

Density and location of simulated signs of injury affect efficacy of ground surveys for Asian longhorned beetle

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Abstract—Surveys for Asian longhorned beetles, *Anoplophora glabripennis* (Motschulsky) (Coleoptera: Cerambycidae), currently rely upon visual examination of trees to discover signs of attack. By embedding simulated *A. glabripennis* oviposition pits and exit holes on open-grown Norway maples, *Acer platanoides* L. (Aceraceae), we evaluated the effect of sign density, height above ground (below or above 2.5 m), and position (bole or branch) when foliage was present or absent on inspector ability to distinguish trees with or without signs. From this, we quantified detectability, or the proportion of trees correctly identified as infested, and determined the time taken to do so. Effectiveness in detecting trees with signs improved when sign density increased, when signs were below 2.5 m, and when oviposition pits were located on boles and exit holes on branches. These main findings require some caveats, due to a number of significant interactions. Foliage presence/absence had no apparent influence on effectiveness; possible reasons are provided for this result. Time-to-find curves, which illustrated the proportion of inspectors who accurately identified an infested tree as a function of survey duration, revealed that for most treatment combinations, most infested trees were detected within the first 2 min of survey time. These findings provide baseline data to assist managers in designing effective protocols for ground surveys of *A. glabripennis*.

Résumé—Les relevés visant à déceler l'existence de populations du longicorne asiatique, *Anoplophora glabripennis* (Motschulsky) (Coleoptera: Cerambycidae), sont basés actuellement sur un examen visuel des arbres qui a pour but de découvrir la présence de signes spécifiques d'attaques. Des encoches de ponte et des trous d'émergence ressemblant à ceux du longicorne asiatique ont été encastrés manuellement sur des érables de Norvège (*Acer platanoides* L. (Aceraceae)) isolés afin d'évaluer l'influence de la densité de ces signes, leur hauteur (à moins ou plus de 2,5 m du sol), et leur position (tronc ou branche), lorsque le feuillage était présent ou absent, sur l'habileté des inspecteurs à distinguer les arbres sans signes d'attaque de ceux possédant des signes artificiels. Ce protocole nous a également permis d'évaluer la proportion des arbres correctement identifiés comme étant attaqués artificiellement, et le temps moyen requis pour déceler ces arbres attaqués. L'efficacité des inspecteurs à déceler les arbres attaqués s'améliorait lorsque la densité de signes augmentait, lorsque les signes étaient placés à moins de 2,5 m, et lorsque les encoches de ponte étaient situées sur le tronc et les trous d'émergence sur

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les branches. Ces résultats sont accompagnés de quelques mises en garde due à la présence d'un certain nombre d'interactions significatives entre les facteurs principaux. La présence ou absence du feuillage n'a eu aucune influence apparente sur l'efficacité de détection; nous offrons quelques interprétations possible pour ce résultat. Des courbes illustrant la proportion des inspecteurs ayant correctement identifié un arbre attaqué en fonction de la durée de l'examen visuel de l'arbre, ont révélé que la plupart des arbres attaqués étaient décelés dans les deux premières minutes de l'examen, et ce pour la majorité des traitements. Les gestionnaires possèdent maintenant des données de base leur permettant de développer des protocoles efficace de dépistage du longicorne asiatique à partir du sol.

Introduction

The first North American population of the Asian longhorned beetle, *Anoplophora glabripennis* (Motschulsky) (Coleoptera: Cerambycidae), was discovered in 1996 in New York City, New York (Haack *et al.* 1997), and it has since been discovered in Chicago (Illinois), Jersey City (New Jersey), Carteret (New Jersey), Worcester (Massachusetts), and at the city limits of Vaughan and Toronto (hereinafter Toronto) (Ontario) (Hopkin *et al.* 2004; Animal Plant Health Inspection Service (APHIS) 2008; North American Plant Protection Organization (NAPPO) 2008). All these introductions involved beetles that had originated in China (APHIS 2005; Carter *et al.* 2009). Most infestations had been established for several years before they were discovered by the public. Several approaches to facilitating early detection of *A. glabripennis* populations are being investigated (Smith and Wu 2008); however, the only operational method currently available to detect and delineate infestations is visual examination of trees for signs or symptoms of attack (Ric *et al.* 2007; Turgeon *et al.* 2007). The development of practical and operational survey plans for this species requires an understanding of the factors that affect the efficacy of these surveys, especially when insect densities are low.

Anoplophora glabripennis, a polyphagous xylophage (Xiao 1992; Yang *et al.* 1995; Lingafelter and Hoebeke 2002; Morewood *et al.* 2003, 2004a, 2004b, 2005; Sawyer 2008), represents a tremendous risk to the tree resources of urban landscapes across North America and Europe (Nowak *et al.* 2001). Species of *Acer* L. (Aceraceae) appear to be the hosts of choice in the invaded landscapes of North America (Haack *et al.* 2006; Turgeon *et al.* 2007; Sawyer *et al.* 2008), and Europe (Hérard *et al.* 2005, 2009; Maspero *et al.*

2007). This beetle attacks healthy trees and is capable of killing them after years of repeated attacks. Several aspects of its biology have been documented (He and Huang 1993; Zhao *et al.* 1993, 1997; Haack *et al.* 1997, 2006; Keena 2002, 2006, 2008; Smith *et al.* 2002, 2004; Morewood *et al.* 2003; Williams *et al.* 2004a, 2004b) and a review of its management has been completed recently (Haack *et al.* 2010).

The detectability or ease of detection of a species during surveys can be influenced by sampling effort and methodology, environmental conditions, species-specific characteristics related to its appearance and behaviour, its habitat use, and its population density (Bulman *et al.* 1999; Hardy and Morrison 2000; Williams 2003; de Solla *et al.* 2005; Mehta *et al.* 2007; Conway *et al.* 2008). Six signs of injury caused by *A. glabripennis* have been identified and are currently used in detection surveys conducted in Toronto's regulated area (Turgeon *et al.* 2007; Smith and Wu 2008): (1) oviposition pits, (2) insect frass or shavings, (3) hollowed bark, (4) exposed larval feeding galleries, (5) adult exit holes, and (6) feeding by adults on twigs, petioles, and foliage. The stem and branches of trees may be inspected for these signs from the ground, by climbing trees, or by using aerial lifts. The use of tree climbers and aerial lifts allows a more thorough inspection of trees, and though these techniques increase the detectability of low-density pest populations, they carry significantly higher time and labour costs than ground surveys. Moreover, the use of aerial lifts is restricted to areas where tree crown is readily accessible (*e.g.*, lifts cannot be used in ravines). Because time is important when responding to the discovery of an exotic-species outbreak, ground surveys, which may sacrifice some efficacy in detecting low-density or obscured signs of attack, are regarded as most practical for covering large areas within a reasonable time frame.

Oviposition pits and exit holes made by adult *A. glabripennis* are difficult to find but are easily recognised by trained personnel. Recently chewed oviposition pits, a few hours to several weeks old, are reddish in colour, but darken over time (Turgeon *et al.* 2007). Their shape varies from a narrow slit (about 1 mm in height) to a nearly circular pit (15 mm in diameter) and can be influenced by bark thickness (Smith *et al.* 2002; Turgeon *et al.* 2007) and texture. Emergence occurs after adults have bored a hole 6–14 mm in diameter through the wood and bark from their pupal gallery inside the tree (unpublished data). Initial attacks by *A. glabripennis* occur near the base of a tree's crown, along the trunk and main branches (Haack *et al.* 2006), but can be found on branches as small as 3.3 cm in diameter, or on exposed roots when densities are high (Kimoto and Duthie-Holt 2004). Both types of sign are evident throughout the year and often remain visible for several years, though their appearance changes with time (Ric *et al.* 2007). Detection of external signs can be affected by weather conditions at the time of day when observations are made (Smith *et al.* 2002; Turgeon *et al.* 2007).

The objective of this study was to measure the detectability of signs simulating *A. glabripennis* emergence and oviposition from the ground. A range of survey conditions were simulated by varying the following factors: (i) density of signs, (ii) height of signs, (iii) location of signs, and (iv) presence/absence of foliage. Inspection outcome was measured in terms of whether the presence or absence of signs was correctly identified, how often signs were detected, and the time taken to find the first sign of attack. This information is intended for use in developing guidelines and recommendations for visual inspection of trees while conducting detection, delimitation, or area-wide surveys targeting this beetle.

