Urban Forestry & Urban Greening 12 (2013) 134–143

Contents lists available at SciVerse ScienceDirect

Urban Forestry & Urban Greening

journal homepage: www.elsevier.de/ufug

A municipal forest report card: Results for California, USA

E. Gregory McPherson*, Louren Kotow

USDA Forest Service, Pacific Southwest Research Station, Urban Ecosystems and Social Dynamics Program, 1731 Research Park Drive, Davis, CA 95618, United States

ARTICLE INFO

Keywords:
Age structure
Pests
Species dominance
Species adaptability
Stability
Species diversity

ABSTRACT

This study integrates two existing computer programs, the Pest Vulnerability Matrix and i-Tree Streets, into a decision-support tool for assessing municipal forest stability and recommending strategies to mitigate risk of loss. A report card concept was developed to communicate levels of performance in terms that managers and the public easily understand. Grades were assigned to four aspects of a stable and resilient municipal forest: Species Dominance, Age Structure, Pest Threat and Potential Asset Loss. The data pool of 29 California municipal forest inventories contained information on 836,943 trees. Letter grades (A–F) were assigned to the four criteria and each city received customized recommendations for improving its grades. Three inventories received final grades of As, 18 received Bs, 6 Cs and 2 Ds. Twelve inventories received their highest grade for Species Dominance. Thirteen inventories received their lowest grade for Age Structure, largely because juvenile trees were underrepresented. Pest Threat received the lowest grade in 11 inventories and reduce Pest Threat was the top priority recommendation in 18 inventories. Four multi-host pests posed the greatest risk: Granulate ambrosia beetle, Asian longhorned beetle, Armillaria root rot and red palm weevil. Sycamore/plane was the most vulnerable taxon, followed by oaks, ash and eucalyptus. Eliminating or limiting the use of highly vulnerable tree species was recommended in nearly every city to reduce Pest Threat and improve Species Dominance. Increased planting of vacant sites with species not vulnerable to the most abundant and severe pests was a frequent recommendation for improving Age Structure. Another common recommendation to improve Age Structure was planned removal and replacement of overabundant mature and senescent taxa such as pear, eucalyptus, jacaranda and carrotwood.

Published by Elsevier GmbH.

There are about 3.8 billion trees in U.S. urban forests that represent a green infrastructure investment valued at $2.4 trillion (Dwyer et al., 2000). Cities, utilities and residents expect these trees to provide ecosystem services and improve human health and well-being for years to come. However, analyses of community forest inventories throughout the country have found these assets to be highly vulnerable to loss from exotic pests and other stressors (Raupp et al., 2006; Ball et al., 2007; Sydnor et al., 2007). The economic impacts of non-native forest insects are substantial. A national study reported that local governments are spending nearly $1.7 billion annually to remove, replace and treat trees attacked by non-native forest insects, and homeowners lost $830 million in property values (Aukema et al., 2011). The cost of treatment, removal and replacement of 17 million ash trees damaged by the emerald ash borer (EAB) (*Agrilus planipennis*) is expected to be $10.7 billion over 10 years (Kovacs et al., 2010). The maximum potential impact of Asian longhorned beetle (ALB) (*Anoplophora glabripennis*) in U.S. cities was estimated at $699 billion (Nowak et al., 2001). These expenditures are projected to increase as globalization spurs pest transport, with the number of new detections growing annually.

For urban foresters, the best means to reduce future pest threats is to adapt their planting plans. By selecting tree species that do not have the same disease and pest susceptibility as the current population, they can effectively reduce the vulnerability of the future urban forest. With some exceptions, such as New York City, there is little evidence that this is occurring in practice (Stephens, 2010). Furthermore, by selecting species well-adapted for long-term success and creating an optimal age structure, managers can assure continuity of tree canopy. This paper describes the integration of two existing computer programs, the Pest Vulnerability Matrix (PVM) and i-Tree Streets, into a decision-support tool for assessing municipal forest stability and recommending strategies to mitigate risk of loss. Also, it demonstrates application of the tool in 29 California cities and summarizes actions needed to increase the stability of these municipal forests.

Introduction

Planting a diverse mix of tree species is a common recommendation as communities reforest or prepare for the devastating

* Corresponding author. Tel.: +1 530 7591723; fax: +1 530 7561409.
E-mail addresses: gmcpherson@fs.fed.us, egmcpherson@ucdavis.edu (E.G. McPherson).

1618-8667/$ – see front matter. Published by Elsevier GmbH.
http://dx.doi.org/10.1016/j.ufug.2013.01.003

impacts of pests such as the EAB. To simplify the task, managers are told to follow the "look around rule" and avoid planting species that are growing in the area, or limit planting of any genus that accounts for more than 15 percent of the population (Michigan Department of Natural Resources, 2007). However, some managers have responded to recent pest outbreaks by simply substituting one species for another, such as Freeman maple (*Acer × freemanni*) for ash (*Fraxinus* sp.), without considering the susceptibility of the maple to pests such as ALB or the genera's predominance in the overall population (Ball et al., 2007). Increasing diversity may not result in greater stability (Arnold, 1980).

We adopt the notion that a goal of managers is to achieve stable municipal forest structures so that budgets are not disrupted by wide-spread losses over a short time. Stability is defined as the low probability that the number of functional trees will decline to the point of disrupting management and diminishing the benefits trees provide (Richards, 1982/1983). Stable forests are resilient to disturbances from pests, storms, drought and other stressors, where resilience is defined as the ability to tolerate alteration before organizing around a new set of structures and processes (Alberti and Marzluff, 2004). Creating more stable municipal forests is more complex than simply planting a diverse mix of species.

There are many possible structural indicators of a stable municipal forest. For example, the model of urban forest sustainability developed by Clark et al. (1997) incorporated an uneven age distribution as well as a diverse species distribution. McPherson's (1998) indicators of sustainability for Sacramento's urban forest included species and age diversity, condition and suitability of the predominant species to growing conditions. In this study we focus on three indicators because data are readily available for assessment purposes: species dominance, age structure and pest threat.

Species dominance

Increasing species diversity is regarded as the primary means for managers to buffer their populations against catastrophic loss from pests and other threats. From an ecological perspective the two components of species diversity are richness, the total number of species in a population, and evenness, the distribution of individuals among species. Urban forests are frequently characterized by a rich assemblage of many species that are unevenly distributed (McBride and Jacobs, 1976). Overreliance on only a few species can increase the risk of catastrophic loss.

Species dominance, as reflected by relative importance value (IV) for each species, better reflects the relative degree to which a species dominates a population than species diversity alone because it incorporates both the number and size of all individuals (McPherson and Rowntree, 1989). Importance values are calculated as the mean of relative abundance and size, the latter based on metrics such as basal area, tree canopy cover and leaf area. If two species have the same number of individuals, the species with the larger trees on average will have the higher IV.

Three distributions of species dominance within a municipal forest are strong dominance, codominance and weak dominance (McPherson and Rowntree, 1989). Strong dominance occurs when the relative importance of one species is greater than 25 percent and there are no subdominants. Decline, disease or senescence of the dominant species can trigger enormous maintenance costs. Codominance occurs when the relative importance values of each codominant species exceed 10 percent and their sum exceeds 25 percent. Codominance provides greater population stability than strong dominance, and more closely resembles the condition in many natural forest ecosystems. Weak dominance exists when importance is relatively evenly distributed among five to ten leading dominants. This pattern promotes resilience by reducing the risk of catastrophic loss from a single disturbance event.

