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Abstract

This paper reports observations made on the life history and biology of *Saperda imitans* Felt & Joutel in black cherry, *Prunus serotina* Ehrh. *S. imitans* was the principle longhorned beetle (Coleoptera:Cerambycidae) reared from bolts collected from 68 wind-thrown black cherry at the Kane Experimental Forest in northwestern Pennsylvania. It was also the only species that overwintered in the sapwood/outer heartwood, and thus impacted the commercial value of these trees. *Gaurotes cyanipennis* (Say) was the only other cerambycid reared from caged bolts taken from wind-thrown black cherry. The cerambycids *Stenocorus vittiger* (Randall), *Arthophylax attenuatus* (Haldman), *G. cyanipennis*, *Neoclytus acuminatus acuminatus* (F.), *Clytus ruricola* (Olivier), *Cyrtophorus verrucosus* (Olivier), and *Astylopsis macula* (Say) were captured in ethanol-baited Lindgren® funnel traps placed in wind-thrown stands, but were not reared from cherry logs. *S. imitans* was not caught in these traps and apparently it is not attracted to ethanol baits. Neither *S. imitans* nor *G. cyanipennis* were reared from completely uprooted trees (dead) or trees with a major portion of the root system still embedded in soil (live). Preferred hosts were black cherry with moist phloem and epicormic branches with <25% live foliage (dying). The density of *S. imitans* galleries was similar for dying trees in each of three diameter classes; 20-30 cm, >30-40 cm, >40cm. Samples taken from the upper half of the first 5 m of black cherry boles had a higher density of galleries than did those from the lower half. The beetle was recovered in low numbers from branches <10 cm in basal diameter. *S. imitans* is univoltine and in 2007 peak emergence of adults occurred from late May to early June. Results identified the condition of wind-damaged black cherry most susceptible to an infestation of *S. imitans*. This information can be used to establish salvage priorities following a weather event such as this.

Trees that are blown down in violent weather and not salvaged on a timely basis often set the stage for additional forest disturbances, such as fire and increased risks for outbreaks of inner-bark and wood-boring insects (Stathers et al. 1994). Delaying salvage also may allow these insects to reduce the quality of logs recovered from damaged stands (e.g., Wickman 1965, Gardiner 1975, Nevill and Whitehead 1996) or to threaten the survival or quality of live trees in portions of a stand that escaped storm damage (Barry et al. 1993, Eriksson et al. 2005).

On 20-21 July 2003, the Allegheny National Forest (ANF) in northwestern Pennsylvania experienced a series of thunderstorms, downbursts and an F1 tornado, causing extensive windthrow (USDA For. Serv. 2004). Trees were

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moderately to severely damaged on 5,000 ha of the 525,000 ha affected by the storm (Evans et al. 2007). Because of concerns expressed by certain environmental groups who objected to the removal of downed woody material following the storm, salvage of windthrown black cherry, *Prunus serotina* Ehrh., was delayed for three growing seasons. Black cherry is the most desired timber species throughout much of the northeastern United States. Cherry logs from the Allegheny Plateau are less prone to gum defects and the heartwood is a lighter pink compared to cherry grown elsewhere (Cassens 2004); therefore, this resource is highly valued for lumber and veneer (Pennsylvania State University 2007).

Saperda imitans Felt & Joutel (Coleoptera:Cerambycidae:Lamiinae) was the most abundant cerambycid reared from the boles of windthrown black cherry in 2005 and 2006. It was the only member of this beetle family that excavated an overwintering gallery in the wood of this tree, making it of special interest because of its potential to degrade cherry logs used for lumber or veneer.

The genus *Saperda* is of economic significance, because several members of the group have an affinity for commercially important tree species in which the larvae feed in the phloem and then excavate overwintering galleries in the sapwood and, in the case of black cherry, the outer heartwood (Solomon 1995). This damage may result in defects that negatively impact the value of timber for veneer . The distribution of *S. imitans* is restricted to northeastern North America (Linsley and Chemsak 1995), and it is considered rare compared to other species of Cerambycidae known from this region (Lingafelter 2007). This windthrow event provided an unusually abundant source of suitable habitat for the beetle that presented an opportunity to learn more about its biology. Current knowledge about *S. imitans* is limited to reports that it feeds on various young hardwoods (Lingafelter 2007) including hickory (Yanega 1996) and that its size and markings may closely resemble some specimens of *S. lateralis* F. and *S. tridentata* Olivier.

