

Monitoring Attack and Flight Activity of *Xylosandrus* spp. (Coleoptera: Curculionidae: Scolytinae): The Influence of Temperature on Activity

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ABSTRACT Wood-boring ambrosia beetles (Coleoptera: Curculionidae: Scolytinae), including *Xylosandrus* spp., are key pests in ornamental nurseries. Knowledge of their activity in spring is important for nursery growers to effectively time their protective sprays. We measured the reliability of ethanol-baited bottle traps for monitoring emergence of overwintered *Xylosandrus* spp. in ornamental nurseries. Detection of initial flight activity by traps was compared with initial attacks on ethanol-injected trap trees. To develop tools for forecasting *Xylosandrus germanus* (Blandford) activity, the relationships between temperature and their attack and flight activity were examined, and the bloom sequence of ornamental plants was examined as phenological indicators of *X. germanus* emergence in Ohio. Captures of *X. germanus* coincided with attacks on trap trees on seven of eight occasions over 2 yr in four nurseries. *Xylosandrus crassiusculus* (Motshulsky) were detected in only one nursery and captures coincided with attacks each year. There was a strong relationship between maximum daily temperatures 20 and 21°C and *X. germanus* attack and flight activity. No attack or flight activity were detected in a monitoring period unless there were 1 or 2 d of at least 20°C. Emergence of *X. germanus* always began after and within 6 d of full bloom on Cornelian cherry dogwood, and usually after and within 4 d of first bloom on Norway maple and full bloom on border forsythia. The traps or phenological indicators can be used by growers to monitor emergence of *X. germanus* to time their initial protective sprays. The relationship between *X. germanus* activity and temperature can be used by growers to make decisions on timing subsequent treatments.

KEY WORDS bottle trap, trap tree, forecasting activity, phenological indicator, ambrosia beetle

Wood-boring ambrosia beetles (Coleoptera: Curculionidae: Scolytinae) bore into the xylem of trees and create galleries, which they inoculate with symbiotic fungi, the source of food for the larvae and adults (Wood 1982). Certain ambrosia beetles preferentially colonize physiologically stressed or dying trees (Hoffman 1941; Wood 1982; Weber and McPherson 1984; Kühnholz et al. 2001; Ranger et al. 2010, 2013). Weber and McPherson (1984) found that the ambrosia beetle *Xylosandrus germanus* (Blandford) was more likely to colonize black walnut trees (*Juglans nigra* L.) with slower growth rates, and concluded that beetles could differentiate between slight differences in host vigor. Ranger et al. (2013) demonstrated that *X. germanus* preferentially landed on and colonized flood-stressed *Cornus florida* L. compared with adjacent nonflooded trees. Ethanol is emitted from trees under physiolog-

ical stress (Moeck 1970, Kimmerer and Kozlowski 1982, Kelsey and Joseph 2001, Ranger et al. 2013), and acts as a primary attractant for ambrosia beetles including *Xylosandrus crassiusculus* (Motshulsky) and *X. germanus* (Graham 1968; Cade et al. 1970; Moeck 1970; Montgomery and Wargo 1983; Klimetzek et al. 1986; Oliver and Mannion 2001; Ranger et al. 2010, 2011a,b, 2012). Ranger et al. (2010, 2011b, 2012) induced attacks by *X. germanus* and other ambrosia beetles by injecting *Magnolia virginiana* L. with ethanol, while noninjected trees and trees injected with water were not attacked.

X. crassiusculus, *X. germanus*, and other exotic ambrosia beetles are damaging pests in ornamental nurseries (Hudson and Mizell 1999; Oliver and Mannion 2001; Hale 2007; Reding et al. 2010, 2011). Both species are native to Asia and have wide host ranges, which include primarily deciduous species (Wood 1982, Solomon 1995). Adult *X. crassiusculus* and *X. germanus* overwinter in galleries of infested trees. Only the females fly and overwintered beetles emerge in spring to colonize new hosts (Wood 1982, Weber and McPherson 1983). Ornamental nursery growers rely on trunk sprays of insecticides to protect trees from attacks by ambrosia beetles (Hudson and Mizell 1999; Oliver and Mannion 2001; Hale 2007; Reding et al.

