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A collaborative approach to preparing for and reacting to emerald ash borer: a case study from Colorado

Kathleen Alexander[1,*], Micaela Truslove[2], Rob Davis[3], Sky Stephens[4] and Ralph Zentz[5]

[1]*Forestry Division, City of Boulder, Boulder, CO 80301, USA*
[2]*Department of Sociology, Colorado State University, Fort Collins, CO 80523, USA*
[3]*Office of the City Forester, City of Denver, Denver, CO 80202, USA*
[4]*Forest Entomologist, Forest Health Protection, United States Forest Service, Lakewood, CO, 80401, USA*
[5]*Forestry Division, City of Fort Collins, Fort Collins, CO 80521, USA*

*Corresponding author Tel: 303-441-3406; E-mail: alexanderk@bouldercolorado.gov

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Collaboration has been the key to success for urban forest management in Colorado, not only collaboration amongst agencies at all levels of government but also in engaging industry allies, coordinating education and outreach efforts and in fostering community support. A unique interagency team, the Emerging Pests in Colorado (EPIC) Workgroup, was formed in 2009 to address the immediate threat from Thousand Cankers Disease (TCD) of walnut and to plan for the arrival of other invasive urban forest pests to Colorado. When the emerald ash borer (*Agrilus planipennis* Fairmaire) (EAB) was detected in Boulder, Colorado in 2013, it marked the westernmost occurrence of EAB in the US, threatening millions of planted and naturalized ash trees representing over 25 percent of the tree canopy throughout Colorado's urban and riparian forests. The detection in Boulder prompted the development of a second multi-agency group, the Colorado EAB Response Team (CORT). The preparedness and established working relationships between stakeholders and responsible authorities allowed for a quick, decisive and unified response. We review as a case study: (1) the formation and history of collaborative interagency groups in Colorado; (2) how the interagency collaborative planning and post-detection EAB response have supported community forestry programmes throughout the state; (3) development of the post-detection EAB management plan and economics behind the strategy in Boulder, Colorado; and (4) the proactive EAB planning and outreach efforts underway in Denver, Colorado.

Background

Colorado, 1870, the beautiful evergreen and aspen forests in the Rocky Mountains stand starkly against the Great Plains. With the exception of a few native tree species such as Plains cottonwood (*Populus deltoides monilifera* Aiton) growing along creek corridors, the eastern half of Colorado was essentially treeless. Today, however, Colorado's Front Range Urban Corridor, which extends from the city of Fort Collins in the north to the city of Colorado Springs in the south (Chronic and Chronic, 1974; Figure 1), is home to a diverse urban forest containing millions of trees. The extensive urban tree canopy reflects a 150-year legacy of tree planting and the stewardship efforts of previous generations.

Few tree species can thrive in the harsh growing conditions in Colorado, which include extreme temperature fluctuations, early fall and late spring snowstorms, late spring freezes, high winds, drought and flash flooding. Although not native, green ash (*Fraxinus pennsylvanica* Marshall) has been planted in urban areas throughout Colorado for over 100 years due to its drought tolerance and ability to grow despite adverse site conditions and weather events. White ash (*Fraxinus americana* L.) has also been planted extensively in Colorado urban areas since the introduction of the 'Autumn Purple' cultivar in the late 1950s. The ease of availability in the nursery industry and beautiful fall colour have added to the popularity of ash and made it a dominant component of the Colorado urban tree canopy with an estimated 1.45 million ash trees in the Denver Metro Area alone.

In September 2013, City of Boulder Forestry staff detected emerald ash borer (EAB, *Agrilus planipennis* Fairmaire) in Boulder, Colorado. This was the first detection of the insect in Colorado, the western-most occurrence in North America and at the time, over 600 miles from the nearest existing infestation in Kansas City, Kansas, US. Since it was first detected in North America in Michigan in 2002, EAB has since killed hundreds of millions of ash

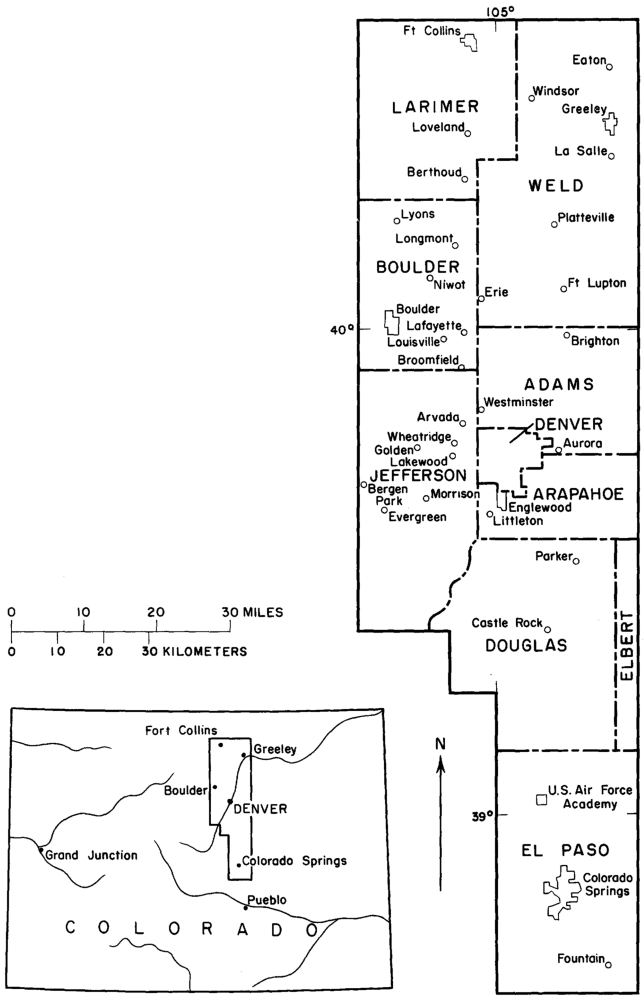

Figure 1 Map of the Colorado front range urban corridor.

trees across the Midwestern and Eastern US and Canada (Herms and McCullough, 2014).

Healthy urban trees provide environmental, economic and health services to communities including air quality improvements, energy savings, stormwater runoff reduction, atmospheric CO_2 reduction and can add thousands of dollars to property values (Anderson and Cordell, 1985). Human health benefits, including reduced incidence of cardiovascular disease and asthma, faster recovery from surgery, improved air quality and increased physical activity, are associated with urban trees (Ulrich, 1984; Frumkin, 2001; Tzoulas *et al*., 2007; Donovan *et al*., 2011; Lee and Maheswaran, 2011; Dadvand *et al*., 2012; Herms and McCullough, 2014). The estimated number of public, private and naturalized ash in Boulder is over 70 000 trees representing 25 percent of the urban tree canopy. The loss of ~25 percent of the urban tree canopy will have considerable economic, social and environmental impacts for decades. Lessons from colleagues across the Midwest indicated that EAB detection, response and management would present a long list of difficult challenges in addition to lost services, including a significant financial burden to individual property owners and at all levels of government from local municipalities to counties, state and federal.

