Cities and the Environment (CATE)

Volume 14 | Issue 1 Article 3

2021

# Exploring the Ecology of Establishing Oak Trees in Urban Settings of the Northeast

Tierney Bocsi
*University of Massachusetts - Amherst*, tbocsi@wisc.edu

Rick W. Harper
*University of Massachusetts - Amherst*, rharper@eco.umass.edu

Paige S. Warren
*University of Massachusetts - Amherst*, pswarren@eco.umass.edu

Stephen DeStefano
*U. S. Geological Survey, Massachusetts Cooperative Fish and Wildlife Research Unit, University of Massachusetts - Amherst*, sdestef@eco.umass.edu



## Recommended Citation

Bocsi, T., R. W. Harper, P. S. Warren, and S. DeStefano. Exploring the ecology of establishing oak trees in urban settings of the Northeast. Cities and the Environment XX: xxx–xxx.

# Exploring the Ecology of Establishing Oak Trees in Urban Settings of the Northeast

Urban forests notoriously lack diversity in the biological communities that inhabit them, from the age and species composition of street trees to wildlife populations. In reaction to invasions of nonnative insects and diseases as well as predicted response to climate change, an emerging number of community foresters and tree wardens are expanding their urban tree planting practices to include a broader assemblage of tree species. These include oaks, among other species able to tolerate and adapt to urban conditions. Oaks are potentially favorable in regions like the northeastern U.S., where they grow extensively in rural forests and demonstrate potential resistance to specific urban pests that have caused challenges for other historically popular and extensively planted street trees. Additionally, they are known to feature a number of wildlife benefits, and their ranges in the Northeast are predicted to expand under many future climate change forecast models. We examine the role of oaks in the urban environment through the lens of the urban forest diversity deficit, reviewing topics that include diversity recommendations, threats by nonnative insects and diseases, and the human-wildlife interface. The goal of this work is to encourage careful consideration of where and when to plant oak trees to help professionals address issues of uniformity, while achieving benefits for urban forest ecosystems and residents.

## Keywords

Diversity, habitat, invasive, pests, oak, urban wildlife

## Acknowledgements

Thank you to Victoria Wallace, Department of Extension, University of Connecticut for a pre-submission review. This work was supported by the USDA National Institute of Food and Agriculture – McIntire Stennis Project #25, Accession #1000762. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

## INTRODUCTION

As human populations continue to grow, so do the urban spaces in which they reside. The United States Census Bureau (2010) reported that nearly 81% of the total U.S. population lives within urban areas. In the conterminous U.S., urban areas increased from 2.5% (19.5 million ha) of U.S. land area in 1990 to 3.1% (24.0 million ha) in 2000. If the growth pattern observed from 1990 to 2000 continues, urban land will occupy approximately 8.1% of U.S. land area by the year 2050. It is estimated that tree cover comprises only 35% of these urban spaces (Nowak et al. 2013). In addition to limiting the size and continuity of natural ecosystems, urban development also homogenizes the landscape, creating an environment with lower biodiversity (Chase and Walsh 2006; Elmqvist et al. 2016; Marzluff 2001; McDonald et al. 2016; Shochat et al. 2010). Various authors suggest that the transformation of Earth's landscape through urbanization leads to unintended consequences, namely invasion and extinction, proposing that these two processes drive the homogenization of Earth's biota (Aronson et al. 2014; Blair 2001; Gaertner et al. 2017; McKinney 2006). Similar drivers may also be perceived in the managed urban forest. In this case, "invasion" is the planting of nonnative ornamentals, and "extinction" is the supplanting of some natives that do not fit conventional ideas of urban landscaping or that may be less likely to succeed in harsh urban environments.

Largely due to degraded growing environments that are inhospitable to many species, urban forests are often lacking in tree diversity, especially along streetscapes. While street trees constitute only a fraction of a typical community's canopy cover, they represent the frontline to urban forests and are highly regarded for their public form and function (Dover and Massengale 2014; Eisenman 2016; Fernandes et al. 2019; Laurian 2019; Mouzon 2016; Seamans 2013). Data from both Maryland and Massachusetts illustrate the dearth of diversity among street tree populations in urban environments (Cumming et al. 2006). Maples (*Acer* spp.) are the most common trees found along urban roadways, comprising upward of 38% and 49% of street trees in Maryland and Massachusetts, respectively. When oak (*Quercus* spp.) populations are also included, these two genera account for nearly two out of every three (64%) street trees in Massachusetts. Norway maple (*Acer platanoides* L.) alone comprises 34% of the street tree species in the state (Cumming et al. 2006). More recent research reflects similar patterns in other parts of the Northeast, including New Jersey, New York, and Pennsylvania, where maples are also found to be a dominant street tree genus (Cowett and Bassuk 2014; Cowett and Bassuk 2017; Cowett and Bassuk 2020). Cumming et al. (2006) posited that, based on the average size of these maples, the trees were likely planted several decades ago, in response to the effects of the invasive Dutch elm disease (DED, *Ophiostoma novo-ulmi* Brasier) pathogen. Such a response to urban reforestation has the potential to be highly problematic considering further insect or disease outbreak. For example, the Asian longhorned beetle (ALB, *Anoplophora glabripennis* Motschulsky) is regarded as one of the world's 100 worst invasive species (Dodds and Orwig 2011). The genus *Acer* is a primary host for this invasive insect, which is known to detrimentally affect at least six maple species (Cumming et al. 2006). Native to China and Korea, ALB was first detected in the city of Worcester, Massachusetts in 2008 (Dodds and Orwig 2011; Elton et al. 2020). Since then, the near monoculture of maples among Worcester's street trees has precipitated the need to remove more than 35,000 urban trees to prevent further invasion in that location (Quinn 2016).

Exemplified by this vulnerability to pests, monocultural urban ecosystems may experience a reduction in resistance and resilience to environmental change and disturbance. A diversity of species with varying sensitivities to environmental conditions ultimately lends itself to greater stability (Clapp et al. 2014). This is particularly important in urban areas, where climate change is predicted to increase ecosystem risks from heat stress, storms, and extreme precipitation, inland and coastal flooding, landslides, air pollution, drought, water scarcity, sea-level rise, and storm surges (IPCC 2014). Diversity also offers the potential for the generation of more ecological and economic benefits (Hooper et al. 2005). Services offered by ecosystems in urban areas, comprised of street tree populations in part, include air filtration, microclimate regulation, noise reduction, rainwater interception, and recreational and cultural values (Bolund and Hunhammar 1999; Dwyer et al. 1992).

In the northeastern United States, a growing number of urban foresters are becoming increasingly aware of urban forest uniformity (Doroski et al. 2020; Harper et al. 2017). They are initiating management regimes that include intentional diversification of trees planted in urban forests to prevent the loss of community tree populations to a single, devastating pest species (D. Lefcourt, City of Cambridge, personal communication, 2016). In addition to expanding canopy cover as a strategy for climate change mitigation, addressing the urban forest diversity deficit is also recommended and implemented to increase resilience and adaptation (Barron et al. 2019; Brandt et al. 2016; Ordóñez and Duinker 2014). Many urban foresters have placed increased emphasis on adhering to designated maximum percent urban tree compositions (%) aimed at substantially enhancing biodiversity. Santamour (1990) recommends that no more than 10% of a species, 20% of a genus, and 30% of a botanical family comprise an urban forest. Ryan and Bloniarz (2008) and Moll (1989) suggest no more than 10% of any one genus. Ball and Tyo (2016) recommend no more than 5% of any one genus. Generally, most urban foresters suggest a goal of no more than 5% to 15% of a species (Clapp et al. 2014; Cumming et al. 2006). When examining the occurrence of street trees like maples in Massachusetts and Maryland, we see that managers have not historically adhered to diversity recommendations.