Materials and methods

Study area and tree species

This study was conducted in Toronto, Ontario, within the boundaries of the regulated area established in 2003 by the Canadian

Food Inspection Agency (2003). The study site consisted of two rows of 48 trees each along the west side of a street. Within each row, trees were about 12 m apart. Efficacy in detecting exit holes was assessed using the row closest to the street: the other row, about 7 m westward, was used for oviposition pits. All trees in this study were Norway maples, *Acer platanoides* L., the predominant tree species lining the streets of this regulated area and the most heavily infested species in Toronto (unpublished data). The trees selected for this study had been inspected annually by arborists since 2003 and no sign or symptom of *A. glabripennis* attack had been found on them when the study was initiated in 2007.

Simulation of beetle-caused injuries on trees

Oviposition pits and exit holes were simulated to control their physical appearance, density, and location. These simulated signs of injury, resembling those shown in Turgeon *et al.* (2007), were embedded by technical staff into tree boles or branches with a diameter exceeding 8 cm. All signs were visible from the ground (*i.e.*, none were placed on top of branches), though not from all vantage points.

Oviposition pits were simulated using a combination of tools: a chisel, a pick tool, and a cordless rotary tool (Dremel Model 800) equipped with a carbide-coated tapered burr (Kutzall Model T-14-E). An outline approximating the size of a nearly circular oviposition pit was scored on the bark with the rotary tool. Both the depth and the size of the scoring varied according to bark thickness (deeper and larger pits were embedded in thicker bark). The pick and chisel were used to abrade the pit to further authenticate an actual oviposition pit. Both tools were used also to duplicate the mandible marks incised by the female along the edges of the pit. Simulated oviposition pits were weathered for a minimum of 3 weeks before the assessments started, to reduce their redness and increase their resemblance to oviposition pits made earlier in the season. The number of simulated oviposition pits per tree varied according to treatment. To standardize their visibility, oviposition pits on trees with more than one pit were placed in an arbitrary fashion within

a 60–100 cm section of bole or branch. This distribution resembled what we had observed on trees with low densities of injuries (unpublished data).

Exit holes, which were placed on different trees from those with oviposition pits, were simulated by drilling holes (10 mm drill bit) about 25 mm deep into the tree. To approximate the darker colour of exit holes, their interiors were rubbed with wood ash from maple firewood. The number of simulated exit holes per tree varied according to treatment. On trees with multiple exit holes, signs were located in an arbitrary fashion within a 60–100 cm section of bole or branch.

All treated trees were assigned a unique number and marked with an aluminum tag at the beginning of the study. The exact location of each tree was geo-referenced using a GPS (Garmin GPSMAP 76: set to North American Datum of 1983 [NAD 83]). The diameter at 1.3 m above ground (DBH) was measured with a Lufkin Executive Thinline 2 m long metal tape (W606PM). Tree height was calculated with a Forester Vertex digital hypsometer. Each tree was randomly assigned to one of the treatments.

Treatments and experimental design

The study employed a repeated measures (within-subjects) factorial design for both types of signs (SAS Institute Inc. 2003). For the oviposition-pit portion of the study, there were four main effects: density (0, 1, 3, or 9 oviposition pits), height (between the ground and below 2.5 m or between 2.5 and 6 m above the ground), position (on the bole or a branch), and foliage (absent or present). The 16 treatment combinations of density, height, and position were replicated three times (*i.e.*, 48 trees). Each tree was surveyed on two occasions: the first assessment took place in April 2007 before bud burst (without foliage) and the second in October 2007 (with foliage).

The experimental design for exit holes was similar to that for oviposition pits except that the densities used were 0, 1, 2, or 4 holes. Low densities of oviposition pits and exit holes were used because the success of pest-detection and -mitigation activities will be measured at these densities. The assessments took place in April

and September 2008 (without and with foliage, respectively).

Two responses were measured each time a tree was examined: (1) whether the status of each experimental tree was correctly categorized by the inspector as “infested” (simulated signs present) or “not infested” (no signs), and (2) the amount of time (in seconds) taken by the inspector to make an accurate determination. These two responses were used to compare “accuracy”, “detectability”, and “duration” among treatments. Accuracy refers to the proportion of trees that were correctly identified as infested or not infested. Detectability denotes the proportion of trees, among those with simulated signs (*i.e.*, density greater than zero), that were correctly identified as “infested” under a given set of survey conditions. Duration refers to the length of time taken by an inspector to identify a tree with a sign of attack.

Inspection staff

Assessments were conducted by 33 experienced inspectors who were actively involved in surveying trees in the regulated area of Toronto. Half of the inspectors had received a college or university education in forestry or a related field such as arboriculture or landscaping. Nearly all of those with a forestry background were certified arborists or were further trained in seed collection, forest management, tree-marking, or logging. Only one-third of these inspectors had previous experience in conducting insect surveys, though this was limited to visual survey for egg masses of gypsy moth, *Lymantria dispar* L. (Lepidoptera: Lymantriidae). Almost 70% of the inspectors had been involved in *A. glabripennis* surveys since late 2003. All had observed real signs of *A. glabripennis* attack on maple in the field and in the laboratory. About 60% of the inspectors were routinely conducting surveys using a combination of techniques (*e.g.*, ground survey, tree climbing or aerial lift); the remainder had conducted only ground surveys.

Inspection methodology

One week before the study began, all inspectors were briefed on the general nature of the study. Inspectors were told that their

efficacy in detecting trees with simulated signs of attack would be evaluated under field conditions. They were not informed of the number or type of treatments being assessed, only that there would be trees with and without signs of attack. Inspectors were asked not to discuss their findings with fellow inspectors at any time during the study. Inspectors were not provided with the results of their assessments.

At the start of each assessment period, inspectors were shown a 30 cm long bolt of maple with simulated oviposition pits or exit holes, to familiarize themselves with the appearance of the simulated signs. At that time they were also informed that their inspection of each tree would be limited to 10 min; however, they were allowed to end it at any time. They were instructed to notify the assessor when they were ready to begin the inspection of each tree and when they either found a sign of injury or considered their inspection complete. Inspectors were supplied with binoculars (8 × 32 Eagle Optics, Platinum class) and allowed to use them at any time during the inspection. The two assessment periods (*i.e.*, with and without foliage) for each type of sign were performed on the same treated trees; however, inspectors started the second assessment at a different tree.

Inspections were conducted between 0800 and 1400 on days with dry weather conditions. Each inspector was accompanied by an assessor who used a stopwatch to record the duration of each inspection (Robic M-457 Clipboard/Stopwatch combination). Upon discovery of a sign, the assessor asked the inspector to point out its location. The assessor recorded whether the identified sign was the simulated sign without informing the inspector of the result of the inspection. Finally, the assessor ensured that the duration of each assessment did not exceed the time limit.

Data analysis

A logistic regression model that employed dummy variables to specify main effects and interactions was used to assess factors affecting detectability (SAS Institute Inc. 2003). An ANOVA followed by the Ryan–Einot–Gabriel–Welsh mean separation test at $P < 0.05$ was used to compare search durations for

accurate detections among treatments (SAS Institute Inc. 2003). In both analyses an “inspector” term was included in the model to account for differences between inspectors, and thus partition this source of variation out of the error term used for testing the significance of other terms in the model. All averages are presented as the mean \pm standard error (SE). The same inspectors were used throughout the study; however, not all inspectors were available for all four assessment periods, resulting in different numbers of inspectors for each assessment period (*i.e.*, with and without foliage for each type of sign).

Time-to-detect curves, which illustrate the relationship between detectability and the time required for accurate detection of a sign, were generated for each treatment combination by plotting the proportion of inspectors that correctly identified trees with signs mimicking *A. glabripennis* injury during each 10 s interval between 0 and 600 s. A line of best fit through the curves for the various treatment combinations ($\pm 95\%$ confidence interval) was generated to indicate the pattern that might be expected under average survey conditions. The curves for the “easiest” (*i.e.*, highest detectability) and “hardest” (*i.e.*, lowest detectability) treatment combinations are also presented, to illustrate the range of detectability over time.

