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Research paper

Effects of emerald ash borer on municipal forestry budgets

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HIGHLIGHTS

- The greatest effect of EAB occurred 5–8 years after confirmation in a state.
- A $280.5 (±79.9) million annual increase in municipal budgets occurred due to EAB.
- EAB reduced budgets for tree pruning, watering, fertilization and safety training.
- Spending on tree and stump removal doubled due to EAB.

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ABSTRACT

This study examines the financial impact of emerald ash borer (EAB, *Agrilus planipennis* Farimaire; Coleoptera: Buprestide) on municipal forestry budgets. Three distinct phases were evident: an initial time period of 0–4 years (little budget change), year 5–8 time period (rapid budget increase), and years 9–12 (rapid budget decrease) after EAB was confirmed in a state. The 5–8 year time period had increased spending as detected through the total forestry budget ($p = 0.011$), total municipal forestry budget (percent forestry budget) as a percentage of the total municipal budget ($p < 0.001$), and per capita spending ($p < 0.001$). A $1.58 per capita increase occurred in annual municipal forestry budgets in states in which EAB was confirmed (EAB+) compared to states without a confirmed EAB case (EAB−). This has a $280.5 (±79.9) million annual impact on municipal budgets. The percent forestry budget increased as the time since EAB was confirmed in a state increased. A mean 0.33% (0.03 SE, $n = 82$) percent forestry budget occurred during the initial 0–4 years after confirmation of EAB. This exponentially increased from 0.47% (0.05 SE, $n = 43$) in year 5 to 1.17% (0.12 SE, $n = 38$) at the peak in year 8, and rapidly declined back to 0.47% (0.05 SE, $n = 51$) in years 10–12 which was a level slightly higher than initial conditions. Federal, state, and local urban forestry managers can use these results to financially plan for the impacts of EAB on municipal forestry budgets.

1. Introduction

Since the confirmation in 2002 of emerald ash borer (EAB, *Agrilus planipennis* Farimaire; Coleoptera: Buprestide) in North America, millions of ash trees (*Fraxinus* spp.) have died as a result of this insect (Herms & McCullough, 2014). White ash (*Fraxinus americana* L.), black ash (*Fraxinus nigra* Marshall), and green ash (*Fraxinus pennsylvanica* Marshall) are three common and highly susceptible North American *Fraxinus* spp. (Poland & McCullough, 2006). Not all North American ash trees are highly susceptible to EAB and the relatively uncommon blue ash (*Fraxinus quadrangulata* Michx.) has been reported to have much less mortality than other *Fraxinus* spp. (Poland & McCullough, 2006; Tannis & McCullough, 2014). Within a few years (e.g., 10–12 years) of EAB entering a location the vast majority of susceptible ash trees are dead or dying (Knight, Brown, & Long, 2013; Klooster, Herms, Knight, Herms, & McCullough, 2014).

Fraxinus spp. in the United States have a $282 billion undiscounted compensatory value in urban environments (Nowak, Stevens, Crane, & Walton, 2003; Poland & McCullough, 2006). By comparison, the Asian longhorned beetle (*Anoplophora glabripennis* Motschulsky) has a potential $669 billion impact with urban trees in the United States (Nowak, Pasek, Sequeira, Crane, & Mastro, 2001). An estimated 37.9 million *Fraxinus* trees occur in developed areas of communities within 25 eastern states in the U.S. (Kovacs et al., 2010). This increases to an estimated 125.3 million *Fraxinus* trees that exist on all developed land as defined by the National Land Cover Database 2001 definition.

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Kovacs et al. (2010) put a perspective on the potential financial impact that EAB would cost over $10.7 billion for the treatment, removal, and replanting of trees within developed land of communities across 25 states in the eastern United States over a ten-year period (2009–2019). The value rises to $37.9 billion if all susceptible *Fraxinus* spp. were removed and replaced at one time. McKenney et al. (2012) estimated in Canada the impact of EAB infestations at CAD $524 million for urban street trees and CAD $890 million when backyard trees were included. Sydnor et al. (2011) estimated the total financial impact of EAB infestations using the landscape tree value, tree removal costs, and cost of tree replacement to be between $13 and $26 billion in four Midwestern states in the U.S. This financial value translates to a $396 to $770 per capita impact. These estimated impacts are being realized and by 2015 over half of the states in the U.S. have confirmed EAB cases (http://www.emeraldashborer.info).

