Seasonal Occurrence and Impact of *Halyomorpha halys* (Hemiptera: Pentatomidae) in Tree Fruit

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J. Econ. Entomol. 102(3): 1133–1140 (2009)

ABSTRACT *Halyomorpha halys* is an introduced stink bug species from Asia that is spreading throughout the Mid-Atlantic United States. It is native to South Korea, Japan, and eastern China, where it is an occasional pest of tree fruit, including apple and pear. Cage experiments with adults placed on apple and peach during critical plant growth stages demonstrate that it can cause damage to developing fruit during mid- and late season growth periods and that feeding occurs on all regions of the fruit. Feeding that occurred during pit hardening/mid-season and final swell periods were apparent as damage at harvest, whereas feeding at shuck split/petal fall in peaches and apples caused fruit abscission. Tree fruit at two commercial farms were sampled weekly in 2006–2007 to determine *H. halys* seasonality. Low densities of nymphs in apple suggest that it is an unsuitable developmental host. Both nymphs and adults were found on pear fruits with peak populations occurring in early July and mid-August, the time when pit hardening/mid-season and swell period damage occurs. At both farms, stink bug damage was greater than 25% damaged fruit per tree. We attribute this to *H. halys* because population densities were significantly higher than native pentatomids at both locations in both beat samples and blacklight trap captures. The data presented here documents the potential for *H. halys* to cause damage in orchards throughout the Mid-Atlantic United States and shows the need for development of appropriate control strategies.

KEY WORDS stink bug, critical fruit damage stage, invasive species, blacklight trap

Halyomorpha halys (Stål) (Hemiptera: Pentatomidae) is a non-native species believed to have been transported from Asia to Allentown, PA, in 1996 (Hoebeke and Carter 2003). Since then, it has spread throughout the Mid-Atlantic States, with isolated populations occurring in Mississippi, Ohio, Oregon, and California. The country of origin for the founding population is unknown as of 2008. The introduction of *H. halys* in the United States is concerning because of its polyphagous feeding habits and preference for tree fruits and soybeans (*Glycine max* L. Merr.) in its native range (Hoffman 1931, Kobayashi et al. 1972, Funayama 2002).

Halyomorpha halys is a pest of tree fruits in Japan and South Korea, particularly in persimmons, apples, and pears (Fujiie 1984, Chung et al. 1995, Choi et al. 2000, Funayama 2002). It is the dominant stink bug pest in South Korean nonastringent persimmons [*Diospyros kaki* L. (Ericales: Ebenaceae)] and Yuzu [*Citrus junos* Siebold (Sapindales: Rutaceae), with peak populations occurring in mid-August (Chung et al. 1995, Choi et al. 2000). Apples may serve as an early-season host for *H. halys* spring adults emerging from overwintering sites, at which time they can inflict significant damage in early- and mid-season apple varieties in Japan (Funayama 2002, 2004).

Feeding damage in tree fruits caused by stink bugs can occur throughout the growing season but is most critical at mid-season development during a period of rapid mitotic growth and again during swell when the developing fruit uptakes water and increases in size. However, damage to apples [*Malus domestica* Borlch. (Rosales: Rosaceae)] may be under-reported because it can be confused with cork spot or bitter pit, two physiological disorders caused by calcium deficiencies (Brown 2003). Cork spot causes discrete brown discolored spots on the exterior of fruit that may be sunken and are accompanied by diffuse brown necrotic tissue underneath. This tissue may be separate from the skin and lacks a stylet puncture (Brown 2003). Feeding injury that occurrs immediately after bloom or when fruit is still small results in aborted or cat-faced fruit (Rings 1957). Feeding damage that occurs at any of these critical growing periods causes unmarketable fruit (Rings 1957). During mid-season fruit development, tissue cells have high mitotic activity, and injury results in damage similar to late-season damage but appear more depressed around the feeding site and the fruit may be gummy (Mundinger and Chapman 1932). Late-season damage differs from cork spot or bitter pit by the presence of a stylet

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0022-0493/09/1133–1140$04.00/0

Table 1. Mean ± SE number of *H. halys* feeding sites after 48-h exposure, shown by location on fruit and growing period

