J Insect Behav
DOI 10.1007/s10905-014-9456-2

Dispersal Capacity and Behavior of Nymphal Stages of *Halyomorpha halys* (Hemiptera: Pentatomidae) Evaluated Under Laboratory and Field Conditions

Doo-Hyung Lee · Anne L. Nielsen · Tracy C. Leskey

Revised: 27 May 2014 / Accepted: 10 June 2014

Abstract The invasive brown marmorated stink bug, *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae), is a highly polyphagous and mobile pest causing crop damage aggregated at the perimeters of crop fields. Understanding the dispersal biology of *H. halys* is critical for the development of reliable monitoring and management strategies. In this study, dispersal ecology of *H. halys* nymphs was studied under laboratory and field conditions. In the laboratory, horizontal and vertical walking capacity was quantified for mobile nymphal stages (i.e., 2nd through 5th instars) and compared with adults. There was a significant difference in the horizontal distance moved by *H. halys* among the life stages tested. Third instars exhibited significantly greater walking distances compared with adults; horizontal walking distances by other nymphal stages were not significantly different from adults. A similar pattern was observed from vertical climbing tests of *H. halys*. Third and 4th instars climbed significantly greater distances compared with 2nd instars and adults, while distances climbed by 5th instars were intermediate. In the field, the walking distance of 3rd and 5th instar nymphs on mowed grass was quantified based on direct observation of individuals for 30 min. Under these conditions, 5th instars moved nearly two-fold greater distances compared with 3rd instars, but surface temperature affected both nymphal stages similarly. Shorter bouts of movement were common at surface temperatures below 25 °C, whereas individuals showed longer walking distances above 25 °C. In mark-release-recapture studies, 4th and 5th instars were released and recaptured in traps baited with attractive pheromonal-based stimuli to estimate dispersal rates under field conditions. When insects were released 5 m from traps, both instars

D.-H. Lee (✉)
Department of Life Sciences, Gachon University, 1342 Seongnam-daero, Seongnam-si, Gyeonggi-do, Republic of Korea
e-mail: dl343@gachon.ac.kr

A. L. Nielsen
Rutgers Agricultural Research and Extension Center, 121 Northville Rd., Bridgeton, NJ 08302, USA

T. C. Leskey
USDA-ARS, Appalachian Fruit Research Station, 2217 Wiltshire Rd., Kearneysville, WV 25430, USA

Published online: 18 June 2014

were first recaptured within 2 h after release, with the recapture rates of 54 and 69 % for 4th and 5th instars over 24 h, respectively. When insects were released 20 m from traps, 4th and 5th instars were first recaptured in less than 5 h, with the recapture rates of 27 and 51 %, respectively. The results of this study indicate that *H. halys* nymphs have strong dispersal capacity with which populations can easily move among host plants and other attractive stimuli at farmscape levels.

Keywords Brown marmorated stink bug · invasive species · movement · mark-release-recapture

Introduction

The invasion of nonindigenous species is an escalating world-wide problem. For example, it is estimated that ca. 50,000 non-native species have been introduced to the United States, and many of them have caused significant environmental and economic losses in managed and natural ecosystems (Pimentel et al. 2000). Recently, the brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae) has emerged as a serious invasive species in agricultural ecosystems and residential areas in the mid-Atlantic regions of the U.S (Leskey et al. 2012a; Inkley 2012; Martinson et al. 2013; Nielsen et al. 2013; Owens et al. 2013). This invasive species is native to China, Japan, Korea, and Taiwan with >100 reported host plants in >45 families (Hoebeke and Carter 2003; Lee et al. 2013a) and has been detected in 40 states and the District of Columbia (see www.stopbmsb.org for updates).

Because *H. halys* is an invasive species attacking such a broad host range and populations are currently under minimal regulation by natural enemies, many crop production systems face a season-long threat posed by this novel pest (Leskey et al. 2012a; Lee et al. 2013a). Pest pressure and economic losses to crops have resulted in growers rapidly changing their management practices by instituting aggressive insecticide programs including frequent applications of broad-spectrum materials (Leskey et al. 2012b; Pfeiffer et al. 2013). This radical shift in management practices has caused severe ecological disruption to orchard agroecosystems and financial burdens for growers. In particular, natural enemy abundance has declined due to the use of broad-spectrum materials (e.g. pyrethroids), leading to secondary pest outbreaks (e.g. mites and aphids), which necessitate additional management inputs (Leskey et al. 2012a).