Age structure

An uneven-aged population allows managers to allocate maintenance costs uniformly over many years, and assures a consistent stream of benefits from stable tree canopy cover. Although neighborhood stands may contain trees of similar age and species, on a city-wide scale tree populations are generally all-aged. This fact can be attributed to planting patterns that are often coincident with land development, as well as cyclical, following episodes of disease or decline (Richards, 1982/1983). McPherson and Rowntree (1989) identified three patterns of age structure in street tree populations. Youthful populations had over 40 percent of the trees in the smallest diameter at breast height (dbh) class. Maturing populations had more individuals in the 16–45 cm dbh classes than in the 0–15 cm class, indicating that most trees were planted 20–50 years ago. Mature populations had a relatively even distribution of trees among all diameter classes, with many mature or senescent trees planted over 50 years ago. Benefits associated with the biomass of these large, old trees may be partially negated by their potential for failure, as well as their high maintenance and removal costs.

Richards (1982/1983) opined that good age diversity was essential for population stability. Richards (1979) sensitivity analysis of street tree survival and population dynamics found that survival rates for recently planted trees drove replacement needs much more than the longevity of mature trees. Consequently, he identified a good age distribution for population stability as having 40 percent of all trees under 20-cm dbh, 30 percent 20- to 40-cm, 20 percent 40- to 60-cm and 10 percent >60-cm. The high proportion in the small dbh class is needed to offset establishment-related mortality.

Pest threat

Historically, pest risks were thought to operate at the species level, as with Dutch elm disease (*Ophiostoma ulmi*) and the widespread loss of monoculture plantings of American elm (*Ulmus americana*) (Raupp et al., 2006). Recent experience with non-specialized pests, such as the EAB, Gypsy moth (*Lymantria dispar*) and Verticillium wilt (*Verticillium* spp.) have caused a change in thinking. Guidelines aimed at protecting urban forests from pest outbreaks, such as no more than 10 percent of a single species, 20 percent of a single genus and 30 percent of a single family (Santamour, 1990), are now outdated. Ball et al. (2007) recommended limiting a single genus to 10 percent of full stocking. They illustrated this rule for a community with 10,000 street tree sites, with 60 percent of these planted. The 10 percent rule means that no more than 1000 trees, not 600 should be of any one genus.

One potential limitation to creating a more even distribution of trees among species is the complexly stressful sites in cities and the need to rely on a few species tolerant to a wide range of growing conditions (Richards, 1982/1983). Planting a wide variety of species for the sole purpose of diversification can be counterproductive if they are not well-adapted to local conditions. However, the goal of selecting well-adapted species need not be a reason to restrict diversification. Bassuk (1990) argued that inventories often contain one hundred or more species, most of which are underutilized. Laćan and McBride (2008) observed that growing conditions in cities will change over time because of climate change, new technologies that influence tree growth, such as engineered soils, and new pest introductions. Selecting a tree well-suited to current conditions is no guarantee that it will be equally well-adapted to future conditions, or "pest-proof." They point out that evidence from recent pest outbreaks indicates that the level of damage to trees has less to do with tree health than with pest biology and host availability. Hence, pest susceptibility of the tree species is of foremost concern.

Assessment tools

The Pest Vulnerability Matrix (PVM) and two pest detection and mapping tools are providing new pest management capacities (Laćan and McBride, 2008). Similarly, computer programs like i-Tree are assisting municipal forest managers in numerous ways (Nowak et al., 2008). Because specifications and applications of these tools have been described elsewhere, this discussion is confined to an overview of their primary features.

Pest Vulnerability Matrix

The PVM is a communication tool aimed at helping managers avoid planting trees that have the same vulnerabilities to pests as the currently most common trees have (Laćan and McBride, 2008). It serves to guide diversification by avoiding replication of pest vulnerabilities among new plantings. The PVM is available to the public as a free Microsoft Excel file. It provides an easy way to identify major pests affecting the population as a whole and comparing how various tree species additions would impact overall vulnerability.

Pest information is aggregated into complexes and each is given a severity rating of low, moderate or severe. Pests of minor importance and emerging pests are graphically highlighted. Tree species are aggregated into taxon by genus unless there are substantial differences in pest susceptibility. Several metrics are calculated by the PVM: total pest count on each taxon, pest overlap (percentage of all pests found on each taxon), tree species affected and proportion of entire inventory affected. The graphical use of color and patterns communicate the relative severity and status of different pests.

PVM was designed for Northern California communities and applied there to illustrate its utility. However, it can be adapted for application in other regions if local experts revise information on insects, diseases and trees. To our knowledge, this had not occurred prior to our study.

Pest detection tools

Two pest detection applications are The Early Detection and Distribution Mapping System (EDDMapS) and iMapInvasives. The former provides easy access through an interactive Web interface to one of the nation's largest databases of invasive pests (Center for Invasive Species and Ecosystem Health, 2005). It encourages citizen scientists to record their observations by maintaining their personal records and providing interactive maps. iMapInvasives was designed to aid in control of invasive species through early detection and rapid response efforts. Its free web-based map and database are being used in several regions by citizens, land owners and land managers (The Nature Conservancy, 2010). These tools can be used by municipal foresters in conjunction with integrated pest management programs.

i-Tree

i-Tree is a suite of urban and community forestry computer tools designed to help communities of all size strengthen their urban forest management and advocacy efforts by quantifying the structure of community trees and the value of ecosystem services that trees provide. Within i-Tree, entire urban forest tree populations are assessed using Eco (formerly UFORE), whereas discrete street tree populations are assessed using Streets (formerly STRATUM). The i-Tree Pest Detection utility establishes a standard protocol for incorporating urban pest detection and monitoring with tree inventories conducted using i-Tree Streets (USDA Forest Service, 2009).

i-Tree Streets uses tree inventory data to quantify structure, function and value of annual benefits. Using a sample or an existing inventory of street trees, this software allows managers to evaluate current benefits, costs, and management needs (Maco and McPherson, 2003; McPherson et al., 2005). i-Tree Eco quantifies urban forest structure, environmental effects, and value to communities from field data and local hourly air pollution and meteorological data (Nowak et al., 2008). The potential impacts of pests are estimated for each tree species in a city using its compensatory value, or the approximate replacement cost. For example, the worst-case scenario for Los Angeles' urban forest was potential losses of \$2.6, \$2.4 and \$1.3 billion for ALB, gypsy moth and EAB, respectively (Nowak et al., 2011).

Study goals

Faced with a variety of tree inventory and pest detection tools, tree managers are sometimes inundated with data, and lacking decision-support that produces insightful analyses and customized recommendations. This study extends the capabilities of the PVM and i-Tree software by interpreting their outputs in ways that help guide managers in their efforts to create more stable municipal forests. The goals of the study were to:

1. Develop a decision-support tool that identifies priority threats and recommends management actions to mitigate those threats.
2. Demonstrate application of the tool using a sample of California communities.
3. Compile results and summarize primary threats and management actions needed statewide.

Methods

The steps used to develop and apply the decision support tool are shown in Fig. 1. A brief description of each step follows. More detailed information is available in Kotow and McPherson (2012).