In this paper we report observations of the beetle's life history, host relations, and describe its damage to black cherry logs.

Methods

Study area. The 1,443 ha Kane Experimental Forest (KEF) (N41º36'26",W78º46'30") lies within the ANF in northwestern Pennsylvania. The region is located within the Northern Unglaciated Allegheny Plateau Section of the Laurentian Mixed Forest Province. These forests are dominated by even-aged, second growth cherry-maple stands, a subtype of the more northern beech-birch-maple forest (Eyre 1980). The most common species are black cherry, sugar maple (*Acer saccharum* Marsh.), red maple (*A. rubrum* L.) and American beech (*Fagus grandifolia* Ehrh.). Elevations range from 548 to 640 m. Most forest stands at KEF are 50 to 100 yr old (USDA For. Serv. 1999).

Attraction of cerambycid adults to ethanol-baited traps. To determine the relative abundance and temporal activity of wood-boring beetles attacking windthrown black cherry, a transect of five Lindgren® 12-unit funnel traps were deployed beginning approximately 21 m from a road edge and spaced 21 m apart in a line perpendicular to the road in each of three wind-damaged stands from 5 May through 31 August 2006. Traps were suspended from a wooden arm attached to a wooden stake ≈ 2 m above ground and baited with ultra high release (UHR) ethanol lures with a release rate of 0.35g/d at 20ºC (Pherotech, Inc., now ConTech Enterprises, Delta, BC, Canada). Approximately 100 ml of ethylene glycol was placed in the bottom of each collection cup to preserve trapped insects. Traps were serviced (samples collected, preservative replaced, lures checked and replaced as needed) once a week.

Within-tree distribution of *S. imitans*. Four bands of bark 30 cm wide and 1.25 m apart were removed from each of 68 windthrown black cherry trees. Band 1 was positioned with the lower edge 25 cm above ground. The base of band 2 was positioned at 1.80 m, band 3 at 3.35 m, and band 4 at 4.9 m. The four bands encompassed the first 5.2 m of the tree bole, the most valuable part of a tree in forest stands managed for sawtimber (Trimble 1965). When accessible, the surface area of each band was determined by measuring its circumference (cm) and multiplying by 30 cm (band width). Occasionally, one or more of the lower bands were partially buried in soil or litter. When this occurred, gallery counts were limited to the exposed portion of the bole. Under these conditions, surface area was determined by multiplying band length (30 cm) by the length of the exposed portion of the circumference. Gallery density was expressed as number/1000 cm^2 of bole area.

Susceptible host conditions. The mean trunk diameter of these 68 black cherry trees at breast height (1.4 m, dbh) was 35.7 ± 0.9 cm. To determine if bark thickness, as reflected by host size (dbh), influenced susceptibility to the beetle, the trees were assigned to one of three size classes; small (20-30 cm diam., n = 16), medium (>30-40 cm, n = 33) or large (>40 cm, n = 19). Bark thickness has been shown to be positively correlated with diameter at breast height in sugar maple (Smith 1969).

To determine host condition preferred by *S. imitans,* sample trees with three bands or more in contact with the ground (n = 32) were classified as resting on the ground. Gallery density on these trees was compared to that of the remaining 36 trees, which were classified as suspended off the ground (Table 1).

A major portion of the root system for 24 trees remained embedded in soil and these individuals possessed many foliated epicormic branches; moist, light colored phloem; and tight bark (live trees). Twenty two trees had mostly dead epicormic branches (or if alive the epicormic branches had < 25% green foliage); brown, moist phloem; and bark that was easily peeled (dying trees). The remaining 22 trees had no evidence of epicormic branching; dry, dark phloem; and loose bark (dead trees).