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2010, 2013; Ranger et al. 2011b). However, synchronizing protective sprays with ambrosia beetle activity is difficult because the beetles are small and difficult to detect. Ethanol-baited bottle traps and funnel traps were effective for monitoring seasonal flight activity of *X. crassiusculus*, *X. germanus*, and other ambrosia beetles in ornamental nurseries (Oliver and Mannion 2001; Gandhi et al. 2010; Ranger et al. 2010, 2011a; Reding et al. 2010, 2011). Therefore, traps could be used to monitor emergence of *Xylosandrus* species in spring, and enable growers to better synchronize their protective sprays with beetle activity. However, traps must reliably detect initial emergence of *Xylosandrus* spp. in spring. If nursery trees are attacked before initial detection of beetles in ethanol-baited traps, traps would be unreliable for monitoring emergence to time protective sprays. Oliver and Mannion (2001) reported that captures of *X. crassiusculus* and *X. germanus* in ethanol-baited funnel traps coincided with their attacks on trees in a research nursery in Tennessee. Additional research that includes multiple locations and years is needed to thoroughly examine the timing between *X. crassiusculus* and *X. germanus* colonization activity and their detection in ethanol-baited traps.

The ethanol-injection technique developed by Ranger et al. (2010) provides a reliable method for inducing colonization of live trees by *X. germanus* and other ambrosia beetles (Ranger et al. 2011b, 2012; Reding et al. 2013). Ranger et al. (2010, 2012) and Reding et al. (2013) demonstrated that ethanol-injected trees were preferentially attacked by *Xylosandrus* spp. while noninjected trees were not attacked. Therefore, ethanol-injected trap-trees should be sensitive detectors of initial colonization activity in nurseries. Using ethanol-injected trees and ethanol-baited traps for monitoring initial emergence of *Xylosandrus* spp. in spring should provide a rigorous test of traps as tools for detecting emergence of *Xylosandrus* spp. Traps would be considered reliable for monitoring initial emergence of *Xylosandrus* spp. if the first detection of these species occurred in traps before or at the same time as in trap trees.

The relationship between insect activity and environmental factors has been used to predict insect pest activity in various cropping systems (Rodriguez-Del-Bosque and Magallanes-Estala 1994, Bostanian et al. 1999, Edde et al. 2006). Reliable tools for predicting pest activity can be used by growers to make pest management decisions such as when or whether to apply insecticide treatments. The relationship between temperature, colonization (attack), and flight activity of *Xylosandrus* species has not been explored. Field data on *Xylosandrus* spp. activity and temperature data could be used to examine the relationship between temperature and beetle activity.

Phenology is the study of recurring biological events in relation to climate and weather changes (Herms 1990, 2004; Mussey and Potter 1997). The seasonal bloom sequence of woody ornamental plants has been used as phenological indicators for emergence of insect pests (Herms 1990, 2004; Mussey and Potter

1997; Hodges and Braman 2004; Cardina et al. 2007). Herms (1990, 2004) developed a degree-day-based phenological calendar of the bloom sequence of woody ornamental plants for Michigan and Ohio. Data on emergence of *X. germanus* and the bloom events listed in the phenological calendar could be used to identify phenological indicators of *X. germanus* emergence in Ohio. If the bloom sequence of nursery plants is a good predictor of *X. germanus* emergence, growers could use these phenological indicators to time their protective sprays (Mussey and Potter 1997, Cardina et al. 2007).

The objectives of the current research were as follows: 1) determine whether ethanol-baited bottle traps reliably detect initial emergence of *Xylosandrus* spp. in spring; 2) examine the relationships between temperature and *X. germanus* attack and flight activity during spring, and use the relationships to develop models for forecasting *X. germanus* activity; 3) determine whether the bloom sequence of woody ornamental plants are reliable phenological indicators of *X. germanus* emergence in Ohio.

Materials and Methods

Bottle Traps, Lures, and Trap Trees. *Traps and Lures.* The traps used in the current research were constructed of two clear plastic bottles (0.5 and 1 liter) with the mouth ends connected by a plastic threaded tube ("Tornado Tube," item WTUB-500, Steve Spangler Science, Englewood, CO), hereafter referred to as bottle-traps (Reding et al. 2011, Ranger et al. 2012). The 1-liter bottle was on top and had two vertical openings ≈ 12.5 by 7.5 cm to allow entrance of ambrosia beetles. The small bottle (0.5 liter) functioned as the collection receptacle and was filled with ≈ 100 ml of a 50% solution of propylene glycol (CAS Registry 57-5506, Sierra Antifreeze/Coolant, Old World Industries, Northbrook, IL) as the killing agent. The baits were commercially available pouch-style dispensers (lures) loaded with 10 ml of 95% ethanol with a release rate of 65 mg/d at a constant 30°C (Standard Release ethanol lures, AgBio, Westminster, CO), and suspended at the top of the trap within the 1-liter bottle. The traps were suspended from posts, so the openings were ≈ 0.5 m above the ground, and lures were replaced as needed (Reding et al. 2010, 2011).