	Location	2006				2007			
		Early	Mid	Late	Control	Early	Mid	Late	Control
Apple	Shoulder	0.78 ± 0.43	0.83 ± 0.33	2.42 ± 0.64	0.07 ± 0.05	0.00 ± 0.00	0.35 ± 0.15	0.44 ± 0.33	0.13 ± 0.06
	Middle	0.78 ± 0.57	1.53 ± 0.35	2.58 ± 0.50	0.27 ± 0.12	0.00 ± 0.00	0.54 ± 0.19	0.61 ± 0.28	0.16 ± 0.10
	Ventral	0.78 ± 0.55	0.80 ± 0.19	0.53 ± 0.22	0.31 ± 0.14	0.00 ± 0.00	0.46 ± 0.31	0.67 ± 0.46	0.44 ± 0.22
	Total damage[a]	2.33 ± 0.90bc	3.17 ± 0.63b	5.53 ± 0.87a	0.65 ± 0.21c	0.00 ± 0.00a	1.35 ± 0.37a	1.72 ± 0.87a	0.72 ± 0.27a
	Aborted fruit[b]	1.21 ± 0.21a	0.23 ± 0.09b	0.33 ± 0.14b	0.15 ± 0.09b	0.92 ± 0.33a	0.14 ± 0.10b	0.00 ± 0.00b	0.21 ± 0.15ab
Peach	Shoulder	—	—	—	—	0.50 ± 0.50	0.06 ± 0.06	2.00 ± 0.44	0.00 ± 0.00
	Middle	—	—	—	—	0.00 ± 0.00	0.56 ± 0.33	2.15 ± 0.63	0.00 ± 0.00
	Ventral	—	—	—	—	0.00 ± 0.00	0.06 ± 0.06	0.77 ± 0.41	0.00 ± 0.00
	Total damage[a]	—	—	—	—	0.50 ± 0.50b	0.69 ± 0.34b	4.92 ± 1.06a	0.00 ± 0.00b
	Aborted fruit[b]	—	—	—	—	2.29 ± 0.29a	0.36 ± 0.13b	0.19 ± 0.10b	1.78 ± 0.55a

[a] Mean no. of feeding locations (sum of all sites) per fruit. Means within a row for each year followed by a different letter are significantly different (Tukey's, $P \leq 0.05$).
[b] Mean ± SE of aborted fruit per replicate. Means within a row for each year followed by a different letter are significantly different ($P \leq 0.05$).

puncture, by being contiguous with the fruit skin, damage at the skin surface is circular in appearance, and corking (necrotic tissue) is uniform (Brown 2003). In apples, the necrotic tissue is often brown, whereas in peaches [*Prunus persica* L. (Rosales: Rosaceae)], cherry [*Prunus spp.* (Rosales: Rosaceae)], and pear [*Pyrus spp.* L. (Rosales: Rosaceae)], corking appears white to brown in color.

The univoltine life history of *H. halys* in the United States suggests that the seasonal dynamics will coincide with the critical damage periods in apple, peach, and pear (Nielsen and Hamilton 2009). Reproductively immature adults ("spring" adults) gradually emerge from overwintering sites in early spring (March to April) and do not produce offspring until early June (Nielsen et al. 2008). These first-generation offspring will go through five nymphal instars throughout the summer months while feeding on a wide range of host plants. First-generation adults ("autumn" adults) will feed until entering a reproductive diapause in September and October. Adults commonly overwinter in man-made structures such as houses.

In the United States, stink bugs are recognized as increasingly important pests in many crops, because of the reduction or replacement of broad-spectrum insecticides that have historically managed native populations (Todd et al. 1994, Riley et al. 1997, McPherson and McPherson 2000, Brown 2003, Leskey and Hogmire 2005). Stink bugs have not historically been a pest in eastern orchards, but changes in management practices could alter species abundance and damage levels. With the introduction of this new pentatomid species, we wanted to determine the potential for *H. halys* as a tree fruit pest. Here we examine the seasonal occurrence and damage potential of *H. halys* in apples, pears, and peaches.