Results

Mean DBH and height of the 48 trees used to assess the efficacy of ground surveys in detecting simulated oviposition pits of *A. glabripennis* were 37.18 ± 1.00 cm and 12.44 ± 0.35 m, respectively. Trees embedded with simulated exit holes, had a mean DBH of 34.36 ± 0.83 cm and a mean height of 11.84 ± 0.29 m. Crown height at the study site was uniform at about 2 m.

Accuracy and detectability

Oviposition pits

Inspector accuracy in determining the status of each experimental tree as “infested” (1, 3,

Table 1. Logistic regression on detectability from the ground of simulated oviposition pits and exit holes of *Anoplophora glabripennis* embedded on large Norway maples in Toronto, Ontario.

Source of variation	Oviposition pits			Exit holes		
	df	Wald's χ^2	$P > F$	df	Wald's χ^2	$P > F$
Inspector*	32	180.31	<0.0001	25	85.84	<0.0001
Density	2	36.42	<0.0001	2	33.10	<0.0001
Height	1	51.50	<0.0001	1	73.66	<0.0001
Position	1	35.12	<0.0001	1	101.51	<0.0001
Foliage	1	0.48	0.4876	1	0.86	0.3545
Density \times height	2	16.92	0.0002	2	11.53	0.0031
Density \times position	2	1.11	0.5732	2	14.21	0.0008
Density \times foliage	2	0.22	0.8936	2	5.23	0.0730
Height \times position	1	0.04	0.8409	1	1.15	0.2837
Height \times foliage	1	2.01	0.1562	1	1.92	0.1658
Position \times foliage	1	2.32	0.128	1	0.41	0.5226
Density \times height \times position	2	9.11	0.0105	2	3.43	0.1796
Density \times height \times foliage	2	4.65	0.0978	2	2.28	0.3198
Height \times position \times foliage	1	4.41	0.0356	1	3.57	0.0589
Density \times height \times position \times foliage	4	1.24	0.7037	4	0.07	0.9654

*Thirty-three inspectors participated in the assessments of oviposition-pit detectability and 26 inspectors in the assessments of exit-hole detectability.

or 9 simulated oviposition pits) or “not infested” (no oviposition pit) was 85% (range 67%–98%). Average detectability of trees with oviposition pits was 0.81 ± 0.01 (range 0.56–0.97); it varied significantly among inspectors (Table 1). Density, height, and position of oviposition pits significantly influenced detectability of trees with simulated oviposition pits (Table 1). Detection improved significantly (*i*) as pit density increased, (*ii*) when pits were located below 2.5 m above ground, and (*iii*) when pits were positioned on the tree bole as opposed to branches (Fig. 1A). The presence/absence of foliage did not affect the detectability of trees with signs of oviposition (Table 1, Fig. 1A).

There was a significant interaction between density and height (Table 1); the increased detectability associated with higher pit densities was much more apparent when pits were located below 2.5 m (Fig. 2A). There were two significant three-way interactions (Table 1). The strongest three-way interaction — density \times height \times position — indicated that the improved detectability associated with increasing density did not hold when oviposition pits were located above 2.5 m and on the bole (Table 2). The other significant three-way

interaction — position \times height \times foliage — suggests subtle effects of foliage on detectability under different position/density combinations.

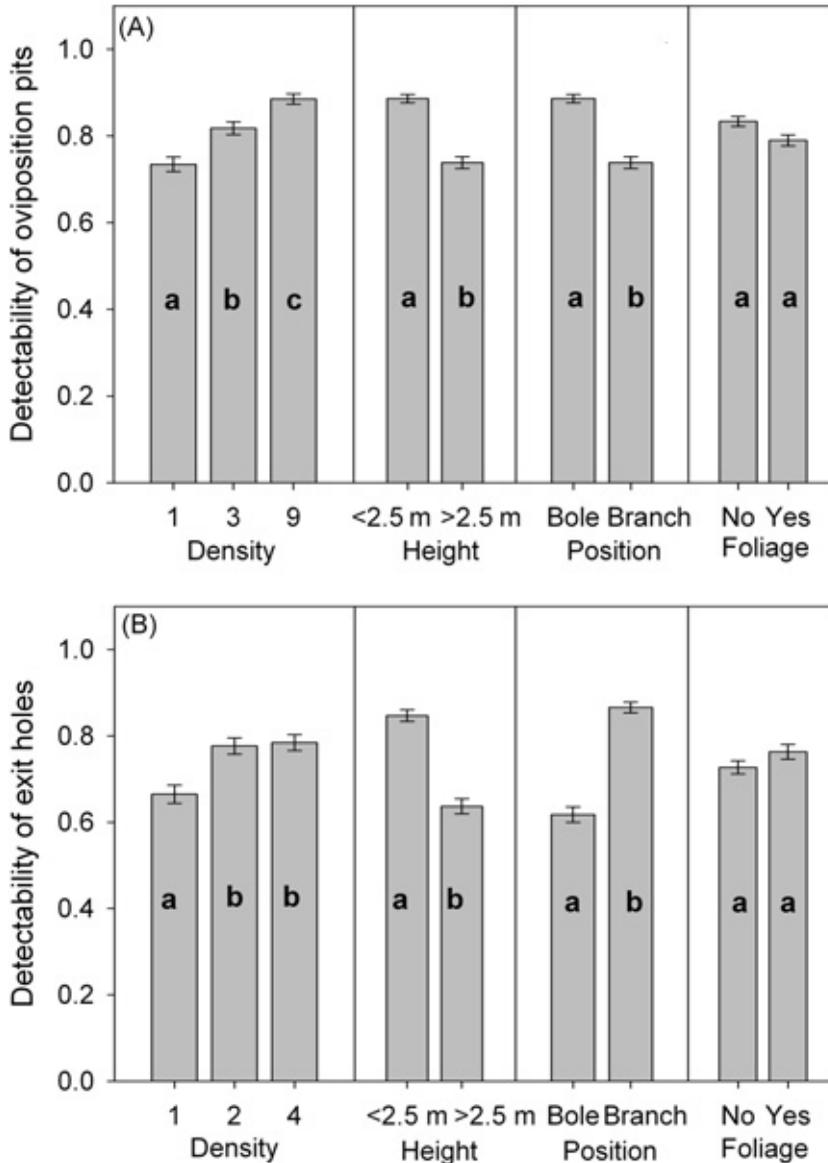
The highest detectability, 0.99, was obtained when nine oviposition pits were located on the bole and below 2.5 m, whereas the lowest detectability, 0.54, was obtained when inspectors were required to detect one oviposition pit located on a branch more than 2.5 m above the ground (Table 2). Substantial variation in within-treatment detectability was noted (range 0.01–0.43), suggesting that not all trees with the same treatment were equally detectable. For example, 4 of the 12 treatments with simulated pits (*i.e.*, density >0) had a within-treatment range of detectability exceeding 0.20.

Of the trees without oviposition pits, inspectors incorrectly declared a tree “infested” (*i.e.*, a false positive) in $4.9 \pm 0.1\%$ of cases, most likely because of missing bark, or tree injuries, such as feeding marks left by squirrels or sapsuckers, that were mistaken for oviposition pits.

Exit holes

Inspector accuracy in identifying trees as “infested” (1, 2, or 4 simulated exit holes) or

Fig. 1. Effects of density, height, position, and presence/absence of foliage on detectability (mean \pm SE) of simulated oviposition pits (A) and exit holes (B) of *Anoplophora glabripennis* embedded on Norway maples in Toronto, Ontario. Within each main effect, bars with the same letter are not significantly different (Ryan–Einot–Gabriel–Welsh test, $P > 0.05$).



“not infested” (no exit hole) was 80% (range 54%–94%). Average detectability of trees embedded with simulated signs of emergence, was 0.74 ± 0.01 (range 0.39–0.92); it varied significantly among inspectors (Table 1). Detectability of trees with exit holes was significantly influenced by density, height, and position, but not by the presence/absence

of foliage (Table 1). Detectability improved significantly (*i*) when exit holes were at higher densities, (*ii*) when they were located below 2.5 m, and, in contrast to oviposition pits, (*iii*) when they were positioned on branches as opposed to the bole (Fig. 1b).