Trap Trees. The trap trees were containerized *Magnolia virginiana* L. injected with 75 ml of 90% ethanol (Ranger et al. 2010, 2012). The trees were injected with ethanol using the Arborjet Tree I.V. Delivery System (Woburn, MA; Ranger et al. 2010). Injection sites were initiated by drilling a single 9.5 mm hole ≈ 16 mm deep into the base of the trees. The hole was immediately plugged with an Arborjet injection port (9.5 mm in diameter), and the ethanol was injected through the port at a delivery pressure of 413.7 kPa (60 psi). The trees were at least 40 mm in diameter at the base of the stem (Ranger et al. 2010, 2011b, 2012; Reding et al. 2013).

Testing the Reliability of Traps for Detecting Emergence of *Xylosandrus* spp. The emergence of *Xylosandrus* spp. was monitored in northern Ohio in com-

Table 1. Locations of Ohio nurseries monitored for *X. germanus* flight (2008–2011) and attack (2010–2012) activity

Nursery ^a	County	Years monitored by			Latitude and longitude ^b
		Traps	Trap trees	Bolts	
Nursery-1	Wayne	2008	NA	NA	40° 52'5.4" N, 82° 2'54.5" W
Nursery-2	Lake	2008–2009	NA	NA	41° 48'7.5" N, 81° 7'19.7" W
Nursery-3	Lake	2008–2011	2010–2011	2012	41° 49'15.0" N, 81° 2'27.4" W
Nursery-4#	Lake	2008–2011	2010–2011	2012	41° 47'54.2" N, 81° 4'40.6" W
Nursery-5#	Lorain	2008–2011	2010–2011	2012	41° 25'35.8" N, 82° 3'57.2" W
Nursery-6	Lake	2010–2011	2010–2011	2012	41° 48'27.8" N, 81° 0'58.1" W
Arboretum-1	Wayne	NA	NA	2012	40° 46'35.3" N, 81° 54'56.8" W

^a #Designates location of USDA-ARS weather station from which data were collected. The Wayne county weather data site was located at The Ohio State University Ohio Agricultural Research and Development Center, in Wooster, Ohio (40° 46'47.2" N, 81° 55'48.6" W).

^b Longitude and latitude coordinates obtained from Flash Earth (<http://www.flashearth.com/>).

mercial nurseries that have experienced damage from *Xylosandrus* spp. (see Table 1 for information on nursery locations). Ethanol-injected trap trees (Ranger et al. 2010) and ethanol-baited bottle traps (Reding et al. 2011) were used to monitor *Xylosandrus* spp. colonization (attacks) and flight activity, respectively.

Ethanol-baited bottle traps and ethanol-injected trap trees were deployed together in ornamental nurseries before ambrosia beetle activity was expected. The traps and trap trees were positioned within 1 m of a wooded border in each nursery (Reding et al. 2011). There were four traps and four trap trees deployed in each nursery. The traps and trap trees were alternated along wooded borders and spaced at least 25 m apart. *Xylosandrus* spp. flight and attack activity were monitored during spring 2010 and 2011 (Table 1). Traps and trap trees were checked every 6–8 d. At that time, beetles were retrieved from traps and transported to the laboratory, and attacks on trap trees were counted and circled with a wax pencil. Then, two attacked trees from each site were transported to the laboratory to extract beetles and determine the species causing the attacks. The remaining trees were retrieved the following week to extract beetles, and new sets of four trap trees were deployed at that time. Trap trees were deployed at 2-wk intervals. Beetles were extracted from all trees by dissecting stems with hand pruners. Encircling the attacks enabled us to determine the time-period attacks occurred and associate the extracted beetles with a specific time-period. The Scolytinae were identified to the species level using available keys (Wood 1982, Rabaglia et al. 2006). In 2010, traps were deployed on 31 March, and trap trees were deployed on 31 March, and 14 and 28 April. In 2010, a period of warm weather that could lead to *X. germanus* activity occurred after deployment of traps and trap trees; consequently, they were checked 2 d after deployment (2 April). In 2011, traps were deployed on 7 April, and trap trees were deployed on 7 and 21 April, and 5 and 19 May.

Examining the Relationship Between Temperature and *X. germanus* Attack and Flight Activity. *X. germanus* colonization (attack) and flight activity, and daily maximum and minimum temperatures were monitored in northern Ohio nurseries to examine the relationships between each activity and temperature.