Colorado is fortunate to have a long history of interagency collaboration amongst foresters. Several interagency working groups already existed at the time of initial EAB detection, and responders were able to build upon established connections. Ultimately, the determination of how successful the interagency collaboration has been in Colorado will be decided in the long term by the following: continued strong interagency collaboration within Colorado across city, state, county and federal levels during EAB response and for future pests; allocation of more resources directed towards urban forestry programmes in response to EAB; a greater awareness amongst Colorado residents on the importance of the urban forest and the potential impacts from invasive pests such as EAB; and successful creation of more resilient urban forests in Front Range Communities through improved tree species diversity, which would include a surviving ash component. For the short term, however, this article will present a case study from Colorado and seek to address the following questions:

- Did the preparedness actions and long-standing working relationships between stakeholders and responsible authorities allow for a quick, decisive and unified response?
- Did the outreach across the Colorado Front Range allow for increased contact with decision-makers and additional municipal resources allocated to EAB response?
- Did efforts by Colorado interagency working groups better position municipalities to respond effectively to EAB?

Creating interagency collaboration and supporting community forestry programmes

A Denver Metro Area urban forestry group was formed in 1980 at the suggestion of Colorado State University Extension to discuss pressing urban forestry issues. By 1985, this group had grown to include other Front Range foresters and became known as the Colorado Urban Forestry Council. Between 1985 and 1988, this council hosted a series of National Urban Tree Symposiums (NUTS) featuring national arboricultural experts, which facilitated information-sharing amongst Colorado foresters and other tree care professionals. The first NUTS symposium in 1985 attracted 230 attendees from 18 states and Puerto Rico.

Increased funding in the early 1990s from the USDA US Forest Service (USFS) Community Forestry Assistance Act of 1978 led to the formation of the Colorado Tree Coalition (CTC), a volunteer-run, non-profit 501(c)(3) organization with a mission to lead statewide efforts to preserve, renew and enhance community forests. CTC has multiple chapters across the state, but the most active is the Front Range Urban Forestry Council (FRUFC), which meets on a bimonthly basis to discuss pertinent urban forestry topics. The CTC works closely with partners such as the USFS, Colorado State Forest Service (CSFS), private utility provider Xcel Energy and corporate and private sponsors to provide programmes and services to communities across Colorado.

CTC programmes include the following:

- *Trees Across Colorado*: Facilitates the growing, purchase and delivery of low-cost shade trees to Colorado communities. This programme has been a successful fundraiser to support grants.

- *Grants*: Since 1991, the CTC has awarded 501 grants totaling over $844 000. These grants have been matched with over $7.8 million in funds and volunteer planting of over 74 110 trees throughout the state.
- *Insect and Disease Committee*: This working group meets throughout the growing season to discuss current issues impacting urban trees and provides reports to the entire Front Range urban forestry community.
- *Colorado TreeView (CO-TreeView)*: Developed by a private firm for the CTC, CO-TreeView (cotreeview.com/cotv) is a no-cost web-based tree inventory and mapping tool used by municipal forestry programmes and other organizations responsible for managing trees to record and map the location, species and condition of the trees that make up Colorado's urban forests.

These efforts provided platforms for engagement amongst scientists, municipal resource managers, educators and industry representatives. Transfer of technical information, shared observations, cross-boundary stewardship efforts and peer relationship development laid the foundation for future efforts like the Emerging Pests In Colorado (EPIC) working group (Table 1).

EPIC working group

In addition to harsh growing conditions, insects and diseases present challenges to Colorado's Front Range urban forest. Proximity to native forests, and those tree species' presence on the urban landscape result in cyclic outbreaks of native pests including mountain pine beetle (*Dendroctonus ponderosae* Hopkins), gambel oak borer (*A. quercicola* Fisher), Douglas-fir tussock moth (*Orgyia pseudotsugata* McDunnough) and several species of Ips beetles (*Ips* sp.). Combined with the difficult environmental growing conditions, the various native species of wood borers, defoliators and canker diseases increase mortality rates in the Front Range urban forests.

Invasive insects and diseases are not new to the Colorado landscape and have significantly shaped today's urban forest. Most notably, Dutch elm disease (DED), caused by the fungus *Ophiostoma ulmi* Buisman, was introduced into the state in the 1970s. Over the past 40 years, an estimated 30 000 American elms across the state were removed due to the disease. In 2005, Boulder, Colorado, was the first location nationally in which Thousand Cankers disease (*Geosmithia morbida* M. Kolarik, E. Freeland, C. Utley and N. Tisserat sp. nov.) of black walnut was identified (Kolarik *et al*., 2011; Tisserat *et al*., 2009). In 2010, Boulder first identified Drippy blight disease of red oak (Sitz *et al*., 2018), resulting from the co-occurrence of the bacterium *Lonsdalea quercina* subsp. *quercina* Hildebrand and Schroth in association with the kermes scale *Allokermes galliformis* Riley.

Prior to TCD causing mortality to black walnuts in Boulder, Colorado urban forests had only faced one significant invasive and deadly pest, DED. Municipal, county and state foresters had limited experience with state or federal quarantines and wood movement issues. By 2008, Boulder had lost over 800 black walnut trees on both public and private property and questions emerged around the potential movement of this infested wood into other states. Local foresters needed to learn quickly about state and national quarantines, legal requirements and authority over intra- and inter-state quarantines, as well as understand wood movement patterns (e.g. Jacobi *et al*., 2011), and associated risk on a local, regional and national scale.

The EPIC working group was formed from, and eventually replaced, the CTC Insect and Disease Committee in response to TCD. Initial attendees included Front Range city foresters, key personnel from the CSFS, Colorado Department of Agriculture (CDA), United States Animal and Plant Health Inspection Service Plant Protection and Quarantine (APHIS) and forest pathologists and entomologists from Colorado State University (Table 1).

The working group's purpose was to establish agency roles and responsibilities pertaining to invasive urban forest pests, quarantine scenarios and wood movement; foster communication amongst agencies; provide updates concerning distribution, spread and control options regarding pests of interest; coordinate the biennial invasive species and pest diagnostic workshops for the 'green industry' (foresters, arborists, and landscapers); and define and develop markets for urban wood.

Federal grant funding channelled through the CSFS was used by EPIC to raise the awareness of the threat of EAB and other invasive pests amongst green industry members. Specific activities included the development of pest factsheets for EAB, TCD and gypsy moth; the creation of an EAB community management plan template; and development of general guidelines for wood disposal when dealing with invasive pests in Colorado. In preparation for the arrival of EAB in Front Range municipalities, EPIC initiated and coordinated an invasive pest workshop focused primarily on EAB preparedness and education in June of 2013. In addition, EPIC members created a state response plan, the first draft of which was released in August of 2013, just weeks prior to the EAB detection in Boulder in September 2013 (Colorado Emerald Ash Borer Response Team, 2015).

EPIC members have supported two statewide efforts that have contributed to EAB management efforts in Colorado. In 2013, Denver secured funding to contract with the USFS and University of California, Davis to develop the Metro Denver Urban Forest Assessment Report (McPherson *et al*., 2013). Prior to the study, some metro area cities had public tree inventories but little data on the total number of public and private trees to aid in pest risk assessment. The study quantified the distribution of current tree canopy cover, estimated the total number of trees per community, mapped locations of potential tree planting sites and identified where tree plantings could best mitigate urban heat islands for the 29 communities that comprise the Denver Metro Area. Using data from the report, local foresters familiar with their own community forests estimated an average of 15 percent ash in most communities totaling ~1.45 million ash trees in the Denver Metro Area. This risk assessment has played a vital role in informing management decisions in response to EAB.