Materials and Methods

Cage Damage Study. To determine whether *H. halys* feeding caused damage during critical fruit growth stages, nylon mesh exclusion cages (29 cm height by 20 cm width) were placed on the terminal ends of flowering or fruit bearing peach (Loring variety) and apple (Red Delicious variety) branches in 2006 (apple only) and 2007 at the Rutgers Fruit and Ornamental Research Extension facility in Cream Ridge, NJ. No insecticide applications were applied to the treatment blocks. Regular fungicide applications were applied to peaches as needed according to the Rutgers University Fruit Management Guidelines (NJAES 2006, 2007).

Damage potential by *H. halys* adults was measured at three critical growth stages for peaches and apples. In peaches, the stages evaluated were shuck-split, pit hardening, and swell; in apples, the critical stages were classified as petal fall, mid-season, and swell. To determine pit hardening and swell in peaches and mid-season and swell in apples, additional fruit were cut and/or measured weekly using a Vernier caliper (BioQuip, Rancho Dominguez, CA) at the shoulder for apples and the fruit center for peaches. These stages were classified as early-, mid-, and late-season damage, respectively, for clarification. During each critical growing period, 15 exclusion cages were tied with twine to individual branches, and two adult *H. halys* were placed inside for 48 h. At the end of each 48-h period, the adults were removed and the cage resecured and left on the branch until harvest. At the beginning of each critical growing period, five additional exclusion cages without adult *H. halys* (control) were placed on branches containing fruit to determine the effect of the cages on fruit development. At harvest (peach, 14 August 2007; apple, 21 September 2006 and 21 September 2007), all cages were removed, and the fruit was harvested and photographed to document feeding damage. The number of mature fruit per cage and the number of aborted or prematurely dropped fruit were recorded. The size of mature fruit and the number of feeding sites per location (defined below) were recorded per mature fruit. Feeding locations were recorded as shoulder, middle, and ventral regions by dividing the fruit into three sections and recording the number of feeding sites within each region. To identify feeding damage, all fruit were peeled and cut, and descriptions of the damage were recorded. Fruit in the control cages were treated identically.