Monitoring Attack Activity. *X. germanus* colonization (attack) activity was monitored in spring during

2010 through 2012 in northern Ohio (see Table 1 for location details). The 2010 and 2011 data were obtained from the trap tree monitoring described previously. In 2012, ethanol-infused sections of *Acer rubrum* L. stems (bolts) were used to monitor *X. germanus* attack activity. *A. rubrum* saplings 2.5–5 cm in diameter (at the base of the trunk) were cut from a woodlot and stored at 7°C for 1–7 d before being infused with ethanol. After storing, the stems were cut into bolts 30 cm long and infused by soaking in 10% ethanol for 24 h. After ethanol infusion, the bolts were allowed to dry for 1 h and the ends were painted with latex enamel interior and exterior paint (Satin Java Brown, Valspar, Wheeling, IL) to reduce desiccation. The bolts were then stored in resealable plastic bags and deployed in the field within 24 h after infusion. Four bolts were deployed in each location (nurseries and an arboretum, Table 1) by positioning within 1 m of a wooded border, spaced at least 25 m apart, and suspended vertically from posts ≈0.5 m above the ground. The bolts were retrieved weekly, and new bolts were deployed at that time. A stereoscopic microscope was used to examine the retrieved bolts to identify attacks. Then, the bolts were dissected using hand pruners to extract the colonizing beetles, which were identified to the species level as previously described.

Monitoring Flight Activity. Ethanol-baited bottle traps were used to monitor *X. germanus* flight activity in ornamental tree nurseries in northern Ohio each spring during 2008 through 2011 (see Table 1 for information on nursery locations). Traps were deployed in ornamental nurseries within 1 m of a wooded border before ambrosia beetle activity was expected. *X. germanus* flight activity was monitored in five nurseries in 2008, and four nurseries in each of 2009 through 2011 (Table 1). Nine traps were deployed per nursery in 2008 and 2009, and eight traps in 2010 and 2011, with traps spaced at least 25 m apart. Traps were checked at 6- to 8-d intervals, and the captured beetles were transported to the laboratory for identification to the species level as previously described.

Monitoring Daily Temperatures. Temperature data for Lake and Lorain counties were obtained from U.S. Department of Agriculture (USDA)–Agricultural Research Service weather stations located at one of the monitored nurseries in each county (41° 47'54.2" N, 81° 4'40.6" W; 41° 26'0.0" N, 82° 3'3.7" W, respectively)

(Table 1). The Wayne County temperature data came from a station located at The Ohio State University's Ohio Agricultural Research and Development Center (OARDC), in Wooster, OH (40° 46' 47.2" N, 81° 55' 48.6" W) (Table 1). The Lake and Lorain County trapping sites were <5 km from a weather station; the 2008 Wayne County site was ≈16 km from the OARDC station, and the 2012 Wayne County site was at the OARDC within 0.5 km of that station.

Phenological Indicators of *X. germanus* Emergence. The association between the bloom sequence of woody ornamental plants and emergence of *X. germanus* in spring was examined. Plant phenology data and associated degree-day accumulations were obtained from the Ohio State University Internet-based Growing Degree Day Phenology Calendar for Ohio (Herms 2004, Herms et al. 2012). Mean cumulative degree-days for first detection of *X. germanus* in Ohio during 2008 through 2011 were compared with the Phenology Calendar's degree-day-based bloom sequence of nursery plants. The Ohio Phenology Calendar Web site displays plant phenologies for Ohio locations based on the date of interest, zip code of the location, and degree-days (50°F lower developmental threshold temperature [Tb]) accumulated from 1 January (Herms et al. 2012). The cumulative degree-days are calculated from daily maximum and minimum temperatures by a sine wave method (Allen 1976, Herms et al. 2012). The Web site uses temperature data from the weather stations described above. The Fahrenheit degree-days (50°F Tb) obtained from the Web site were converted to the Celsius scale (10°C Tb). The degree-days for first detection of *X. germanus* for each county were based on the date of first detection (in at least one nursery) in that county. Mean DD for first detection of *X. germanus* each year were the mean of all counties monitored that year. There were a total of nine county-site locations during the 4-yr monitoring period (Table 1).

Data Analysis. Logistic regression was used to examine the relationship between maximum daily temperatures and *X. germanus* attack or flight activity as measured by their occurrence in trap trees and bolts or ethanol-baited traps, respectively. Logistic regression is used to analyze binary data such as presence or absence (one or zero) responses (Quinn and Keough 2002, Analytical Software 2003). The occurrence of *X. germanus* (in trap trees and bolts or in traps) during a trapping period was, therefore, designated present or absent. Preliminary examination of the data indicated no *X. germanus* attacks or captures occurred, in Ohio, unless maximum daily temperatures of at least 20.0°C (68°F) occurred during the trapping period. Observations from other locations suggested that attacks and captures of *X. germanus* might be more closely associated with maximum daily temperatures of at least 21.1°C (70°F). Therefore, *X. germanus* attack and capture events (present or absent) were regressed against the number of days in the trapping period with maximum daily temperatures ≥20.0 or ≥21.1°C. The logistic function was of the form $p = [e^{(B_0 + B_1 \times X)} / (1 + e^{(B_0 + B_1 \times X)})]$ where p is the probability of