Many approaches have been proposed and further tested to manage populations of urban *Fraxinus* spp. that were exposed to EAB (Herms & McCullough, 2014; McCullough, Mercader, & Siegert, 2015). These actions include letting *Fraxinus* spp. die and removing those that pose an unacceptable risk to human injury or property damage (Hauer, 2012; VanNatta & Hauer, 2012). Others have proposed the preemptive removal of *Fraxinus* spp. in anticipation they will ultimately die or to harvest trees for timber or firewood prior to wood degradation (McCullough et al., 2015; Vannatta, Hauer, & Schuettpelz, 2012). Several protocols for treating *Fraxinus* spp. with systemic insecticides have also been developed with efficacies of nearly 100% of some treatments with protecting trees from mortality (Herms & McCullough, 2014; Herms, McCullough, Smitley, Clifford, & Cranshaw, 2014; McCullough, Poland, Anulewicz, Lewis, & Cappaert, 2011; Smitley, Doccola, & Cox, 2010). McCullough et al. (2015) list additional integrated approaches to manage EAB including girdled *Fraxinus* spp. trap trees, phloem reduction, and adopting Slow Ash Mortality (SLAM) protocols.

Fraxinus trees are common in the urban landscapes on public and private lands with some public street tree populations having *Fraxinus* spp. as the most abundant (Ball, Mason, Kiesz, McCormick, & Brown, 2007; Raupp, Cumming, & Raupp, 2006). Nationally in the United States, *Fraxinus* spp. was the second most common genera after *Acer* spp. in 12 studied communities (Raupp et al., 2006). At a state level, in South Dakota 36.3% of the street tree population was *Fraxinus* spp. (Ball et al., 2007). Across public and private maintained land areas (residential and business districts) statewide in Minnesota, VanderSchaaf and Jacobson (2011) reported 15.1% of trees were *Fraxinus* spp. Regionally within the Minneapolis and Saint Paul, MN metropolitan area (Anoka, Carver, Dakota, Hennepin, Ramsey, Scott, and Washington counties) 13.7% of urban trees within maintained areas (residential and business districts) on public and private lands were *Fraxinus* spp. (VanderSchaaf & Jacobson, 2011).

At a municipal level, *Fraxinus* has a $221 million structural value that include 573,000 trees comprising 17.4% of all public and private trees and 13.7% of all leaf area across the entire urban forest land area in Milwaukee, WI (i-tree, 2008; Sivyer, 2010). The Milwaukee street tree population of over 30,000 *Fraxinus* trees is currently under an intensive insecticide treatment to maintain the public resource (Krouse, 2010; Sivyer, 2010). In Canada an estimated 1.2 million street trees are *Fraxinus* spp. (McKenney et al., 2012). Thus, as a common tree, *Fraxinus* spp. poses an important asset to manage or liability upon death.

The loss of public and private trees has economic, ecological, and social impacts (Donovan & Butry, 2010; Donovan & Butry, 2011; Kondo, Low, Henning, & Branas, 2015; Miller, Hauer, & Werner, 2015; Vogt, Hauer, & Fischer, 2015; Wolf, Measells, Grado, & Robbins, 2015). Donovan et al. (2013) found the incidence of human death and respiratory ailments increased as the time since EAB was found in an area increased. While a causal relationship cannot be made from that study, the correlation is consistent with the human health literature and an expected positive relationship of trees and people in urban environments (Miller et al., 2015; Wolf et al., 2015). The loss of *Fraxinus* trees leads to reduced air pollutant update, less storage of rainwater, decreased carbon uptake, and other reductions in ecological benefits (Herms & McCullough, 2014; i-tree, 2008; Miller et al., 2015; Vannatta et al., 2012). Whether one likes it or not, managing EAB infestations will cost money for responding to tree mortality or preventing the death of *Fraxinus* trees (Hauer, 2012; Hauer, Vogt, & Fischer, 2015; VanNatta & Hauer, 2012). However, the retention of *Fraxinus* trees through the use of systemic insecticides was the most economically favored alternative (Vannatta et al., 2012).

The purpose of this study was to investigate the effect of EAB infestations on municipal forestry budgets. First we wanted to see if there was a difference in municipal tree budgets in states that have confirmed EAB versus states that did not have a confirmed case. We further investigated if there was an association since the time that EAB was found in a state and municipal tree budgets. We also ascertained if a change in funding of various forestry activities (e.g., pruning, planting, removal, education, etc.) occurred. Likewise, if total municipal funding changed as a result of EAB infestations was ascertained. Finally we quantified if contractor spending for urban forestry operations was changed as a result of EAB infestations in a state.

2. Methods

Information on municipal forestry operations and approaches to manage public tree populations was collected using a questionnaire for the 2014 fiscal year. Permission was granted by the Author's local Institutional Review Board to collect information from human subjects. The data used in this study was part of a long-form 109 question survey and sent to 1723 communities in all 50 United States. Survey delivery used the U.S. postal service with a self-addressed return envelope sent to each community. The multiple contacts approach of Dillman, Smyth, and Christian (2014) included a pre-notice letter, survey sent with a cover letter, reminder e-mail, survey and cover letter sent to nonrespondents, and postcard reminder sent to nonrespondents occurred for the long-form version. A subsequent short-form version with 53 questions was sent with the third follow-up survey with a cover letter and a final email reminder to non-respondents. Local contact information for the person who was most responsible for community tree activities was supplied by over 40 state urban and community forestry coordinators. In states that contact information was not available and communities that coordinators did not have a key contact person, municipal websites were searched for a person who is responsible for municipal trees or the person in charge of a department identified as most likely responsible for community trees. Lacking this information, a person from administration (i.e., city clerk, city manager, mayor) was sent the survey.