Branch bark thickness and the moisture content of the inner bark where cerambycid larvae feed may influence oviposition and larval survival. Large diameter branches of black cherry with thick bark appeared to retain moisture longer than thin-barked ones; however, thicker bark may inhibit oviposition, especially in the cerambycid subfamily Lamiinae in which females of many species (Linsley 1961), including those in the genus *Saperda* (e.g., Drouin and Wong 1975, Nord *et al.* 1972), use their mandibles to chew a depression in the bark where they oviposit (Linsley 1961). We addressed this issue by comparing *S. imitans* gallery density/1000 cm^2 among branches of different sizes (basal diameter); ten small diam. (< 5 cm basal), 39 medium diam.(5 – 10 cm) and 15 large diam. (> 10 cm) branches taken from the 24 wind-thrown black cherry

Table 1. Sample sizes for different host conditions utilized by *S. imitans* infesting wind-thrown black cherry trees at the Kane Experimental Forest, Pennsylvania (2005).

Tree Size (dbh cm)	Tree Position		Condition of Epicormic Branches		
	On the Ground	Off the Ground	Alive	Dead	Absent
> 40	7	9	5	4	7
> 30 – 40	11	22	14	8	11
20 – 30	14	5	5	10	4

with live epicormic branches. A band of bark 30 cm wide was removed from the base of each branch and another where branch diam. approached 1 cm. Area of each band was calculated as the branch circumference at the point where the band was removed × 30 cm (the width of the band). The density of *S. imitans* galleries on the two bands were averaged to quantify infestation density for each branch.

Number of larval instars. Twice a week in 2005, beginning in late May, larvae were removed from beneath the bark of a number of windthrown black cherry trees infested by *S. imitans* and identified to species. Larvae were killed in a mixture of 95% ethanol (70 ml), kerosene (10 ml), acetic acid (20 ml), and dioxane (10 ml) (K.A.A.D) (Triplehorn and Johnson 2005), and then stored in 80% ethanol.

To document larval instars, maximum head capsule widths (in dorsal view) were measured to the nearest 0.001 mm. The length and width of larvae and adults were measured to the nearest 0.5 mm using a Nikon® stereomicroscope (model SMZ 1500) and a calibrated ocular micrometer.

Saperda imitans larvae were distinguished from *Gaurotes cyanipennis* (Say) larvae, the only other cerambycid encountered, by the appearance of their galleries. Galleries of *G. cyanipennis,* confirmed by the presence of adults in their natal galleries, were found to be relatively narrow compared to those of *S. imitans*.

Adults of *S. imitans* were reared from bolts removed from windthrown cherry logs selected systematically while inspecting damaged stands. These log sections were 20-30 cm in dia. and 30-40 cm long. They were placed in several outdoor emergence cages constructed of galvanized trash cans covered with screening and with drainage holes drilled in the bottom. Beetles were removed daily and placed in 3.8 L, wide-mouthed glass jars with screened tops. Initially, several beetles occupied each jar, but as soon as a mating pair was noted the pair was removed and placed in a separate jar to observe mating and to determine whether this species constructed an oviposition niche. To encourage continued mating and oviposition, pairs were provided either fresh cherry foliage and a piece of cherry wood with the bark intact, or only wood with intact bark, or only foliage. The latter was included because adults of other species of *Saperda* are known to feed on host foliage (e.g., Drouin and Wong 1975, Nord et al. 1972.)

Statistical analyses. Wilcoxon Signed Rank Tests were used to compare densities at different band heights and to identify heights (bands) with significantly higher mean densities of galleries. For each tree, the difference in gallery density for each pair of heights was the variable analyzed using the Wilcoxon test. The four heights yield six Wilcoxon tests comparing pairs of heights. The experimentwise Type I error rate for these six tests was controlled at 0.05 using the Bonferroni adjustment of the P values. The effect of tree size (large, medium and small diameter classes, Table 1) on the density of *S. imitans* was evaluated using a one-way ANOVA. For this analysis, density/1000 cm^2 was defined using all four sample heights. A two-way factorial ANOVA was used to test for differences in gallery density for the treatment factor position of windthrown trees relative to the ground (on or off the ground). Tukey's multiple comparison test was used to control the experimentwise Type I error rate at 0.05 for the set of all 15 possible pairwise comparisons among the 6 simple effect means of the factorial treatment design. Gallery density (denoted X) was transformed to Log_{10} (X+1) to better satisfy the equal variance (of treatment groups) and normality assumptions of ANOVA. Statistical testing was based on the transformed data, but descriptive results show the means of the untransformed data for ease of interpretation of treatment differences. All means are presented with their associated standard error shown after the ± symbol. Analyses were completed in Minitab (2007).