In 2016, the City of Fort Collins conducted a community-wide assessment of the urban forest utilizing the i-Tree Eco software suite developed by the USFS Northern Research Station and various partner organizations (i-Tree Eco, n.d.). This study revealed that although ash species represented 15 percent of that city's urban forest on a per-stem basis, ash trees comprised 33 percent of the total urban tree canopy cover, 26 percent of the carbon sequestration and 24 percent of the total carbon storage, further illustrating the importance of this cohort to Colorado urban forests (Davey Resource Group, 2016 (unpublished report)).

Table 1 Organizational composition of the interagency EAB response in Colorado.

Collaborating organization	Acronym	Organizational function	Organizational membership	Website
Boulder County		County	County forestry and communications personnel	www.bouldercounty.org
City of Boulder Forestry	COB	Municipal	City urban forestry personnel	EABBoulder.org
City of Denver Forestry		Municipal	City urban forestry personnel	BeASmartAsh.org
City of Fort Collins Forestry		Municipal	City urban forestry personnel	www.fcgov.com/forestry
Colorado Department of Agriculture	CDA	State	State regulatory personnel	www.colorado.gov/agmain
Colorado Emerald Ash Borer Incident Command Structure	EAB ICS	Initial interorganizational EAB response group	Federal, state, county, municipal, university and green industry representatives	
Colorado EAB Response Team	CORT	Current interorganizational EAB response group	Federal, state, county, municipal, university and green industry representatives	EABColorado.com
Colorado Nursery and Greenhouse Association	CNGA	Non-profit trade association	Retail and wholesale nursery and greenhouse operators, retail garden centres, academic institutions and government agencies	www.coloradonga.org
Colorado State Forest Service	CSFS	State	State forestry personnel	csfs.colostate.edu
Colorado State University and CSU Extension	CSU	State	University researchers and Extension personnel	www.colostate.edu
Colorado Tree Coalition	CTC	Non-profit	State and municipal forestry and green industry representatives	Coloradotrees.org
CTC Emerging Pests in Colorado workgroup	EPIC	Interorganizational collaborative workgroup	Federal, state, and municipal forestry representatives, university researchers and green industry representatives	
Front Range Urban Forestry Council Chapter of the CTC	FRUFC	Non-profit	Federal, state, and municipal forestry representatives, university researchers, and green industry representatives	
Green Industries of Colorado	GreenCO	Non-profit trade association	Alliance of 7 trade associations representing the Colorado horticulture and landscape industry	Greenco.org
International Society of Arboriculture, Rocky Mountain Chapter	ISA-RMC	International arboriculture professional association	Commercial arborists and other tree care professionals	isarmc.org
United States Department of Agriculture Animal and Plant Health Inspection Service Plant Protection and Quarantine	APHIS	Federal	Federal regulatory personnel	www.aphis.usda.gov
United States Department of Agriculture Forest Service	USFS	Federal	Federal forestry personnel	www.fs.fed.us
University of Colorado, Boulder	CU	State	University arborist personnel and university researchers	www.colorado.edu

Boulder EAB detection and Colorado response

Many Front Range communities had been using baited prism traps provided by APHIS for EAB detection since 2007 with no positive EAB detections. In 2012, the insect was detected in Kansas City, Kansas. This detection in a neighbouring state led to changes in EAB monitoring protocols within the City of Boulder. In 2013, Boulder Forestry staff began detection sampling of all

dead or dying public ash prior to removal. In September 2013, forestry staff found EAB adult beetles in the first dead ash tree sampled. In accordance with federal regulations, life stages of the suspected EAB were collected and sent to certified APHIS identifiers for positive identification.

APHIS, the agency responsible for administering the national EAB quarantine declared EAB in Colorado an 'incident' similar to a wildfire and applied the Incident Command System (ICS) (Bigley and Roberts, 2001; US Federal Emergency Management Agency, 2018). The ICS established an interagency communication protocol and developed mitigation and management strategies but also provided a structure to create and distribute public outreach materials. The EAB ICS was in place from September 2013 to April 2015. Administrative responsibilities then transitioned to the Colorado EAB Response Team (CORT).

Due to the need to respond rapidly, an issue-focused approach to stakeholder engagement (Colvin *et al*., 2016) was used to identify key stakeholders considered as essential in response to the detection of EAB in Colorado. These stakeholders were included within the CORT either due to their direct involvement in quarantine activities, because they represented industries or organizations that would be directly involved in managing infested trees and moving infested material, or would be impacted by regulations associated with the federally mandated quarantine. This included the core members from EPIC and representatives from the University of Colorado Boulder (CU), Boulder County, foresters from communities near the EAB quarantine area and liaisons from the Colorado Nursery and Greenhouse Association, Green Industries of Colorado and International Society of Arboriculture Rocky Mountain Chapter. Although the EPIC working group and the CORT shared many common members, the two had different goals. Unlike EPIC whose efforts were broader and addressed all emerging pests of concern, the CORT had a strict focus on EAB, and its objectives included coordinating the statewide EAB response, development of coordinated messaging, management of the EABColorado.com website, dissemination of research results and state quarantine administration.

Delimitation survey

Ash is one of the most abundant tree species in Colorado comprising ~15 percent of all deciduous trees in urban areas and ~12 percent in the City of Boulder (McPherson *et al*., 2013). The Metro Denver Urban Forest Assessment Report (McPherson *et al*., 2013) estimated that there were 656 000 public and private trees in the City of Boulder. Of the 51 000 total city park and public street rights-of-way trees, 6016 (11.9 percent) were either green or white ash at the time of detection with an appraised value of $14.6 million (City of Boulder public tree inventory data).

At the site of the original Boulder detection, there was one dead ash tree and five symptomatic trees, and the Colorado detection was over 600 miles from the nearest infestation in Kansas City, Kansas. APHIS personnel initially thought that EAB was detected early enough and that it represented an isolated outlier population and could potentially warrant eradication efforts. Outlier populations had been targets of eradication efforts in Michigan, Ohio, Indiana, Maryland and Virginia between 2003 and 2009 for small infestations with known origins well beyond the quarantine (Herms and McCullough, 2014). However, this idea was abandoned after initial visual surveys in nearby neighbourhoods detected other symptomatic trees.

The initial detection prompted a delimitation survey in Boulder to establish the boundaries of the EAB infestation and focus management efforts. Boulder Forestry staff collaborated with the CDA, APHIS, CSU Extension, Boulder County, CU and forestry staff from nine Front Range cities to collect samples and peel branches using branch sampling protocols developed by the Canadian Forest Service (Ryall *et al*., 2011). The Canadian Forest Service methodology was chosen due to Boulder Forestry staff's familiarity with the protocols gained during training in 2011 at the Society of Municipal Arborists conference in Milwaukee, Wisconsin. Additionally, Dr. Krista Ryall, co-developer of the protocol, presented the branch sampling process at a June 2013 EPIC sponsored Invasive Species Workshop in Fort Collins, Colorado.

The city was divided into a sampling grid consisting of 38 sampling units, with each unit being one square-mile in area. The centre point of the first grid was established using the first tree detection. Crews removed two, 3–4 inch diameter branches from each of 10 public ash trees within each sampling unit. The sample branches were taken mid-crown on the south or west (warmer) sides of each tree. Samples were labelled with a unique number indicating the sampling unit, the tree within the sampling unit and the branch within the tree. The bark was peeled from each of the branch samples using drawknives, and the wood examined closely for the presence of EAB larvae. All larvae found were sent to CSU for identification. A total of 768 branches were peeled representing 384 public ash trees sampled. The Canadian Forest Service protocol was modified to include only public ash trees due to the difficulty in obtaining samples from private ash trees. Obtaining permission from private property owners is difficult because 52 percent of properties in the city of Boulder are non-owner occupied (City of Boulder, 2018a).