In this review, we examine the presence and impact of oaks in the urban environment to evaluate their role as street trees, since they are commonly and increasingly being used in urban greening and diversification efforts. We explore literature that focuses on two of the major implications of planting trees in human-dominated landscapes, with respect to diversity: infestation by invasive insects and nonnative diseases in monoculture ecosystems, and the attraction of wildlife to urban environments. These factors are especially pertinent to oaks, which are valued for their resilience and urban forest benefits (Peper et al. 2007; Searle et al. 2012; Sonti et al. 2019), including their potential to increase biodiversity by providing wildlife habitat and food (Greco and Airola 2018; Wood and Esaian 2020). We consider the status (i.e., percent composition) of oaks in urban forests currently and touch upon how their distributions are expected to respond to future climate scenarios. Lastly, we use this information to provide suggestions for urban forestry professionals (e.g., community foresters and tree wardens) about where and when it may be appropriate to plant oak trees in their communities.

## SOURCES FOR REVIEW AND SYNTHESIS

We searched peer-reviewed literature for information regarding general topics like urban biodiversity, wildlife, and insects and diseases. Four books (DeGraaf and Yamasaki 2001; Martin et al. 1951; McShea and Healy 2002; Tallamy 2009) were essential in gathering specific ecological information for oaks, especially regarding these trees as resources for wildlife. We reviewed other sources, including urban forestry trade journals, magazines, fact sheets, and conference proceedings, for recent data regarding urban forest composition, as well as trends in the field. Informal solicitation of information from urban forestry professionals also contributed to our knowledge of current goals and management practices. City foresters, arborists, tree wardens, and urban forestry faculty from Massachusetts and New York were contacted via e-mail. We asked questions of these authorities regarding planting habits and considerations related to oak trees in the urban environment and in response to invasive pest infestations. We also requested professional opinion on tree selection and performance, specifically regarding oaks, based on their anecdotal experience and street tree inventory data. Of the 14 urban forestry professionals contacted, seven responded. We rendered four of these comments most useful to cite within our work (see personal communications from Lefcourt, Bassuk, and Antonelli).

## OAK TREES AND THEIR BENEFITS TO WILDLIFE

Oak trees offer an abundance of benefits to wildlife. They are an important food source, with acorns rating at the top of the wildlife food list. Although acorns may not be preferred by many species, they are abundantly available, particularly in the winter when other food items are scarce (Martin et al. 1951). The storage of acorns as a future food resource for recovery during the winter months is common in caching species, like squirrels and the acorn woodpecker (*Melanerpes formicivorus*) (Hannon et al. 1987; Wauters et al. 2002). They are also important for bears during hyperphagia in the fall (Noyce and Garshelis 2010). Oaks play a significant role in shrub communities of the interior West, a region with limited food sources (McShea and Healy 2002). In the east, oak trees have become increasingly significant for wildlife with the decline of both American chestnut (*Castanea dentata* (Marsh.) Borkh.) and American beech (*Fagus grandifolia* Ehrh.) (McShea and Healy 2002). Several wildlife species are known to consume acorns, from squirrels and other rodents to waterfowl and deer. Van Dersal (1940) found that upward of 186 species of birds and mammals feed on oaks, while McShea and Healy (2002) assert that the distribution of many species corresponds with or relies on the range of oak trees. Martin et al. (1951) document 96 species known to consume acorns and estimate that acorns comprise anywhere from 5% to 25% of most species' diets.

In addition to acorn production, oak trees support wildlife species by providing cover and nesting sites, as well as supplies for these habitat elements. They host dozens of cavity-nesting bird species, including chickadees, bluebirds, woodpeckers, and owls (Tallamy 2009). In some oak species, young trees retain their dried, dead leaves through winter. This phenomenon, known as marcescence, provides thermal cover and protection from predators. Perhaps one of the most notable yet underrated benefits of oaks is their significance to Lepidopteran species. The genus *Quercus* supports more than 500 species of moths and butterflies, more than any other plant genus (Tallamy and Shropshire 2009). In sustaining Lepidopteran species, oak trees add to the food sources available to birds. Most importantly, oaks in the urban environment present natural opportunities for food and cover. According to DeGraaf and Yamasaki (2001), upward of 193 wildlife species use red oak (*Quercus rubra* L.) habitat in New England alone (Table 1). The authors generated natural history accounts for each species that breeds, winters, or resides in New England and created a species-habitat matrix to document relationships. They used 11 forest cover types that are predominant in New England to describe forest/wildlife habitat associations. Red oak habitat also includes associate species black oak (*Quercus velutina* Lam.), scarlet oak (*Quercus coccinea* Münchh.), and chestnut oak (*Quercus montana* Willd.), as well as hickory (*Carya* spp.) and red maple (*Acer rubrum* L.). Of the 193 terrestrial vertebrates known to use red oak habitat, 23 prefer these stands over other cover types (Table 1). While planting more oaks in an urban setting would not provide the same degree of habit suitability available in natural forest systems, there is an opportunity to support variable taxa with tree species that are highly impactful for wildlife. Single street trees are less likely to achieve the high levels of biodiversity that natural systems support, but they may serve as corridors between urban parks, which could generate many of the same benefits (Angold et al. 2006; Fernández-Juricic 2000, Mahan and O’Connell 2005, Nielsen et al. 2014, Wood and Esaian 2020).

**Table 1.** Taxa (number of species) that utilize *Q. rubra* habitat in New England. GU = general use; PB = preferred breeding habitat; PNB = preferred nonbreeding habitat. (Adapted from DeGraaf and Yamasaki 2001.)

| | **Total** | **GU** | **PB** | **PNB** | **PB & PNB** |
|---|---|---|---|---|---|
| **Amphibians** | 15 | 13 | 2 | 0 | 0 |
| **Reptiles** | 16 | 15 | 1 | 0 | 0 |
| **Birds** | 114 | 101 | 12 | 3 | 2 |
| **Mammals** | 48 | 41 | 6 | 6 | 5 |

## OAK TREES AND HUMAN-WILDLIFE INTERACTIONS

A variety of ecological effects may result from increasing the presence of oak trees in the urban environment, particularly regarding wildlife. Many wildlife species rely heavily on oaks for food and cover in rural forests (DeGraaf and Yamasaki 2001; Martin et al. 1951; Tallamy and Shropshire 2009; Tietje et al. 2005), but this is also true for wildlife in urban areas (Clatterbuck and Harper 1999; Conniff 2014: Longcore and Rich 2003). For example, caching species like jays and squirrels, which depend on acorn production and directly influence oak dispersal (Logan 2005; McShea and Healy 2002), can become prolific in the built environment as urban adapters (Bateman and Fleming 2014; Engels and Sexton 1994; Minor and Urban 2010). Since many Lepidopteran species require oak hosts, pollination and pollinator biodiversity as well as conservation can benefit from increased presence of trees within this genus (Hall et al. 2017; Hausmann et al. 2015; Somme et al. 2016). Residents may also benefit from access to nature and increased biodiversity in the built landscape (McKinney et al. 2018; Southon et al. 2017; Southon et al. 2018). Surveys indicate urban residents enjoy and value wildlife, especially birds

(Belaire 2015; Clergeau et al. 2001; Kretser et al. 2009; Shaw et al. 1985). Research has further demonstrated that residents are specifically interested in attracting wildlife to their backyards and that they gain personal satisfaction from feeding wildlife (Gilbert 1982; Horvath and Roelans 1999; Ishigame and Baxter 2007; Jones 2011).