Density and position of exit holes interacted such that when holes were located on branches,

Fig. 2. Mean (\pm SE) detectability of simulated oviposition pits and exit holes of *Anoplophora glabripennis* embedded on Norway maples in Toronto: interactions between density and height of oviposition pits (A); and, interactions between density and position (B) and between density and height (C) of exit holes.

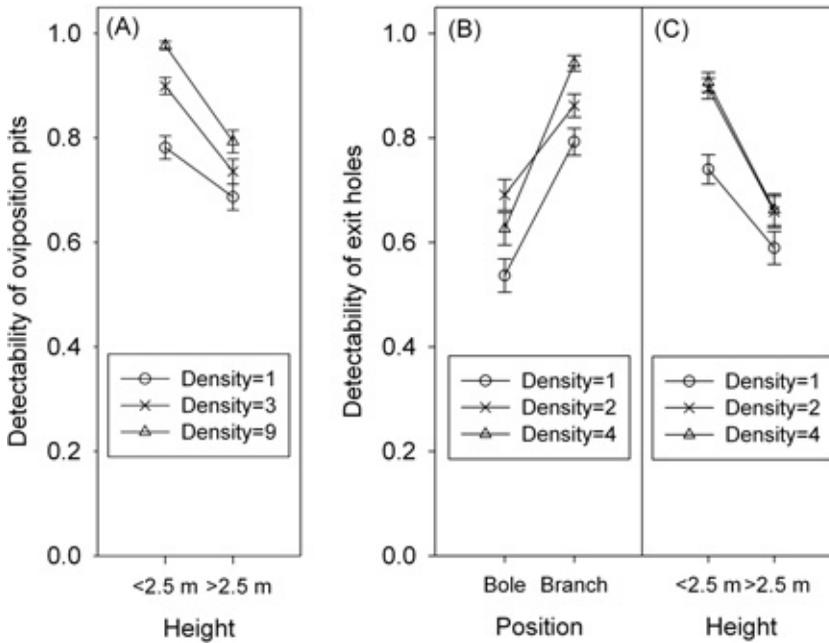


Table 2. Detectability (mean \pm SE) of simulated oviposition pits and exit holes of *Anoplophora glabripennis* assessed by experienced inspectors conducting visual inspections of large Norway maples from the ground in Toronto.

Type of sign	Density	Below 2.5 m		Above 2.5 m	
		On bole	On branch	On bole	On branch
Oviposition pits	1	0.874 \pm 0.025	0.690 \pm 0.035	0.833 \pm 0.028	0.540 \pm 0.038
	3	0.914 \pm 0.021	0.885 \pm 0.024	0.885 \pm 0.024	0.586 \pm 0.037
	9	0.994 \pm 0.006	0.960 \pm 0.015	0.816 \pm 0.029	0.770 \pm 0.032
Exit holes	1	0.634 \pm 0.044	0.846 \pm 0.033	0.439 \pm 0.045	0.740 \pm 0.040
	2	0.886 \pm 0.029	0.902 \pm 0.027	0.496 \pm 0.045	0.821 \pm 0.035
	4	0.813 \pm 0.035	1.000 \pm 0.000	0.439 \pm 0.045	0.886 \pm 0.029

detectability improved with increasing density, but this was not the case when holes were located on the bole (Fig. 2B). A significant interaction between density and height was related to a stronger density effect when holes were located lower on the tree (Fig. 2C).

The lowest detectability, 0.44, was recorded when a single exit hole was located high on the bole, whereas the highest, 1.00, was obtained when two or four exit holes were located on

low branches (Table 2). The range of within-treatment detectability, 0.00–0.75, was greater than that observed for oviposition pits. Six of the 12 treatments with signs of emergence had a within-treatment range of detectability of less than 0.20; for two of these treatments the range exceeded 0.60.

Of the 12 trees without exit holes, inspectors incorrectly declared a tree infested (*i.e.*, a false positive) in $1.2 \pm 0.5\%$ of cases.

Table 3. Analysis of variance on the time taken to accurately detect from the ground simulated oviposition pits and exit holes of *Anoplophora glabripennis* embedded in large Norway maples in Toronto.

Source of variation	Oviposition pits			Exit holes		
	df	<i>F</i>	<i>P</i> > <i>F</i>	df	<i>F</i>	<i>P</i> > <i>F</i>
Inspector	32	4.08	<0.0001	25	4.07	<0.0001
Density	2	5.12	0.006	2	8.18	0.0003
Height	1	108.72	<0.0001	1	48.52	<0.0001
Position	1	90.94	<0.0001	1	5.21	0.0227
Foliage	1	0.3	0.586	1	3.44	0.0641
Density × height	2	10.68	<0.0001	2	5.00	0.0069
Density × position	2	5.13	0.006	2	15.24	<0.0001
Density × foliage	2	0.41	0.6625	2	1.12	0.3278
Height × position	1	2.29	0.1305	1	20.32	<0.0001
Height × foliage	1	6.9	0.0087	1	1.31	0.2535
Position × foliage	1	2.18	0.1398	1	0.36	0.5497
Density × height × position	2	10.25	<0.0001	2	0.86	0.4252
Density × height × foliage	2	3.34	0.0357	2	0.25	0.7756
Height × position × foliage	1	4.78	0.0289	1	0.08	0.7755
Density × height × position × foliage	4	0.87	0.4803	4	2.22	0.0653

Duration of search

Oviposition pits

On average, inspectors took 49 ± 1 s to correctly identify a tree with simulated oviposition pits. The average amount of time required by each inspector to find the signs of oviposition (range 12–96 s) varied significantly among inspectors (Table 3). The time required to find a sign of oviposition was significantly influenced by pit density, height, and position (Table 3). Detection was significantly faster when nine pits were placed on the tree, but there was no significant difference in search duration between one and three pits (Fig. 3A). Search time was also shorter (*i*) when pits were embedded below 2.5 m and (*ii*) when pits were positioned on the bole as opposed to branches (Fig. 3A). The presence of foliage did not affect the time required to locate oviposition pits (Table 3, Fig. 3A).

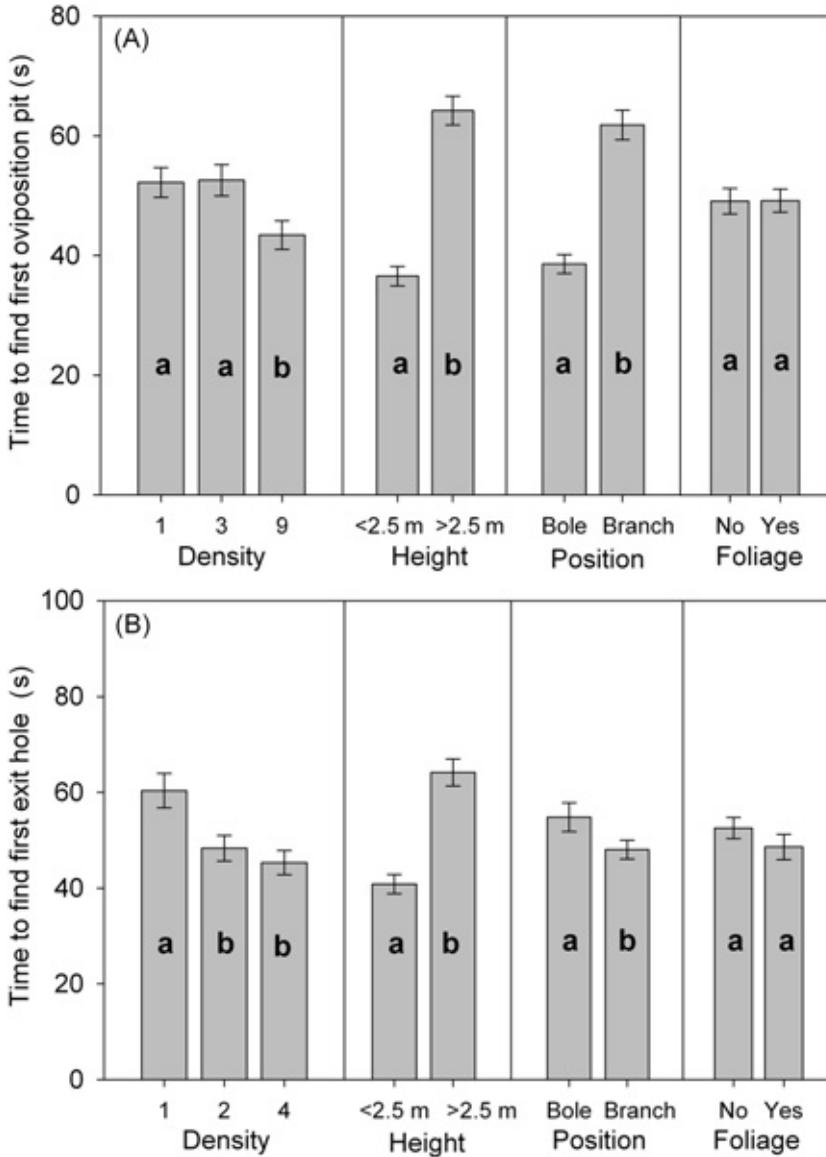
There were three significant two-way interactions in the search-duration model for oviposition pits (Table 3). Pit density and height interacted such that there was a drastic reduction in search duration when nine pits were located below 2.5 m on the tree; however, density had little effect on search duration when pits were located above 2.5 m (Fig. 4A). For the height × foliage interaction, the search when pits were located