Results

Attraction of cerambycid adults to ethanol-baited traps. Seven species of cerambycids were captured in the Lindgren® funnel traps in storm-damaged stands during 15 weeks of trapping: *Cyrtophorus verrucosus* (Olivier), *Microgoes oculatus* (LeConte), *Anthophylax attenuatus* (Haldman*), Stenocorus vittiger* (Randall), *Neoclytus acuminatus acuminatus* (F.), *G. cyanipennis, Clytus ruricola* (Olivier) and *Astylopsis macula* (Say) (Table 2). *S. imitans* was not recovered from the ethanol-baited traps even though it was the dominant species reared (n = 80) from bolts of black cherry. It was the only cerambycid that excavated an overwintering gallery in sampled cherry bolts. Larvae of *G. cyanipennis* also were recovered from wind-thrown cherry. When these larvae complete development they exit the log and overwinter in litter (Knull 1946).

Biology of *Saperda imitans*. The first of 80 adults of *S. imitans* emerged in outdoor rearing cages on 29 May 2007 and emergence continued through 26 June (Fig. 1). Peak emergence occurred between the last week of May and the first week of June. The sex ratio was ~1:1, 39 males and 41 females.

In captivity adults fed on the midribs and petioles of cherry leaves. Mating occurred in glass rearing jars and beetles remained *in copula* for one to several hours. Oviposition was never observed in either rearing jars containing fresh cherry bolts or in the field.

Tree excavations revealed that larvae fed beneath the outer bark and engraved an erratic, shallow gallery in the inner bark (phloem), leaving little evidence of activity on the surface of the sapwood (Fig. 2). Early instars packed their galleries tightly with dark brown frass. Once the larva entered the wood to excavate the over-wintering gallery, the frass contained light brown to reddish wood chips. When they reached the final instar, larvae tunneled perpendicularly or slightly obliquely an average of 2.5 ± 0.05 cm (n = 80) into the sapwood or outer heartwood before turning and boring parallel to the wood grain (Fig. 3). Average total gallery length was 4.1 ± 0.01 cm. Over-wintering galleries were plugged with frass and excelsior-like wood shavings immediately posterior to

Table 2. Number and date of capture for cyrambycids attracted to ethanol-baited Lindgren® funnel traps at the Kane Experimental Forest, Pennsylvania.

Species	**Dates Captured (mo/da/yr): Number Captured**
Cyrtophorus verrucosus	5-30-06: 9, 5-17-05: 1, 5-30-06:1, 6-26-06: 2
Microgoes aculatus	6-19-06: 2, 6-26-06: 1, 7-4-06: 2,7-31-06: 1
Anthophylax attenuatus	5-30-06: 1, 6-19-06: 1, 6-26-06: 1
Sstenocorus vittiger	6-19-06: 1, 6-26-06: 1
Neoclytus a. accuminatus	9-19-06: 1, 6-26-06: 1
Gaurotes cyanipennis	5-30-06: 1, 6-12-06: 1, 6-19-06: 6, 6-26-06: 1
Clytus ruricola	6-13-05: 14, 6-20-05: 8, 6-28-05: 14, 7-5-05: 6, 7-12-05: 3, 7-19-05: 3, 7-25-05: 1
Astylopsis macula	6-28-05: 1, 7-19-05: 1