The survey started on November 4, 2013, and was completed on January 15, 2014, with over 1000 hours invested by 15 different federal, state and local agencies. EAB was detected in five grids in central Boulder, but due to the flight ability of the insect, difficulty in detecting low-level populations, and rate of spread in Midwest communities, it was assumed other parts of Boulder were likely infested at low pest populations.

The CORT, in coordination with city and county foresters, continued trapping and sampling symptomatic trees in other parts of Boulder County as well as in other counties along the Front Range. EAB has since been detected within the original quarantine boundaries in the cities of Longmont in 2016 and Lyons in 2017 by local arborists, Lafayette in 2017 by Boulder County staff and Superior in 2018 in a green prism trap. In 2019, EAB was detected in three additional counties adjacent to Boulder County. It was found in the cities of Broomfield (Broomfield County) by a local resident, Westminster (Adams County) by the city forestry staff and in Berthoud (Larimer County) by an arborist.

Public and industry outreach

The goals of outreach efforts were to:

- teach research-based EAB detection protocols to public and private urban forest managers to aid in detection efforts in communities outside of Boulder;

- raise awareness regarding potential impacts of EAB on communities;
- provide research-based information to the public to aid in management decisions, reduce inappropriate pesticide use and encourage homeowners to make management plans for privately owned and managed trees; and
- discourage movement of infested material to reduce human-assisted spread of the insect to communities outside of the EAB quarantine area.

Though individual agencies may have done so for their respective outreach programmes, joint metrics to evaluate the efficacy of CORT outreach efforts were not in place when outreach activities were occurring; however, this is an important consideration when making decisions regarding efficient resource allocation.

The CORT produced and distributed information to both the green industry and general public, but due to limited resources, CORT efforts were focused on industry education using a 'train the trainer' approach to broaden outreach efforts. In addition to news releases, media inquiries and the state managed website, interagency efforts since the pest discovery include presentations to decision-makers, homeowners and industry groups. In addition, a series of diagnostic and detection workshops were implemented in 2013–2016. Over 450 foresters and landscape professionals from six states were trained in EAB diagnosis and detection methods. During driving tours in Boulder in 2016–2017, over 360 decision makers, foresters and other resource managers and landscape professionals from across Colorado, Nebraska and Wyoming interacted to discuss community impacts and field diagnosis. The CORT team was awarded a Team Collaboration Award from Colorado State University Extension for their work on the delimitation survey and detection workshops.

Boulder EAB strategy and economics

The City of Boulder Forestry workgroup directly maintains 51 000 public trees in city parks and street rights-of-way with a total appraised value of over $110 million. The workgroup consists of a staff of seven foresters with a 2018 budget of $1.5 million. The Forestry workgroup is responsible for all aspects of public tree care including planting, pruning, removals, integrated pest management, tree risk assessments, inventory, development review and tree protection. Arborist licensing, public education and enforcement of diseased and dangerous tree codes allow the workgroup to influence management of an estimated 600 000 trees on private property (McPherson *et al*., 2013) since the city does not have jurisdictional authority to directly manage these trees.

The public component of Boulder's urban forest provides nearly $5.2 million in annual environmental, economic and social services benefits ($50.39 per capita, an average of $102.48 per tree). These beneficial services include air quality improvements, energy savings, stormwater runoff reduction, atmospheric CO_2 reduction and contributions to the social and economic health of the community. Boulder's urban forest reduces electric energy consumption by 3909 MWh and annual natural gas consumption by 137 736 therms, for a combined annual value of $442 432. In addition, these trees remove 17.2 tons of pollutants from the air, including ozone (O_3), nitrogen dioxide (NO_2), sulphur dioxide (SO_2) and particulates (PM10) for an overall annual air quality benefit of $66 282. The urban tree canopy from the public trees covers 651 acres. This canopy reduces annual stormwater runoff by more than 30.6 million gallons and protects local water resources by reducing sediment and pollution loading. To date, Boulder's community trees have sequestered 36 892 tons of carbon. They continue to sequester an additional 2254 tons of carbon each year for an annual net benefit valued at $43 084. (Davey Resource Group, 2015 (unpublished report)).

Immediately following the detection of EAB, emails and phone calls received by the Boulder Forestry workgroup regarding the city's response and management strategy indicated public opinion was polarized. Some were concerned about the impacts of pesticides on the environment and non-target organisms, whilst others were focused on ash tree preservation. Boulder Forestry chose not to rush to adopt a long-term EAB plan but rather enacted a short-term emergency response to the pest during 2014–2015. The delay allowed for a more deliberate planning approach that included gathering information about other cities' management strategies and soliciting public input. The short-term response included increased tree planting, removals of public ash in poor health, the release of biocontrol agents and limited use of the insecticide emamectin benzoate in the five grids where EAB was detected during the delimitation survey.

To aid in development of a long-term EAB Strategy, Boulder Forestry consulted with US and Canadian EAB researchers for guidance on EAB management strategies and to gain information about possible differences in the insect's behaviour in Colorado. Boulder formed a city EAB Interdepartmental Strategic Team to develop a long-term strategy to manage EAB and ensure consistency across other city departments managing ash trees. In 2013–2015, Boulder Forestry requested information from several cities in the Midwest currently dealing with EAB including Madison and Milwaukee, Wisconsin, Kansas City, Kansas and Des Moines, Iowa (pers. comm with city foresters). Information requested included the scope of forestry operations, number of ash trees each city managed, specific EAB management strategies used such as pesticide usage and timing of removals, outreach methods utilized and how each city was addressing wood disposal. Commonalities existed such as pesticide usage, need for ash removal prior to tree mortality to prevent failures and an increased need for outreach. However, cities differed on the percent of public ash treated, aggressiveness of tree removals, wood disposal options and outreach methods utilized (Table 2).

Previous complaints from residents following both tree removals and pesticide applications indicated neither was a popular choice within the City of Boulder. Discussions with city foresters in Wisconsin, Kansas and Iowa (pers. comm with city foresters) however, revealed they employed a combination of tree removals and pesticide applications. This was consistent with (Liu, H. 2013) who discussed the management within 12 Pennsylvania communities that included removals to mitigate risk, pesticide application to preserve high-value ash trees and an emphasis on tree planting, and (Sadof, 2017) who found a

Table 2 Municipal EAB strategies.

City	Scale	Treatment plan (public trees)	Public awareness efforts					Disposal practices
			City website	Public service announcements and media releases	Door hangings/ fliers/signage in town	Toll-free phone line	Informational workshops	
Milwaukee, WI (detected in July 2012)	• ~ 33 000 ash on public streets • ~587 000 ash trees at risk in Milwaukee (17% of all trees in state)	• Treat 80% (27 000 trees) of public ash street trees. • Only treat trees >8″ diameter (2-year rotation – 50% annually) whilst transitioning to alternative species.		✓	✓			• No public information.
Kansas City, MO (detected in July 2012)	• ~20 000 public ash • 400 000 private ash • 4.6 million+ ash in Greater Kansas City's nine county region	• Partial treatment and removal • Continued monitoring • Replace lost tree canopy	✓	✓	✓	✓	✓	• Two disposal sites for residents and local businesses. • Develop new disposal site, operated as public/private partnership.
Des Moines, IA (detected in November 2013)	• 47 000 public ash • ~ 100–120 k private ash	• Treat 45% (14 000 trees) of 'high impact' public street and park ash trees. • Removal of large ash w/poor structure and most small ash. • Remove 6000 public ash not suitable for treatment over next 6 years. • Plant replacement trees.	✓	✓	✓		✓	• Temporarily disposing at city marshalling yards. • Final solution uses MWA Compost Centre and/or landfill.
Madison, WI (detected in November 2013)	• 21 700 ash street trees, estimated 30 000 ash in parks and many thousands more on private property	• Treat 50% (10 000 trees) of public ash street trees. • Only treat trees >10″ diameter in good condition. • Preemptively remove street trees in poor condition or under power lines. • Replace removed trees.	✓ Very extensive 'Homeowner's toolkit online	✓	✓			• Residents have option of free wood drop off at city recycling centre; keeping wood at home for wood or mulch or work with certified arborist to properly dispose of material • The Sawmill Project: The Streets Division received grant from the Wisconsin Department of Natural Resources to lease portable sawmill – for 2 years, the City of Madison will work with Dane County and other interested municipalities on testing market for lumber made from urban trees, including those that are removed due to the EAB.