All communities with over 50,000 people received the questionnaire. Half of the communities between with 25,000 and 49,000 people were randomly picked for participation and 10% of places between 2500 and 24,999 people were randomly asked to participate in the study. All communities were selected from the Community and Activity Reporting System (CARS) maintained by the USFS at http://apps.fs.fed.us/NICPortal/default.cfm?action=Login. Community population used the 2010 census as maintained in the CARS dataset and the US Census Bureau (2010).

The year when a state had a confirmed EAB case (EAB+), or if EAB was not confirmed prior to 2015 (EAB-), followed EAB timeline records from http://emeraldashborer.info/timeline.cfm. In two

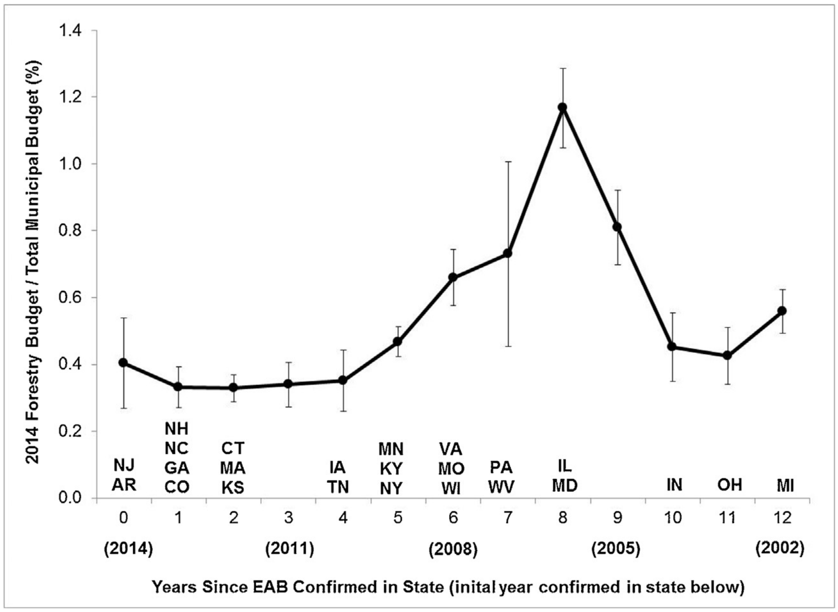

Fig. 1. Temporal effect of emerald ash borer (*Agrilus planipennis* Farimaire) on municipal forestry budgets as a percentage of the total municipal budget (n = 366).

states (Maryland and Virginia) that EAB was confirmed, eradicated, and reconfirmed, the most recent confirmation year was used. The year since EAB was confirmed in a state is expressed as 0 = EAB in 2014, 1 = 2013, 2 = 2012 . . . 10 = 2004, 11 = 2003, and 12 = 2002. No states in this study had EAB confirmed in year 3 (2011) or year 9 (2005). Unweighted budget values were extrapolated for 2011 by using the mean composite values for the adjoining years (2010 and 2012). Likewise, the 2005 value used the mean values from 2004 and 2006 to develop an unweighted mean for 2005. This extrapolation was only used for illustrative purposes presented later in this paper and not used for any statistical tests. All communities that reported budget data were analyzed for the respective base year (e.g., 2014, 2013, etc.).

A one-way ANOVA was used to test if budget indices (per capita forestry budget, forestry budget as a percent of total budget, total forestry budget), contractor spending (total amount and per capita contract budget), and 18 tree activity areas (e.g., tree planting, tree removal, tree pruning, training, public education, administration, etc.) were different among states with and without a confirmed EAB case with a null hypothesis of no difference. Acceptance of the alternative hypothesis of a difference was concluded with $p < 0.10$. A highly significant finding is interpreted at $p < 0.01$, significant at $0.01 \leq p < 0.05$, and marginally significant at $0.05 \leq p < 0.10$. Linear regression fixed models were used to test an a priori assumption that no difference existed between the dependent budget index values and the independent variables (Table 1). Three time periods after an EAB infestation was discovered in states (0–4 years, 5–8 years, and 9–12 years) were also used to test and describe an effect of EAB infestation on municipal budgets. All modeling was conducted in SPSS Version 21.0.

3. Results

States with a confirmed EAB infestation were found to differ with an increase in municipal forestry budget indices (total budget, per capita spending, percent of municipal budget spent on forestry activities) over time. A difference was found in the percent forestry budget of total municipal budget (percent forestry budget) for states that had EAB infestations than EAB− states. Forestry budgets as a percent of total budget ($F = 5.240$; df = 1, 462; $p = 0.023$) were greater in EAB+ states (0.57%, 0.03 SE, n = 269). Likewise, EAB− states spent less (0.46%, 0.03 SE, n = 195) as a percent forestry budget than EAB+ states spent (Table 2).