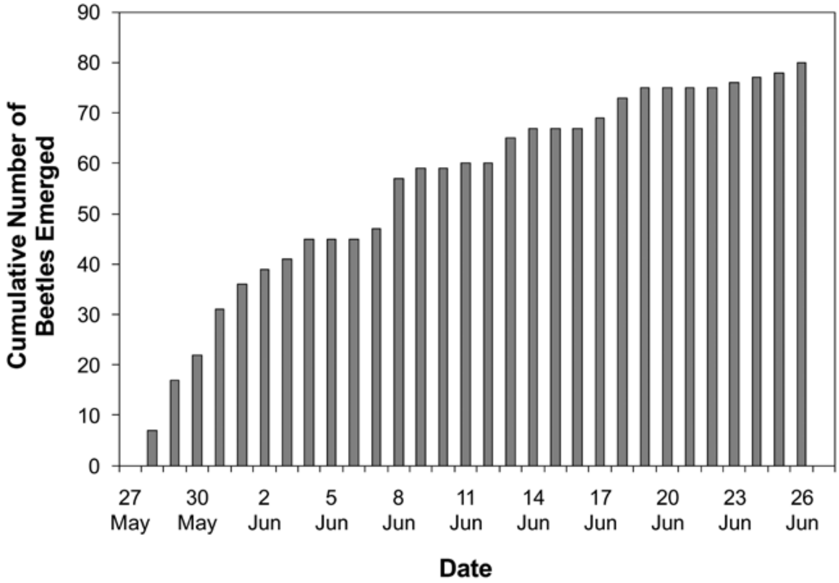

Figure 1. Temporal pattern of emergence for adults of *Saperda imitans* reared from black cherry bolts in outdoor cages. Kane, PA, 2007.

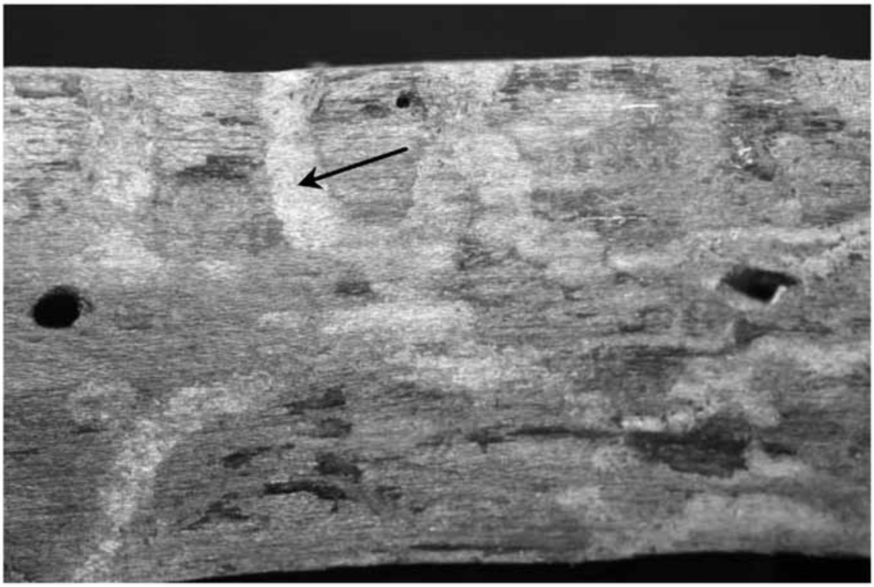

Figure 2. Larval gallery of *Saperda imitans* on the surface of black cherry sapwood. Gallery width (arrow) is 5 mm.