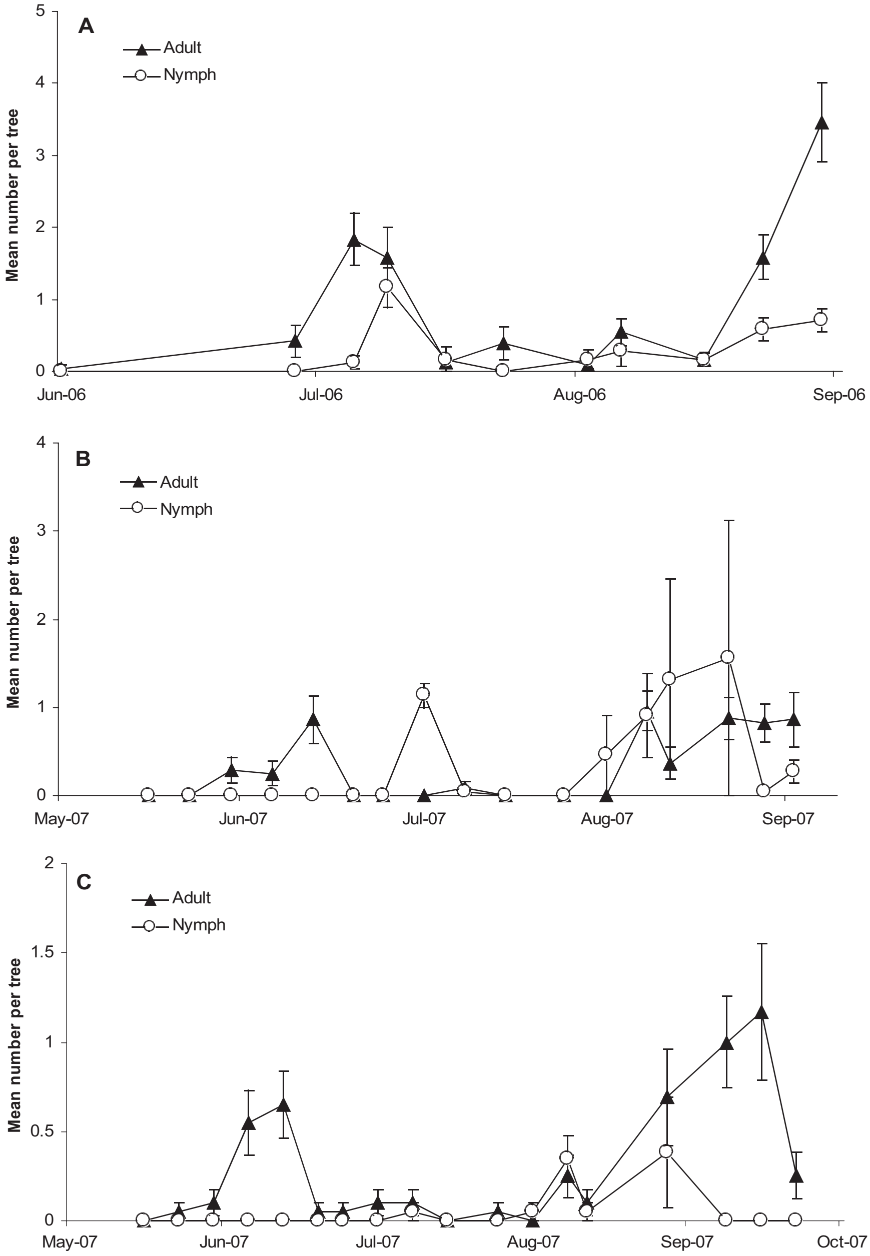

Fig. 1. Seasonality of *H. halys* adults and nymphs in (A) pear 2006, (B) pear 2007, and (C) apple 2007 in Macungie, PA.

Seasonal Occurrence. During 2006 and 2007, two commercial orchards (Lichtenwalner Farms, Macungie, PA, and Peaceful Valley Farms, Pittstown, NJ) were sampled weekly from petal fall until harvest to determine seasonal stink bug densities. These locations were selected to represent high (PA) and low (NJ) *H. halys* population densities. At each location, 20 pear [10 pear *Pyrus spp.* (Rosaceae: Rosales), 10 Asian pear (*P. pryifolia* (Burm.) Nak.] and 20 apple [*Malus domestica* (Rosaceae: Rosales)] trees were selected for sampling. Each tree was sampled by the beating sampling method from 1.5 to 3.0 m in height around the circumference of the tree (Southwood and Henderson 2000). Each tree limb was tapped sharply three times with a rubber bat to dislodge insects into a canvas beat sheet (71 by 71 cm; BioQuip). All dislodged pentatomid species were collected and taken to the laboratory for species identification and life stage determination. Regular pesticide spray regimens were maintained for other fruit pests according the Rutgers University Fruit Management Guidelines (2006, 2007) in each orchard. A 110-Volt blacklight trap (Gempler's, Madison, WI) was run at each location from 1 May to 1 October to supplement beat