Despite the many wildlife-related benefits offered by oak trees, it is important to consider their potential disadvantages, especially from the human dimension standpoint. There are certainly costs that may be perceived concerning urban wildlife. Negative perceptions of urban wildlife are often attributed to species for their numbers or for potential threats that they pose to people and property. Generally, these include damage to plants and structures, droppings, threats to pets, annoyance to humans, animal bites, and transmission of disease (DeStefano and DeGraaf 2003; Nowak and Dwyer 2000). Thus, public attitudes are largely influenced by the types of contact and experiences residents have with urban wildlife (Conover 1997). Urban wildlife that are frequently dubbed problematic include small and large mammals (Clark 1994; Kilpatrick and Walter 1997), especially carnivores (Beckmann et al. 2004; Timm and Baker 2007). Where these species create conflict, measures to avoid, deter, or even remove them are often instituted (Hadidian 2015).

The concept of "wildlife acceptance capacity" (WAC) factors heavily into human perceptions of wildlife. Decker and Purdy (1988) defined WAC as the maximum wildlife population level in an area that is acceptable to people. There can be significant variation in WAC among different individuals or stakeholder groups, and tolerance may change through time (Goodale et al. 2015; Organ and Ellingwood 2000). WAC is strongly influenced by how people perceive risks associated with wildlife, such as threats to health and safety (Decker et al. 2002).

Increasing oak trees in the urban environment could potentially exacerbate human-wildlife conflict if doing so contributes to meeting or exceeding the WAC for a species. As previously described, many wildlife species rely on the acorns dropped by oaks as a staple of their diet (Martin et al. 1951). Some of these species, such as deer and small mammals, are considered a nuisance when they occur in high densities. Planting more oaks could increase the abundance of wildlife species that consume acorns, thereby approaching or exceeding the WAC for these species. Similarly, with expanded populations of prey species, there may be opportunity for an increase in predator populations as their food sources become more abundant. For example, coyotes (*Canis latrans* Say), which commonly utilize urban areas (Grinder and Krausman 2001), feed on small mammals, whose distribution would likely be affected by oak trees. More importantly, the coyote is known as a nuisance species, occasionally posing threats to humans and their pets (Bateman and Fleming 2012).

When examining the possible ramifications of oak trees in the urban environment, an important relationship evidently exists between oak mast, small mammals, insect vectors, and Lyme disease, caused by *Borrelia burgdorferi* (Jones, et al. 1998; Ostfeld et al. 1996; Ostfeld et al. 1998). Both the population numbers and behavioral habits of white-footed mice (*Peromyscus leucopus* Rafinesque) and white-tailed deer (*Odocoileus virginianus* Zimmermann) are strongly influenced by acorn production, with mast years yielding increased numbers of both species within oak stands. Mouse densities tend to increase following mast production, while deer respond to mast years by foraging in forests dominated by oaks over other stand types (Clotfelter et al. 2007; McShea and Schwede 1993). Of the species known to host larval deer ticks (*Ixodes scapularis* Say), scientists have concluded that the white-footed mouse is the host most likely to transmit the Lyme disease bacterium (Jones et al. 1998; Kelly et al. 2008; Kremen and Ostfeld 2005). White-tailed deer are notorious for harboring adult deer ticks, which are ungulate specialists (Huang et al. 2019; McShea and Schwede 1993; Ostfeld et al. 1996). Consequently, the location of deer in the fall determines where larval deer ticks, produced by adult deer ticks, occur in the landscape. This causes heavy concentrations of larval ticks in forests dominated by oak trees during mast years, when deer exploit the abundance of acorns. As a result, larval ticks co-occur in time and space with white-footed mice, increasing the likelihood for transmission of Lyme disease (Ostfeld et al. 1998). Complexities to this dynamic relationship are introduced when land use and human behavior are considered. Increasing development and incidents of Lyme disease, especially in the Northeast (Rosenberg et al. 2018), pose risks to human health, with recent research indicating that threats are not restricted to suburban and natural settings (Jobe et al. 2007; VanAcker et al. 2019). These findings suggest that caution should be exhibited in urban green space and residential landscape design (Jackson et al. 2006; VanAcker et al. 2019).

## PLANTING OAK TREES AS A RESPONSE TO INVASIVE INSECTS

Invasive insect pests have the capacity to cause wide-scale disturbance and destruction in natural and urban ecosystems (Dampier et al. 2015, Gandhi and Herms 2010; Heleno et al. 2009; Kenis et al. 2008). Many native tree species abundant in Northeast forests and historically preferred as street trees have experienced significant decline due to nonnative insect invasions. While oaks are not pest-free, there are far fewer accounts of such largescale, dramatic losses to invasive insects compared to other landscape trees. For example, the emerald ash borer (EAB, *Agrilus planipennis* Fairmaire), an introduced pest from Asia, has killed tens of millions of ash trees in rural and urban areas throughout the range of ash tress (*Fraxinus* spp.) in North America (McCullough et al. 2015). In southeastern Michigan, it has caused virtually 100% mortality of ash species (Gandhi et al. 2008). In addition to ecological ramifications, infestations at this scale are also damaging to the economy. Based on stumpage value alone, loss of the ash resource in Michigan is projected to exceed $1.7 billion (Poland and McCullough 2006). EAB is but one of many non-native pests to negatively affect ecosystems and economies in the U.S.

Considered one of the most destructive wood borers to invade the region in recent years, ALB is native to China and Korea (Haack et al. 2010; Hu et al. 2009). The pest was first detected in the U.S. during 1996, where it was introduced to New York City. Most recently, it has been found in central and eastern Massachusetts, namely the city of Worcester (Childs 2016a). Susceptible tree species include – but are not limited to – maple, horse chestnut (*Aesculus* spp.), birch (*Betula* spp.), ash, poplar (*Populus* spp.), willow (*Salix* spp.), and elm (*Ulmus* spp.). ALB infests healthy host plants and proceeds to actively feed and move throughout the tree via extensive larval tunneling. In as little as one or two years, repeated attacks in the vascular tissue and structural weakness can lead to host death (Childs 2016a; Haack et al. 2010); however, plants may live substantially longer. Specifically, the beetle targets sugar maple (*Acer saccharum* Marsh.), red maple, and Norway maple. This is particularly problematic in a region like New England, where both sugar maple and red maple are prominent hardwood species, and where Norway maple was extensively planted in urban settings, not only in response to the devastating effects associated with DED, but also for its structural resistance to failure under intense weather events (Elton et al. 2020; Shatz et al. 2013).

While oaks appear to be plausible alternatives to planting more maples, since they are potentially unsuitable hosts for ALB (Raupp et al. 2006), the genus is not immune to infestation from invasive insects. Following accidental introduction to Massachusetts in the 1860s, the gypsy moth (*Lymantria dispar* L.) has spread throughout the Northeast, where it causes considerable damage to numerous tree species, but especially oak stands in New England (Childs 2016b; Gandhi and Herms 2010). Gypsy moth defoliation has both direct and indirect, as well as short- and long-term, implications for oak communities. In addition to tree decline and mortality, wide scale defoliation can cause changes in light, temperature, and moisture regimes, along with the alteration of nutrient cycles (Gandhi and Herms 2010). Other ecological consequences include stand patchiness, sporadic masting, and modifications in successional patterns and watershed characteristics. Impacts such as these have the potential to consequently affect wildlife distribution patterns (Foss and Rieske 2003). Stress from gypsy moth defoliation also impacts acorn production, resulting in the decrease or elimination of this important wildlife food source (Gandhi and Herms 2010). In addition to ravaging Northeast forests, high numbers of gypsy moth are even more problematic in urban settings, where urticating hairs and frass production cause human health concerns (Foss and Rieske 2003).

The likelihood of gypsy moth outbreaks depends to some extent on oak mast. Mast years occur every 2 to 5 years, resulting in large acorn crops. Acorns are a dominant dietary component for white-footed mice, which are important predators of gypsy moth pupae. In years between oak mast, mouse densities are reduced, yielding increased numbers of gypsy moth and initiating potential for outbreaks of this invasive pest (Jones et al. 1998). Some research and anecdotal evidence indicate that gypsy moth caterpillars prefer white oak (*Quercus alba* L.) over other species of the genus, with variation in results and location (Foss and Rieske 2003; Kauffman and Clatterbuck 2006; Lance 1983; Santamour 1990). It is likely that a combination of foliar characteristics influences oak susceptibility to infestation (Foss and Rieske 2003).