capturing *X. germanus* or attacks by *X. germanus*, X is the number of days in the trapping period with maximum temperatures ≥20.0 or ≥21.1°C, B_0 is the constant, and B_1 is the regression coefficient that measures the rate of change in probability for a given X (Quinn and Keough 2002). The G statistic (likelihood ratio χ^2 based on the residual deviance) was used to assess the models (Sokal and Rohlf 1995, Quinn and Keough 2002). In addition, classification tables of observed and predicted responses for attacks or captures were developed to assess each model. In the classification tables, the predicted event designations for absent or present were based on estimated probabilities (p) of <0.50 or ≥0.50, respectively (Analytical Software 2003).

Results

Monitoring to Compare *Xylosandrus* spp. Attack and Flight Activity. In Ohio, *X. germanus* flight and attack activity followed a similar pattern each year (Fig. 1). In 2010, initial attacks by *X. germanus* on trap trees and captures in traps were detected on 6 April and coincided in three of the four nurseries. In the fourth nursery, nursery-3, *X. germanus* were detected in trap trees 6 d before detection in traps (14 and 20 April, respectively). In 2011, *X. germanus* initial attacks on trap trees and captures in traps were detected on 28 April and coincided in all four nurseries. *X. crassiusculus* was detected only in the Lorain County nursery, and first detection coincided in trap trees and traps in 2010 (6 May) and 2011 (19 May).

The Relationship Between Temperature and *X. germanus* Activity. **Attack Activity.** Logistic analysis revealed strong significant relationships between *X. germanus* attack activity and the number of days during the trapping period with maximum temperatures ≥20°C ($G = 36.0$; $df = 1$; $P < 0.0001$) or ≥21.1°C ($G = 29.6$; $df = 1$; $P < 0.0001$) (Table 2). Total predictions for the ≥20 and ≥21.1°C models were correct 87 and 82% of the time, respectively (Table 3). Accurate predictions of attacks were more frequent in the 20°C model than for no attacks, while in the 21.1°C model the accuracy of predictions were the same for attacks and no attacks (Table 3). When there were 0, 1, 2, or 3 d with temperatures ≥20°C in the trapping period, the predicted probabilities of attacks by *X. germanus* were 0.128, 0.369, 0.700, and 0.903, respectively (Fig. 2). When there were 0, 1, 2, or 3 d with temperatures ≥21.1°C in the trapping period, the predicted probabilities of attacks by *X. germanus* were 0.206, 0.477, 0.762, and 0.918, respectively (Fig. 2). There were no attacks by *X. germanus* on trap trees or bolts unless there was at least 1 d in the trapping period with temperatures ≥20.0°C.

Flight Activity. Logistic analysis revealed strong significant relationships between *X. germanus* flight activity and the number of days during the trapping period with maximum temperatures ≥20°C ($G = 86.61$; $df = 1$; $P < 0.0001$) or ≥21.1°C ($G = 72.56$; $df = 1$; $P < 0.0001$) (Table 2). Total predictions for the ≥20 and ≥21.1°C models were correct 87 and 85% of the time, respectively (Table 3). Accurate predictions of no *X. germanus* captured were more frequent than for

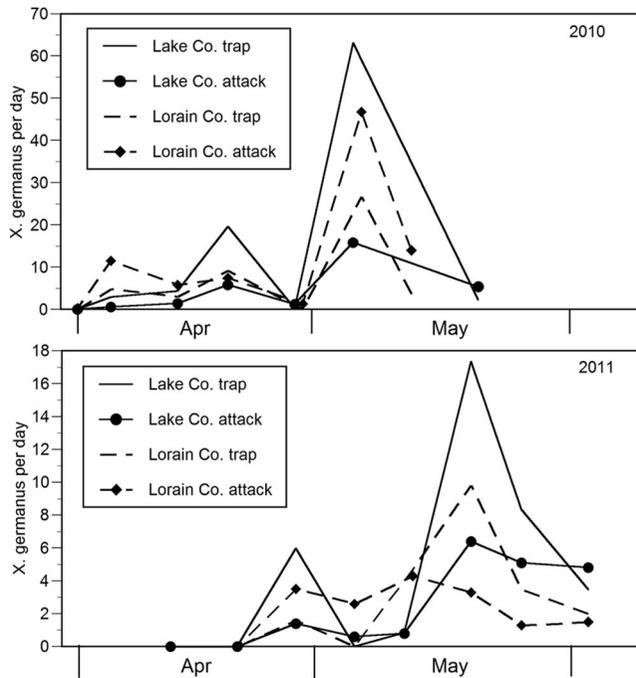


Fig. 1. *X. germanus* spring flight and attack activity as recorded by captures in ethanol-baited traps and attacks on ethanol-injected trap trees, respectively. The attack and capture data for Lake Co. are the pooled means from the three nurseries.