Continued

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City	Scale	Treatment plan (public trees)	Public awareness efforts				Disposal practices
			City website	Public service announcements and media releases	Door hangings/ fliers/signage in town	Toll-free phone line	Informational workshops	
Loveland, CO (not officially detected yet)	• 800 city park ash trees	• Preemptively remove very young and old ash • Identify heritage trees to treat and preserve. • Removal and replacement are one process; if they cannot replace, they will not remove.		✓				N/A
Boulder, CO (detected in September 2013)	• 6000 public ash street and park trees • Estimated 70000+ private and naturalized ash • More than 1.45 million ash in metro Denver area	• Treat 25% (1500 trees) of significant public ash; 500/year on 3-year rotation). • Only treat ash >10″ diameter. • Proactively removing ash in poor condition. • Remove remaining 4500 public ash as they get infested. • Plant replacement trees.		✓	✓	✓	✓	• All chips and logs from public trees brought back to city Forestry wood lot; desirable species milled or chipped and utilized for biomass via Boulder County MOU; larger stumps tub ground into mulch for city use. • For private tree removals, residents have option of keeping wood or mulch at home or work with licensed certified arborists to properly dispose of material (each company different); residents may also bundle branches for curbside compost or participate in yard waste drop off for wood <6″ diameter.

combination approach was the most palatable for the City of Indianapolis, Indiana.

Boulder Forestry used the information collected from the above resources and gathered input from the community through three public open houses and numerous presentations to homeowner groups to develop a long-term strategy for EAB management in Boulder. The strategy balanced tree removals and pesticide applications and included increased tree planting, proactive removal of ash trees in poor condition followed by removal of ash as they became symptomatic, selective treatment of public ash trees, release of biocontrol agents, a varied approach to wood disposal and increased public outreach. Boulder Forestry then developed six main themes for EAB management in Boulder that included the following: protect public safety and minimize liability; maintain a healthy, diverse and sustainable urban forest; maintain or increase the urban tree canopy to maximize the environmental, social and economic services provided to Boulder; minimize risks to non-target organisms from pesticide applications; minimize costs; and minimize disruption to other forestry operations. Case studies have shown that a well-conceived ash management plan makes sense economically, socially and ecologically (Liu, 2018). Staff presented the proposed EAB management strategy to Boulder City Council in October 2015 and received unanimous support.

The City of Boulder approved funding for the EAB programme through the Capital Improvement Program budget rather than the city's general operating budget to ensure a stable funding source. The approved funding for all EAB activities is $4 520 000 for 2015–2025 with an average annual expenditure of $410 900. Funding past 2025 is planned, but specific allocations have not yet been established to provide flexibility as the infestation progresses.

Over the next 10 years, EAB management will have a significant direct budgetary impact, not only to the city government but also to city residents, as most ash trees are located on private property.

Tree inventory and urban tree canopy analysis

At the time of EAB detection in 2013, the Boulder public tree inventory was 13 years old. A crucial starting point for any EAB long-term strategy is a current public tree inventory and benefit analysis (Liu, 2013). To update basic tree inventory data such as tree location, species, size (diameter at breast height (DBH)) and tree condition for every public tree, Boulder Forestry piggybacked off an existing tree inventory contract through the City of Denver to procure a consultant. The inventory data was imported into an asset management programme (AMP). Updated inventory data and the use of an AMP were critical to determine where to focus planting and treatment efforts, estimate future costs and track all maintenance performed. The same consultant developed an Urban Forest Resource Analysis report to provide a 'snapshot' of the current population, structure, condition and services provided by Boulder's urban forest resource. Boulder Forestry collaborated with Trimble and Digital Globe, partners of the Rockefeller Foundation's 100 Resilient Cities initiative, to complete an analysis of the existing urban tree canopy and establish a baseline figure prior to significant mortality due to EAB. Using LiDAR data and aerial imagery from 2013, the analysis showed Boulder had an average canopy cover of ~16 percent.

Planting

To adequately maintain the tree canopy, it is imperative to plant trees in anticipation of losses. Since the 2013 detection, Boulder Forestry has planted 2508 trees on public property, an average of 500 trees annually, focusing on neighbourhoods most heavily impacted by the beetle. An additional 400 trees on average are planted annually on public property through private development and city Parks and Transportation projects. A minimum of 36 unique species are planted annually, and an average of 87 percent of newly planted trees are large-maturing shade trees to maximize environmental services. The average cost to purchase and plant a 2″ caliper tree is $400, and annual planting costs are ~$200 000. Even with the increase in planting efforts, tree removals have continued to outpace planting.

Trees purchased for public tree planting projects in Boulder are obtained from multiple sources. An increasing number of tree species are grown at nurseries within Colorado such as catalpa (*Catalpa speciosa* Warder), thornless honeylocust (*Gleditsia triacanthos var. inermis* L.) and swamp white and bur oak (*Quercus bicolor* Willd., *Quercus macrocarpa* Michx.); however, to maximize species diversity, it is necessary to import species that cannot be grown economically in Colorado such as sugar maple (*Acer saccharum*), yellow buckeye (*Aesculus flava*), white oak (*Quercus alba*) and London planetree (*Platanus x acerifolia* Aiton). Local nurseries routinely import tree stock from IL, KS, MN, MO, OR, TN, WA and WI (Laura Pottorff, CDA, personal communication, May 2019). The CDA enforces the Colorado Nursery Act, which regulates the sale and distribution of all plants in Colorado to provide consumer environment and industry protection against insect, disease and weed pests. The CDA issues a certificate of inspection or plant health certificate for all nursery stock entering Colorado stating that the material is apparently free from insect pests and plant diseases. Despite the protections, the biosecurity risk is high as many pests are moved in nursery stock and may be difficult to detect during certain life stages (Colorado Revised Statutes, 2018 (Title 35 Article 26)).

Removals

Research indicates expected mortality of untreated green and white ash in infested areas can exceed 99 percent (Klooster *et al*., 2014). Observations from foresters in the Midwest indicate ash trees killed by EAB dry out, become brittle and start to fail within a few years of mortality; therefore, tree removals are a critical component of a city EAB management strategy. Prior to the rapid decline of public trees due to EAB in 2016–2018, the focus was on removal of ash in poor condition, those compromised by other insect pests, high risk ash trees, trees with poor placement (e.g. under power lines), those with poor structure and any topped or improperly pruned ash trees. Ash trees were also being phased out through private development and city projects. By 2016, when ash mortality due to EAB was becoming prevalent, the focus shifted to removal of untreated ash trees exhibiting any signs of EAB infestation. Since the initial detection, 1806 public ash trees have been removed at an average cost of $366/tree. The estimated contracted removal cost

for the remaining untreated public ash trees is ~$1.54 million. The number of private property ash trees removed to date is not known.