Tree inventories

Computerized street and park tree inventories that had been conducted or updated within the past 5 years were solicited from communities thought to have tree surveys through e-mails distributed statewide by urban forestry networks such as CAL FIRE, California Urban Forest Council and California ReLeaf. Approximately 60 cities responded initially, but many could not participate because their inventories were not completed or were outdated. Non-respondents were contacted three times before being dropped from the study. Twenty-nine inventories were received, with 24 arriving between July and November 2009 and the remaining arriving between April and December 2010.

Inventories were prepared for analysis by converting to Excel format, standardizing with botanical names and checking for outliers and missing or erroneous data. If critical data, such as tree name and dbh, could not be obtained the tree was excluded from analysis. The final analysis included 836,943 trees from the 29 cities, with 6 climate regions represented in the sample (Fig. 2).

Cultivars and species were aggregated to the genus level for application in the PVM. Exceptions included several species-rich genera with dissimilar vulnerabilities. Evergreen and deciduous oaks (*Quercus* sp.) were separated because of evergreen oaks susceptibility to sudden oak death disease (*Phytophthora ramorum*). Once aggregated and labeled, taxa comprising less than one percent of the inventory were grouped together as "Other" and not assigned a pest value in the PVM analysis.

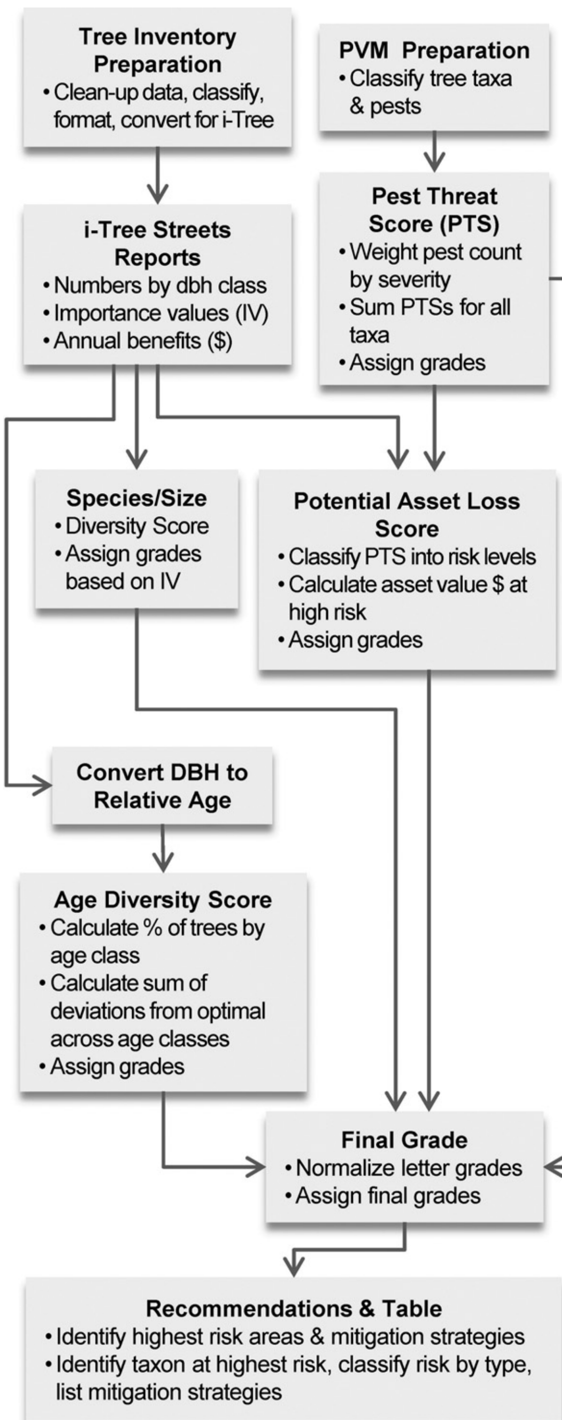

Fig. 1. Steps in the process of developing report cards and recommendations using the Pest Vulnerability Matrix (PVM) and i-Tree Streets.

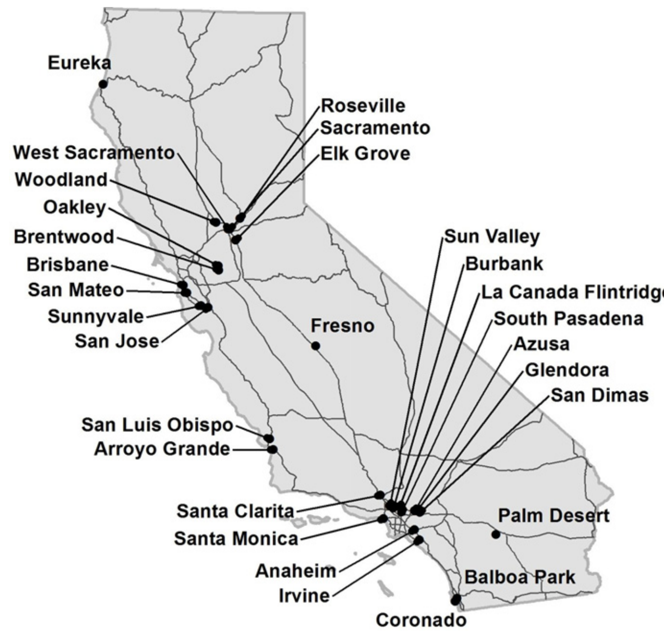

Fig. 2. Map of California, USA with locations of cities that supplied tree inventory data.

In the tree inventories, dbh was measured to the closest centimeter or recorded by size class. Size class data were converted into standard i-Tree Streets dbh classes for processing. The dbh classes were converted into four relative age classes: juvenile, semi-mature, mature and senescent. Converting dbh to age is inexact because mature dbh size and the average annual increment of dbh growth vary among species. In the simplest terms, a 25-cm dbh plane/sycamore (*Platanus* sp.) may be juvenile, while the same size crabapple (*Malus* sp.) may be mature. To establish species-specific relations between dbh and age classes maximum dbh was obtained for each species from the California Register of Big Trees (Urban Forest Ecosystems Institute, 1995–2012a). The register records dbh for the largest specimen of each native and naturalized tree species growing in California. An informal comparison of these data with comparable data from the USDA Forest Service street and park tree database indicated that the largest trees grew to about 80 percent of their respective Big Trees' dbh (McPherson and Peper, 2012). Thus, maximum dbh (dbh_x) for each inventoried species was 80 percent of the value recorded for each Big Tree species. The data breakpoints for age classes were defined as:

- Juvenile – <15 percent dbh_x
- Semi-mature – 15–40 percent dbh_x
- Mature – 40–80 percent dbh_x
- Senescent – >80 percent dbh_x

Each tree's inventoried dbh was used with the specie's dbh_x and the age class breakpoints above to categorize it by age class. The percentage of all trees in each age class was calculated by species.

Formatted tree inventories were imported to i-Tree Streets to generate reports on structure, function and value. Each taxon in the inventory was matched to one of the 20–22 species that were intensively studied in each climates zone's reference city (Peper et al., 2001a,b). Correctly matching species from the inventory to their corresponding reference city species insured that the appropriate allometric and growth equations were applied to calculate biomass and ecosystem services. For non-matching species, each sampled species was classified with four descriptors (Urban Forest Ecosystems Institute, 1995–2012b):

- tree type: broadleaf, conifer, palm
- life form: evergreen, deciduous
- mature tree size: large, medium, small
- growth rate: very fast, fast, medium fast, medium, slow medium, slow, very slow

The 20–22 species in each of the six California reference cities were similarly classified. Each non-match from the inventory was matched with the best fitting reference city species according to the four descriptors. If several species matched, the assignment was made based on taxonomic criteria (same genus) or expert knowledge about the species' architecture.