Over the 12 year time period, Fig. 1 depicts three distinct phases that affected forestry budgets: an initial time period of 0–4 years (little budget change), years 5–8 (rapid budget increase), years 9–12 (rapid budget decrease). The 11 states in years 0–4 had a mean percent forestry budget of total municipal budget at or below 0.40% (mean 0.34%, 0.03 SE, n = 82) and was lower than the 0.56% (0.03 SE, n = 382) in all other EAB+ and EAB− locations ($F = 14.481$; df = 1, 462; $p < 0.001$) (Fig. 1). This mean value increased from 0.47% (0.05 SE, n = 43) in year 5 to 1.17% (0.12 SE, n = 38) in year 8. The 12 states in this 5–8 year category had a 0.75% (0.05 SE, n = 136) mean forestry budget for this time period that was greater than all other EAB− and EAB+ places ($F = 41.532$; df = 1, 462; $p < 0.001$). The percent forestry budget decreased to approximately 0.47% (0.05 SE, n = 51) in years 9–12 for the three states in this time period and was similar ($F = 0.677$; df = 1, 462; $p = 0.411$) to the 0.52% (0.05 SE) for all other EAB+ and EAB- places outside of this time period.

No difference between EAB− and EAB+ states was found for the total forestry budget ($F = 1.45$; df = 1, 476; $p = 0.228$) as shown in Table 2. A difference ($F = 6.45$; df = 1, 476; $p = 0.011$) was detected in states 5–8 years after EAB was confirmed with forestry spending at $1,277,541 (361,881 SE, n = 138) compared to $652,712 (55,155 SE, n = 340) in EAB− and EAB+ states outside this time period. The 0–4 year ($p = 0.373$) and 9–12 year ($p = 0.507$) time periods had mean budgets that were statistically no different than EAB− states and the other two time periods.

Linear modeling further supports a temporal relationship of EAB in a state on municipal budgets. Several iterative models were tested for response variables (total budget, per capita, percent forestry budget) with consistent results showing an effect of EAB in a state on budgets. Community population and the 5–8 year time period were significant predictors ($R^{2adj} = 0.800$, $F = 955$; df = 2, 475; $p < 0.001$) of total money spent in municipal forestry operations (Table 3). Population of a community is a strong predictor of budget ($6.40 per person, $t = 43.3$, $p < 0.001$) and a state five to eight years past EAB confirmation also was a strong predictor ($434,121 per community more spent on average, $t = 3.83$, $p < 0.001$) as shown in Table 3.

A marginally significant difference was detected on forestry budgets on a per capita basis between EAB− and EAB+ states

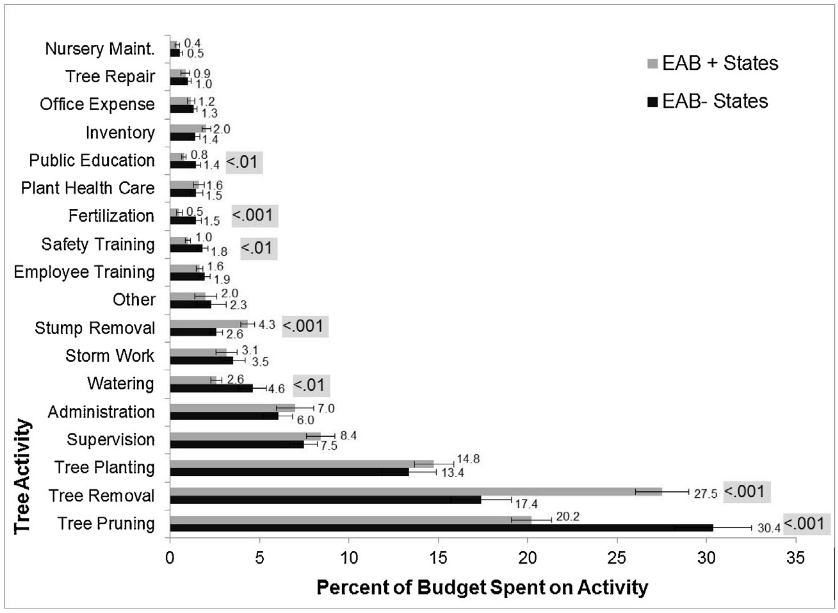

Fig. 2. Percent of 2014 forestry budget spent on tree activities in states with a confirmed emerald ash borer (EAB, *Agrilus planipennis* Farimaire) case (EAB+) and states without a confirmed EAB (EAB−) case (n = 268).

Table 1
Variables tested in initial and final regression models.