captures for both models. When there were 0, 1, 2, or 3 d with temperatures $\geq 20^{\circ}\text{C}$ in the trapping period, the predicted probabilities of capturing *X. germanus* were 0.058, 0.319, 0.781, and 0.964, respectively (Fig. 3). When there were 0, 1, 2, or 3 d with temperatures $\geq 21.1^{\circ}\text{C}$ in the trapping period, the predicted probabilities of capturing *X. germanus* were 0.172, 0.493, 0.820, and 0.955, respectively (Fig. 3). *X. germanus* were not captured in traps when there were < 2 d in the trapping period with temperatures $\geq 20.0^{\circ}\text{C}$.

Phenological Indicators. In northern Ohio during 2008 through 2011, *X. germanus* were first detected as early as 6 April (2010) and late as 28 April (2011). First captures of *X. germanus* in ethanol-baited bottle-traps across all years occurred at a mean of 76 DD (base 10°C , $n = 9$, range: 57–93 DD) (Table 4). The first capture of *X. germanus* always occurred after and within six calendar days of the DD total for full bloom on Cornelian cherry dogwood (*Cornus mas* L., 54 DD), within 4 d and usually after first bloom on Nor-

way maple (*Acer platanoides* L., 64 DD) and full bloom on border forsythia (*Forsythia \times intermedia* Zabel, 64 DD), and by the DD total for full bloom on Allegheny serviceberry (*Amelanchier laevis* Wiegand, 94 DD) (Herms et al. 2012; Table 4).

Discussion

The current research demonstrated that ethanol-baited bottle traps were reliable for monitoring *X. germanus* emergence in the spring. Emergence of overwintered beetles was detected in traps at the same time as in trap trees on seven of eight occasions. In addition, the seasonal pattern (increase and decrease) of attacks and captures were similar each year. Oliver and Mannion (2001) also found that timing of attacks on trees by *X. germanus* and *X. crassiusculus* coincided with captures in ethanol-baited traps in Tennessee. The attraction of *X. germanus* to ethanol-baited traps and ethanol-injected trees increases as ethanol emission increases (Klimetzek

Table 2. Parameter estimates and statistics for the logistic models predicting *X. germanus* attacks and trap captures during spring, based on the number of days in the trapping period with maximum temperatures ≥ 20.0 or $\geq 21.1^{\circ}\text{C}$.

Event	Model	n	Parameter	df	Estimate	SE	Wald χ^2	P > χ^2
Attacks	$\geq 20.0^{\circ}\text{C}$	77	B0 (constant)	1	-1.91818	0.67128	8.180	0.0042
			B1 (days $\geq 20.0^{\circ}\text{C}$)	1	1.38230	0.37233	13.764	0.0002
	$\geq 21.1^{\circ}\text{C}$	77	B0 (constant)	1	-1.34787	0.57379	5.523	0.0188
			B1 (days $\geq 21.1^{\circ}\text{C}$)	1	1.25652	0.34993	12.888	0.0003
Captures	$\geq 20.0^{\circ}\text{C}$	132	B0 (constant)	1	-2.78189	0.58962	22.278	<0.0001
			B1 (days $\geq 20.0^{\circ}\text{C}$)	1	2.02545	0.39511	26.317	<0.0001
	$\geq 21.1^{\circ}\text{C}$	132	B0 (constant)	1	-1.56914	0.40176	15.288	<0.0001
			B1 (days $\geq 21.1^{\circ}\text{C}$)	1	1.54252	0.28932	28.409	<0.0001

Table 3. Percentage of *X. germanus* attack or capture predictions classified correctly; predictions were based on the number of days in the trapping period with max temperatures ≥ 20.0 or $\geq 21.1^\circ\text{C}$

Event	Days in trapping period with max temperature	<i>X. germanus</i> attack and capture activity		
		Total predictions	Present	Absent
Attacks	$\geq 20.0^\circ\text{C}$	87.0 (77)	89.1 (55)	81.8 (22)
	$\geq 21.1^\circ\text{C}$	81.8 (77)	81.8 (55)	81.8 (22)
Captures	$\geq 20.0^\circ\text{C}$	87.1 (132)	85.6 (90)	90.5 (42)
	$\geq 21.1^\circ\text{C}$	84.8 (132)	80.0 (90)	95.2 (42)

The classifications (percentage predicted correctly) were based on a probability ≥ 0.50 classified present and < 0.50 absent.