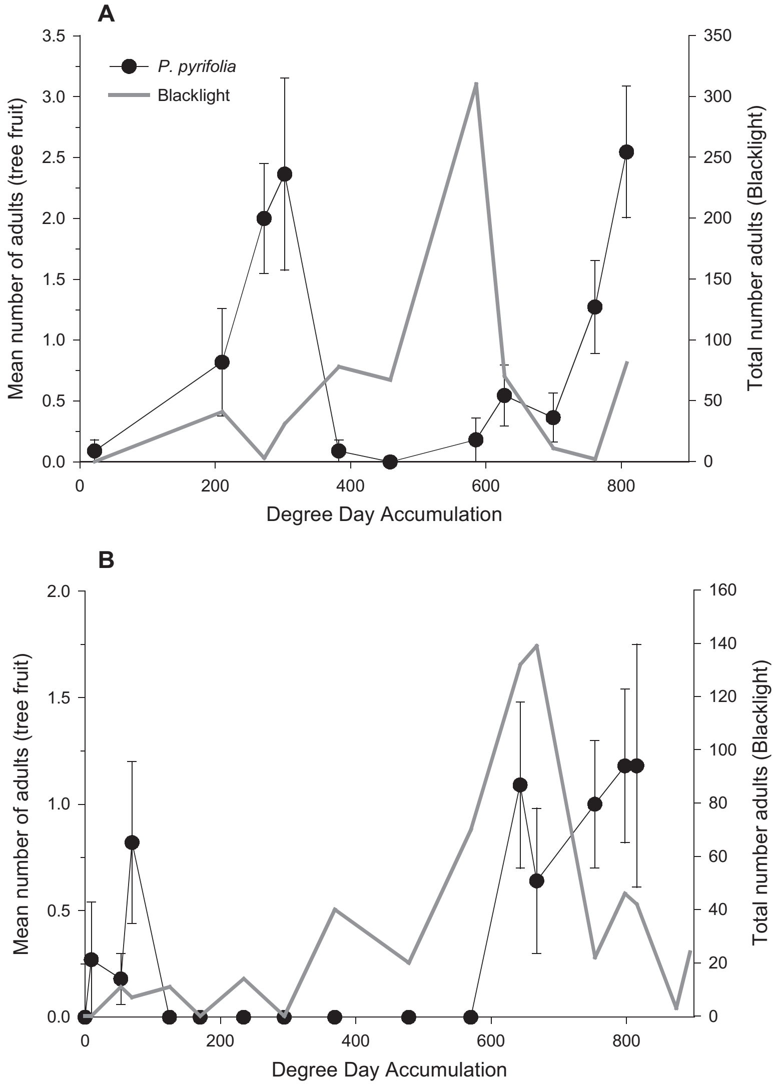

Fig. 2. Temporal dynamics (mean ± SE) of *H. halys* in Asian pear orchards from limb-tapping and flight activity of adults as indicated by blacklight trap in Macungie, PA (A, 2006; B, 2007).

sampling assessment of population density and flight activity of stink bugs. The blacklight traps were placed in an open area of the farm in front of a shed or shilo and emptied bi-weekly, and all stink bugs were collected, identified, and recorded.

Damage Estimates. At harvest, 25 fruit per tree were randomly picked from 10 trees per location and type (see previous section). Apples at the Pennsylvania location were harvested depending on variety beginning 4 September until 15 October, whereas apples from the New Jersey location plus pears from both farms were harvested on 3 September 2006 and 4 September 2007. Fruit were peeled and cut to determine the number of damaged fruit per tree.

Statistical Analysis. Data from the cage damage study were analyzed using a two-way general linear model (GLM) with Tukey's pairwise comparison at $P \leq 0.05$ for critical growing period (damage treatment) and tree species for each year. Seasonal occurrence data were analyzed similarly as life stage (nymph [all nymphal stages combined], adult, and total [nymph and adult combined]) and host plant. When needed, data for damage treatment, host plant, and density were transformed using square root$(x + 1)$. To compare the relative abundance of *H. halys* to other phytophagous pentatomid species, beat sampling results for all non-*H. halys* species were combined because of low population levels. Mean abundance for *H. halys* and non-*H. halys* (other stink bugs) were calculated and analyzed using a one-way GLM and Tukey's mean separation at $P \leq 0.05$. The proportion of damaged fruit per tree at each location were calculated using arcsine-transformed data and analyzed using a one-way GLM and Tukey's mean sepa-

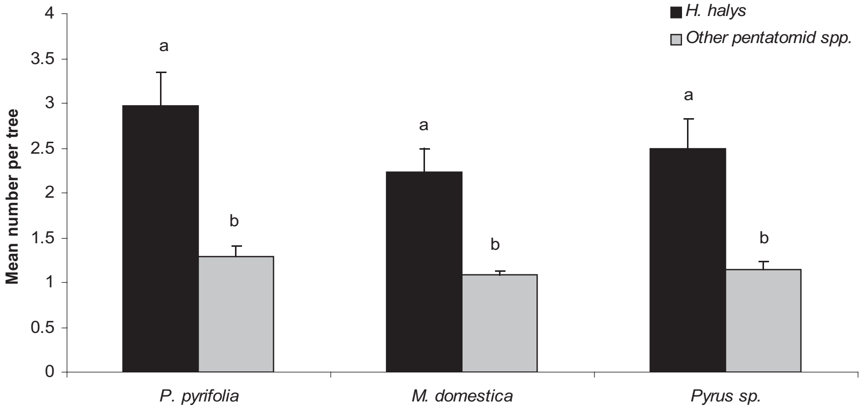

Fig. 3. Density (mean ± SE) of phytophagous pentatomids in tree fruit at Lichtenwalner Farms (Macungie, PA).

ration at $P \leq 0.05$. All analyses were done using SAS v.9.1 (2002–2003). Data are presented as untransformed means. Blacklight trap captures for all pentatomids species are presented as seasonal totals.