Variable	Definition	Mean (SE), n
TreeBudget	Response, $ spent on all forestry operations	801,595 (107,800), 477
BudgetCap	Response, $ spent per capita	8.76 (0.45), 477
BudgetPer	Response, tree budget percentof municipal budget	0.52 (0.02), 463
TotalBudget	Response, $ (millions) on all municipal functions	202.6, (26.7), 551
Contract	Response, $ spent on contracting	313,750 (111,980), 410
Population	2010 Census Population	91,871 (13,611), 677
StateYear	Initial year that EAB confirmed in a state	2008 (0.18), 366
ConfirmYears	Number of years since EAB was confirmed	5.9 (0.18), 366
EAB0-4	1 if EAB confirmed 0–4 years ago, else 0	NA, (NA), 115
EAB5-8	1 if EAB confirmed 5–8 years ago, else 0	NA, (NA), 178
EAB9-12	1 if EAB confirmed 9–12 years ago, else 0	NA, (NA), 73
EAB	1 if EAB confirmed in state, else 0	NA, (NA), 366

Table 2
Municipal forestry budgets from 2014 in states with (EAB+) and without (EAB−) emerald ash borer (EAB, *Agrilus planipennis* Farimaire) and as a function of time since EAB was confirmed in a state.

Years Since EAB Confirmed in State (actual year confirmed)	% Forestry Budget of Total Municipal Budget (SE, n)	$ Per Capita Forestry Budget (SE), n	$ Per Capita Spent on Contracting (SE), n	$ Total Forestry Budget (SE), n
0 (2014)	0.40 (0.27, 4)	5.93 (3.00, 4)	2.42 (0.82, 4)	936,914 (881,052, 4)
1 (2013)	0.33 (0.30, 24)	6.05 (1.25, 24)	2.39 (0.73, 21)	764,267 (235,426, 21)
2 (2012)	0.33 (0.25, 39)	5.78 (0.56, 40)	2.12 (0.37, 34)	407,851 (70,972, 34)
4 (2010)	0.35 (0.36, 15)	6.95 (2.04, 16)	1.01 (0.34, 13)	837,771 (369,443, 13)
5 (2009)	0.47 (0.30, 43)	7.20 (0.81, 43)	2.42 (0.46, 39)	1,766,964 (1,074,983, 39)
6 (2008)	0.66 (0.57, 48)	8.08 (0.94, 48)	1.79 (0.32, 39)	1,002,366 (372,281, 39)
7 (2007)	0.73 (0.73, 7)	7.37 (2.65, 8)	4.42 (2.39, 7)	632,490 (487,616, 7)
8 (2006)	1.17 (0.73, 38)	24.03 (3.05, 39)	9.77 (1.57, 34)	1,208,915 (175,171, 34)
10 (2004)	0.45 (0.32, 10)	4.88 (0.99, 12)	2.20 (0.47, 10)	653,163 (293,903, 10)
11 (2003)	0.43 (0.43, 26)	7.35 (1.47, 27)	2.78 (0.56, 24)	556,151 (240,412, 24)
12 (2002)	0.56 (0.26, 15)	10.02 (1.52, 15)	2.23 (0.54, 15)	725,071 (169,884, 15)
EAB− States	0.46 (0.03, 195)	7.88 (0.61, 202)	2.77 (0.34, 171)	675,166 (71,587, 202)
EAB+ States	0.57 (0.53, 269)	9.46 (0.65, 276)	3.31 (0.32, 240)	948,693 (186,785, 240)
All States	0.52 (0.02, 464)	8.76 (0.45, 478)	3.09 (0.23, 411)	801,595 (107,800, 477)
ANOVA Contrast (EAB+ & EAB−)	F = 5.240; df = 1462; p = 0.023	F = 2.978; df = 1476; p = 0.085	F = 1.329; df = 1409; p = 0.250	F = 1.454; df = 1476; p = 0.228
ANOVA Contrast (Between Years)	F = 12.021; df = 10,265; p < 0.001	F = 9.259; df = 10,258; p < 0.001	F = 9.583; df = 10,229; p < 0.001	F = 0.521; df = 10,265; p = 0.875

Table 3
Effect of community population and emerald ash borer (*Agrilus planipennis* Farimaire) on municipal forestry budgets 5–8 years after confirmation within a state.