et al. 1986; Ranger et al. 2011a, 2012; Reding et al. 2011). The numbers of attacks by *X. germanus* increased on ethanol-injected trees with increasing concentrations of injected ethanol (Ranger et al. 2012), and traps baited with ultra-high release ethanol lures were more attractive than low-release lures (Ranger et al. 2011a). Reding et al. (2011) found that bottle traps baited with two ethanol baits (same type of lures used in the current study) were more sensitive for detecting initial emergence of *X. germanus* than traps with one bait. Each trap in the current study had only one bait. The concentrations of ethanol emitted from traps and trap trees were not determined in the current study. If ethanol was emitted from the trap trees at a higher rate than from traps, the trap trees would have been more attractive to *X. germanus*. This might explain the slight difference between trap trees and traps in detecting initial emergence of beetles.

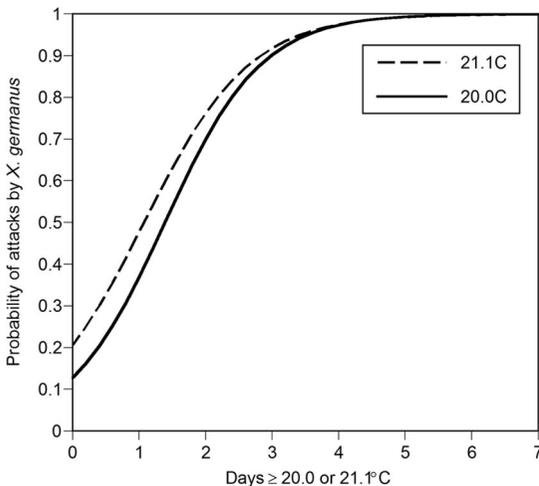


Fig. 2. Logistic regression model of the relationship between *X. germanus* attack activity as represented by (p) the probability of attacks by *X. germanus* on ethanol-injected trap trees or ethanol-infused bolts and (X) the number of days in the trapping period with temperatures ≥ 20.0 or 21.1°C . The logistic equation for 20.0°C was $P = [e^{(-1.91818 + 1.38230 \times X)} / (1 + e^{(-1.91818 + 1.38230 \times X)})]$, and for 21.1°C $P = [e^{(-1.34787 + 1.25652 \times X)} / (1 + e^{(-1.34787 + 1.25652 \times X)})]$.

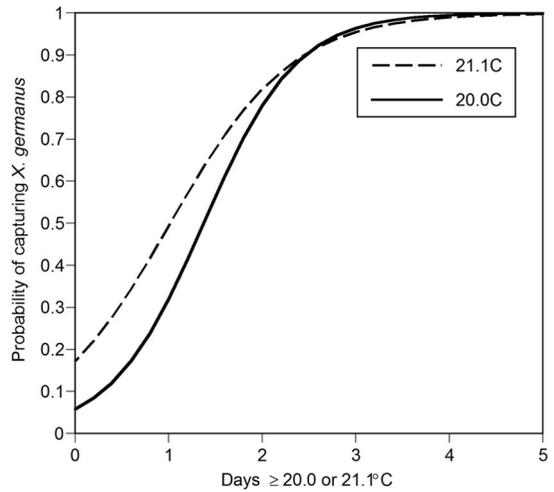


Fig. 3. Logistic regression model of the relationship between *X. germanus* flight activity as represented by (p) the probability of capturing *X. germanus* in ethanol-baited bottle traps and (X) the number of days in the trapping period with temperatures ≥ 20.0 or 21.1°C . The logistic equation for 20.0°C was $p = [e^{(-2.78189 + 2.02545 \times X)} / (1 + e^{(-2.78189 + 2.02545 \times X)})]$, and for 21.1°C $p = [e^{(-1.56914 + 1.54252 \times X)} / (1 + e^{(-1.56914 + 1.54252 \times X)})]$.

X. crassiusculus have been uncommon or absent in previous studies in Ohio (Gandhi et al. 2010; Ranger et al. 2010, 2011a, 2012, 2013; Reding et al. 2010, 2011, 2013), and were detected in only one nursery in the current study. *X. crassiusculus* were first detected in Ohio in 2007 in Wayne County (Lightle et al. 2007). In the current study, it was detected in only the Lorain County nursery. Since that time, *X. crassiusculus* was detected in Lake County, OH (M.E.R., unpublished data). *X. crassiusculus* has been in the southeastern United States since 1974 and tends to be more problematic than *X. germanus* in nurseries in that region (Hudson and Mizell 1999, Oliver and Mannion 2001, Hale 2007, Frank and Sadof 2011, Reding et al. 2013). *X. germanus* is the most problematic ambrosia beetle in Ohio nurseries (Ranger et al. 2010, 2011b; Reding et al. 2010, 2013). If *X. crassiusculus* is a relatively new introduction to Ohio, it may become more widespread over time and potentially more problematic in Ohio.