## PLANTING OAK TREES AS A RESPONSE TO INVASIVE PATHOGENS

In addition to insects of importance, tree populations may also succumb to invasive pathogens, which can have similarly detrimental effects (Loo 2008; Lovett et al. 2006). This is especially true in the urban environment, where low levels of diversity in the urban forest limit resiliency to the spread of insects and disease. A classic example of this involves the renowned American elm (*Ulmus americana* L.). Dutch elm disease, which was introduced from Europe on shipments of unpeeled veneer logs, is regarded as one of the most devastating shade tree diseases in the U.S. The fungal pathogen that causes DED is transported by elm bark beetles and transmitted by root grafts, resulting in tree wilting, as well as yellowing and browning of leaves. Following infection, these symptoms continue throughout the tree's crown, resulting in eventual host-plant death (Brazee 2017; Swingle et al. 1949). Dutch elm disease was first detected in 1930 and spread nationwide by 1977, decimating populations of elm, a fast-growing, stress-tolerant hardwood species that once prolifically lined streets, parks, and landscapes throughout North American communities (Schlarbaum et al. 1998).

Similarly, chestnut blight, caused by *Cryphonectria parasitica* (Murrill) Barr, is a fungal disease that pervaded eastern hardwood forests at a rate of 24 miles per year (Schlarbaum et al. 1998). Cankers from the disease were sighted in New York City in 1904 (Anagnostakis 2001).

First detected on shade trees, chestnut blight contaminated nearly all adult chestnut trees by the 1950s (Anagnostakis 1987; Schlarbaum et al. 1998). Like the elms, the chestnut fell from its former status as a major component of eastern hardwood forests in the U.S. Consequently, wildlife species were dramatically impacted with the loss of this significant mast crop, placing more reliance on other food sources, like acorns. While oak trees in the Northeast are essentially unaffected by DED and chestnut blight, the risk of infection from other pathogens of importance remains.

Oak wilt, caused by the fungus *Ceratocystis fagacearum* (Bretz) Hunt, is a serious pathogen relative to oaks. First discovered in Wisconsin during 1942, it has since caused the dramatic and rapid death of red oak throughout parts of the mid-west and in many western states. In Wisconsin (Juzwik et al. 2008), localized areas of the state have experienced loss of more than 50% of oak populations (Rexrode and Brown 1983) due to the presence of this pathogen. In the Northeast, oak wilt threatens oak trees constituting the oak-hickory forest types (Juzwik et al. 2008). Infection is indicated by sudden wilting and death of host tree foliage and may sometimes manifest as fungal mats that form below the bark. The disease is most prominently dispersed through root grafts but may be vectored by insects, namely sap-feeding beetles (Family *Nitidulidae*) and bark beetles (Family *Curculionidae*) that carry fungal spores to new hosts (EPPO 2001; Rexrode and Brown 1983).

The origin of oak wilt is unknown, though it is suspected that native populations of the pathogen may be found in Mexico, Central America, and northern South America (Juzwik et al. 2008). In the U.S., oak wilt ranges from the mid-west, south to Texas, and east to Pennsylvania, with localized detections in New York (Munck 2017). Red oak (*Erythrobalanus*) species can succumb within weeks of infection and are more susceptible than white oak (*Leucobalanus*) species, which may take several years to experience mortality (Juzwik et al. 2008; Munck 2017; Santamour 1990). Though oak wilt is likely a greater threat to rural forests outside of the region, potential range expansion of oak wilt, along with differences in oak species resistance, have direct implications for urban forests in the Northeast. With pest and disease outbreaks potentially on the horizon, careful thought to the selection of less-susceptible oaks planted with consideration for street tree diversity can help to maintain an urban forest that is more robust to invasion.

## CLIMATE CHANGE

Along with resistance to specific urban pests, oak trees in the Northeast are anticipated to fair well under future climate change forecast models, where forest range types shift increasingly northward (Bradley and Harper 2014; Iverson et al. 2008a). As global temperatures continue to rise, oaks adapted to more southerly climates could exhibit tolerance and even expansion under warmer conditions. A comparison of climate change scenarios and resulting suitable habitat indicated that the oak-hickory forest type is expected to expand north, especially under higher emissions scenarios. Coniferous forests of the Northeast and the maple-birch-beech (*Fagus* spp.) forest type, in contrast, are predicted to contract (Iverson et al. 2008b).

Planting southerly oak species in specific locales of the Northeast could assist the migration of species northward (Williams and Dumroese 2013), giving them a head start in anticipation of shifting weather patterns and an extended growing season. This seems to be on the radar for some urban forestry professionals. In the city of Cambridge, Massachusetts, more trees from the Mid-Atlantic area, especially oaks, are being selected and installed due to the current and future impacts of climate change. The hope is that these trees are more resilient to drought conditions experienced during the summer months but can survive through harsh winter conditions as well (D. Lefcourt, City of Cambridge, personal communication, 2021). It is important to note that insect and pathogen pressure is likely to increase with climatic warming (Iverson et al. 2008b; Vose et al. 2012, Yang 2009), though it is unknown to what extent oaks will be affected as southern species move north.

## CONCLUSIONS

In the context of diversity, invasion susceptibility, and wildlife in urban environments, oak trees have the potential to improve the urban forest. Urban forests infamously lack biodiversity, especially regarding street tree genera, where near monocultures threaten the health and resilience of urban tree populations plagued by diversity deficits (Galvin 1999). While some city departments and foresters still strive to find what Bassuk (1990) refers to as the ‘perfect urban tree,’ many urban foresters have started to recognize the importance of increasing the diversity of the trees that they select for planting (Raupp et al. 2006). One of the main drivers behind this recent management strategy shift in the northeastern U.S. has been in relation to the catastrophic loss of trees from exotic insect and disease infestations, including ALB, EAB and DED. Oak trees are not known hosts to these high-profile insect or disease pests, making them especially favored candidates for urban tree planting efforts (Haack et al. 1997; N. Bassuk, Cornell University, personal communication, 2015; Raupp et al. 2006).

While increasing oak trees may appear advantageous in some scenarios, there are drawbacks to consider. We have indicated that augmentation of oaks in the urban environment may become less desirable if wildlife populations demonstrably increase and exceed acceptable citizen thresholds. Acorns can also cause oaks to be viewed negatively in situations where they cause direct discomfort to urban residents. During mast years, mature oak trees are notoriously associated with a “messiness” caused by heavy acorn production, where sidewalk conditions have been compared to walking on ball bearings. The potential for increased prevalence of zoonotic diseases and susceptibility to gypsy moth infestation, as well as the threat of infestation from the lethal oak wilt pathogen, are also important factors to consider. With these possible ramifications in mind, we might be wary of creating another monoculture situation if aiming to improve diversity with species from this genus. For example, though not evenly distributed statewide, an average of 15% of Massachusetts street trees are comprised of oaks (Cumming et al. 2006). Furthermore, we see that oaks represent 22% of trees replanted in response to ALB invasion in the city of Worcester (R. C. Antonelli, City of Worcester, personal communication, 2016).

