites of Christmas trees. Integrated Pest Management Program. North Carolina State University. 5 pp.

Sinclair, W.A. and H.H. Lyon. 2005. Diseases of trees and shrubs. 2nd ed. Cornell University Press. Ithaca, NY. 660 pp.

Stobbart, M. and M. Johnston. 2012. A survey of urban tree management in New Zealand. Arboriculture & Urban Forestry 38: 247-254.

Tobin, P. C., R.M. Turcotte and D.A. Snider. 2013. When one is not necessarily a lonely number: initial colonization dynamics of *Adelges tsugae* on eastern hemlock *Tsuga canadensis*. Biological Invasions 15: 1925-1932.

Town of Monson, Massachusetts. 2017. RePlanting Monson Tree Committee. https://www.monson-ma.gov/replanting-monson-tree-committee

Treiman T. and J. Gartner. 2005. What do people want from their community forests? Results of a public attitude survey in Missouri, U.S. Journal of Arboriculture 31: 243-250.

Treiman T. and J. Gartner. 2004. Community forestry in Missouri, U.S.: Attitudes and knowledge of local officials. Journal of Arboriculture 30: 205-213.

Trotter, R.T. and A. Evans. 2010. Native Communities on an exotic tree: The arthropod community on *Tsuga chinensis* in New England; a potential ecological surrogate for *T. canadensis*. *In* Proceedings of the fifth symposium on hemlock woolly adelgid in the eastern United States. USDA Forest Service. Forest Health Technology Enterprise Team. Morgantown, WV.

United States Bureau of Labor Statistics. 2016. Volunteering in the United States. Retrieved from http://www.bls.gov/news.release/volun.nr0.htm.

United States Census. 2010. United States Department of Commerce. Online: https://ask.census.gov/faq.php?id=5000&faqId=5971 Accessed: 24 January 2015.

United States Census. 2016. Our changing Landscape. United States Department of Commerce. Online: https://www.census.gov/content/dam/Census/library/visualizations/2016/comm/acs-rural-urban.pdf Accessed: 15 June 2019.

United States Forest Service. 2015. Environmental justice. United States Department of Agriculture. Online: http://www.fs.fed.us/research/urban/environmental-justice.php Accessed: 01 July 2014.

United States Department of Agriculture, Office of the Chief Economist. Natural Resources and the Environment – Forest Service. Online: https://www.usda.gov/oce/sustainable/mission_areas.htm Accessed: 04 May 2017.

Uva, R.H., J.C. Neal and J.M. Ditomaso. 1997. Weeds of the Northeast. Cornell University Press. Ithaca, NY. 408 pp.

van den Berg, M., W. Wendel-Vos, M. van Poppel, H. Kemper, W. van Mechelen and J. Maas. 2015. Health benefits of green spaces in the living environment: A systematic review of epidemiological studies. Urban Forestry & Urban Greening 14: 806-816.

van den Berg, M., J. Maas, R.A. Verheij and P.P. Groenewegen. 2010. Green space as a buffer between stressful life events and health. Social Science & Medicine 70: 1203-1210.

Ward, J.S., M.E. Montgomery, C.A.S.-J. Cheah, B.P. Onken and R.S. Cowles. 2004. Eastern hemlock forests: Guidelines to minimize the impacts of hemlock woolly adelgid. USDA Forest Service. Morgantown, WV. 27 pp. Online: http://na.fs.fed.us/pubs/tps/eastern_hemlock/eastern_hemlock.pdf Accessed: 02 June 2015.

Wargo, P.M. and J.C. Fagan. 2000. Hemlock mortality after hemlock woolly adelgid attack: role of *Armillaria. In* Proceedings of Symposium on Sustainable Management of Hemlock Ecosystems in Eastern North America, 22-24 June 1999, Durham, NH. USDA Forest Service General Technical Report GTR-NE-267. 237 pp.

Watson, G.W., A.M. Hewitt, M. Custic and M. Lo. 2014. The management of tree root systems in urban and suburban settings: a review of soil influence on root growth. Arboriculture & Urban Forestry 40: 193-217.

Webb, R.E., J.R. Frank, and M.J. Raupp. 2003. Eastern hemlock recovery from hemlock woolly adelgid damage following imidacloprid therapy. Journal of Arboriculture 29: 298-302.

Westphal L.M. 2003. Urban greening and social benefits: a study of empowerment. Journal of Arboriculture 29: 137-147.

Westphal L.M. and G. Childs. 1994. Overcoming obstacles creating volunteer partnerships. Journal of Arboriculture 92: 28-32.

Weston, P. A. and R. W. Harper. 2009. Potential of *Tsuga* spp. from western North America and Asia as replacements for eastern hemlock (*Tsuga canadensis*). Arboriculture & Urban Forestry 35: 5-9.

Wolfe, K. 2003. Freeway roadside management: The urban forest beyond the white line. Journal of Arboriculture 29: 127-136.

Yamasaki, M., R.M. DeGraaf, and J.W. Lanier. 2000. Wildlife habitat associations in eastern hemlock — birds, smaller mammals, and forest carnivores. *In* Proceedings of the symposium on sustainable management of hemlock ecosystems in eastern North America. USDA Forest Service. Durham, NH. Online: http://na.fs.fed.us/fhp/hwa/impacts/wildlife_habitat_associations.pdf Accessed: 27 May 2015.

Young, R.F., K.S. Shields and G.P. Berlyn. 1995. Hemlock woolly adelgid (Homoptera, Adelgidae) – stylet bundle insertion and feeding sites. Annals of the Entomological Society America 88: 827-835.