Three reports were exported to Excel for further analyses. A population summary report contained tree numbers by taxon and dbh class. A structure report listed IVs by taxon, where IVs were calculated as the mean of relative abundance, tree canopy cover and leaf area. A benefit report enumerated the value of annual ecosystem services by taxon. A description of methods used in i-Tree Streets to calculate annual benefits can be found in McPherson et al. (2005).

Pest Vulnerability Matrix

The PVM was adapted for statewide application by adding new tree taxa found in the 29 tree inventories, as well as new pests that they were known to host. Pest-host tables in the published literature (Wait, 1986; Dirr, 1998; Dreistadt et al., 2004) and websites (UC Division of Agriculture and Natural Resources, 2012) were consulted to determine susceptibility and severity. Six experts agreed to review the revised matrix. Specifically, they were asked to (1) provide both pest susceptibility and severity ratings for the five new tree taxa for which pest-host data could not be found, (2) review the accuracy of data from the literature for one new tree taxon and (3) review the accuracy for the 103 previously listed pests, noting any geographic differences in susceptibility and severity between the same pest in Southern and Northern California. The final PVM contained 174 tree taxon, and information on 123 pests, of which 72 were insects and 51 were diseases.

Report card grades

The concept of reporting grades for various indicators of a stable municipal forest was adopted because report cards communicate levels of performance in terms that managers and the public easily understand. The ultimate goal was for poor grades to motivate municipal arborists to alter their management actions in ways that would improve their grades and increase the resilience of their forests. Grades from the report card and management recommendations that followed were intended to motivate action by providing:

- a commonly understood metric (i.e., letter grades A to F)
- a baseline against which improvement can be measured
- clear identification of areas where intervention is most needed
- comparisons with similar cities that motivate local efforts to improve grades
- recommendations that may be locally unpopular, but have standing because their source is a reputable third-party

Grades were assigned to each of four criterion that represent different dimensions of a stable and resilient municipal forest.

Species dominance

In the ideal municipal forest, tree numbers are relatively evenly distributed among dozens of well-adapted species. The distribution of size matters too, as over-reliance on a few species made up of large, old trees increases the risk of losing substantial canopy cover and associated benefits from a pest attack or other disturbance. The Species Dominance grade was calculated as the sum of IVs of the top five taxa in each city. IVs summed to 100 for all trees in each city. Therefore, a higher total IV for the top five taxa reflected greater risk of over-reliance on too few species.

Age structure

Because young trees are most vulnerable to loss from stressors and vandalism, the ideal municipal forest contains a preponderance of juveniles that constantly replace dying trees. The ideal forest primarily consists of maturing and mature trees that will produce ecosystem services for generations to come. It has relatively few senescent trees that are expensive to maintain, remove and replace. For this criterion we adopted Richards' (1982/1983) recommendation that an optimal distribution of relative age classes for population stability is 40 percent juvenile, 30 percent semi-mature, 20 percent mature and 10 percent senescent trees. The Age Structure grade was calculated by first determining the percentage of all trees in each relative age class. The difference between these percentages and the respective optimal percentages was calculated and absolute values were summed to express deviation from optimal across all relative age classes.

Pest threat

The municipal forest's pest threat level depends on the total number of pests that are attracted to the tree population, as well as their severity. Ideally, trees responsible for producing the bulk of ecosystem services host few pests, and those pests are relatively harmless. Determining the Pest Threat score for each taxon was a multi-step process (Fig. 1).

- PVM counted the number of pests affecting each tree taxon
- The PVM pest count was weighted by severity wherein low = 1, moderate = 3 and severe = 5. For example, the weighted pest count for ash with pest counts of 9 (low severity), 5 (moderate severity) and 3 (high severity) was 39 ($[9 \times 1] + [5 \times 3] + [3 \times 5] = 39$).
- The taxon's weighted pest count was multiplied by its IV to reflect the magnitude of asset at risk. Using the example above, if the IV of ash was 8.6 percent, the final pest threat score was 335 (8.6×39).
- Resulting pest threat scores by taxon were summed for each city.

Potential asset loss

The urban forest is an asset because it produces a steady stream of ecosystem services. The dollar value of annual benefits produced by the municipal forest is one measure of its asset value. The ideal municipal forest consists of individual trees that will be producing a high level of services into the future because they are relatively invulnerable to threats from pests, storms, drought and other stressors. Alternatively, if millions of dollars of ecosystem services are produced by species highly vulnerable to pest attacks, the potential loss is high. By understanding the role each taxon plays in producing services, as well as its pest threat level, the manager can identify whether to curtail or increase its use. To determine a grade for this criterion, each taxon was classified into one of five risk levels (i.e., very low to very high) based on its pest threat score. Breakpoints for risk classes were established to achieve a relatively even distribution across the higher risk levels, with four percent of all taxa classified as high and four percent as very high. The Potential Asset Loss score was calculated for each city as the percentage of total asset value from all trees that was produced by taxa classified as high or very high risk.

Scores and final grade

Scores for each of the four criteria were converted to letter grades by assigning a B− to the mean scores and distributing scores proportionately among the 15 grades from A+ to F−. Lacking a robust data set from which to develop a standard grading system,

Table 1
Cities, human and tree numbers and report card grades (United States Census Bureau, 2000).

City	Population	Tree Nos.	Sp/size	Age	Pest threat	Asset loss	Final grade
Anaheim	334,425	106,849	A+	B	A−	A	A
Azusa	47,074	11,232	A+	B	B	B	B+
Balboa Park	1,256,951	15,605	F	D+	C	F	D−
Brentwood	42,000	601	A+	B+	A+	A+	A+
Brisbane	3597	467	A−	A−	B+	B+	A−
Burbank	104,317	28,563	C	D+	B	A−	B−
Chula Vista	212,756	29,573	B+	A	A−	C+	B+
Coronado	24,100	9296	D−	B−	A−	C	C+
Elk Grove	129,184	107,607	A−	B	B−	B+	B+
Eureka	25,435	1304	A−	B	A	B−	B+
Fresno	466,714	85,575	B	D+	B+	A	B
Glendora	50,370	13,485	A	D+	B	A−	B
Irvine	193,956	58,364	F	B+	C+	D	C−
La Canada Flintridge	20,318	14,173	D	C−	F	D+	D
Oakley	28,822	4526	B	F	D	C	C−
Palm Desert	47,047	10,188	B	D+	A	A	B+
Roseville	107,158	37,975	D+	B+	D+	C	C
Sacramento	453,781	87,188	C+	A+	D+	B	B
San Dimas	35,714	9106	B+	B	B−	C+	B
San Jose	929,936	4774	B+	B−	B	B	B
San Luis Obispo	42,963	17,981	A	A−	C−	B−	B
San Mateo	91,601	19,220	B	B+	D+	B+	B
Santa Clarita	168,008	49,915	C+	B+	D+	D+	C+
Santa Monica	88,050	32,345	B+	C+	A	A−	B+
South Pasadena	24,292	9111	B	D-	B+	B−	B−
Sun Valley	75,848	637	C	A−	A−	B−	B
Sunnyvale	130,519	36,891	B	B	B+	A	B+
West Sacramento	44,162	20,790	B+	C	D+	C−	C+
Woodland	51,144	13,602	B	A−	C	A−	B+

we arbitrarily elected to curve grades around the B− mean. Final grades were calculated as the average of individual letter grades across the four criteria, assuming equal weighting. The calculation was accomplished by assigning points (1 for A+, 15 for F−) to each letter grade, summing the points and averaging across the four criteria.