below 2.5 m was shorter in the absence of foliage, but the opposite was observed when pits were located above 2.5 m (Fig. 4B). Density and position of oviposition pits also interacted such that, for pits located on the bole, search duration decreased as pit density increased; however, for pits located on branches, less time was required to detect trees with a single pit than those with three pits (Fig. 4C).

As with detectability, there was a significant density × height × position interaction (Table 3). In this case the relationship between a short search duration and the highest pit density did not hold when pits were located on the bole or on branches above 2.5 m (Table 4). The other significant three-way interactions, density × height × foliage and height × position × foliage (Table 3), were associated with a slightly stronger effect of foliage when pits were located on high branches.

The fastest detections (about 16 s) occurred on trees with nine oviposition pits located on the bole and below 2.5 m whereas the slowest (more than 60 s) were associated with any density of oviposition pits located on branches higher than 2.5 m (Table 4). Inspectors spent, on average, 176 s before correctly identifying any of the 12 trees that had no oviposition pits

Fig. 3. Effects of density, height, position, and presence/absence of foliage on the amount of time (mean \pm SE) taken to detect simulated oviposition pits (A) and exit holes (B) of *Anoplophora glabripennis* embedded on Norway maples in Toronto. Within each main effect, bars with the same letter are not significantly different (Ryan–Einot–Gabriel–Welsh test, $P > 0.05$).



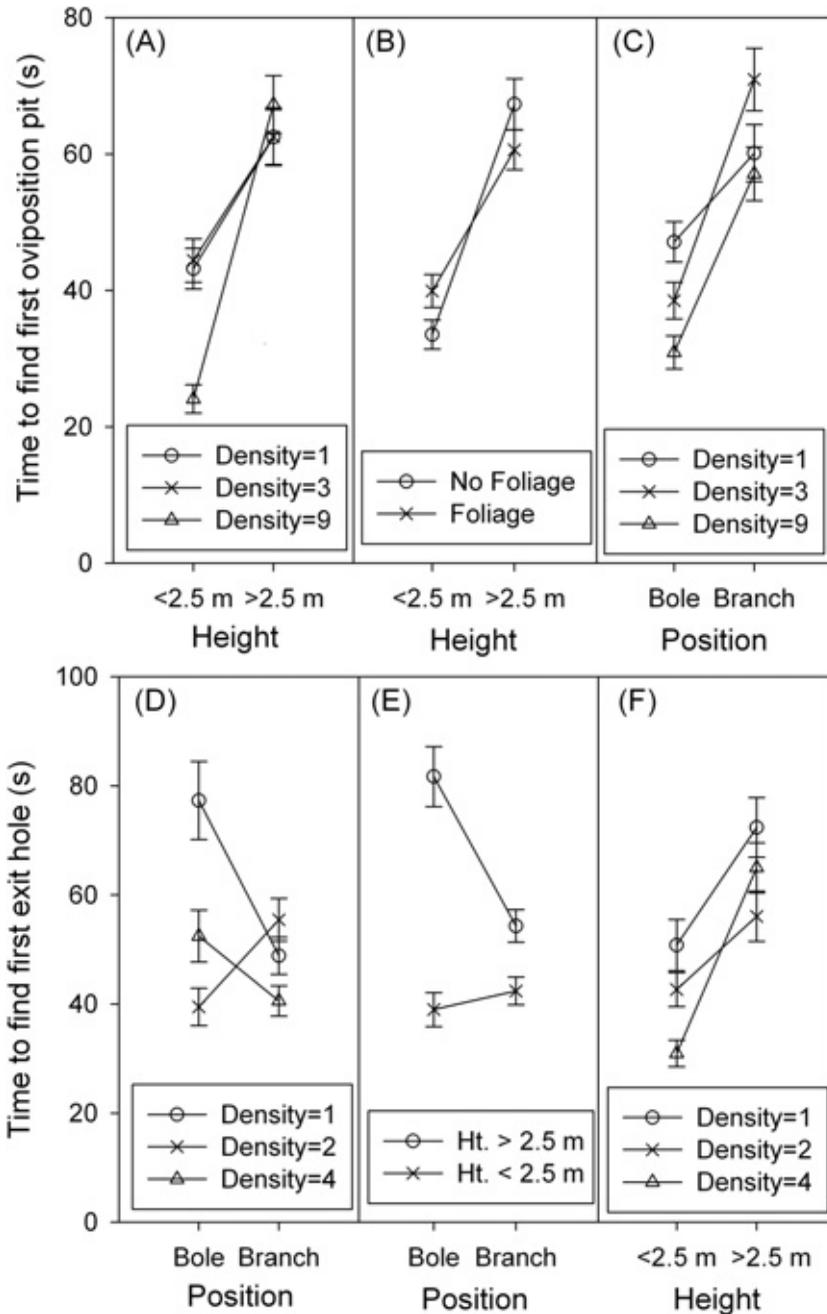
as not infested, but took only 99 s to declare a tree infested when it was not (false positive).

Exit holes

Inspectors took on average 51 ± 2 s to correctly identify a tree with embedded exit holes. Search duration (range 27–79 s) varied significantly among inspectors (Table 3). The

time required to locate signs of *A. glabripennis* adult emergence from a tree was significantly influenced by the density, height, and position of exit holes (Table 3). Searches were shorter when (i) exit-hole densities were greater than 1, (ii) when exit holes were located below 2.5 m above the ground, and (iii) when they were positioned on branches as opposed to the bole

Fig. 4. Mean (\pm SE) time required to find the first simulated oviposition pit or exit hole of *Anoplophora glabripennis* embedded on Norway maples in Toronto: interactions between density and height (A), between height and foliage (B), and between density and position (C) of oviposition pits; and interactions between density and position (D), between height and position (E), and between density and height (F) of exit holes.



(Fig. 3b). Once again, the presence of foliage had no effect on the time required to locate one or multiple exit holes (Table 3, Fig. 3B).

There were three significant two-way interactions in the search-duration model for exit holes (Table 3). For the density \times position

Table 4. Time (in seconds; mean \pm SE) taken by experienced inspectors to accurately detect from the ground simulated oviposition pits and exit holes of *Anoplophora glabripennis* embedded in large Norway maples in Toronto.