Results

Cage Damage Study. *Halyomorpha halys* adults fed on developing apple and peach fruits during each of the three critical stages of development evaluated. Damage appeared similar to that described for other pentatomid species. Mid-season fruits appeared dimpled, whereas late-season damage appeared as white or brown corking close to the surface of the skin.

Apple. In apple, significantly higher damage levels were observed at harvest during the swell period fruit compared with the petal fall and mid-season periods in 2006 (2006: $F = 15.75$, df = 3,66, $P \leq 0.001$; 2007: $F = 2.24$, df = 3,71, $P = 0.091$; Table 1). The number of aborted fruit was significantly higher in the petal fall periods in both years (2006: $F = 15.64$, df = 3,69, $P \leq 0.001$; 2007: $F = 4.26$, df = 3,29, $P = 0.013$). Fruit damaged during mid-season and swell periods had low levels of aborted fruit that were similar to the control treatment. The number of feeding sites in the ventral region was lower than the other locations during the swell period in 2006. This was not apparent in 2007 but does indicate that *H. halys* will feed in the ventral region of developing fruit, but it may not be a preferred location during swell (Table 1).

Peach. Similar results were observed in peach, with swell period damage being significantly greater than damage during other growth periods (2007: $F = 10.92$, df = 3,21, $P = 0.002$). Early-season treatments had the highest fruit abortion levels but were not significantly different from controls (2007: $F = 16.15$, df = 3,34, $P \leq 0.001$). The ventral region of the peach had lower number of feeding sites than the shoulder and middle sections of the developing fruits at shuck split, pit hardening, and swell.

Seasonal Occurrence. Beat sampling results indicated that, in 2006, spring adults and nymphal populations in pear peaked in early July (2.75 ± 0.54 nymphs and adults per tree). A second peak occurred in late August/early September (Fig. 1) because of the eclosion of autumn adults and late-instar nymphs. In 2007, a similar pattern was observed, although spring adult and nymphal (early instars) population peaks were more temporally separated. Egg masses were found in Asian pear on four separate dates in 2007 (2 July and 2, 13, and 23 August). In 2006, *H. halys* populations in apple were too low to detect any seasonal patterns.

Comparison of adult *H. halys* temporal dynamics in Asian pear (as indicated by beat samples) to the flight activity of adults (as measured by blacklight traps) showed a different relationship (Fig. 2). Using a base temperature (T_o) of 13.93°C, degree-day accumulation began on 31 May when adults were consecutively present in traps (Nielsen et al. 2008). A peak in flight activity was observed in early August (≈600 DD) because of dispersal of newly eclosed autumn adults to suitable hosts. This peak occurred just before the increase in abundance in pears and apples (Fig. 1), indicating that autumn adults may be moving to new host plants at suitable phenological periods.

Beat sampling results indicate that *H. halys* is the predominant stink bug species present at Lichtenwalner Farms (*Pyrus* sp.: $F = 14.49$, df = 1,54, $P < 0.001$; *P. pyrifolia:* $F = 18.13$, df = 1,54, $P < 0.001$; *M. domestica:* $F = 24.65$, df = 1,43, $P < 0.001$; Fig. 3). Pentatomid abundance at Peaceful Valley Farms in Pittstown, NJ, was too low to document temporal dynamics or for statistical analysis; however, in 2006, two adult *H. halys* and one other pentatomid species were collected; in 2007, six *H. halys* and two other pentatomid species were collected. Blacklight trap collections showed similar trend at both farms (Table 2). At Lichtenwalner Farms, 1201 and 581 *H. halys* adults were collected from the blacklight trap in 2006 and 2007, respectively, compared with 5 and 10 individuals collected for all other pentatomid species in 2006 and 2007, respectively.