Based on the details of our synthesis, we suggest that planting oak trees will have the greatest positive impact in specific communities where the genus is not overly-represented (i.e., does not already exceed 10%–20%) in the local street tree population. Expansion of oak populations in urban forests might be considered carefully, and perhaps avoided, in communities where there are concerns for infestation by gypsy moth, oak wilt infection, and/or perhaps even the transmission of tickborne disease. Species-specific planting decisions may help to mitigate potential effects of pests and pathogens, as well as wildlife. In anticipation of human-wildlife conflict or negative reactions to acorn abundance in residential areas, oak species that are particularly attractive to wildlife could be planted along the outskirts of urban centers or carefully incorporated into urban parks. This may help mitigate some of the issues surrounding oak mast. Residents may be notified that, during mast years, there will likely be increased abundance of mammals and possibly tickborne diseases. During intervening years, when acorn production is minimal, threats to invasion by gypsy moth might be expected. Finally, the use of oak trees in efforts to promote urban forest diversity offers the potential for increasing urban forest resilience as climate change progresses. It is ever important to reiterate the urban forestry mantra “right tree, right place” when considering which species to plant, as suitability, adaptability, and potential liabilities exist with each management decision.

## LITERATURE CITED

Anagnostakis, S. L. 1987. Chestnut blight: the classical problem of an introduced pathogen. Mycologia 79: 23–37.

Anagnostakis, S. L. 2001. The effect of multiple importations of pests and pathogens on a native tree. Biological Invasions 3: 245–254.

Angold, P. G., J. P. Sadler, M. O. Hill, A. Pullin, S. Rushton, K. Austin, E. Small, B. Wood, R. Wadsworth, R. Sanderson, and K. Thompson. 2006. Biodiversity in urban habitat patches. Science of the Total Environment 360: 196–204.

Aronson, M. F. J., F. A. La Sorte, C. H. Nilon, M. Katti, M. A. Goddard, C. A. Lepczyk, P. S. Warren, N. S. G. Williams, S. Cilliers, B. Clarkson, C. Dobbs, R. Dolan, M. Hedblom, S. Klotz, J. L. Kooijmans, I. Kühn, I. MacGregor-Fors, M. McDonnell, U. Mörtberg, P. Pyšek, S. Siebert, J. Sushinsky, P. Werner, and M. Winter. 2014. A global analysis of the impacts of urbanization on bird and plant diversity reveals key anthropogenic drivers. Proceedings of the Royal Society B 281: 20133330.

Ball, J., and S. Tyo. 2016. Diversity of the urban forest: We need more genera, not species. Arborist News 25: 48–53.

Barron, S., S. Nitoslawski, K. L. Wolf, A. Woo, E. Desautels, and S. R. J. Sheppard. 2019. Greening blocks: A conceptual typology of practical design interventions to integrate health and climate resilience co-benefits. International journal of Environmental Research and Public Health 16: 4241.

Bassuk, N. L. 1990. Street tree diversity making better choices for the urban landscape. In: Proceedings of the 7th Conference of the Metropolitan Tree Improvement Alliance (METRIA), The Morton Arboretum, Lisle, IL, 8-10 Apr 1997. METRIA: 71–78.

Bateman, P. W., and P. A. Fleming. 2012. Big city life: carnivores in urban environments. Journal of Zoology 287: 1–23.

Bateman, P. W., and P. A. Fleming. 2014. Does human pedestrian behaviour influence risk assessment in a successful mammal urban adapter? Journal of Zooling 294: 93–98.

Beckmann, J. P., C. W. Lackey, and J. Berger. 2004. Evaluation of deterrent techniques and dogs to alter behavior of "nuisance" black bears. Wildlife Society Bulletin 32: 1141–1146.

Belaire, J. A., L. M. Westphal, C. J. Whelan, and E. S. Minor. 2015. Urban residents' perceptions of birds in the neighborhood: biodiversity, cultural ecosystem services, and disservices. The Condor 117: 192–202.

Blair, R. B. 2001. Birds and butterflies along urban gradients in two ecoregions of the U.S. Pages 33–56 in: Lockwood, J. L., and M. L. McKinney (Eds.), Biotic homogenization. New York, NY: Kluwer Academia/Plenum Publishers.

Bolund, P., and S. Hunhammar. 1999. Ecosystem services in urban areas. Ecological Economics 29: 291–301.

Bradley, B., and R. W. Harper. 2014. Can community forests in the Northeastern U.S. keep pace with a changing climate? Arborist News 23: 44–47.

Brandt, L., A. D. Lewis, R. Fahey, L. Scott, L. Darling, and C. Swanston. 2016. A framework for adapting urban forests to climate change. Environmental Science and Policy 66: 393–402.

Brazee, N. 2017. Fact sheets: Dutch elm disease. Center for Agriculture, Food and the Environment, University of Massachusetts Amherst. Retrieved from https://ag.umass.edu/landscape/fact-sheets/dutch-elm-disease. Accessed Nov 2018.

Chase, J. F., and J. J. Walsh. 2006. Urban effects on native avifauna: a review. Landscape and Urban Planning 74: 46–69.

Childs, R. 2016a. Fact sheet: Asian longhorned beetle. Center for Agriculture, Food and the Environment, University of Massachusetts Amherst. Retrieved from https://ag.umass.edu/landscape/fact-sheets/asian-longhorned-beetle. Accessed Nov 2018.

Childs, R. 2016b. Fact sheet: Gypsy moth. Center for Agriculture, Food and the Environment, University of Massachusetts Amherst. Retrieved from https://ag.umass.edu/landscape/fact-sheets/gypsy-moth. Accessed Nov 2018.

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

Clark, K. D. 1994. Managing raccoons, skunks, and opossums in urban settings. In: Halverson, W. S., and A. C. Crabb (Eds.), Proceedings of the 16th Vertebrate Pest Conference, The Westin Hotel, Santa Clara, CA, 28 Feb 1994. University of California, Davis: 317–319.

Clatterbuck, W. K., and C. Harper. 1999. Urban trees for wildlife. The University of Tennessee Agricultural Extension Service, R12-4910-17-001-00 SP530-15M-3/99.

Clergeau, P., G. Mennechez, A. Sauvage, and A. Lemoine. 2001. Human perception and appreciation of birds: A motivation for wildlife conservation in urban environments of France. Pages 69–88 in: Marzluff, J. M., R. Bowman, and R. Donnelly (Eds.), Avian ecology and conservation in an urbanizing world. Boston, MA: Springer.

Clotfelter, E. D., A. B. Pedersen, J. A. Cranford, N. Ram, E. A. Snajdr, V. Nolan Jr., and E. D. Ketterson. 2007. Acorn mast drives long-term dynamics of rodent and songbird populations. Oecologia 154: 493–503.

Conniff, R. 2014. Urban nature: how to foster biodiversity in world's cities. Yale Environment 360, Yale School of Forestry and Environmental Studies. Accessed 09 May 2019.

Conover, M. R. 1997. Wildlife management by metropolitan residents in the United States: practices, perceptions, costs, and values. Wildlife Society Bulletin 25: 306–311.

Cowett, F. D., and N. L. Bassuk. 2014. Statewide assessment of street trees in New York State, USA. Urban Forestry and Urban Greening 13: 213–220.

Cowett, F. D., and N. L. Bassuk. 2017. Street tree diversity in three northeastern U.S. states. Arboriculture and Urban Forestry 43:1–14.

Cowett, F. D., and N. L. Bassuk. 2020. Street tree diversity in Massachusetts, U.S.A. Arboriculture and Urban Forestry 46: 27–43.

Cumming, A. B., D. B. Twardus, and W. D. Smith. 2006. National forest health monitoring program: Maryland and Massachusetts street tree monitoring pilot projects. Newtown Square, PA: USDA Forest Service, Northeastern Area State and Private Forestry.

Dampier, J. E. E., R. W. Harper, L. Schwartzberg, and R. H. Lemelin. 2015. A comparison of arborists' and horticulturists' preferences of *Tsuga chinensis* to *T. canadensis* in the urban landscape. Arboriculture and Urban Forestry 41: 41–48.

Decker, D. J., and K. G. Purdy. 1988. Toward a concept of wildlife acceptance capacity in wildlife management. Wildlife Society Bulletin 16: 53–57.