It is clear that management approach for *H. halys* must change because the current tactics are not ecologically or financially viable. A key consideration for developing sustainable management programs is that invasion of this pest into cultivated crops is perimeter-driven causing higher crop damages along the border than in the interior of crop fields (Leskey et al. 2012b). This dispersal pattern of *H. halys* becomes apparent especially for adults when colonizing crops from overwintering sites and dispersing among host plants in/around agricultural landscapes. After then, both adults and nymphs are often observed switching between wild hosts and cultivated crops along the border of crop fields, depending on host plant phenology and nutritional requirements of *H. halys* (Lee et al. 2013a). Therefore, understanding of the dispersal capacity and pattern of both adult and nymphal stages is fundamental to develop site-specific management tactics for *H. halys* populations.

Empirical data indicate that adult *H. halys* has strong dispersal capacity based on flight (e.g. >5 km per day; Wiman et al. 2014) with flight behaviors affected by abiotic conditions such as temperature and wind speed (Lee et al. unpublished data). Thus, although progress has been made towards the understanding of dispersal capacity and behavior of *H. halys* adults (Lee et al. 2013b; Wiman et al. 2014), little is known about the dispersal biology of *H. halys* nymphs. *H. halys* nymphs, except for the first instars residing around egg masses, can inflict fruit injury in the same manner as adults do (Nielsen and Hamilton 2009; Leskey et al. 2012a). Moreover, field observations suggest that nymphs are very mobile and have movement capacity sufficient to traverse between plots at farm scales. For example, all nymphal stages, except for the first instar, were consistently captured in the baited pyramid traps deployed on the ground between orchard borders and surrounding woodlots (e.g. Leskey et al. 2012b).

In the studies reported here, we determined dispersal capacity and behavior of *H. halys* nymphs in laboratory and field settings. In the laboratory, we used a video tracking system and a climbing arena to measure baseline horizontal and vertical walking capacity, respectively, of mobile nymphal stages, i.e. 2nd through 5th instars, compared with that of adults. Under field conditions, we conducted direct observations of nymphal movement to quantify their walking distances and patterns. Finally, we conducted mark-release-recapture (MRR) studies to establish nymphal dispersal capacity and diurnal patterns of movement toward olfactory stimuli deployed in an agricultural setting.

Materials and Methods

Insect

Wild *Halyomorpha halys* were collected periodically from wild host plants from July through September 2013 in the vicinity of Kearneysville, WV, USA (39° 31′ N, 77° 53′ W). Insects were maintained in field cages (1.8 m^3) provided with food resources including a potted peach tree, potted mullein plants, potted soybean plants, *Ailanthus* tree branches, *Paulownia* tree branches, and apples. This field cage setting provided a reliable pool of subjects for subsequent experiments that experienced conditions similar to free-ranging wild populations.

Horizontal Walking in Laboratory

Horizontal movement of *H. halys* nymphs and adults was tracked and recorded using a video camera (RE-350, Canon, Inc., Tokyo, Japan) linked to Noldus EthoVision software (version 3.1.16, Noldus Information Technologies, The Netherlands). Five Petri-dish arenas (10 cm diameter; 1.5 cm tall) were set up in a dark room at ~25 °C and backlit using fluorescent lights to aid in tracking of insects. This setting allows providing insects with sufficient light in the experimental arena (i.e., Petri-dish) while making insects clearly contrast to the white background. All stages of *H. halys* tested were collected from the field cage, held together in the laboratory condition, and used in the walking tests within eight hours. Four distinct nymphal stages (2nd through 5th) and one adult were randomly placed among the five experimental arenas and all experimental arenas were video-recorded simultaneously at a capture rate of six samples per second for 1 h. This bioassay design was initially developed for tracking adult *H. halys* (Lee et al. 2013b, c), but was customized for tracking smaller individuals, i.e. nymphs, in this study. Input filters were adjusted by setting the minimum and maximum distances moved to 0.42 and 6.00 cm per second, respectively, to account for potential "cursor bounce" (variation in the position of the tracked individual due to constant recalculation of the center of the acquired subject) in EthoVision. Each trial lasted 60 min and 22 individuals were tested for each life stage. Total distance moved was analyzed using ANOVA with Tukey's HSD to compare distances among different life stages (JMP Genomics 5.0, SAS Institute).

Vertical Climbing in Laboratory

Vertical mobility of *H. halys* nymphs (2nd through 5th) and adults was evaluated in the laboratory at ~25 °C by observing insects placed inside and at the base of clear polycarbonate cylinders (7 cm diameter; 30 cm tall) (Lee et al. 2013b, c). A new group of *H. halys* were collected for this climbing trial but handled as described above. Individuals were randomly assigned to five experimental arenas under fluorescent lights (~5,400 lux) and the vertical position of each individual was recorded every 30 s. If the insect reached the top of the cylinder, the cylinder was immediately inverted. Individuals were tested for 5 min in each of three consecutive trials totaling 15-min duration. Total distance climbed for 15 min was recorded and analyzed using ANOVA with Tukey's HSD to compare distances among different life stages (JMP Genomics 5.0, SAS Institute). A total of 40 individuals were tested for each life stage, but individuals that failed to grip and climb the cylinder surface were not included in the data analysis.