Pesticides

Pesticides are an important component of EAB management programmes as they can preserve ash trees, reduce EAB populations via mortality of adult beetles during maturation feeding, spread tree removal and replacement costs over a longer time period, reduce public safety concerns associated with large numbers of dying trees and spread the loss of environmental services provided by the urban tree canopy over a longer period of time (McCullough and Mercader, 2012; Vannatta *et al*., 2012; Herms and McCullough, 2014; Kovacs *et al*., 2010). Criteria for treatment of public ash trees in Boulder include good tree health and condition, free from major defects, a minimum of 10-inches diameter at breast height, good location and the presence of a functional irrigation system. Research has shown that one pesticide product with the active ingredient emamectin benzoate has provided up to 3 years of nearly 100 percent EAB control in some trials (Herms and McCullough, 2014). The goal is to treat 25 percent of public ash trees total on a 3-year rotation with emamectin benzoate. The average size of treated trees is 17″ DBH. Property owners are allowed to treat public ash trees adjacent to their properties if the tree meets the above criteria for public treatments. The cost to treat approximately one-third of the 25 percent of selected public ash trees annually with emamectin benzoate is $45 000 or an average of $5.49 per diameter inch (measured as DBH).

Biocontrols

APHIS rears the EAB biocontrol agents for release in infested areas and provides them at no cost to cooperators. In Boulder, the larval endoparasitoid *Tetrastichus planipennisi* Yang was released in 2014–2016; the egg parasitoid, *Oobius agrili* Zhang and Huang, was released over a 6-week period in both spring 2015 and 2016; larval ectoparasitoid *Spathius agrili* Yang was released in 2015–2016; and larval ectoparasitoid *Spathius galinae* Belokobylskij and Strazanac was released in 2015. The release sites in Boulder contain naturalized green ash within creek corridors where infested, dying trees pose little threat to public safety. The City of Boulder, along with Syracuse, NY and Naperville, IL, was invited to participate in a 6-year research study involving EAB biocontrols. The research question centres on the effectiveness of the combination of insecticides plus biocontrol releases to assess if chemical treatment will protect ash trees long enough for parasitoid populations to sufficiently increase in order to protect larger diameter ash trees (Gould *et al*., 2018).

Wood disposal and utilization

There are challenges to the utilization of urban wood including low quality, inconsistent quantity, lack of utilization plans, logistical challenges, quarantine restrictions and lack of local sawmills and kilns. Within urban settings, trees tend to grow around nails, fences and cables, potentially decreasing the wood quality and damaging wood processing equipment. Many urban trees also lean over homes and other hardscapes, posing safety concerns during tree removal operations prompting tree care companies to remove smaller and less marketable sections of wood (Nash, 2009). Prior to 2014, all logs and chips generated from Boulder Forestry operations were stored at the city's operations facility and were ground into mulch, which was either utilized within the city's parks system or moved offsite for composting by an outside vendor, a practice that continues today. Boulder also utilizes chips in biomass fuel boilers at two Boulder County facilities, partners with a local company to turn ash logs into wood pellets and mills logs for public sale. Despite these diversion tactics, disposal costs for 2017–2018 exceeded $100 000.

Enforcement

Existing Boulder city code allows staff to conduct enforcement efforts on private property to address hazards posed by infested, diseased and/or dangerous trees. Discussions with the Boulder Risk Management office indicated the city has a duty to enforce city regulations for dead ash trees located on private property but have the potential to threaten public property. Boulder Forestry identifies private property dead ash trees during a summer survey and enforces removal as needed. Prior to the EAB detection, Boulder Forestry enforced on an average of 10 properties annually for dangerous trees. Since 2013, the number of enforcements rose from 9 in 2015 to 82 in 2016, 118 in 2017 and 182 in 2018. The number is expected to continue to rise as EAB populations and tree mortality increase across the city.

Urban Forest Strategic Plan

Many EAB-related factors such as tree diversity, pesticide use and challenges associated with wood utilization are not unique to EAB and are applicable to other tree species and pests. Therefore, instead of developing just an EAB-specific Management Plan for the city, Boulder Forestry developed a broader Urban Forest Strategic Plan (UFSP) that includes long-term management for invasive pests including EAB. The results from the extensive UFSP-specific public outreach helped inform the recommendations, priorities and implementation strategies for the UFSP and informed a marketing plan focused on cultivating long-term stewardship of Boulder's urban forest. The UFSP was formally approved in June 2018 (City of Boulder, 2018a, b).

Education and outreach: EAB and UFSP

Outreach is a critical component of response to an invasive tree pest to not only educate the public about management options available regarding private trees but also to solicit input and garner support for citywide plans for pest response. The CORT has produced numerous public media news releases, and its members have participated in over 150 media interviews since the initial detection.

In addition to outreach and public engagement through the collaborative statewide response, Boulder Forestry performed extensive outreach to support both the citywide EAB response and solicit input for the UFSP process. Between 2016 and 2018, efforts were undertaken to actively engage the community on threats to the urban tree canopy and options to achieve urban tree canopy goals. These outreach activities follow an evolution

of engagement that began with expanding the public's awareness and understanding of the urban forest and the role of Boulder Forestry, and moved towards encouraging the public to become advocates, acting to help preserve and maintain their urban forest.

A city website was created containing Boulder-specific EAB information, maps with public ash tree data and an EAB story map. Staff attended meetings of homeowner associations, organizations made up of the residents of a subdivision tasked with the creation and enforcement of rules for the neighbourhood, to educate and gain public support for the city's EAB Response Strategy, hosted public information sessions and staffed information tables at city events and retail outlets. Boulder Forestry also provides consultations to local businesses and homeowners to discuss ash replacement and EAB management and provides annual presentations to citizen advisory boards. The City Forester has also participated in study sessions with Boulder City Council to provide updates and solicit targeted feedback. Ongoing public education is accomplished through public notification during tree maintenance activities such as letters about pesticide applications and the placement of door hangers about planned ash tree removals. The City also formed a forestry technical working group to discuss options for both the UFSP and the potential for forming a volunteer urban forestry stewardship programme.

Deferred maintenance

Discussions with Midwest foresters currently dealing with EAB indicated a need to prioritize EAB over other forestry-related work, due to the large number of trees that will be impacted, the documented rate at which EAB populations build and kill trees and the potential liability from the large number of standing dead ash trees (City forestry staff, personal communications, 2013–2015). Deferred maintenance presents a significant opportunity cost to urban forestry programmes as staff time is increasingly directed to EAB management and control. Whilst funding for Boulder Forestry has increased since 2014, EAB response and recent weather events have also required managers to reallocate maintenance budgets to respond to these emergencies to reduce public safety risk. As a result, pruning rotations have been extended from 8 to 10 years for city park trees and from 10 to 15 years for public street right-of-way trees. As more money is allocated to higher priority tree removals and storm damaged trees, less is available for routine pruning. Costs for contracted tree work have risen since detection, placing further strain on Boulder's urban forestry budget. For example, tree removal costs for trees $<15''$ DBH have risen an average of 75 percent and 36 percent for trees $>16''$ DBH since the EAB detection. Discussions with local tree care companies indicate the increase in costs is due to demand for services due to EAB and damage from recent weather events, labour shortages, local cost of living, quarantine restrictions and adjusting tree maintenance practices to address greater risk associated with EAB-infested trees.