There was a strong relationship between temperatures ≥ 20 and $\geq 21.1^\circ\text{C}$, and *X. germanus* activity in the spring. The $\geq 20^\circ\text{C}$ models were slightly better at predicting *X. germanus* activity than the $\geq 21.1^\circ\text{C}$ models. No *X. germanus* activity was detected by our monitoring methods when maximum daily temperatures were Because *X. germanus* overwinter as adults, spring emergence should not depend on the beetles completing temperature-related postdormancy development. Minimum temperature thresholds related to initiating activity in spring have been reported for several other Scolytinae that overwinter as adults (Daterman et al. 1965). The temperature-based models of *X. germanus* activity developed in the current research should be valuable tools for managing this pest in nurseries. Predictions derived

Table 4. First captures of *X. germanus* in relation to phenology of woody ornamental nursery plants in Ohio, and mean degree-days based on a 10°C lower developmental threshold

Scientific name	Common name	Event	Mean DD 10°C ^a
<i>Magnolia stellata</i> Maxim.	Star Magnolia	First bloom	46
<i>Forsythia</i> × <i>intermedia</i> Zabel	Border Forsythia	First bloom	48
<i>Cornus mas</i> L.	Cornelian cherry dogwood	Full bloom	54
<i>Acer platanoides</i> L.	Norway maple	First bloom	64
<i>Forsythia</i> × <i>intermedia</i>	Border Forsythia	Full bloom	64
<i>Xylosandrus germanus</i>	Black stem borer	First capture	64 (2009)
<i>Pyrus calleryana</i> Decne.	Chanticleer callery pear	First bloom	68
<i>X. germanus</i>	Black stem borer	First capture	68 (2011)
<i>Prunus sargentii</i> Rehd.	Sargent cherry	First bloom	71
<i>Pieris japonica</i> D. Don ex G. Don	Japanese Pieris	Full bloom	72
<i>X. germanus</i>	Black stem borer	First capture	73 (2010)
<i>Magnolia</i> × <i>soulangiana</i>	Saucer Magnolia	First bloom	74
<i>Chaenomeles speciosa</i> (Sweet) Nak.	Common flowering quince	First bloom	76
<i>X. germanus</i>	Black stem borer	First capture	76 (all years)
<i>Pyrus calleryana</i> Decne.	Bradford callery pear	First bloom	79
<i>Prunus subhirtella</i> Miq.	Weeping Higan cherry	First bloom	81
<i>Rhododendron</i> 'P.J.M' ^b	PJM Rhododendron	First bloom	82
<i>Magnolia stellata</i>	Star Magnolia	Full bloom	83
<i>X. germanus</i>	Black stem borer	First capture	90 (2008)
<i>Amelanchier laevis</i> Wiegand	Allegheny serviceberry	Full bloom	94

^a The degree-days for *X. germanus* first captures are the mean (year) DD for those years. The degree-days for the plant phenologies are means for Ohio, obtained from the Ohio State University Web site on Growing Degree Days and Phenology for Ohio (<http://www.oardc.ohio-state.edu/gdd/>) (Herms et al. 2012).

^b P.J.M. Rhododendrons are hybrids from crosses between *Rhododendron carolinianum* Rehd. and *Rhododendron dawricum* L. var. *sempervirens*.

from the models can be used to forecast *X. germanus* activity, and enable growers to make more informed decisions on timing their protective sprays.

Phenological stages of woody nursery plants were reliable indicators of *X. germanus* emergence in Ohio. First detection of *X. germanus* always occurred within 6 d of Cornelian cherry dogwood full bloom, and 4 d of Norway maple first bloom and border forsythia full bloom. Growers can use this association to time their initial sprays to prevent attacks by *X. germanus*. However, further research should be done to establish phenological indicators of *X. germanus* emergence in other locations.

The consistent association between *X. germanus* emergence and plant phenological stages combined with the 20.0°C activity threshold can be used to predict activity during early to mid-spring in northern Ohio. Using the phenological indicators combined with extended weather forecasts should provide reliable predictions of *X. germanus* emergence. Traps or trap trees could be used to detect emergence or confirm emergence has occurred. Initial protective sprays could be timed to coincide with the phenological indicators or based on captures of *X. germanus* in traps. Then, timing of subsequent sprays could be based on whether periods of temperatures $\geq 20^\circ\text{C}$ are forecast. If cold temperatures are forecast, growers could wait until warmer weather is predicted to apply protective sprays. Greater prediction accuracy in timing sprays will enhance management of *X. germanus*, and save growers money both from avoiding unnecessary insecticide applications and from better timed and more effective protection of nursery trees.

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