Recommendations

Customized management recommendations and a risk mitigation table were developed for each city. Criteria that received the lowest grades were identified as highest priorities for intervention. Recommendations consisted of management strategies to mitigate threats that posed the highest risks. The risk mitigation table identified the criterion most responsible for each high-risk taxon, as well as mitigation strategies.

Results

Grades and recommendations

Three inventories received final grades of As, 18 received Bs, 6 Cs and 2 Ds (Table 1). Twelve inventories received their highest grade for Species Dominance. Thirteen inventories received their lowest grade for Age Structure. With one exception (Oakley), the low grades were because juvenile trees were underrepresented in the population. Increasing the juvenile population was the second most frequent top priority recommendation. Pest Threat received the lowest grade in 11 inventories and reduce Pest Threat was the top priority recommendation in 18 inventories.

Biggest pest threats

Of pests designated as severe threats, four multi-host insects and diseases posed the greatest risk to the inventories we assessed (Table 2). The Granulate ambrosia beetle (GAB) (*Xylosandrus crassiusculus*) was a threat in 26 of 29 inventories, and over 40 percent of the trees in four municipal inventories were vulnerable to this pest. Armillaria root rot (ARR) (*Armillaria* sp.) was a severe pest that threatened over 30 percent of the inventoried trees in 17 cities. Asian longhorned beetle (ALB) was the third most severe pest, threatening 10–40 percent of the trees in 15 inventories. Red palm weevil (RPW) (*Rhynchophorus ferrugineus*) was a severe threat in the 10 inventories with large numbers of palms.

Of the non-severe pests, powdery mildew (*Sawadaea tulasnei*) posed a threat to over 30 percent of the inventoried populations in 17 cities. Soft scales (15 inventories) (e.g., *Icerya purchase*) and defoliating caterpillars (e.g., *Malacosoma* sp.) (12 inventories) were abundant as well. Armored scales (*Diaspididae*) achieved the 30 percent threat threshold in 8 cities, while 74 percent of Coronado's inventory was susceptible to this pest. Palms account for over one-half of this San Diego island city's tree population. Other pests found to be important threats because of their relative abundance were Armillaria root rot, aphids (*Braggia* sp., *Aphis* sp., *Sitobion* sp., *Euthoracaphis*, *Dilachnus*), root and crown rot (*Phytophthora* sp., *Pythium* sp.) and hypoxylon (*Hypoxylon mammatum*) and nectria cankers (e.g., *Nectria galligena* and *cinnabarina*).

Table 2
The number of inventories for which a pest was listed among the three most severe. Data are classified by percentage of inventory vulnerable to the pest.

Pest	Percentage of inventory vulnerable			
	9–30	30–39	40–74	Total
Granulate ambrosia beetle	14	8	4	26
Armillaria root rot	4	11	6	21
Red palm weevil	7	2	1	10
Asian longhorned beetle	7	8	0	15
Psyllids	2	1	1	4
Eucalyptus longhorned borer	2	0	0	2
Pink rot	1	0	1	2
Sudden oak death	2	0	0	2
Emerald ash borer	1	0	0	1
Fireblight	1	0	0	1

Table 3
Number of inventories for which each taxon was listed as the number 1, 2 or 3 highest risk. The weighted score assumes Nos. 1, 2 and 3 risks are weighted 3, 2 and 1, respectively.

Taxon	No. 1 risk	No. 2 risk	No. 3 risk	Wtd. score
Sycamore/Plane	9	2	0	31
Evergreen oak	3	3	1	16
Ash	2	3	2	14
Eucalyptus	4	1	0	14
Deciduous oak	1	0	11	14
Mexican fan palm	2	2	0	10
Sweetgum	1	1	5	10
Pine	0	2	6	10
Magnolia	1	2	1	8
Ficus	2	0	1	7
Pistache	0	3	0	6
Crape myrtle	1	1	0	5
Cypress	1	1	0	5
Pear	0	1	1	3
Camphor	1	0	0	3
Jacaranda	0	1	1	3
Queen palm	1	0	0	3
Cherry	0	1	1	3

Most vulnerable tree taxa

Sycamore/plane has been planted extensively because of its tolerance to a wide range of growing conditions and attractive form. It was the most vulnerable taxon among the inventoried populations, foremost at-risk in 9 cities and the second most vulnerable in two other cities. Using a simple weighting of 3, 2 and 1 for taxon listed 1, 2 and 3 in terms of at-risk from pests, sycamore/plane's score of 31 was about twice that of evergreen oak (16 in Table 3). Sycamore/plane ia vulnerable to severe pests such as GAB, ALB and ARR, as well as moderately severe pests such as powdery mildew, anthracnose (*Apiognomonia platani*), sycamore canker stain (*Ceratocystis fimbriata* f.sp. *platani*) and soft scales. Although the level of vulnerability varies among species (*P. racemosa*, *occidentalis*, *orientalis*, × *acerifolia*) and cultivars (e.g., 'Bloodgood', 'Columbia', 'Liberty', 'Yarwood'), no single genotype has exhibited resistance to more than one or two of these maladies (Svihra and McCain, 1992).

The oak genus was subdivided into evergreen and deciduous because only evergreen oaks are susceptible to sudden oak death, a severe disease threat. Both evergreen and deciduous oaks are vulnerable to another severe pest, GAB, as well as the moderately severe pests Armillaria root rot and powdery mildew. Both types of oaks are vulnerable to a host of less severe pests including aphids, borers, heart rot (e.g., *Ganoderma* sp.), hypoxylon and nectria cankers, armored scales and defoliating caterpillars. Also, they are susceptible to emerging pests, the glassy-winged sharpshooter (*Homalodisca vitripennis*) and goldspotted oak borer (*Agrilus auroguttatus*). The latter pest has killed over 80,000 native oaks in San Diego County (UC Riverside, 2012). Although native and introduced oaks have been widely planted in California cities, the last decade has seen a resurgence of native oak planting. Because oaks host a myriad of pests, they were rated among the most vulnerable taxon.

Ash was among the most vulnerable taxon because of their susceptibility to anthracnose and two emerging threats, EAB and ALB. Also, they were susceptible to moderately severe threats from verticillium wilt, ash plant bug (*Leptoypha minor*) and clearwing borers (e.g., *Podosesia syringa*e).

Eucalyptus (*Eucalyptus* sp.) was introduced to California during the Gold Rush and quickly became a ubiquitous feature of the landscape. Recent predilection for native plants has reduced the prominence of eucalypts in younger age classes. However, many veteran eucalypts still persist, as evidenced by it being the most at-risk taxon in four cities. Psyllids (family *Psyllidae*) and the eucalyptus longhorned borer (*Phoracantha semipunctata*, *P. recurva*) were severe threats and Armillaria root rot was a moderately severe threat. Emerging threats included the eucalyptus snout beetle (*Gonipterus scutellatus*) and glassy winged sharpshooter.