Table 2. Pentatomid species abundance from blacklight traps in Macungie, PA, and Pittstown, NJ

Pentatomid species	2006		2007	
	PA	NJ	PA	NJ
Halyomorpha halys	1,201	27	581	60
Acrosternum hilare	1	0	3	0
Euschistus servus	0	0	0	2
E. tristigmus	0	0	0	0
E. variolarius	1	0	3	3
Thyanta spp.	3	3	1	3
Banasa spp.	1	0	3	0

Damage Estimates. Stink bug feeding damage to fruit at harvest was >25% per tree at both locations each year (Fig. 4). In 2006 at the New Jersey farm, 47.0 ± 6.5% of the apples sampled per tree was damaged; 24.6 ± 4.5% of the pears sampled per tree was damaged. In Pennsylvania, 89.7 ± 6.1% of the fruit sampled per tree for apple and 72.5 ± 7.0% of pears sampled had stink bug damage. In 2007, in Pennsylvania, 69.6 ± 4.3 and 64.9 ± 3.0% of sampled fruit had stink bug damage in the apples and pears, respectively. In New Jersey, 42.9 ± 8.0 and 29.0 ± 4.5% damaged fruit per tree was observed in apple and pear, respectively, in 2007. Damage was significantly higher each year in Pennsylvania compared with New Jersey for both apple and pear (apple—2006: $F_{1,12} = 21.03$, $P \leq 0.001$; 2007: $F_{1,25} = 9.73$, $P = 0.004$; pear—2006: $F_{1,7} = 25.07$, $P \leq 0.001$; 2007: $F_{1,5} = 37.96$, $P \leq 0.001$).

Discussion

This is the first work done that documents damage by the invasive species *Halyomorpha halys* in the northeastern United States. It caused damage both to apple and peaches at the critical stages of fruit development, with the majority of feeding occurring late in the season, just before harvest. Beat samples showed that *H. halys* is present in orchards during periods when mid-season and swell period damage can occur. The phenological data collected from beat samples and blacklight traps suggest that the majority of late-season damage that occurs during swell is caused by the "fall adults." Mid-season damage that occurs during the mitotically active periods of fruit development was likely caused by nymphs, although populations were low, suggesting that there is a low threshold for mid-season damage by *H. halys* nymphs in pear and apple. Apple and pear may not be optimal developmental hosts for *H. halys* nymphs (Funayama 2004). Instead, adults may use these hosts when emerging from diapause and then again late in the season, just before harvest, when fall adults prepare to enter diapause. This type of host switching behavior based on plant phenology is common among stink bugs.

Binns and Nyrop (1992) stated that temporal dynamics of a species must be considered when developing a sampling program to make pest management decisions. Beat sampling is the preferred sampling method for stink bugs in a variety of agricultural commodities, including tree fruit. However, stink bug populations can be difficult to detect because of nocturnal activity and hiding behaviors. The use of blacklight traps to monitor stink bug populations helps to alleviate this problem. In our study, blacklight samples at each farm gave an indication of adult flight activity and provided an additional estimate of population size. Blacklight traps were capable of detecting overwintering adults as they dispersed into orchards at low population levels and first-generation adults that we hypothesize are dispersing to tree fruit before harvest, at the critical late-season period.