Decker, D. J., T. B. Lauber, and W. F. Siemer. 2002. Human-wildlife conflict management: a practitioner's guide. Ithaca, NY: Northeast Wildlife Damage Management Research and Outreach Cooperative.

DeGraaf, R. M., and M. Yamasaki. 2001. New England wildlife: habitat, natural history, and distribution. Hanover, NH: University Press of New England.

DeStefano, S., and R. M. DeGraaf. 2003. Exploring the ecology of suburban wildlife. Frontiers in Ecology and the Environment 1: 95–101.

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 for Research 41: 1729–1742.

Doroski, D. A., M. S. Ashton, and M. C. Duguid. 2020. The future urban forest – A survey of tree planting programs in the Northeastern United States. Urban Forestry and Urban Greening 55: 126816.

Dover, V., and J. Massengale. 2014. Street design: The secret to great cities and towns. Hoboken, NJ: Wiley.

Dwyer, J. F., E. G. McPherson, H. W. Schroeder, and R. A. Rowntree. 1992. Assessing the benefits and costs of the urban forest. Journal of Arboriculture 18: 227–234.

Eisenman, T.S. 2016. Greening cities in an urbanizing age: The human health bases in the nineteenth and early twenty-first centuries. Change Over Time 6: 216–246.

Elmqvist, T., W. C. Zipperer, and B. Güneralp. 2016. Urbanization, habitat loss, biodiversity decline: solution pathways to break the cycle. Pages 139–151 in: Seta, K., W. D. Solecki, and C. A. Griffith, (Eds.), Routledge handbook of urbanization and global environmental change. New York, NY: Routledge.

Elton, A.J., B.S. Weil and R.W. Harper. 2020. The Worcester tree initiative: A community NGO at the center of reclaiming an urban forest. Arborist News 29(4): 34-37.

Engels, T. M., and C.W. Sexton. 1994. Negative correlation of blue jays and golden-cheeked warblers near an urbanizing area. Conservation Biology, 8(1): 286-290.

European and Mediterranean Plant Protection Organization (EPPO). 2001. Diagnostic protocols for regulated pests: *Ceratocystis fagacearum*. EPPO Bulletin 31: 41–44.

Fernandes, C. O., I. M. da Salva, C. P. Teixeira, and L. Costa. 2019. Between tree lovers and tree haters. Drivers of public perception regarding street trees and its implications on the urban green infrastructure planning. Urban Forestry and Urban Greening 37: 97–108.

Fernández-Juricic, E. 2000. Avifaunal use of wooded streets in an urban landscape. Conservation Biology 14: 513–521.

Foss, L. K., and L. K. Rieske. 2003. Species-specific differences in oak foliage affect preference and performance of gypsy moth caterpillars. Entomologia Experimentalis et Applicata 108: 87–93.

Gaertner, M., J. R. U. Wilson, M. W. Cadotte, J. S. MacIvor, R. D. Zenni, and D. M. Richardson. 2017. Non-native species in urban environments: patterns, processes, impacts and challenges. Biological Invasions 19: 3461–3469.

Galvin, M. F. 1999. A methodology for assessing and managing biodiversity in street tree populations: a case study. Journal of Arboriculture 25: 124–128.

Gandhi, K. J. K., and D. A. Herms. 2010. Direct and indirect effects of alien insect herbivores on ecological processes and interactions in forests of eastern North America. Biological Invasions 12: 389–405.

Gandhi, K. J. K., A. Smith, R. P. Long, R. A. J. Taylor, and D. A. Herms. 2008. Three-year progression of emerald ash borer-induced decline and mortality in southeastern Michigan. In: Mastro, V., D. Lance, R. Reardon, and G. Parra (Eds.) Emerald ash borer research and development meeting, Pittsburgh, PA, 23–24 Oct 2007. USDA Forest Health Technology Enterprise Team, Morgantown, WV, FHTET-2008-07: 27.

Gilbert, F. F. 1982. Public attitudes toward urban wildlife: a pilot study in Guelph, Ontario. Wildlife Society Bulletin 10: 245–253.

Goodale, K., G. J. Parsons, and K. Sherren. 2015. The nature of the nuisance—damage or threat—determines how perceived monetary costs and cultural benefits influence farmer tolerance of wildlife. Diversity 7: 318–341.

Greco, S. E., and D. A. Airola. 2018. The importance of native valley oaks (*Quercus lobata*) as stopover habitat for migratory songbirds in urban Sacramento, California, USA. Urban Forestry and Urban Greening 29: 303–311.

Grinder, M. I., and P. R. Krausman. 2001. Home range, habitat use, and nocturnal activity of coyotes in an urban environment. Journal of Wildlife Management 65: 887–898.

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.

Haack, R. A., K. R. Law, V. C. Mastro, H. S. Ossenbruggen, and B. J. Raimo. 1997. New York's battle with the Asian long-horned beetle. Journal of Forestry 95: 11–15.

Hadidian, J. 2015. Wildlife in U.S. cities: managing unwanted animals. Animals 5: 1092–1113.

Hall, D. M., G. R. Camilo, R. K. Tonietto, J. Ollerton, K. Ahrné, M. Arduser, J. S. Ascher, K. C. R. Baldock, R. Fowler, G. Frankie, D. Goulson, B. Gunnarsson, M. E. Hanley, J. I. Jackson, G. Langellotto, D. Lowenstein, E. S. Minor, S. M. Philpott, S. G. Potts, M. H. Sirohi, E. M. Spevak, G. N. Stone, and C. G. Threlfall. 2017. The city as a refuge for insect pollinators. Conservation Biology 31: 24–29.

Hannon, S. J., R. L. Mumme, W. D. Koenig, S. Spon, and F. A. Pitelka. 1987. Poor acorn crop, dominance, and decline in numbers of acorn woodpeckers. Journal of Animal Ecology 56: 197–207.

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 41: 1–19.

Hausmann, S. L., J. S. Petermann, and J. Rolff. 2015. Wild bees as pollinators of city trees. Insect Conservation and Diversity 9: 97–107.

Heleno, R. H., R. S. Ceia, J. A. Ramos, and J. Memmott. 2009. Effects of alien plants on insect abundance and biomass: a food-wed approach. Conservation Biology 23: 410–419.

Hooper, D. U., F. S. Chapin, J. J. Ewel, A. Hector, P. Inchausti, S. Lavorel, J. H. Lawton, D. M. Lodge, M. Loreau, S. Naeem, B. Schmid, H. Setälä, A. J. Symstad, J. Vandermeer, and D. A. Wardle. 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecological Monographs 75: 3–35.

Horvath, T., and A. M. Roelans. 1999. Backyard feeders: not entirely for the birds. Anthrozoös 4: 232–236.

Hu, J., S. Angeli, S. Schuetz, Y. Luo, and A. E. Hajek. 2009. Ecology and management of exotic and endemic Asian longhorned beetle *Anoplophora glabripennis*. Agricultural and Forest Entomology 11: 359–375.

Huang, C., S. C. Kay, S, Davis, D. M. Tufts, K. Gaffett, B. Tefft, and M. A. Diuk-Wasser. 2019. High burdens of *Ixodes scapularis* larval ticks on white-tailed deer may limit Lyme disease risk in a low biodiversity setting. Ticks and Tick-borne Diseases 10: 258–268.

International Panel on Climate Change (IPCC). 2014. Climate Change 2014: Synthesis Report. Retrieved from http://www.ipcc.ch/report/ar5/syr/. Accessed Nov 2018.

Ishigame, G., and G. S. Baxter. 2007. Practice and attitudes of suburban and rural dwellers to feeding wild birds in Southeast Queensland, Australia. Ornithological Science 6: 11–19.

Iverson, L. R., A. M. Prasad, and S. N. Matthews. 2008a. Modeling potential climate change impacts on the trees of the northeastern United States. Mitigation and Adaptation Strategies for Global Change 13: 487–516.