Model Variables	Unstandardized Coefficients B	Unstandardized Coefficients Std. Error	Standardized Coefficients Beta	t-test Statistics *t*-value	t-test Statistics Sig.	Correlations Zero-order	Correlations Partial
Initial Model All Indicators (R^2 =0.801 R^2adj =0.799, SE = 109,801, F(4,473) = 476, p < 0.001)							
(Intercept)	127,328	75,957		1.68	0.094		
Population	6.398	0.148	0.888	43.31	0.000	0.891	0.893
EABYears0to4	−16,877	142,358	−0.003	−0.12	0.906	−0.041	−0.005
EABYears5to8	430,913	122,633	0.078	3.51	0.000	0.116	0.159
EABYears9to12	5075	169,418	0.001	0.03	0.976	−0.030	0.001
Final a priori Model (R^2 = 0.801, R^2adj = 0.800, SE = 109,807, F(2,475) = 955, p < 0.001)							
(Intercept)	124,108	59,884		2.07	0.039		
Population	6.399	0.148	0.888	43.35	0.000	0.891	0.893
EABYears5to8	434,121	113,299	0.079	3.83	0.000	0.116	0.173

(Table 3). Per capita, an EAB+ state spent $9.46 ($0.65 SE, n = 276) per capita compared to $7.88 (0.61 SE, n = 202) spent per capita in EAB– states (F = 2.98; df = 1, 476; p = 0.085) on all forestry activities. At the state level, as the time increased after a confirmed EAB infestation, per capita spending on forestry activities increased (F = 24.9; df = 1, 476; p < 0.001) to $12.27 (1.15 SE, n = 138) during the five to eight year post-infestation time period. Spending declined to $7.54 (0.90 SE, n = 54) in the 9–12 year time period after EAB was confirmed and this was similar to EAB- states (F = 0.912; df = 1, 476; p = 0.326).

The amount of money spent on contracting changed as a result of EAB introduction over time. There was no difference between EAB– and EAB+ locations on a per capita (F = 1.33; df = 1, 409; p = 0.250) or total amount (F = 0.711; df = 1, 409; p = 0.400) basis for contracting budgets (Table 2). However, in the 5–8 year time period post EAB confirmation, a significant per capita increase in contracting (F = 14.1; df = 1, 409; p < 0.001) occurred. EAB+ states in that time period spent $4.43 (0.59 SE, n = 119) compared $2.54 (0.22 SE, n = 292) in EAB– states. Total amount spent on contracting in the 5–8 was not as conclusive (F = 3.831; df = 1, 409; p = 0.051) with $658,864 (382,669 SE, n = 119) in EAB+ and $178,195 (18,526 SE, n = 292) in EAB– states. Not surprising, when accounting for population, a linear regression model that included population and each time period revealed contracting was $286,108 (62,387 SE) higher on average during the 5–8 year time period than in other time periods (Table 4).

Differences were found on the percent of municipal forestry budgets spent on tree activities (Fig. 2). On a percentage basis of the total forestry budget, tree removal (F = 19.7; df = 1, 266; p < 0.001) and stump removal (F = 10.6; df = 1, 266; p < 0.001) increased in EAB+ states. Tree removal increased from 17.4% (EAB–) to 27.5% (EAB+) and stump removal from 2.6 (EAB–) to 4.3% (EAB+), thus 31.8% of the municipal forestry budget was spent on these two activities. Five tree activity budget areas (tree pruning, tree watering, safety training, public education, and fertilization) represented a subsequent smaller percent of the total budget in EAB+ than EAB– states. The percent of budget spent on tree pruning was lower (F = 20.4; df = 1, 266; p < 0.001) at 20.2% in EAB+ states than the 30.4% reported in EAB– states. A reported smaller percent was spent on tree watering (F = 7.33; df = 1, 266; p < 0.01), safety training (F = 7.08; df = 1, 266; p < 0.01), public education (F = 6.76; df = 1, 266; p < 0.01), and fertilization of trees (F = 10.5; df = 1, 266; p < 0.001) in EAB+ states. Interesting there was no significant change in the percent spent of tree planting which was 14.2% combined in all states. There was also no significant increase in total municipal budgets as a result of EAB infestations suggesting reallocation of money from other tree activities and possibly from other municipal budget areas (Table 5).

4. Discussion

The findings from this study are not surprising. Municipal forestry budgets have been impacted by EAB infestations as reported anecdotally and published in many peer-reviewed papers, popular articles, and conference reports (Herms & McCullough, 2014). This insect is also having a negative effect on electrical utility budgets with the removal of dead *Fraxinus* trees that could fall onto utility lines (Personal Communication Goodfellow, 2015). This study has quantified the impact of EAB infestations at the state level in the United States as expressed as a per capita index, percent forestry budget, and total forestry budget. The municipal budget impact approximately doubled during the peak years (5–8 years post state confirmation). This is the mean increase during the time period and was even greater and approximately triple in cost at the peak around year eight.

Using the $1.58 (0.45 SE) per capita difference found between EAB– and EAB+ states also demonstrates the potential magnitude of EAB infestations on municipal budgets. This equates to a 20% increase of the per capita index for municipal forestry budgets relative to EAB- states. A total 177.5 million people live in the 25 states that currently have confirmed EAB cases (US Census Bureau, 2010). Assuming all urban places in these 25 states are similar to the data from locations in this study, EAB has a current annual effect of $280.5 (±79.9) million on municipal budgets. This figure does not include the value of private trees.