Table 4
Number of inventories for which it was recommended to eliminate, limit (to less than 5 percent) or reduce planting of the taxon and develop removal and replacement (Rem & Repl) plan for senescent trees.

Taxon	Eliminate	Limit	Reduce	Rem & Repl
Sycamore/Plane	11	4	2	5
Ash	5	5	0	3
Eucalyptus	3	2	4	7
Evergreen oak	3	11	3	3
Mexican fan palm	3	0	0	0
Sweetgum	3	3	5	0
Pine	2	9	0	4
Deciduous oak	0	5	3	3
Magnolia	2	4	5	0
Pistache	0	4	0	3
Crape myrtle	2	3	4	0
Pear	0	3	2	8
Ficus	2	2	0	3
Hackberry	0	2	0	0
Maple	0	2	2	0
Tristania	0	2	0	0
Camphor	0	0	3	0
Yew pine	0	0	2	2
Jacaranda	0	0	0	6
Carrotwood	0	0	0	6
Chinese elm	0	0	0	5
American elm	0	0	0	4
Melaluca	0	0	0	2

Planting restrictions

Recommendations to restrict planting of a taxon were (1) eliminate until 2020, (2) limit to less than 2 or 5 percent of trees planted and (3) reduce new planting reliance. The recommendation to eliminate planting occurred when the taxon was at a very high-risk because of its susceptibility to pests as evidenced by its Pest Threat score. In some cases, the taxon was over-dominant as well. Limiting planting of a taxon was recommended when the taxon was at high-risk and relatively abundant in the juvenile age class. Reducing reliance on the taxon in new plantings was recommended when the taxon was over-abundant in the juvenile age class.

Because of its vulnerability to pests and high asset value in many inventories, we recommended that planting of sycamore/plane be discontinued in 11 cities, planting strictly limited in four cities and numbers reduced in two others (Table 4). We recommended that five cities eliminate planting of ash and another five strictly limit its use to reduce susceptibility to pest threats in the future. Recommended restrictions on planting eucalyptus, evergreen oak, Mexican fan palm (*Washingtonia robusta*) and other taxon are listed in Table 4.

Remove and replace

Municipal arborists develop removal and replacement plans when the predominant tree species are becoming senescent. Such plans target removal of high-risk trees and phase in replacement plantings. We recommended development of removal and replacement plans for taxa when the percentages of trees in the mature and senescent age classes were well above the 20 and 10 percent values deemed desirable.

Removal and replacement plans were most frequently recommended for pear (*Pyrus* sp.) (8 inventories), eucalyptus (7), jacaranda (*Jacaranda mimosifolia*) and carrotwood (*Cupaniopsis anacardioides*) (6 each, Table 4). Other taxa reaching the end of their service lives in several inventories were sycamore/plane and Chinese elm (*Ulmus parvifolia*) (5 inventories), pine (*Pinus* sp.) and American elm (*Ulmus americana*) (4) and ash, oak and ficus (primarily *Ficus microcarpa* 'Nitida') (3).

Discussion

To our knowledge this is the first study that combines structural measures (i.e., species dominance and age structure) with pest vulnerability measures to assess the stability of municipal forests. Such a multidimensional approach provides managers with recommendations that can address young tree care, removal and replacement of senescent trees, as well as tree planting issues. For example, the two lowest scoring cities received Ds and Fs in Species Dominance and Potential Asset Loss. Both populations were dominated by a single taxon, eucalypts in Balboa Park and evergreen oaks in the La Canada Flintridge. These two dominant species had very high Pest Threat levels. Because of their relative dominance they were responsible for providing 73 and 48 percent of the municipal forests' asset value, respectively. Eliminating planting of eucalypts and evergreen oaks were top priority recommendations. The second priority was to limit new planting of species such as pine, sycamore/plane and crapemyrtle (*Lagerstroemia indica*) because of their vulnerability to pests and overuse. Other recommendations included: evaluate if each potential species for planting is vulnerable to the most abundant and severe pests, select disease resistant cultivars/hybrids, develop an integrated pest management program to reduce pest severity, inspect and prune young trees for structure and form at least every other year and attend to the health and replacement of senescent trees. In Balboa Park, over 50 percent of the melaluca (*Melaluca* sp.) and cedar (*Cedrus* sp.) were mature or senescent. In La Canada Flintridge, 87 percent of the Chinese elm and 54 percent of the olive (*Olea europaea*) fell into the mature and senescent age classes.

Species dominance

Although California street tree inventories are relatively rich in species, numbers tend to be concentrated among few species. Muller and Bornstein (2010) found that fewer than nine species accounted for over 50 percent of all trees in 18 California communities. We found that three taxa accounted for over 50 percent of total IV in cities that received the lowest grades for Species Dominance. Those taxa were Queen palm (*Syagrus romanzoffiana)*, pepper (*Schinus* sp.) and pine in Coronado, oak, cedar and sweetgum (*Liquidamber styraciflua*) in La Canada Flintridge and sycamore/plane, oak and redwood (*Sequoia sempervirens*) in Roseville. Municipal forests in these cities exhibited patterns of codominance, similar to many temperate climate cities (McPherson and Rowntree, 1989). The remaining inventories reflected patterns of weak dominance, wherein importance was relatively evenly dispersed among five to ten leading dominants. While this pattern implies minimal risk of loss from a single dominant species, the pest vulnerability and adaptability of the leading dominants is critical to rotation lengths and management costs. Although our analysis did not address trends in diversity over time, we recognize others' concern that the diversity of California's municipal forests is declining (Lesser, 1996; Muller and Bornstein, 2010).

Age structure

We found that many municipal forests lacked a youthful age structure. In 12 of the 13 inventories that received their lowest grade for Age Structure, juvenile trees were underrepresented. In a study of 21 Southern California street tree inventories, Lesser (1996) found that a relatively small percentage of trees reached the semi-mature age class, resulting in large numbers of juvenile trees. We can only speculate as to the cause for these contradictory findings. For instance, budgets for tree planting may not have kept pace during the past two decades. Levels of young tree care may have slipped, resulting in higher mortality rates. In any case, planting more trees to improve age diversity is a goal that provides many municipal foresters in California the opportunity to increase the resilience of their forests.

Pest threat and potential asset loss

Our results suggest that multi-host pests such as GAB, ARR, ALB and RPW pose the greatest threat to the state's municipal forests. This will challenge arborists because there are so many tree hosts. For instance, GAB is a severe threat to ficus, golden rain (*Koelreuteria* sp.), crape myrtle, sweetgum, magnolia (*Magnolia* sp.), oak, Chinese elm, plum (*Prunus cerasifera*), cherry (*Prunus* sp.) and redbud (*Cercis* sp.).

Unlike the Midwest where EAB is a present threat, there is less urgency to act in California because many of the most severe pests are emerging threats (e.g., GAB, ALB and RPW). However, the threat is real. In 2005 the ALB, a severe threat to sycamore/plane, elm, maple (*Acer* sp.), hackberry (*Celtis* sp.) and ash, was found on wood packing material in a Sacramento warehouse (Lydick, 2011). Los Angeles-Long Beach-Santa Ana, California is a top commodity import region at risk of establishing new alien forest insects at a rate of one every 4–5 years.