Iverson, L. R., A. M. Prasad, S. N. Matthews, and M. Peters. 2008b. Estimating potential habitat for 134 eastern US tree species under six climate scenarios. Forest Ecology and Management 254: 390–406.

Jackson, L. E., E. D. Hilborn, and J. C. Thomas. 2006. Towards landscape design guidelines for reducing Lyme disease risk. International Journal of Epidemiology 35: 315–322.

Jobe, D. A., J. A. Nelson, M. D. Adam, and S. A. Martin, Jr. 2007. Lyme disease in urban areas, Chicago. Emerging Infectious Diseases 13: 1799–1800.

Jones, C. G., R. S. Ostfeld, M. P. Richard, E. M. Schauber, and J. O. Wolff. 1998. Chain reactions linking acorns to gypsy moth outbreaks and Lyme disease risk. Science 279: 1023–1026.

Jones, D. 2011. An appetite for connection: why we need to understand the effect and value of feeding wild birds. Emu 111: 1–7.

Juzwik, J., T. C. Harrington, W. L. MacDonald, and D. N. Appel. 2008. The origin of *Ceratocystis fagacearum*, the oak wilt fungus. Annual Review of Phytopathology 46: 13–26.

Kauffman, B. W., and W. K. Clatterbuck. 2006. Forest management strategies to minimize the impact of gypsy moth. The University of Tennessee Agricultural Extension Service, R12-4910-026-004-06 SP678-1.5M-6/06 06-0331.

Kenis, M., M. Auger-Rozenberg, A. Roques, L. Timms, C. Péré, M. J. M. Cock, J. Settele, S. Augustin, and C. Lopez-Vaamonde. 2008. Ecological effects of invasive alien insects. Biological Invasions 11: 21–45.

Kelly, D., W. D. Koenig, and A. M. Liebhold. 2008. An intercontinental comparison of the dynamic behavior of mast seeding communities. Population Ecology 50: 329–342.

Kilpatrick, H. J., and W. D. Walter. 1997. Urban deer management: a community vote. Wildlife Society Bulletin 25: 388–391.

Kremen, C., and R. S. Ostfeld. 2005. A call to ecologists: measuring, analyzing, and managing ecosystem services. Frontiers in Ecology and the Environment 3: 540–548.

Kretser, H. E., P. D. Curtis, J. D. Francis, R. J. Pendall, and B. A. Knuth. 2009. Factors affecting perceptions of human-wildlife interactions in residential areas of northern New York and implications for conservation. Human Dimensions of Wildlife 14: 102–118.

Lance, D. R. 1983. Pages 201–224 in: Ahmad, S (Ed.), Herbivorous insects: host-seeking behavior and mechanisms. Ney York, NY: Academic Press.

Laurian, L. 2019. Planning for street trees and human–nature relations: Lessons from 600 years of street tree planting in Paris. Journal of Planning History 18: 282–310.

Logan, W.B. 2005. Oak: The frame of civilization. New York, NY: W.W. Norton and Company.

Longcore, T., and C. Rich. 2003. Urban oaks and urban oak woodlands. Oaks: 7.

Loo, J. A. 2008. Ecological impacts of non-indigenous invasive fungi as forest pathogens. Pages 81–96 in: Langor, D. W., and J. Sweeney (Eds.), Ecological impacts of non-native invertebrates and fungi on terrestrial ecosystems. Dordrecht, Netherlands: Springer.

Lovett, G. M., C. D. Canham, M. A. Arthur, K. C. Weathers, and R. D. Fitzhugh. 2006. Forest ecosystem responses to exotic pests and pathogens in eastern North America. Bioscience 56: 395–405.

Mahan, C. G., and T. J. O'Connell. 2005. Small mammal use of suburban and urban parks in central Pennsylvania. Northeastern Naturalist 12: 307–314.

Martin, A. C., H. S. Zim, and A. L. Nelson. 1951. American wildlife and plants: a guide to wildlife food habits. New York, NY: Dover Publications, Inc.

Marzluff, J. M. 2001. Worldwide urbanization and its effects on birds. Pages 19–47 in: Marzluff, J. M., R. Bowman, and R. Donnelly (Eds.), Avian ecology and conservation in an urbanizing world. Boston, MA: Springer.

McCullough, D. G., N. F. Schneeberger, S. A. Katovich, and N. W. Siegert. 2015. Pest alert: Emerald ash borer. USDA Forest Service, Northeastern Area State and Private Forestry. Retrieved from https://www.fs.usda.gov/naspf/publications/pest-alert-emerald-ash-borer-na-pr-02-04. Accessed Nov 2018.

McDonald, R. I., P. J. Marcotullio, and B. Güneralp. 2013. Urbanization and global trends in biodiversity and ecosystem services. Pages 31–52 in: Elmqvist, T. M. Fragkias, J. Goodness, B. Güneralp, P. J. Marcotullio, R. I. McDonald, S. Parnell, M. Schewenius, M. Sendstad, K. C. Seto, and C. Wilkinson (Eds.), Urbanization, biodiversity and ecosystem services: challenges and opportunities. Dordrecht, Netherlands: Springer.

McDonald, T., G.D. Gann, J. Jonson, and K. W. Dixon. 2016. International standards for the practice of ecological restoration–including principles and key concepts. Society for Ecological Restoration: Washington, DC, USA. Soil-Tec, Inc.,© Marcel Huijser, Bethanie Walder.

McKinney, M. L. 2006. Urbanization as a major cause of biotic homogenization. Biological Conservation 127: 247–260.

McKinney, M.L., I. Kowarik, and D. Kendal. 2018. The contribution of wild urban ecosystems to liveable cities. Urban Forestry and Urban Greening 29: 334–335.

McShea, W. J., and G. Schwede. 1993. Variable acorn crops: responses of white-tailed deer and other mast consumers. Journal of Mammalogy 74: 999–1006.

McShea, W. J., and W.M. Healy. (Eds.) 2002. Oak forest ecosystems: ecology and management for wildlife. Baltimore, MD: The Johns Hopkins University Press.

Minor, E., and D. Urban. 2010. Forest bird communities across a gradient of urban development. Urban Ecosystems 13: 51–71.

Moll, G. 1989. Improving the health of the urban forest. Pages 119–130 in: Moll, G., and S. Ebenreck (Eds.), Shading our cities: a resource guide for urban and community forests. Washington, DC: Island Press.

Mouzon, S. 2016. Street trees are essential for walk appeal. Public Square. Retrieved from https://www.cnu.org/publicsquare/2016/12/19/street-trees-are-essential-walk-appeal. Accessed Oct 2020.

Munck, I. 2017. Pest alert: Oak wilt in the northeastern United States. USDA Forest Service, Northeastern Area State and Private Forestry. Retrieved from https://www.fs.usda.gov/naspf/publications/pest-alert-oak-wilt-northeastern-united-states-na-pr-02-17. Accessed Nov 2018.

Nielsen, A. B., M. van den Bosch, S. Maruthaveeran, and C. K. van den Bosch. 2014. Species richness in urban parks and its drivers: A review of empirical evidence. Urban Ecosystems 17: 305–327.

Nowak, D. J., and J. F. Dwyer. 2000. Understanding the benefits and costs of urban forest ecosystems. Pages 11–25 in: Kuser, J. (Ed.), Urban and community forestry in the northeast. New York, NY: Kluwer Academia/Plenum Publishers.

Nowak, D. J., E. J. Greenfield, R. E. Hoehn, and E. Lapoint. 2013. Carbon storage and sequestration by trees in urban and community areas of the United States. Environmental Pollution 178: 229–213.

Noyce, K. V., and D. L. Garshelis. 2010. Seasonal migrations of black bears (*Ursus americanus*): causes and consequences. Behavioral Ecology and Sociobiology 65: 823–835.