Type of sign	Density	Below 2.5 m		Above 2.5 m	
		On bole	On branch	On bole	On branch
Oviposition pits	1	31.3 \pm 2.8	57.4 \pm 5.5	62.3 \pm 5.0	62.8 \pm 6.8
	3	35.1 \pm 3.5	54.0 \pm 5.3	41.7 \pm 4.1	94.0 \pm 7.7
	9	15.5 \pm 2.3	32.9 \pm 3.4	50.0 \pm 4.3	85.5 \pm 7.1
Exit holes	1	62.9 \pm 9.0	41.6 \pm 4.6	98.0 \pm 11.3	57.1 \pm 5.0
	2	28.8 \pm 3.4	56.3 \pm 4.9	58.4 \pm 6.7	54.6 \pm 6.2
	4	31.3 \pm 3.5	30.5 \pm 3.3	91.6 \pm 9.9	51.8 \pm 4.3

interaction, the shortest detection times were associated with a density of 2 when holes were located on the bole; however, at the same density, detection times were longest when holes were on branches (Fig. 4D). Exit holes located above 2.5 m were found much sooner when positioned on branches rather than on the bole, but when they were located below 2.5 m, search durations were similar for branches and boles (Fig. 4E). Less time was taken to find exit holes when the density per tree was 4, but only when they were located below 2.5 m (Fig. 4F).

On average, at least 30 s was required to locate four exit holes located on the bole or on a branch below 2.5 m, while about 60–100 s was required to locate exit holes embedded on the bole above 2.5 m (Table 4). Of the 12 trees that had no exit holes, inspectors required 160 s to correctly identify a tree as not infested and 111 s to declare a tree infested when it was not (false positive).

Time-to-find curves

Inspectors had a maximum of 600 s to examine each tree, yet, under average survey conditions, the time-to-find curves for oviposition pits (Fig. 5A) and exit holes (Fig. 5B) reached an asymptote at about 120 s. More specifically, 89.7% and 90.1% of all trees correctly identified by inspectors as having oviposition pits ($n = 1695$) and exit holes ($n = 1093$), respectively, were identified as such within 120 s of the beginning of the inspection. The oviposition-pit curve reached a higher asymptote and had tighter confidence intervals than the exit-hole curve, indicating

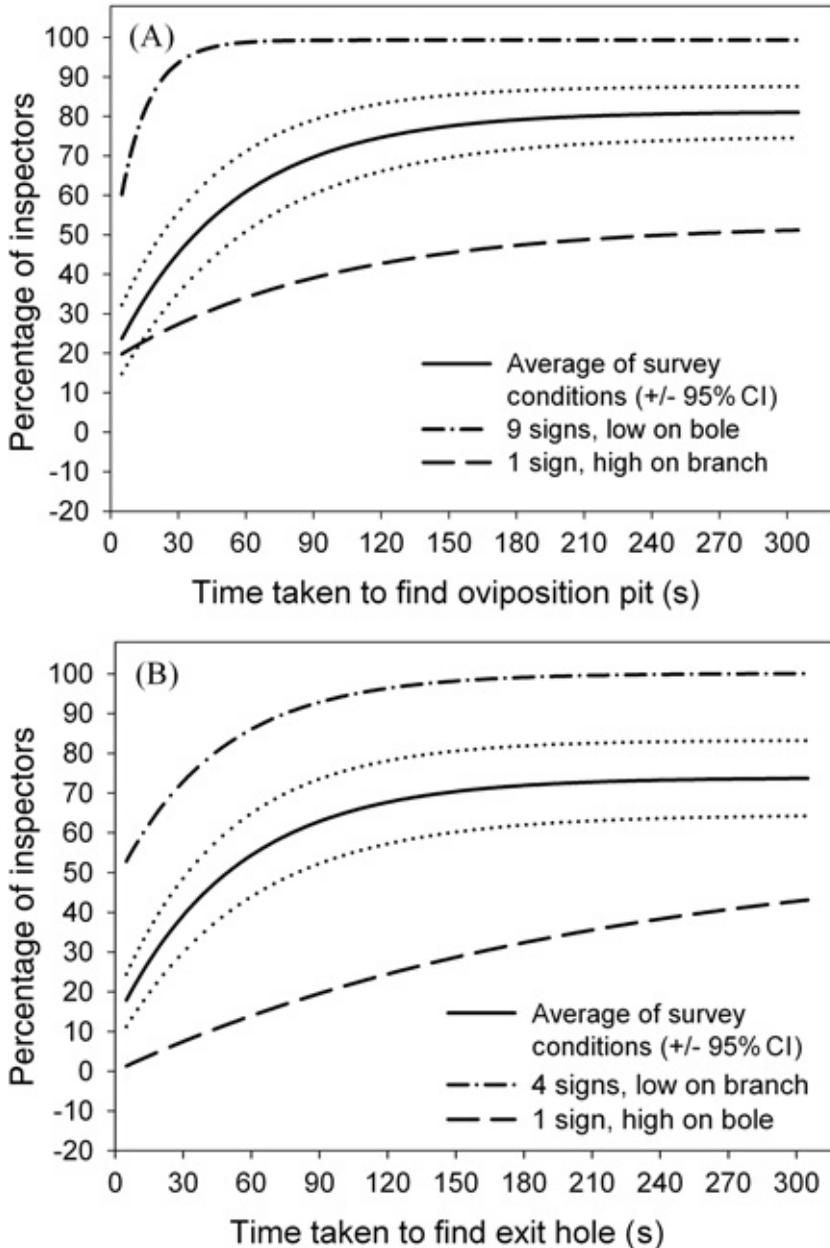
that inspectors were more accurate and consistent in identifying trees with signs of oviposition than of emergence. Less than 1% of the detections of oviposition pits (0.6%) and exit holes (0.8%) occurred after 300 s. The longest search for oviposition pits took 551 s, whereas that for exit holes lasted 374 s.

Discussion

The locations of our simulated signs on trees were consistent with the typical within-tree distribution of *A. glabripennis* signs of attack observed in urban landscapes. The DBHs of our trees were intermediate between those of the Norway maples (31.0 \pm 2.6 cm) and silver maples (*Acer saccharinum* L.) (40.3 \pm 6.9 cm) used by Haack *et al.* (2006) to establish the within-tree distribution of *A. glabripennis* oviposition pits and exit holes. Haack *et al.* (2006) recommended that inspectors focus their search for signs of attack by *A. glabripennis* on the upper trunk and lower branches of maple trees.

We found that detectability increased and searches were shorter when oviposition pits were at higher densities, located lower on the tree, and positioned on the bole. Trends similar to those for oviposition pits were obtained for density and height of exit holes; as for position, survey efficacy improved when holes were located on branches rather than the bole. Our findings for density and height are not surprising, given that greater survey success was associated with treatments that contributed to increased visibility and thus allowed the signs of attack to be observed more readily. The difference in survey efficacy

Fig. 5. Cumulative percentages of inspectors who correctly identified trees with simulated oviposition pits (A) or exit holes (B) as a function of time (in seconds) elapsed since the beginning of the search.



between signs of oviposition and emergence with respect to position could have been due to the visibility or contrast of each type of sign against the bark of the branch or bole. The bark of the experimental maple tree branches was pale gray and smooth, whereas that of the bole was dark with regular intersecting ridges. We speculate that the contrast provided by

oviposition pits was relatively similar in both positions (*i.e.*, reddish brown dots against gray branches and a brown bole), whereas that provided by exit holes was not (*i.e.*, black dots were more readily visible against the background offered by the smooth gray branches than by the dark and ridged bark of the bole). The visibility of oviposition pits may

not differ from that of exit holes on all tree species, but differences in the conspicuousness of both types of sign among tree species have been reported (Turgeon *et al.* 2007).

Overall detectability for trees with oviposition pits (0.81) was slightly higher than for trees with exit holes (0.74). This slight difference in detectability (0.07) does not appear to be due to differences in the range of densities tested for each sign (1, 3, and 9 oviposition pits *versus* 1, 2, and 4 exit holes): detectability of one oviposition pit and one exit hole was 0.73 and 0.66, respectively. Rather, we hypothesize that it could be due to the difference in their appearance or contrast against the background of the branches and bole (*i.e.*, reddish brown pits *versus* black dots). Oviposition pits and exit holes are only two of the six signs of *A. glabripennis* attack currently used in detection surveys (Turgeon *et al.* 2007; Smith and Wu 2008). The inclusion and use of these other signs of attack would only improve the detectability rates reported here.