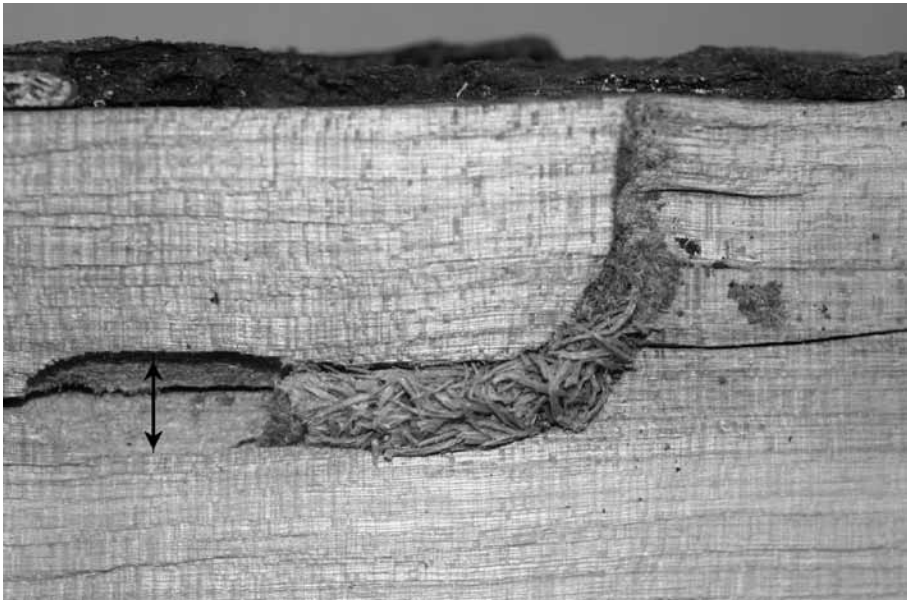

Figure 3. Over-wintering gallery of *Saperda imitans* in black cherry. The pupal chamber (arrow) is 8 mm wide.

the pupal cell (Fig. 3). Excavation of galleries in October-November and again in March indicated pupation occurred in spring. Emerging adults chewed oval exit holes through the bark. Dimensions of these exit holes averaged 5.4 ± 0.15 mm long by 3.4 ± 0.11 mm wide (n = 50).

Susceptible host conditions. Large branches contained significantly (P = 0.010) more insects/1000 cm^2 (1.23 ± 0.54, n = 15) than branches 5-10 cm in diameter (0.23 ± 0.11, n = 39). *Saperda imitans* galleries were not observed in branches <5 cm in diameter.

There was no significant difference in the mean density of *S. imitans* galleries/1000 cm^2 of bole surface area (F = 1.00; df = 2,65; MS = 4.248E-07 ($\log_{10}$ x + 1); P = 0.37211) among small, medium, and large diameter trees where X is the density aggregated over all four samples for each tree in each class.

Wilcoxon's Test based on Bonferroni adjusted P-values (Table 3) demonstrated that gallery density at heights 1 (mean = 1.8 ± 0.7/1000 cm^2) and 2 (mean = 2.1 ± 0.7) were not significantly (P = 1.00) different; the same held true for densities at heights 3 (mean 4.1 ± 1.1) and 4 (mean = 5.7 ± 1.4) (P = 0.48). Densities at heights 3 and 4 were significantly greater (P =0.02 and 0.00, respectively) than the density at height 1. Density at height 4 was significantly (P = 0.006) greater than density at height 2. Densities at bole heights 2 and 3 were not significantly different (P = 0.036).

Epicormic branch condition on windthrown cherry and tree position relative to the ground significantly affected *S.imitans* gallery density. There was also a significant interaction between tree position and condition of epicormic branches; trees on the ground had more live epicormic branches compared to trees off the ground (Table 4). Tukey's pairwise comparisons (Table 5) indicated that gallery density on trees that were off the ground with dying epicormic branches (i.e., some foliage retained but it had discolored or wilted) was significantly higher than

Table 3. Matrix of Bonferroni adjusted *P* values from Wilcoxon's Test for differences in the density of *S. imitans* galleries at different band heights.

Band Height	**Mean (±S.E.) Number of Galleries / 1000cm^2**	**Band 2**	**Band 3**	**Band 4**
Band 1	1.8(0,7)	1.00	0.02	0.001
Band 2	2.1(0.7)	__	0.36	0.001
Band 3	4.1(1.1)	__	__	0.48
Band 4	5.7(1.4)			

Table 4. Results of ANOVA testing for effects of the condition of epicormic branches (absent, dead, alive) and the position (on the ground, off the ground) of black cherry blow-down on the log-transformed density (Log_{10} X+1) where X is density of *S. imitans* galleries/1000cm^2 of bole area. Kane, PA 2005..