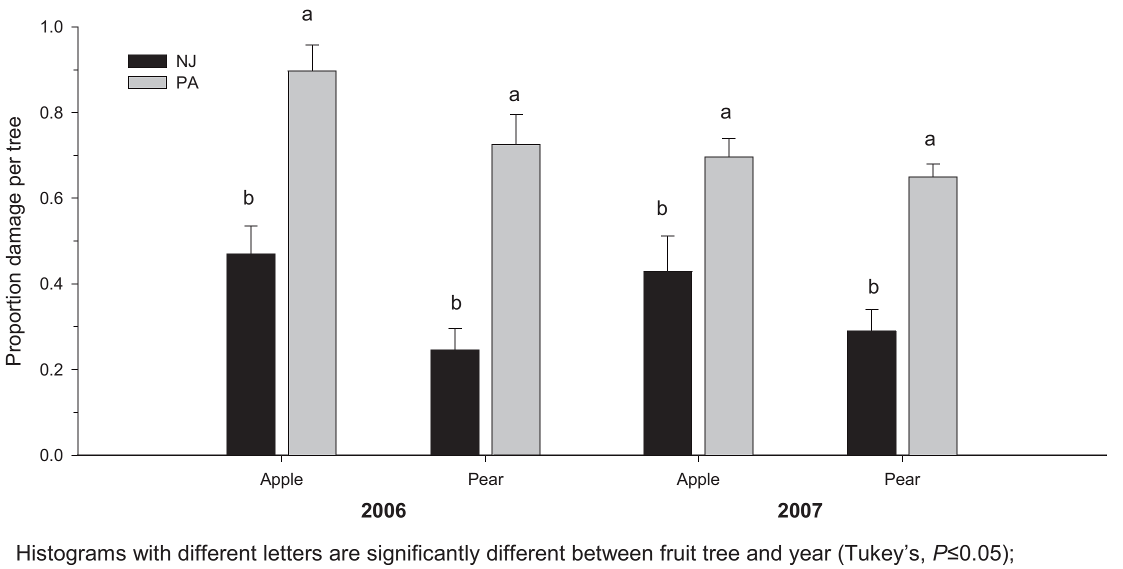

Fig. 4. Proportion of stink bug damaged fruit in apple and pear in 2006 and 2007 from Lichtenwalner Farms (PA) and Peaceful Valley Farms (NJ).

Adult *H. halys* likely use developing pome fruits early in the season as a nutrient source during reproductive maturation and then again before diapause to increase fat bodies (Funayama 2004). Our data present the first study documenting the seasonality and damage caused by *H. halys* in tree fruit in the United States and provide the initial step to developing a management program. Although no action thresholds for any stink bug species exist in the Northeast for tree fruit, losses ranging from 27 to 69% should be considered economic damage. Because *H. halys* was the dominant stink bug species found, the majority of this damage is likely attributable to the high densities of *H. halys* observed, showing the need for the development of action thresholds and control measures. Our data suggest that once *H. halys* populations are found in blacklight samples, beat sampling in the orchard should begin. If *H. halys* is detected, early-season management programs should be implemented. We found less than five specimens per 20 trees in late May and early June. Additional research needs to be conducted regarding economic thresholds, but it suggests that densities of one adult per 10 trees could result in damage. Later in the season, temporal dynamics show a population peak in late August/early September, just before harvest, depending on the variety. During this time, first-generation late-instar nymphs and adults are abundant and seem to cause the majority of damage in Pennsylvania and New Jersey. A primary concern among growers is how to reduce damage that occurs before harvest (during the swell critical growth stage), when most insecticide use is prohibited because of preharvest intervals. Pyramid traps baited with aggregation pheromone have been effective at reducing native stink bug populations in orchards (Leskey and Hogmire 2005). *Halyomorpha halys* is attracted to yellow pyramid traps baited with methyl (*E, E, Z*) 2,4,6-decatrieonate, especially during late August/early September, when they are not attracted to blacklight traps (Tada et al. 2001, Khrimian et al. 2008). The pheromone traps may have potential as a mass-trapping tool for first-generation adult *H. halys* in an orchard setting and should be studied further.

Based on the data presented here, it is anticipated that *H. halys* will become a pest of late-season tree fruit, including apples, pears, and peaches in the Mid-Atlantic region. Damage in peaches may not be as severe, because most peaches in this region are harvested before the occurrence of late instars and first-generation adults. However, as *H. halys* disperses into southern peach-growing regions, it may become bivoltine (Nielsen et al. 2008) and as a result be present during susceptible stages of peach development. More survey work needs done to determine how widespread populations of *H. halys* are in the eastern United States and whether similar damage levels are occurring in other areas.

Acknowledgments

We thank P. Shearer for assistance with design of the cage study. We are grateful for the assistance of K. Hamilton, K. Bernhard, and A. Wagner throughout the study. We also thank to Lichtenwalner Farms (Emmaus, PA), Peaceful Valley Farms (Pittstown, NJ), and Rutgers Tree Fruit and Extension Center (Cream Ridge, NJ) for access to fruit trees.

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Received 21 October 2008; accepted 25 February 2009.