There was no reduction in the detectability of signs of attack when foliage was present. Several factors may have contributed to this result. We speculate that the high proportion of inspectors with many years of experience in surveying *A. glabripennis* may have played a role, as they had learned to examine foliage-obscured branches or boles from many angles and various distances. Also, the size and crown form of experimental trees were such that the leaves did not obscure any sign and occurred almost entirely at the end of branches; thus, once an inspector had moved under the crown, the presence of leaves appeared to have had little effect on the appearance and visibility of simulated signs from the ground. Moreover, the average tree height was about 12 m, yet the highest signs on the tree were located only between 2.5 and 6 m above the ground, primarily because this was where most *A. glabripennis* attacks had been initiated (Haack *et al.* 2006), but also because of concern for the safety of the technicians who created the artificial signs of attack. Whether this finding (*i.e.*, detectability is not affected by the presence of foliage) would apply when signs of attack (*i*) are located higher in Norway maples, (*ii*) are

farther from the bole and near foliage, (*iii*) are placed on tree species with a different bark or crown density, or (*iv*) are embedded on younger trees, where foliage would hide a greater portion of the branch- and stem-wood, is not known. Finally, we recorded only the time at which inspectors began tree inspection; we do not know whether the presence of foliage affected the distance at which they began inspection or how they scanned trees for signs.

Some of our findings require some qualification, owing to a number of significant interactions among main effects. For example, both oviposition pits and exit holes were located more easily when they occurred at higher densities, but this density effect was much less apparent when they were placed higher in the tree (above 2.5 m). This finding makes some intuitive sense: when signs are in hard-to-find places (*i.e.*, higher in the tree), having more of them makes little difference in terms of survey speed or sign detectability. Many of the remaining interactions, however, were subtle and (or) counterintuitive. For example, the presence of foliage appeared to delay inspectors in their search for oviposition pits when these were located below 2.5 m but to facilitate their discovery when above 2.5 m. We suggest that many of these counterintuitive interactions relate to the specifics of sign placement on trees and to the survey approach or technique used by the various inspectors. Although the technician who created the signs attempted to ensure uniformity in visibility within and among treatments, it is likely that for certain treatment combinations, signs were consistently easier, or harder, to find than might be expected under more controlled conditions. As an example of the within-treatment variation in this experiment, of the three trees that were marked with a single oviposition pit located on a low branch, detectability, averaged over all inspectors, varied between 0.48 for replicate 3 and 0.91 for replicate 2. As mentioned earlier, this within-treatment variation in detectability exceeded 0.20 for several treatments. This considerable variation in the visibility of signs within a given treatment, for some treatments only, may have contributed to many of the counterintuitive interactions reported here.

Our results also indicate that regardless of survey conditions, a certain percentage of trees with a low density of signs of attack will remain undetected. A more important finding, however, is that extending the duration of ground surveys beyond 2 min did little to improve the detectability of signs of attack on open-grown maple trees. One approach to improving detectability would be for each tree to be inspected simultaneously by a team of inspectors rather than by a single one. For example, based on the average search duration curve for exit holes (Fig. 5B), a single examiner has about a 50% chance of finding the exit hole in the first minute; if a second independent survey also lasting 60 s was carried out on that tree, basic algebra suggests that there would be a 25%, 50%, and 25% probability that both inspectors, only one of them, and neither of them, respectively, would find the sign. Thus, using two examiners per tree for 1 min each would result in a higher probability of detection than a single one spending 5 min (or more) at the tree.

Our findings, though limited to the study of only a few of many factors that may affect survey efficiency, are intended to aid in designing surveys to detect or delimit the areal extent of an infestation of *A. glabripennis*. As outlined above, our results indicate that on maple the optimal search duration varies with the density and location of simulated signs of attack. Given that at the planning stage of these surveys, the density and distribution of signs of beetle attack are unknown, the search duration will have to be selected on the basis of, and consistent with, survey objectives. For example, if the objective is to detect a relatively large infestation over a vast territory, the time-to-find curve derived from our best-case scenarios (*i.e.*, oviposition: high densities of pits low on the bole (Fig. 5A); emergence: high density of holes on low branches (Fig. 5B)) could be used as a guideline to identify an appropriate search duration. In this case, inspection of each tree could be limited to 60 s or less, which is the time required before the time-to-find curves for oviposition and emergence reach an asymptote. Conversely, if the objective is to detect as many infested tree as possible within a small or known-to-be-infested

area, the time-to-find curves from our worst-case scenarios (*i.e.*, oviposition: low density of pits high on branches (Fig. 5A); emergence: low density of holes high on the bole (Fig. 5B)) could be used. A more appropriate search duration for this type of survey could be 3–4 min per tree, which is the time required to reach the asymptote. Alternatively, average survey conditions could be assumed and a survey duration not exceeding 2 min should be adequate to detect most maple trees with either of these signs of attack. Note, however, that these search durations were obtained with experienced inspectors. Thus, it is recommended that inspectors be trained to recognise all the signs of *A. glabripennis* attack and that their efficiency in detecting trees with signs of injury, such as those caused by oviposition and emergence, within the selected time frame / search duration be assessed prior to the initiation of surveys. This assessment could be performed until inspectors can reach or exceed a threshold that would provide the desired level of confidence in the survey results.

Operational surveys for detecting and delimiting invasive species must strike a workable balance between detectability, operational speed requirements, and short- and long-term costs. Such surveys are often carried out in areas where an invasive alien species is at low population levels. This is particularly true for the delimitation process, which aims to determine the spatial boundaries of a known invasion through surveys carried out at the outer edge of the established population. In our study we examined the detectability and search duration associated with relatively low-density signs of *A. glabripennis* attack on maple trees, using experienced staff under controlled weather conditions. Our results provide baseline data on the effort required to survey *A. glabripennis* under a variety of plausible scenarios. This information, (*i.e.*, measures of detectability and sampling effort) can now be incorporated into the design and development of ground-survey programs whose objectives are to detect or delineate low-density populations of *A. glabripennis*. Furthermore, our approach could serve as a template for the development of sampling or survey programs targeting other species of animals.

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References

- Animal Plant Health Inspection Service (APHIS). 2005. Asian longhorned beetle (*Anoplophora glabripennis*) fact sheet. United States Department of Agriculture, Animal Plant Health Inspection Service, January 2005 [online]. Available from http://www.aphis.usda.gov/lpa/pubs/fsheet_fa_notice/fs_phalb.pdf [accessed 4 February 2009].
- APHIS. 2008. Asian long horned beetle [online]. United States Department of Agriculture, Animal Plant Health Inspection Service, Plant Pest Information. Available from http://www.aphis.usda.gov/plant_health/plant_pest_info/asian_lhb/index.shtml [accessed 4 February 2009].
- Bulman, L.S., Kimberley, M.O., and Gadgil, P.D. 1999. Estimation of the efficiency of pest detection surveys. *New Zealand Journal of Forestry Science*, **29**: 102–115.
- Canadian Food Inspection Agency. 2003. Toronto – Vaughan, Ontario – Regulated Area [online]. Available from <http://www.inspection.gc.ca/english/plaveg/pestrava/anogla/mc/mapcarrege.shtml> [accessed 4 February 2009].
- Carter, M.E., Smith, M.T., Turgeon, J.J., and Harrison, R.G. 2009. Analysis of genetic diversity in an invasive population of Asian longhorned beetles in Ontario, Canada. *The Canadian Entomologist*, **141**: 582–594.
- Conway, C.J., Garcia, V., Smith, M.D., and Hughes, K. 2008. Factors affecting detection of burrowing owls nests during standardized surveys. *Journal of Wildlife Management*, **72**: 688–696.
- de Solla, S.R., Shirose, L.J., Fernie, K.J., Barrett, G.C., Brousseau, C.S., and Bishop, C.A. 2005. Effect of sampling effort and species detectability on volunteer based anuran monitoring programs. *Biological Conservation*, **121**: 585–594.
- Haack, R.A., Bauer, L.S., Gao, R.T., McCarthy, J.J., Miller, D.L., Petrice, T.R., and Poland, T.M. 2006. *Anoplophora glabripennis* within-tree distribution, seasonal development, and host suitability in China and Chicago. *The Great Lakes Entomologist*, **39**: 169–183.
- Haack, R.A., Hérard, F., Sun, J.H., and Turgeon, J.J. 2010. Managing invasive populations of Asian longhorned beetle and citrus longhorned beetle: a worldwide perspective. *Annual Review of Entomology*, **55**: 521–546.
- Haack, R.A., Law, K.R., Mastro, V.C., Osenbruggen, H.S., and Raimo, B.J. 1997. New York's battle with the Asian longhorned beetle. *Journal of Forestry*, **95**: 11–15.
- Hardy, P.C., and Morrison, M.L. 2000. Factors affecting the detection of elf owls and western screech owls. *Wildlife Society Bulletin*, **28**: 333–342.
- He, P., and Huang, J. 1993. Adult behavior of *Anoplophora glabripennis*. *Acta Entomologica Sinica*, **36**: 51–55.
- Hérard, F., Jollivet, C., and Reynaud, P. 2005. Gestion des foyers de capricornes asiatiques : en France, Autriche, Allemagne et Italie, l'éradication est lancée. *Phytoma*, **583**: 22–26.
- Hérard, F., Maspero, M., Ramualde, N., Jucker, C., Colombo, M., Ciampitti, M., and Cavagna, B. 2009. *Anoplophora glabripennis* infestation (Col.: Cerambycidae) in Italy. *Bulletin OEPP (Organisation Européenne et Méditerranéenne pour la Protection des Plantes/European and Mediterranean Plant Protection Organization)*, **39**: 146–152.
- Hopkin, A., de Groot, P., Turgeon, J.J. 2004. Alien forest insects: What's bugging us in Ontario? Emerald ash borer and Asian longhorned beetle [online]. *Forest Health and Biodiversity News*, **8**: 1–2, 5. Available from <http://cfs.nrcan.gc.ca/news/328> [accessed 4 February 2009].
- Keena, M.A. 2002. *Anoplophora glabripennis* (Coleoptera: Cerambycidae) fecundity and longevity under laboratory conditions: comparison of populations from New York and Illinois on *Acer saccharum*. *Environmental Entomology*, **31**: 490–498.
- Keena, M.A. 2006. Effects of temperature on *Anoplophora glabripennis* (Coleoptera: Cerambycidae) adult survival, reproduction and egg hatch. *Environmental Entomology*, **35**: 912–921.
- Keena, M.A. 2008. Phenology of the Asian longhorned beetle under simulated annual environmental fluctuations. *In Proceedings of the 19th United States Department of Agriculture*