Our recommendation to eliminate planting of sycamore/plane in 11 cities is not unprecedented. Following Santamour's (1990) 30–20–10 guideline, Galvin (1999) recommended suspending planting of red maple (*Acer rubrum*) until the population dropped from 34 to 10 percent of all species in Mount Rainier, MD. More recently, EAB outbreaks have prompted moratoriums on planting ash (Shour, 2010). The sycamore/plane complex contains several species and cultivars with different planting rates and susceptibility to anthracnose and powdery mildew (Svihra and McCain, 1992). How their vulnerability to emerging pests varies among taxon is not well understood.

Remove and replace

Our finding that pear was the taxon most frequently in mature and senescent age classes was surprising. 'Bradford' pear (*Pyrus calleryana* 'Bradford') was widely planted throughout the U.S. in the 1970s and 1980s for its attractive flowers, fall color and disease resistance. Fruitless cultivars reduced maintenance costs and the small-stature tree could be planted in relatively constrained sites. However, the structural defect wherein multiple branches originate from a single point on the bole, resulted in limb failures as trees matured (Galvin, 1999). Given the cultivar's maintenance problems, the large number of mature and senescent trees remaining on California streets was unexpected.

Limitations of the approach

Although our approach is novel in that it combines two distinctly different tools to present a unique picture of the relative roles of criteria that contribute to stability, it has several limitations. The scope of analysis could be expanded to include other indicators, such as stocking level, tolerance to drought and storms and the relative invasiveness of taxa. Our approach relied on tree inventories and pest severity ratings that were only a "snapshot in time." As new pest threats emerge and forest structure changes with time, study findings will become increasingly outdated. Similarly, the scale of analysis was city-wide, which missed the importance of the spatial arrangement of taxa within a city to pest vulnerability and disease transmission (Sun, 1992). Our approach was limited to the municipal forest, a relatively small component of the urban forest that has its own unique structure, function and value (Miller, 2007). For example, in Guangzhou, China the street tree population was less diverse, contained more large-stature taxa and exhibited higher levels of spatial continuity than park and campus trees (Jim and Liu, 2001). Recommendations for a municipal forest may not be directly transferable to other components of a city's urban forest.

The scope and accuracy of our analysis was constrained by the data we received. We planned to include tree condition as a criterion, but inventory data were inconsistent and unreliable. Tree dbh ranges were unique to each inventory. Tree aging became less accurate as dbh size class ranges increased. Binning of several species into the same taxon led to inaccuracies, especially when substantial differences in mature size were present. Finally, participating cities were not selected at random, and probably represent higher achieving communities that have recognized the value of investing in a tree inventory.

Despite these shortcomings, the report cards allow cities to compare their grades with others in comparable cities. Also, they create standardized baselines against which progress can be measured. The report cards reveal areas of proficiency and deficiency, and offer prioritized recommendations to guide managers interested in improving their municipal forest's grades. The report card concept and the tools used to conduct the analyses can be adapted for application in other regions of the U.S.

Summary and conclusion

The municipal forest report card approach combined aspects of the PVM, a spreadsheet that quantified the extent and severity that pests affected each tree population; and i-Tree Streets, a computer program that calculated and monetized the annual dollar value of ecosystem services provided by the trees. Grades were awarded to four indicators of a stable municipal forest, with the highest grades for:

- Species dominance – weak dominance with IVs distributed evenly among the top 5–10 taxa.
- Age structure – youthful population with about 40 percent juveniles and 30 percent semi-mature, 20 percent mature and 10 percent senescent ages.
- Pest threat – low vulnerability to the most severe and abundant pests.
- Potential asset loss – low percentage of asset value residing in high and very high risk taxa.

Application of the report card approach to 29 municipal forest inventories comprising 836,943 trees found that four multi-host pests posed the greatest risk: GAB, ALB, ARR and RPW. Sycamore/plane was the most vulnerable taxon, followed by oaks, ash and eucalyptus. Thirteen inventories received their lowest grade for poor Age Structure, primarily because they lacked sufficient juvenile trees to perpetuate the population.

We recommended several strategies for managers to use to increase stability so that budgets are not disrupted by wide-spread losses over a short time. Reducing Pest Threat was the top priority recommendation in 18 inventories. To improve Age Structure, increased planting of vacant sites with species that are not vulnerable to the most abundant and severe pests was the next most frequent recommendation. Eliminating or limiting the use of a species was recommended in nearly every city to reduce Pest Threat and improve Species Dominance. Another strategy was planned removal and replacement of overabundant mature and senescent taxa such as pear, eucalyptus, jacaranda and carrotwood.

California's municipal forests are green infrastructure investments that provide many economic, psychological and cultural benefits. These benefits are not insured and trees face a plethora of human-caused and natural challenges. Achieving a stable municipal forest structure is fundamental to sustaining a high level of services into the future. The recipe is different for each city and frequently, it is more complicated than simply planting a diverse mix of tree species. The report card approach offers a multidimensional perspective on stability. While the intent was for the report cards and recommendations to promote greater awareness and more focused actions by managers to increase the stability of their municipal forests, only time will tell if they achieve this goal.

Acknowledgements

Thanks to Drs. David Burger and Larry Costello, both at UC Davis, for helpful reviews of an earlier version of this paper. The following individuals provided valuable suggestions for modifications to the Pest Vulnerability Matrix: Dr. Tom Gordon, Ed Perry (both UC Davis), Dr. Tim Paine (UC Riverside), Don Hodel (UC Cooperative Extension), Dr. Steve Seybold and Dr. Chris Fettig (US Forest Service, PSW Research Station). We thank representatives of the participating cities for their participation and patience. Finally, we are indebted to Gary Man, USDA Forest Service Forest Health Management, for his support and insightful comments throughout the research process.