This is not the first time that a major urban forest health event has significantly affected municipal budgets. Four previous assessments of municipal forestry operations were conducted in 1974, 1980, 1986, and 1993 during periods of differing levels of Dutch elm disease (DED, *Ophiostoma ulmi* (Buisman) Nannf.) causing elm mortality (Giedraitis & Kielbaso, 1982; Kielbaso, Beauchamp, Larison, & Randall, 1988; Ottman & Kielbaso, 1976; Tschantz & Sacamano, 1994). Percent forestry budgets were 0.54% in 1974 which was during a time period of significant loss of elms (*Ulmus* spp.) from DED (Ottman & Kielbaso, 1976). This forestry percentage of total municipal budget increased to 0.81% in 1980. This time period was both an era of continued or expanding loss of elms and demonstration projects and technology transfer on best management approaches for slowing DED losses (Giedraitis & Kielbaso, 1982). By 1986 the percent forestry budget of total municipal spending decreased to 0.49% in 1986 which coincided with decreased loss of elms from DED in the Midwest and northeast U.S. and implementation of effective DED sanitation programs (Kielbaso et al., 1988). An overall 0.31% mean value was reported in 1993 which was during a time period of continued decreased loss of elms and smaller trees that replaced elms. Many elms were already killed and gone or effective control programs were in place in many communities (Tschantz & Sacamano, 1994). The findings from this study are consistent with the financial impact found during the 1974–1993 time period.

Table 4
Effect of community population and emerald ash borer (*Agrilus planipennis* Farimaire) on forestry contracting budgets 5–8 years after confirmation within a state.

	Unstandardized Coefficients		Standardized Coefficients	t-test Statistics		Correlations	
Model Variables	B	Std. Error	Beta	*t*-value	Sig.	Zero-order	Partial
Initial Model All Indicators (R^2 = 0.957 R^2adj = 0.956, SE = 642,879, F(5,217) = 964, p < 0.001)							
(Intercept)	−347,881	41,810		−8.32	0.000		
Population	6.429	0.081	0.965	78.94	0.000	0.968	0.969
EABYears0to4	−45,836	78,366	−0.008	−0.59	0.559	−0.041	−0.029
EABYears5to8	279,228	67,508	0.055	4.14	0.000	0.096	0.201
EABYears9to12	26,084	93,262	0.004	0.28	0.780	−0.023	0.014
Final a priori Model (R^2 = 0.939, R^2adj = 0.939, SE = 559,414, F(2,408) = 3159, p < 0.001)							
(Intercept)	−354,781	32,970		−10.76	0.000		
Population	6.429	0.081	0.965	79.09	0.000	0.968	0.969
EABYears5to8	286,108	62,387	0.056	4.59	0.000	0.096	0.221

Table 5
Effect of community population and emerald ash borer (*Agrilus planipennis* Farimaire) on total municipal budgets after confirmation within a state.

	Unstandardized Coefficients		Standardized Coefficients	t-test Statistics		Correlations	
Model Variables	B	Std. Error	Beta	*t*-value	Sig.	Zero-order	Partial
Initial Model All Indicators (R^2 = 0.896 R^2_{adj} = 0.895, SE = 203,431,906, F(4,550) = 1170, p < 0.001)							
(Intercept)	45,426,828	13,160,456		3.45	0.001		
Population	15,999	23.400	0.946	68.32	0.000	0.946	0.946
EABYears0to4	14,031,370	24,777,322	0.008	0.57	0.571	−0.004	0.024
EABYears5to8	−1,733,507	20,817,249	−0.001	−0.08	0.934	0.046	−0.004
EABYears9to12	−29,229,325	30,131,836	−0.014	−0.97	0.332	−0.026	−0.041
Final a priori Model (R^2 = 0.895 R^2_{adj} = 0.895, SE = 203,171,223, F(1,549) = 4690, p < 0.001)							
(Constant)	44,337,364	8,958,510		4.95	0.000		
Population	15,999	23.342	0.946	68.48	0.000	0.946	0.946

Thus, the increased budgetary cost from EAB infestations and the temporal effect on a municipal budget is consistent with the DED experience (Campana & Stipes, 1981; Kostichka & Cannon, 1984; Miller & Schuman, 1981; Sherwood & Betters, 1981).

The biggest effect on budgets occurred during years 5–8 after state-level confirmation which is consistent with exponential mortality from EAB infestations (Knight et al., 2013; Klooster et al., 2014). Several places in the U.S. have confirmed EAB infestations and have already gone through the initial building years (years 0–4 since confirmation in a state in this study), the exponential increasing mortality phase (years 5–8), and declining loss phase (years 9–12). In states that have just confirmed the presence of EAB or those with a confirmed case in the past few years, results from this study depict the urgency for planning and allocating resources to manage EAB. A variety of management approaches exist (McCullough et al., 2015). Since managing EAB infestations will cost money, whether one likes it or not, a strategy to minimize costs is the best approach.