Ordóñez, C., and P. N. Duinker. 2014. Assessing the vulnerability of urban forests to climate change. Environmental Reviews 22: 311–321.

Organ, J. F., and M. R. Ellingwood. 2000. Wildlife stakeholder acceptance capacity for black bears, beavers, and other beasts in the East. Human Dimensions of Wildlife 5: 63–75.

Ostfeld, R. S., F. Keesing, C. G. Jones, C. D. Canham, and G. M. Lovett. 1998. Integrative ecology and the dynamics of species in oak forests. Integrative Biology 1: 178–186.

Ostfeld, R. S., C. G. Jones, and J. O. Wolff. 1996. Of mice and mast: ecological connections in eastern deciduous forests. BioScience 46: 323–330.

Peper, P. J., E. G. McPherson, J. R. Simpson, S. L. Gardner, K. E. Vargas, and Q. Xiao. 2007. New York City, New York Municipal Forest Resource Analysis. USDA Forest Service, Pacific Southwest Research Station, Center for Urban Forest Research. Retrieved from https://www.fs.usda.gov/treesearch/pubs/45969. Accessed Oct 2020.

Poland, T. M., and D. G. McCullough. 2006. Emerald ash borer: invasion of the urban forest and the threat to North America's ash resource. Journal of Forestry (April/May) 2006: 118–124.

Quinn, T. 2016. Asian longhorned beetle still in Worcester. Worcester Magazine. Retrieved from https://worcestermag.com/2016/04/07/asian-longhorned-beetle-still-worcester/41738. Accessed Nov 2018.

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 and Urban Forestry 32: 297–304.

Rexrode, C. O., and D. Brown. 1983. Forest insect and disease leaflet 29: Oak wilt. USDA Forest Service. Retrieved from https://www.fs.fed.us/foresthealth/publications/fidls/index.shtml. Accessed Nov 2018.

Rosenberg, R., N. P. Lindsey, M. Fischer, C. J. Gregory, A. F. Hinckley, P. S. Mead, G. Paz-Bailey, S. H. Waterman, N. A. Drexler, G. J. Kersh, H. Hooks, S. K. Partridge, S. N. Visser, C. B. Beard, and L. R. Petersen. 2018. Vital signs: Trends in reported vectorborne disease cases — United States and Territories, 2004–2016. Morbidity and Mortality Weekly Report 67: 496–501.

Ryan, H. D. P., and D. V. Bloniarz. 2008. Selecting street tree species and planting locations. HortNotes 19: 1–3.

Santamour, F. S. 1990. Trees for urban planting: diversity, uniformity, and common sense. In: Proceedings of the 7th Conference of the Metropolitan Tree Improvement Alliance (METRIA), The Morton Arboretum, Lisle, IL, 8-10 Apr 1997. METRIA: 57–65.

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: Britton, K. O. (Ed.), Exotic pests of eastern forests conference proceedings, Nashville, TN, 8-10 Apr 1997. USDA Forest Service and TN Exotic Pest Plant Council: 45–54.

Seamans, G. S. 2013. Mainstreaming the environmental benefits of street trees. Urban Forestry and Urban Greening 12: 2–11.

Searle, S. Y., M. H. Turnbull, N. T. Boelman, W. S. F. Schuster, D. Yakir, and K. L. Griffin. 2012. Urban environment of New York City promotes growth in northern red oak seedlings. Tree Physiology 32: 389–400.

Shatz, A. J., J. Rogan, F. Sangermano, Y. Ogneva-Himmelberger, and H. Chen. 2013. Characterizing the potential distribution of the invasive Asian longhorned beetle (*Anoplophora glabripennis*) in Worcester County, Massachusetts. Applied Geography 45: 259–268.

Shaw, W. W., W. R. Mangun, and J. R. Lyons. 1985. Residential enjoyment of wildlife resources by Americans. Leisure Sciences 7: 361–375.

Shochat, E., S. B. Lerman, J. M. Anderies, P. S. Warren, S. H. Faeth, and C. H. Nilon. 2010. Invasion, competition, and biodiversity loss in urban ecosystems. BioScience 60: 199–208.

Somme, L., L. Moquet, M. Quinet, M. Vanderplanck, D. Michez, G. Lognay, and A. Jacquemart. 2016. Food in a row: urban trees offer valuable floral resources to pollinating insects. Urban Ecosystems 19: 1149–1161.

Sonti, N. F., R. A. Hallett, K. L. Griffin, and J. H. Sullivan. 2019. White oak and red maple tree ring analysis reveals enhanced productivity in urban forest patches. Forest Ecology and Management 453: 117626.

Southon, G. E., A. Jorgensen, N. Dunnett, H. Hoyle, and K. L. Evans. 2017. Biodiverse perennial meadows have aesthetic value and increase residents' perceptions of site quality in urban green-space. Landscape and Urban Planning 158: 105–118.

Southon, G. E., A. Jorgensen, N. Dunnett, H. Hoyle, and K. L. Evans. 2018. Perceived species-richness in urban green spaces: cues, accuracy and well-being impacts. Landscape and Urban Planning 172: 1–10.

Swingle, R. U., R. R. Whitten, and E. G. Brewer. 1949. Dutch elm disease. Pages 451–452 in: Trees, the Yearbook of Agriculture. USDA, U.S. Government Publishing Office, Washington, DC.

Tallamy, D. W. 2009. Bringing nature home: how you can sustain wildlife with native plants. Portland, OR: Timber Press.

Tallamy, D. W., and K. J. Shropshire. 2009. Ranking Lepidopteran use of native versus introduced plants. Conservation Biology 23: 941–947.

Tietje, W., K. Purcell, and S. Drill. 2005. Oak woodlands as wildlife habitat. In: Giusti, G. A., McCreary, D. D., and Standiford, R. B. (Eds.) A planner's guide for oak woodlands, second edition. University of California, Division of Agriculture and Natural Resources, Publication 3491.

Timm, R. M., and R. O Baker. 2007. A history of urban coyote problems. In: Nolte, D. L., W. M. Arjo, and D. H. Stalman (Eds.), Proceedings of the 12th Wildlife Damage Management Conference, Corpus Christi, TX, 9-12 Apr 2007. National Wildlife Research Center: 272–286.

U.S. Census Bureau. 2010. Census Urban Area Facts. Retrieved from https://www.census.gov/geo/reference/ua/uafacts.html. Accessed Nov 2018.

VanAcker, M. C., E.A.H Little, G. Molaei, W. I. Bajwa, and M.A. Diuk-Wasser. 2019. Enhancement of risk for Lyme disease by landscape connectivity, New York, New York, USA. Emerging Infectious Diseases 25: 1136–1143.

Van Dersal, W. R. 1940. Utilization of oaks by birds and mammals. Journal of Wildlife Management 4: 404–428.

Vose, J. M., D. L. Peterson, and T. Patel-Weynand. 2012. Effects of climatic variability and change on forest ecosystems: a comprehensive science synthesis for the U.S. forest sector. Gen. Tech. Rep. PNW-GTR-870. Portland, OR: USDA Forest Service, Pacific Northwest Research Station. Retrieved from https://www.fs.usda.gov/treesearch/pubs/all/42610.

Wauters, L. A., G. Tosi, and J. Gurnell. 2002. Interspecific competition in tree squirrels: do introduced grey squirrels (*Sciurus carolinensis*) deplete tree seeds hoarded by red squirrels (*S. vulgaris*)? Behavioral Ecology and Sociobiology 51: 360–367.

Williams, M. I., and R. K. Dumroese. 2013. Preparing for climate change: Forestry and assisted migration. Journal of Forestry 111: 287–297.

Wood, E. M., and S. Esaian. 2020. The importance of street trees to urban avifauna. Ecological Applications 30: e02149.

Yang, J. 2009. Assessing the impact of climate change on urban tree species selection: A case study in Philadelphia. Journal of Forestry 107: 364–372.