Source	**DF**	**MS**[a]	**F-ratio**	***P***
Condition of epicormic branches	2	4.6183	5 .12	0.009
Tree position	1	3.8325	4.25	0.044
Epicormics*Position	2	4.0045	4.44	0.016
Error	62	0.9028		

[a] Mean square

Table 5. Results of Tukey's all pair-wise comparisons for mean (±SE) densities of *S. imitans* galleries/1000cm^2 of bole area by tree position and status of epicormic branches (absent, dead, alive) using means of four sample bands for each of 68 wind-thrown black cherry trees dissected near Kane, PA 2005.

	Epicormic branches[a]		
Tree Position[a]	**Dying**	**Absent**	**Alive**
Off the ground (n=36)	7.83 ± 1.7 A	4.30 ± 2.0 AB	0.12 ± 1.7 B
On the ground (n=32	1.48 ± 2.1 B	5.00 ± 1.8 AB	1.34 ± 1.9 B

[a]values that share the same letter are not significantly different based on analysis of log-transformed density, but treatment means of untransformed data are presented to facilitate interpretation of magnitude of treatment differences.

gallery density for trees in contact with the ground with epicormic branchess in the same condition. Gallery density on wind-thrown cherry that never produced these branches (i.e., tree roots were completely or nearly completely pulled out of the soil) did not differ significantly regardless of tree position. Gallery density on trees with live epicormic branches was similar for trees both on and off the ground.

Number of instars. A frequency diagram of head capsule widths failed to clearly separate larval instars (Fig. 4). The extensive overlap most likely resulted from sexual dimorphism. A histogram of larval head capsule widths with irregular and overlapping peaks is not uncommon for cerambycids in general (e.g., Pershing and Linit 1989, Forschler and Nordin 1991) and other species of *Saperda* in particular (e.g., Nord et al.. 1972, Drouin and Wong 1975). Head capsule widths for *S. imitans* ranged from 0.77 to 3.08 mm.

Adult females (n = 36) averaged 13.7 ± 0.1 mm in length compared to 11.6 ± 0.1 mm for males (n = 44), and females had a longer and wider terminal abdominal segment. The average length of preserved final instar larvae (n = 282) was 24.3 ± 0.2 mm.

Discussion

Host specificity and preferred substrate conditions vary among species in the genus *Saperda*. In North America host preference for *S. tridentata* approaches monophagy on *Ulmus* spp., especially *U. americana* L. The two most important European species (the large poplar longhorn, *S. carcharias* (L.) and the small poplar longhorn, *S. populnea* (L.)) (Kenis and Hilszczanski 2004) are oligophagous on both *Populus* and *Salix* (Evans et al. 2004). In eastern North America, *S. lateralis* is polyphagous and infests species of broadleaved trees in several genera (e.g., *Ulmus, Tilia, Fraxinus, Acer, Quercus*) (Lingafelter 2007). Similarly, preferred substrate conditions, such as host moisture