Grants and partnerships

Even with additional EAB funding, there is not enough money to meet community expectations. The City of Boulder has received grants and has formed partnerships to increase funding to grow programmes. Some examples include the TreeOpp programme, a wood utilization project funded by a $200 000 grant. This is a partnership between Boulder Forestry, the Boulder Public Library and the Ready to Work programme at Bridge House, an organization that helps homeless adults re-enter the workforce. Ash trees are transformed into lumber, art and usable goods through woodworking apprenticeships and job training programmes. The participants raised awareness about EAB by sharing information with over 2000 community members at public markets and workshops. Kiln-dried ash wood is also sold to the public through a local recycler.

The Boulder Tree Recovery Program was funded through the Arbor Day Foundation, a national nonprofit conservation and education organization dedicated to tree planting and supported by members, donors and corporate sponsors. The programme provides 285 1-gallon trees, each ~1–1.5 feet in height, annually to residents, encouraging tree planting on private property and fostering tree diversity. The Boulder Tree Sale results in the sale of over 150 15-gallon trees, each ~8 feet in height, to city residents annually. Tree costs are subsidized through the city's Forestry, Climate Commitment and Water Conservation Programmes.

Proactive EAB planning in Denver

DENVER recognized 5 years prior to the Colorado EAB detection the need for increased tree diversity to improve resilience to invasive species. In 2008, the city removed all species of ash from its approved street tree planting list. In 2012–2014, funding was secured to update the city tree inventory and produce the Metro Denver Urban Forest Assessment to provide Denver and its 28 neighbouring municipalities with baseline canopy cover data and create an opportunity to educate leadership on the value of, and potential threats to, the urban forest.

As of early 2019, EAB had not yet been detected in Denver. City government officials understood, however, that EAB impacts would range from public safety risks to environmental health impacts to decreasing property values; therefore, the city leadership viewed EAB as a broader city-wide issue rather than a forestry problem. In 2014, an interdepartmental steering committee established five keystone elements to build Denver's plan of action including engaging in a powerful education campaign, protecting qualified ash trees through a chemical treatment programme, establishing a proactive replacement programme ahead of tree loss, developing strategies to encourage the planting of trees on private property and evaluating wood utilization strategies.

Denver Forestry organized a tour to the Midwestern US in 2015 to learn from the experiences of municipalities impacted by EAB including Chicago, IL, and both Milwaukee and Madison, WI. The Denver contingent included staff from Denver Forestry, the Budget Management Office, the Mayor's Office of Sustainability, the Office of Communication and Marketing and a member of City Council. The group spent a week meeting with host cities, learning about their programmes, and touring impacted areas.

The tour successfully justified and secured an annual $2.9 million Forestry budget expansion in 2016, increasing the programme's general fund budget by 90 percent. Funding

included nine additional positions, the completion of an inventory for all 187 000 Denver street trees, support for proactive street tree planting with a goal to plant a diverse palette of 3300 new trees annually, a preventative EAB treatment programme for 9000 public ash trees, ~30 percent of their public ash tree population, on a 3 year rotation with emamectin benzoate, increased contracted services for woody debris recycling and support to contract with a professional marketing company on a public awareness campaign.

The public tree inventory update included data on private properties with visible ash trees. The knowledge that 36 000 private parcels included at least one ash tree helped strengthen the message to city leadership that Denver must substantially increase EAB education efforts. In 2016, Denver launched the 'Be a Smart Ash' campaign to encourage residents to act by identifying ash trees and making a plan for treatment, tree replacement or removal. The marketing team recommended moving away from more traditional EAB education plans and created a user-friendly webpage (www.beasmartash.com). An integrated campaign utilizing direct mail to every homeowner in the city with an ash tree in the right-of-way and media outreach with ad placements in print and on radio and TV stations increased website traffic. Branded items including T-shirts, stickers and magnets were distributed at community events. Bus tail ads, posters, digital and pay-per-click ads, Be A Smart Ash tree tags and wraps for treated public ash trees, a dedicated Twitter account (@BeASmartAsh) and content on neighbourhood social networking accounts will continue to raise awareness and drive traffic to the website throughout the 5-year campaign.

The team developed marketing materials to generate public awareness, including animated videos, free leaf recycling bags with an ash identification infographic and Spanish language outreach (www.protejamoslosfresnos.org). Additionally, Denver Forestry collaborated with the Denver Botanic Gardens to create an original EAB song and a music video.

The success of the Be A Smart Ash campaign is being tracked through internal engagement report metrics. In 2017–2018, the website had 238 508 unique pageviews, 1.7 million users engaged via social media platforms and more than two-thirds of Denver residents were reached through the advertising campaign. Although targeted towards Denver residents, the entire Front Range region shares media outlets, so the campaign has had a region-wide impact.

Lessons learned from EAB in Colorado

Collaboration

Collaboration amongst peer agencies rooted in professional respect and focusing on open communication were critical to Colorado's success in preparing for the arrival of EAB. Clarifying agency roles, responsibilities and limitations in advance of detection hastened response and education efforts. Collaborative interagency teams can aid in detection efforts, research best management practices and develop education and outreach materials and response plan templates to aid local and state governments. Communities directly affected by pest detections are often rapidly overwhelmed by the demands of pest response and management, media requests and need for public outreach. An established collaborative team can help provide initial guidance and consistent up-to-date information, so communities can focus on management activities.

Detection

EAB is very difficult to detect in its early stages because ash trees exhibit no symptoms when initially infested (Anulewicz *et al.*, 2007). By the time an ash tree is declining, multiple generations of beetles have emerged and colonized new ash trees (Siegert *et al.*, 2010; Mercader *et al.*, 2012). A variety of techniques should then be utilized to improve the probability of detection. Investment in continuous detection efforts of highly damaging invasive species can result in cost savings (Mehta *et al.*, 2007). EAB was detected in Colorado communities through various means including sampling of declining and dead trees during routine maintenance activities, tips from tree care companies and trapping.

Targeted surveys using ash branch collection and peeling to detect larval stages are helpful in delimiting EAB populations in early infestation and in focusing management efforts but are time consuming. A single municipality may not be able to conduct a survey on its own without assistance from other agencies or volunteers due to workload and resource limitations.

Planning

Understanding the resource at risk, education and engagement of leadership, partnerships, industry education and public awareness are key. Up-to-date tree inventories permit resource managers to better assess risk, develop cost estimates and plan response measures. If possible, municipalities should document the presence of ash on adjacent private property to infer the expected level of private property impacts. Conducting an urban tree canopy assessment will allow managers to develop a canopy cover baseline, set canopy goals and track canopy change over time. Furthermore, resource managers should assess and update current local tree ordinances and regulations beforehand in order to strengthen tree diversity requirements, develop and strengthen industry licensing programmes, and protect against extensive canopy loss.

The clear message received from the varied management plans and stories shared when speaking to or visiting Midwestern cities was to plan now rather than waiting until EAB arrives. Develop a local plan and choose to proactively manage the issue. Management plans will necessarily be place-based, and their components will vary depending upon the value and condition of the ash resource and the value residents placed upon community trees.