Vannatta et al. (2012) found retention of *Fraxinus* trees though systemic insecticides retained the highest net benefit and benefit/cost (B/C) ratio. Two approaches based on compensatory tree value and annual ecosystem functional values were used to develop the conclusion. Letting EAB progress and removing trees once dead was the second best option. Preemptive removal had the lowest net benefit and B/C. Several additional studies came to this same conclusion and found that retention of *Fraxinus* trees through insecticide treatment was more cost-efficient than letting ash trees die and the costs associated with tree removal, tree planting, and lost ecosystem function benefits (Kovacs, Haight, Mercader, & McCullough, 2014; McCullough & Mercader 2012; Sargent et al., 2013).

The findings on *Fraxinus* tree retention in areas with EAB infestations was consistent with findings in the 1970's with retention of American elm (*Ulmus americana* L.) trees. Best DED sanitation was found to be the most cost efficient, returning the highest net benefit and B/C (Miller & Schuman, 1981; Sherwood & Betters, 1981). Kostichka and Cannon (1984) also found this same effect with DED management that the best control program retained the greatest number of elms over time, costs were spread over time, and this option returned the highest net benefits and B/C compared to other alternatives. During that time period some municipalities developed alternatives (i.e., linear frontage tax, utility bill additions, special assessments) to general funding financing of urban forestry operations. These approaches are still in place and are more common now than 40 years ago (Hauer & Peterson, 2015).

The challenge for a municipality is how best to budget for managing EAB infestations. Removing trees after they die is likely to exceed the capacity to remove trees using in-house staff. This creates the necessity for contracting with private tree care firms, hiring more municipal staff, or reallocating staff from other municipal areas for an EAB response. Results from this study found contracting budgets increased significantly; however, we did not investigate if some hiring of additional staff or remobilization of a municipal work force occurred. Visual observation of contract budgets suggests seven to nine years after EAB is confirmed in a state, contracting budgets were above mean baseline contract budgets. Prior to the need for contracting, a municipality should develop contract specifications, industry work and performance standards, layout the bid request and identify the selection process. Developing management protocols at a time of mass loss of *Fraxinus* trees that are not treated to prevent death can be difficult and likely will result in ineffective results (VanNatta & Hauer, 2012; Vannatta et al., 2012; Miller et al., 2015).

Another challenge is the potential reallocation of resources for tree and stump removal at the expense of tree pruning, other tree activities, and other municipal services. A reduction in tree pruning leads to deferred maintenance which given enough time become more costly or leads to a reduction in tree condition (Hauer et al., 2015; Miller & Sylvester, 1981; Miller & Schuman, 1981; Ryder & Moore, 2013; Vogt et al., 2015). Tree planting budgets were unchanged which is problematic. Not replacing trees lost to EAB in a timely manner reduces the future net benefits that an urban tree population can provide (McPherson et al., 1997; Vogt et al., 2015). A reduction in the budget percentage allocated to watering as reported in EAB+ states can led to slower tree growth and higher mortality with inadequate watering (Gilman, 2001; Vogt et al., 2015). It is possible that the increased percentage allocated to tree and stump removal resulted from an increased budget. The data from this study did not find such a budget increase on a total municipal budget. Rather, the increase came as a percentage of the total municipal budget allocated to forestry which tripled at the peak from the baseline years when EAB was initially discovered in a state.

The preemptive removal approach has the prospect of spreading the costs over several years and to also stabilize labor needs. Treatment of *Fraxinus* trees also follows this spreading the cost over time and the retention of benefits. Treatment of ash trees returned the highest net present value and benefit cost ratio compared to no control or preemptive removal (Kovacs et al., 2014; McCullough & Mercader, 2012; Sargent et al., 2013; Vannatta et al., 2012). Delaying the onset of EAB into an area was found by Kovacs et al. (2011) to be more effective than letting new satellite EAB populations to be established. Development of enabling policies for cities to aggregate their budgets across jurisdictions improves net benefits of urban trees (Kovacs et al., 2014). Thus active management and active policies is preferred over no action.

5. Conclusion

Results from this study demonstrate the financial impacts of EAB of municipal forestry budgets. A temporal three-phase relationship was found that is much like a roller-coaster ride. You have the initial building phase of insect populations much like the queuing of people onto the ride. You have the rapid building of costs to respond to EAB. This ever increasing financial cost is much like the ascent and the increasing input of energy that is propelling the ride up a steep slope. A third phase then occurs with the rapid reduction of spending as fewer trees remain, much like the downward roller coaster decent and slowing as energy is dissipated. A fourth phase is a likely scenario with repeated upward and downward movements of budgetary impacts before returning to a more normal state much like the end of the roller coaster ride before it returns back for the next ride. The fourth phase is starting in some locations and the story on that part is forthcoming over the next decade. The DED literature actually has the fourth phase story told with repeated upward and downward costs associated with elm regeneration, disease incidence increases, and disease abatement as mortality slows in an area after most trees are killed.

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