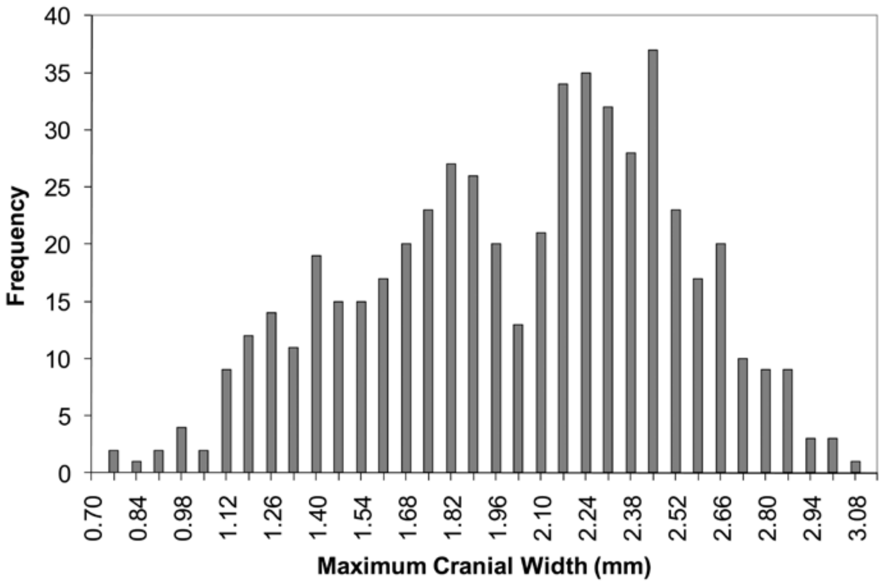

Figure 4. Distribution of maximum cranial widths for larval stages of *Saperda imitans* (n = 534).

content, nutrients and temperature, differ from one species to another. For example, *S. cretata* Newman (Solomon 1995) and the gall former *S. inornata* Say (Nord et al. 1972) attack apparently healthy hosts while *S. carcharias* is capable of infesting both healthy and weakened hosts (Evans et al. 2004). *Saperda vestita* Say prefers stressed and weakened *Tilia* spp. (Johnson and Williamson 2006), and *S. lateralis* is associated with dead hosts (Stein and Tagestad 1976).

Yanega (1996) stated that *S. imitans* utilizes "various dead hardwoods," implying that the species has several different hosts. Specimens have been recovered from *Carya* spp. (Felt and Joutal 1904), *Salix* spp. (Linsley and Chemsak 1995) and *Acer* spp. (Vlasak and Vlasakova 2002). To the best of our knowledge, however, it has never been recovered in large numbers from these hosts. The relatively high numbers found in the windthrown black cherry at the KEF suggests that *P. serotina* may be a common host for this cerambycid Our work at the KEF associated this species with dying or recently dead hosts; that is, host material with relatively tight bark and moist inner bark. Downed but live trees with root systems partially buried in the soil with many live epicormic branches did not have high densities of *S. imitans* larvae and neither did dead trees with loose bark and dry inner bark.

Hanks (1999) recommended four categories for classifying host condition at the time of attack by species of Cerambycidae. Because none of his categories strictly match our observations for *S. imitans*, using his classification was problematic. The closest comparison is his description for a "stressed host (SH)." The key criterion in this category is that "infested hosts usually die, often as a direct result of larval colonization." Infested windthrown black cherry we observed at KEF died even in the absence of *S. imitans* The insect may have hastened mortality, but it did not appear to be the cause.

In their description of the genus, Linsley and Chemsak (1995) stated that all species breed in living trees. While true for several species of *Saperda*, many utilize trees that have been subjected to a severe stress from which the host is not likely to recover. Examples include *S. imitans* in black cherry damaged by severe wind documented in this study as well as *S. tridentata* in elms dying from Dutch elm disease (Solomon 1995). Our observations indicated that *S. imitans* adults feed on host leaves and petioles or the bark of twigs prior to mating and oviposition, similar to most species in the genus (Linsley and Chemsak 1995).

Many species of *Saperda* require two to several years to complete a single generation, variation that can be attributed mainly to differences in latitude for a widely distributed species such as *S. candida* (F.) (USDA ARS 1965). Similarly, variables such as the moisture content (e.g., Nakamura 1994) and nutritional quality of the phloem (e.g., Akbulut and Linit 1999) and meteorological conditions (e.g., Watari et al. 2002) may affect rate of development of cerambycid larvae. The pattern of adult emergence from caged bolts (Fig. 1) and observations of larval development under field conditions suggest that adults of *S. imitans* emerge and oviposit once a year. Individuals emerging after the first week of June most likely represent eggs deposited relatively late during the previous growing season. Even though variation in the substrate conditions mentioned above affect cerambycid development rates (e.g., Pershing and Linit 1989), all of our caged bolts came from trees that were in similar condition (dying) and were cut at the same time to minimize variation in host condition. In terms of susceptibility of wind-thrown black cherry to infestation by *S. imitans*, results of this study may help forest owners to establish salvage priorities in order to minimize grade loss.

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