References

Alberti, M., Marzluff, J.M., 2004. Ecological resilience in urban ecosystems: linking urban patterns to human and ecological functions. Urban Ecosystems 7, 241–265.
Arnold, H.F., 1980. Trees in Urban Design. Van Nostrand Reinhold, New York.
Aukema, J., Leung, B., Kovacs, K., Chivers, C., Britton, K., Englin, J., Frankel, S., Haight, R., Holmes, T., Liebhold, A., McCullough, D., Von Holle, B., 2011. Economic impacts of non-native forest insects in the continental United States. PLoS ONE 6, e24587, doi:24510.21371/journal.pone.0024587.
Ball, J., Mason, S.J., Kiesz, A., McCormick, D., Brown, C., 2007. Assessing the hazard of emerald ash borer and other exotic stressors to community forests. Arboriculture & Urban Forestry 33, 350–359.
Bassuk, N.L., 1990. Street tree diversity making better choices for the urban landscape, trees for the nineties: landscape tree selection, testing, evaluation and introduction. In: Proceedings of 7th Conference Metropolitan Tree Improvement Alliance, Lisle, IL, Morton Arboretum, pp. 71–78.
Center for Invasive Species and Ecosystem Health, 2005. EDDMapS, Center for Invasive Species and Ecosystem Health, September 25, 2012, http://eddmaps.org
Clark, J.R., Matheny, N.P., Cross, G., Wade, V., 1997. A model of urban forest sustainability. Journal of Arboriculture 23, 17–30.
Dirr, M.A., 1998. Manual of Woody Landscape Plants: Their Identification, Ornamental Characteristics, Culture, Propagation and Uses. Stipes Publishing L.L.C, Champaign, IL.
Dreistadt, S.H., Clark, J.K., Flint, M.L., 2004. Pests of Landscape Trees and Shrubs: An Integrated Pest Management Guide. Publication 3359. University of California, Division of Agriculture and Natural Resources. Oakland, CA.
Dwyer, J.F., Nowak, D.J., Noble, M.H., Sisinni, S.M., 2000. Connecting People with Ecosystems in the 21st Century: An Assessment of Our Nation's Urban Forests. Gen. Tech. Rpt. 490. USDA Forest Service, Pacific Northwest Research Station. Portland, OR.
Galvin, M.F., 1999. A methodology for assessing and managing biodiversity in street tree populations: a case study. Journal of Arboriculture 25, 124–128.
Jim, C.Y., Liu, H.T., 2001. Species diversity of three major urban forest types in Guangzhou City, China. Forest Ecology and Management 146, 99–114.
Kotow, L., McPherson, E.G., 2012. California Municipal Forest Health Threat Assessment. Final Project Report. USDA Forest Service, Pacific Southwest Research Station. Albany, CA.
Kovacs, K.F., Haight, R.G., McCullough, D.G., Mercader, R.J., Siegert, N.W., Liebhold, A.M., 2010. Cost of potential emerald ash borer damage in U.S. Communities, 2009–2019. Ecological Economics 69, 569–578.
Laćan, I., McBride, J.R., 2008. Pest Vulnerability Matrix (PVM): a graphic model for assessing the interaction between tree species diversity and urban forest susceptibility to insects and diseases. Urban Forestry & Urban Greening 7, 291–300.
Lesser, L.M., 1996. Street tree diversity and dbh in Southern California. Journal of Arboriculture 22, 180–186.

Lydick, J., 2011. Threat's to California's urban forests: protecting community green infrastructure. California Trees 19, 1–4.
Maco, S.E., McPherson, E.G., 2003. A practical approach to assessing structure, function, and value of stree tree populations in small communities. Journal of Aboriculture 29, 84–97.
McBride, J., Jacobs, D., 1976. Urban forest development: a case study, Menlo Park, California. Urban Ecology 9, 245–266.
McPherson, E.G., 1998. Structure and sustainability of Sacramento's urban forest. Journal of Arboriculture 24, 174–190.
McPherson, E.G., Peper, P.J., 2012. Urban tree growth modeling. Arboriculture & Urban Forestry 38, 175–183.
McPherson, E.G., Rowntree, R.A., 1989. Using structural measures to compare twenty-two U.S. street tree populations. Landscape Journal 8, 13–23.
McPherson, E.G., Simpson, J.R., Peper, P.J., Maco, S.E., Xiao, Q., 2005. Municipal forest benefits and costs in five U.S. cities. Journal of Forestry 103, 411–416.
Michigan Department of Natural Resources, 2007. Emerald Ash Borer Community Preparedness Plan. IC 4106. Michigan Department of Natural Resources, Lansing, MI.
Miller, R.W., 2007. Urban Forestry: Planning and Managing Urban Greenspaces, 2nd ed. Waveland Press, Long Grove, IL.
Muller, R.N., Bornstein, C., 2010. Maintaining the diversity of California's municipal forests. Arboriculture & Urban Forestry 36, 18–27.
Nowak, D.J., Crane, D., Stevens, J., Hoehn, R., Walton, J., Bond, J., 2008. A ground-based method of assessing urban forest structure and ecosystem services. Arboriculture & Urban Forestry 34, 347–358.
Nowak, D.J., Hoehn, R.E., Crane, D.E., Weller, L., Davila, A., 2011. Assessing Urban Forest Effects and Values, Los Angeles' Urban Forest. Resource Bulletin NRS-47. U.S. Department of Agriculture, Forest Service, Northern Research Station, Newtown Square, PA.
Nowak, D.J., Pasek, J.E., Sequeira, R.A., Crane, D.E., Mastro, V.C., 2001. Potential effect of Anoplophora glabripennis (Coleoptera: Cerambycidae) on urban trees in the United States. Forest Entomology 94, 116–122.
Peper, P.J., McPherson, E.G., Mori, S.M., 2001a. Equations for predicting diameter, height, crown width and leaf area of San Joaquin Valley street trees. Journal of Arboriculture 27, 306–317.
Peper, P.J., McPherson, E.G., Mori, S.M., 2001b. Predictive equations for dimensions and leaf area of coastal Southern California street trees. Journal of Arboriculture 27, 169–180.
Raupp, M.J., Cumming, A.B., Raupp, E.C., 2006. Street tree diversity in Eastern North America and its potential for tree loss to exotic borers. Arboriculture & Urban Forestry 32, 297–304.
Richards, N.A., 1979. Modeling survival and consequent replacement needs in a street tree population. Journal of Arboriculture 5, 251–255.
Richards, N.A., 1982/1983. Diversity and stability in a street tree population. Urban Ecology 7, 159–171.
Santamour, F.S., 1990. Trees for urban planting: diversity, uniformity and common sense. Proceedings of the 7th Conference of the Metropolitan Tree Improvement Alliance, 57–65.
Shour, M., 2010. Iowa Emerald Ash Borer Readiness Plan. Iowa Department of Agriculture and Land Stewardship, Ames, IA.
Stephens, M., 2010. Tree procurement contracts: New York City's quest for amazing trees. City Trees 46, 10–12.
Sun, W.Q., 1992. Quantifying species diversity of streetside trees in our cities. Journal of Arboriculture 28, 91–93.
Svihra, P., McCain, A.H., 1992. Susceptibility of planetrees to anthracnose and powdery mildew in California. Journal of Arboriculture 18, 161–163.
Sydnor, T.D., Bumgardner, M., Todd, A., 2007. The potential economic impacts of emerald ash borer (*Agrilus planipennis*) on Ohio, U.S. Communities. Arboriculture & Urban Forestry 33, 48–54.
The Nature Conservancy, 2010. iMapInvasives, The Nature Conservancy, September 25, 2012, http://www.imapinvasives.org
UC Division of Agriculture and Natural Resources, 2012. UC IPM Online, UC Division of Agriculture and Natural Resources, August 11, 2011, httP://www.ipm.ucdavis.edu
UC Riverside, C.f.I.S.R., 2012. The Goldspotted Oak Borer, UC Riverside, Center for Invasive Species Research, November 1, 2012, http://cisr.ucr.edu/goldspotted_oak_borer.html
United States Census Bureau, 2000. State & County Quick Facts, United States Census Bureau, http://quickfacts.census.gov/qfd/states/06000.html
Urban Forest Ecosystems Institute, 1995–2012a. California Big Trees, Urban Forest Ecosystems Institute, February 11, 2011, http://www.ufei.org/Bigtrees/
Urban Forest Ecosystems Institute, 1995–2012b. SelecTree, January 25, http://selectree.calpoly.edu/
USDA Forest Service, P.S.R.S., Center for Urban Forest Research 2009. i-Tree Pest Detection, USDA Forest Service, September 25, 2012, http://www.itreetools.org/iped
Wait, D.D., 1986. Ornamental Plants: Their Care, Use Propagation and Identification. E.H.C, Modesto, CA.