- Interagency Research Forum on Invasive Species, Annapolis, Maryland, 8–11 January 2008. Edited by K. MacManus and K.W. Gottschalk. United States Department of Agriculture, Forest Service General Technical Report NRS-P-36. p 37.
- Kimoto, T., and Duthie-Holt, M. 2004. Exotic forest insect guidebook. Plant Pest Survey Unit, Canadian Food Inspection Agency.
- Lingafelter, S.W., and Hoebeke, E.R. 2002. Revision of *Anoplophora* (Coleoptera: Cerambycidae). Entomological Society of Washington, Washington, D.C.
- Maspero, M., Jucker, C., and Colombo, M. 2007. First record of *Anoplophora glabripennis* (Motschulsky) (Coleoptera Cerambycidae Lamiinae Lamiini) in Italy. Bollettino di Zoologia Agraria e di Bachicoltura, Serie II, **39**: 161–164.
- Mehta, S.V., Haight, R.G., Homans, F.R., Polasky, S., and Venette, R.C. 2007. Optimal detection and control strategies for invasive species management. Ecological Economics, **61**: 237–245.
- Morewood, W.D., Neiner, P.R., McNeil, J.R., Sellmer, J.C., and Hoover, K. 2003. Oviposition preference and larval performance of *Anoplophora glabripennis* (Coleoptera: Cerambycidae) in four eastern North American hardwood tree species. Environmental Entomology, **32**: 1028–1034.
- Morewood, W.D., Hoover, K., Neiner, P.R., McNeil, J.R., and Sellmer, J.C. 2004a. Host tree resistance against the polyphagous wood-boring beetle *Anoplophora glabripennis*. Entomologia Experimentalis et Applicata, **110**: 79–86.
- Morewood, W.D., Neiner, P.R., Sellmer, J.C., and Hoover, K. 2004b. Behavior of adult *Anoplophora glabripennis* on different tree species under greenhouse conditions. Journal of Insect Behavior, **17**: 215–226.
- Morewood, W.D., Hoover, K., Neiner, P.R., and Sellmer, J.C. 2005. Complete development of *Anoplophora glabripennis* (Coleoptera: Cerambycidae) in northern red oak trees. The Canadian Entomologist, **137**: 376–379.
- North American Plant Protection Organization (NAPPO). 2008. Asian longhorned beetle, *Anoplophora glabripennis*, confirmed in Worcester County, Massachusetts [online]. Available from <http://www.pestalert.org/oprDetail.cfm?oprID=336> [accessed 4 February 2009].
- Nowak, D., Pasek, J.E., Sequeira, R.A., Crane, D.E., and Mastro, V.C. 2001. Potential effect of *Anoplophora glabripennis* (Coleoptera: Cerambycidae) on urban trees in the United States. Journal of Economic Entomology, **94**: 116–122.
- Ric, J., de Groot, P., Gasman, B., Orr, M., Doyle, J., Smith, M.T., Dumouchel, L., Scarr, T., and Turgeon, J.J. 2007. Detecting signs and symptoms of Asian longhorned beetle injury: training guide. Canadian Forest Service, Natural Resources Canada, Ottawa, Ontario.
- SAS Institute Inc. 2003. SAS user's guide: statistics. Release 9.1. SAS Institute Inc., Cary, North Carolina.
- Sawyer, A.J. 2008. Annotated host list for the Asian longhorned beetle, February 22, 2008 [online]. Available from http://www.aphis.usda.gov/plant_health/plant_pest_info/asian_lhb/downloads/hostlist.pdf [accessed 5 February 2009].
- Smith, M.T., and Wu, J.Q. 2008. Asian longhorned beetle: renewed threat to northeastern USA and implications worldwide. International Pest Control **50**: 311–316.
- Smith, M.T., Bancroft, J., and Tropp, J. 2002. Age-specific fecundity of *Anoplophora glabripennis* (Coleoptera: Cerambycidae) on three tree species infested in the United States. Environmental Entomology, **31**: 76–83.
- Smith, M.T., Tobin, P., Bancroft, J.S., Li, G.H., and Gao, R.T. 2004. Dispersal and spatiotemporal dynamics of Asian longhorned beetle (Coleoptera: Cerambycidae) in China. Environmental Entomology, **33**: 435–442.
- Turgeon, J.J., Ric, J., de Groot, P., Gasman, B., Orr, M., Doyle, J., Smith, M.T., Dumouchel, L., and Scarr, T. 2007. Détection des signes et des symptômes d'attaque par le longicorne étoilé: guide de formation. Service canadien des forêts, Ressources naturelles Canada, Ottawa, Ontario.
- Williams, A.K. 2003. The influence of probability of detection when modeling species occurrence using GIS and survey data. Ph.D. dissertation, Faculty of the Virginia Polytechnic Institute and State University. Blacksburg, Virginia.
- Williams, D.W., Lee, H.P., and Kim, I.K. 2004a. Distribution and abundance of *Anoplophora glabripennis* (Coleoptera: Cerambycidae) in natural *Acer* stands in South Korea. Environmental Entomology, **33**: 540–545.
- Williams, D.W., Li, G., and Gao, R. 2004b. Tracking movements of individual *Anoplophora glabripennis* (Coleoptera: Cerambycidae) adults: application of harmonic radar. Environmental Entomology, **33**: 644–649.
- Xiao, G. 1992. Forest insects of China. China Forestry Publishing House, Beijing, People's Republic of China.
- Yang, X., Zhou, J., Wang, F., and Cui, M. 1995. A study on the feeding habits of the larvae of two species of longicorn (*Anoplophora*) to different tree species. Journal of Northwest Forestry College, **10**: 1–6. [In Chinese with English abstract.]
- Zhao, R., Lu, Z., Lu, X., and Wu, X. 1993. Life table study of *Anoplophora glabripennis* (Coleoptera: Cerambycidae) natural populations. Journal of Beijing Forestry University, **15**(4): 125–129.