Colorado cities including Boulder, Denver and Fort Collins have received additional staff and funding due to EAB planning efforts. Urban forestry programme managers can take measures to educate political and business leaders and the public regarding the importance of the urban tree canopy. During the EAB response, Colorado city foresters increased contact with upper level municipal or state decision-makers, the media and other agencies and used these contacts to promote urban forestry. Efforts are underway in these cities to explore options to assist low income and other vulnerable populations with EAB-related costs, including reforestation, which can be significant (Kovacs *et al.*, 2010,

Vannatta *et al*., 2012). Heynen *et al*. (2006) found that inequalities in urban reforestation efforts following urban canopy loss due to invasive species attacks and other factors can have lasting negative impacts on marginalized populations. Furthermore, these populations can be impacted by unscrupulous business practices, so promoting industry professionalism is of paramount importance to protecting vulnerable residents.

Management

Coordinating removals, pesticide applications, wood utilization operations and sourcing tree stock at a regional rather than a local scale can improve economies of scale. Collaborating with neighbouring municipalities or piggybacking off other governmental contracts may reduce staff time, streamline operations, reduce expenses and prevent competition for a limited number of available contractors by cooperatively soliciting for contracts. Experience in Colorado indicates honouring arborist licenses from nearby communities reduces staff time and is preferred amongst arborists due to reduced testing and paperwork.

Proactively removing untreated ash trees during routine management and development projects can improve efficiency. Observations indicate ash trees killed by EAB dry out, become brittle and start to fail within several years after mortality. Allowing trees to reach the point of failure is unacceptable from the standpoint of public safety. Consistent with the observations of researchers and municipal foresters in the Midwest, pesticides have been effective in Boulder at slowing EAB population growth allowing for longer term management rather than reacting to a backlog of dead, dying and often hazardous trees (Herms and McCullough, 2014).

Economics and partnerships

When dedicated EAB management funding is not available, or available at an insufficient level, creative ways can be found to generate revenue, decrease costs and fund new opportunities through partnerships and grants. Examples could include funding ash removal and replacement projects in natural areas through conservation and restoration budgets and finding unique opportunities to utilize or even sell wood products rather than dispose of it in more traditional ways.

Often the majority of urban tree canopy is on private property. Because municipal forestry operations are stretched during EAB management, fostering local private non-profit partnerships can help support tree planting and care efforts on private property. Two successful Colorado examples include the CTC Trees Across Colorado programme to facilitate the growing, purchase and delivery of low-cost shade trees to Colorado communities and the partnership between the city of Boulder and a local recycler to mill and sell urban lumber to residents. Municipalities should look for options to help defray costs for those in lower income neighbourhoods for tree planting, pesticide treatments and removals.

Although the financial contributions due to agency collaboration were not tracked, anecdotally the involved agencies were able to leverage the collaborations to save resources such as money and staff time. Outreach and media requests were spread amongst multiple agencies reducing the demand upon a single agency point of contact. The development, production and printing of outreach materials was divided and shared, and materials were distributed regionally, so all involved agencies and communities benefitted. Other municipalities were able to utilize and apply data and outcomes from the Metro Denver Urban Forest Assessment Report and Fort Collins i-tree analysis for risk assessment within their own community without the additional expense of contracting the service. Municipalities have been able to save money by participating in bulk purchasing of tree stock or the CTC grant programmes and reduce staff time by piggybacking on other governmental contracts for tree inventory, pesticide applications and chip hauling.

Outreach

Provide up-to-date information on local government websites regarding pesticide options, appropriate replacement tree species and local licensed and insured tree care companies to prepare for an increase in public relations. Defining and implementing communication protocols in advance to engage appropriate stakeholders, facilitate information exchange and develop consistent messaging amongst different levels of government and the public is also important. Public awareness does not always equate to action by individual private property owners, but broad communication about the issue may motivate policymakers, community foresters, homeowner associations and other decision-makers to act. Last, develop metrics to evaluate the efficacy of different outreach and engagement activities to determine where limited funds and resources are best directed.

Conclusion

The environmental, social, health and economic services of urban forests are well-documented (Dwyer *et al*., 1992; McPherson *et al*., 2005, 2013). Urban foresters are tasked with managing the municipal tree resource to maximize these services whilst managing risk and minimizing costs. This task is unique to each community and is complicated by social expectations, economic and environmental policy, an ever-changing urban landscape, invasive pests and climate change.

EAB presents several challenges for municipalities. EAB management and the subsequent loss of urban tree canopy will pose a significant financial burden to municipalities and individual private property owners and will impact the services provided for decades (Greene and Millward, 2016). Cities face increased liability from standing dead trees and opportunity costs as a result of deferred maintenance as staff resources and funds are diverted to EAB management activities.

Although not native, both green and white ash have been planted in urban areas across Colorado for over 100 years. As a result, ash now comprises over 15 percent by number in public tree inventories and upwards of 25 percent of the urban tree canopy in many Colorado communities including Boulder, Denver and Fort Collins. To recover from the inevitable loss of tree canopy will require enormous action – both public and private – and unprecedented levels of collaboration between public land managers, political leaders, private landowners and municipal planners.

EAB presents a unique opportunity for urban forestry programmes to improve and grow when developing strategies to overcome these challenges. Thus, it is essential for urban forest managers to seek strategic collaborative opportunities, create broad-based, forward-thinking urban forest management plans capable of addressing a variety of potential threats and maintain a dialogue with decision-makers and residents in order to raise awareness about the threats posed by invasive forest pests and to promote and sustain many benefits provided by the urban tree canopy.

The preparedness and long-standing working relationships between stakeholders and responsible authorities within Colorado allowed for a quick, decisive and unified response. Pre-detection collaboration focused on role clarification allowed involved agencies within Colorado to anticipate and understand necessary actions, and who would perform each action, at the time of and post EAB detection. The well-established relationships allowed for a rapid timeframe on a visual survey, defining protocols for the Boulder delimitation survey, coordination and implementation of the survey. The collaborations expanded capacity for statewide outreach activities post detection when Boulder Forestry was overwhelmed with questions from the public and upper management and internal processes.

The extensive outreach conducted by the EPIC workgroup and the CORT allowed for increased contact with decision-makers across all levels of government and led to the allocation of additional resources to local urban forestry programmes. EPIC's outreach efforts resulted in invitations to speak to members of the Colorado State Legislature, Metro Mayors Caucus (coalition of the Denver metro area mayors), Colorado Municipal League (coalition of municipal city managers) and the Colorado Parks and Recreation Association about the challenges associated with EAB. Members of the CORT were also invited to present to selected municipal officials and stakeholders in other Front Range cities about anticipated impacts of EAB and local mitigation strategies. Efforts in Boulder, Denver and Fort Collins resulted in increased staffing and operational funding to support EAB planning, response and outreach activities.

Historical interagency working groups such as EPIC and the CORT better positioned Front Range municipalities to respond effectively to EAB. Efforts to train Front Range city foresters on EAB detection and management coupled with the Colorado State Response Plan and Community Management Plan templates have prepared municipal forestry staff to detect, plan for and manage EAB once it arrives in other communities. Post detection meetings provided a forum to share observations and transfer technical information. Diagnostic workshops instructed green industry personnel on proper identification of the pest. Educational van tours through impacted areas in Boulder, led by interagency personnel, demonstrated to decision-makers in other communities the impact and costs associated with EAB within Boulder.

Collaboration amongst agencies, understanding the urban forest resource, education and engagement of leadership, partnerships, industry education and public awareness were some of the most critical components of Colorado's success in preparing for the arrival of EAB.

Conflict of interest statement

None declared.

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