Direct Observations in the Field

Observations of walking behavior of 3rd and 5th instars were conducted in a grassy field (30×60 m; ~15-cm tall grass) at the USDA-ARS, Appalachian Fruit Research Station, Kearneysville, WV (39° 21′ 26″ N, 77° 52′ 44″W) in July and August 2013. Observations were made at different times of day (06:30–17:00) to measure walking capacity and behavior of nymphs across different abiotic conditions and times of day. Abiotic conditions including temperature (WT389, Control Company, Friendswood, TX), humidity (EL-USB-2+, Lascar Electronics Inc., Erie, PA), and light intensity (LX-105, Reed Instruments, Quebec, CA), were measured directly at grass surface level to account for conditions experienced by *H. halys* nymphs. In each trial, a 3rd instar and a 5th instar were followed separately by one of two human observers. At the onset, nymphs were gently placed on the grass and observers followed their movements visually for 30 min. Observer position was maintained at the maximum distance possible to reliably follow the nymph. Every 5 min, the location of nymphs was marked on the ground, so that the shape of walking path could be mapped and measured at the end of the observation period. Total distance of walking path and net distance from start to finish point of walking were measured; the ratio between the two distances (i.e. net/total) was calculated to represent the straightness of walking path. Thirty three individuals were tested for each life stage. Total walking distance and net walking distance were log-transformed and analyzed using ANOVA. The ratio of net distance divided by total distance, representing the straightness of walking path, was arcsine-transformed and analyzed using ANOVA (JMP Genomics 5.0, SAS Institute).

Mark-Release-Recapture Study

Mark-release-recapture (MRR) trials were conducted for 4th and 5th instars of *H. halys* in an open mowed field (70×180 m; ~20-cm tall vegetation) at a diversified organic farm in Berkeley County, WV, USA (39° 23′ 23″ N, 78° 04′ 38″ W) in July and August 2013. Nymphs were marked by painting color dots on their pronota using oil-based paint markers (Uchida of America, Corp., Torrance, CA). In this MRR study, 4th instar was used instead of 3rd for the practical reason: the small body size of 3rd made it difficult to paint a large number of them without damaging the insects. Marked nymphs were released from the center of circular experimental plots in which 1) 8 pyramid traps were placed 5 m away from the release point as recapture stations at every 45.0° or 2) 16 pyramid traps were placed 20 m away from the release point at every 22.5°. The distance to the nearest woodlot was ~20 m from the traps in both 5- and 20-m plots. Each pyramid trap (122 cm tall; 51 cm wide at the base) (AgBio, Inc., Westminster, CO) was baited with 10 mg of *H. halys* aggregation pheromone [(3S,6S,7R,10S)- and (3R,6S,7R,10S)-10,11-epoxy-1-bisabolen-3-ol in approximately 3.5:1 ratio] plus 62 mg of a synergist [methyl (*E,E,Z*)-2,4,6-decatrienoate (*MDT*)] (Khrimian et al. 2013; Weber et al. 2014). These olfactory stimuli have proven to be a strong attractant for both adults and nymphs (Weber et al. 2014; Leskey et al. unpublished). In each experimental plot, 4th and 5th instars were tested simultaneously, where 50 and 100 individuals of each instar were released in the 5-m and 20-m distance settings, respectively. This study was replicated six and four times in 5 and 20-m plots, respectively. The two nymphal instars were marked 24 h in advance and held separately in plastic containers (15 cm tall; 11 cm diameter) and released by opening lids ca. 30 min after sunrise. All traps were checked and emptied every hour for 12 h and then at 24 h after the release. After the initial 12-h observation period, a kill strip containing dimethyl 2,2-dichlorovinyl phosphate (Hercon Vaportape II, Hercon Environmental, Emigsville, PA) was placed inside of trap collecting jar to prevent *H. halys* from escaping during the overnight period (Leskey et al. 2012b). Recapture rates were compared using the Pearson's chi-square analysis (JMP Genomics 5.0, SAS Institute). In addition to marked individuals, wild *H. halys* nymphs (i.e. unmarked individuals), which were captured in the traps, were also counted throughout the study.

Results

Horizontal Walking in Laboratory

There was a significant difference in the horizontal distance moved by *H. halys* among the life stages tested in the Petri dish arenas ($F_{4,84}$=3.1115, P=0.0194) (Fig. 1a). Third instars moved significantly greater distances compared with adults (P<0.05). Second, 4th and 5th instars exhibited intermediate walking distances with no significant difference compared with 3rds or adults in the study.

Vertical Climbing in Laboratory

There were 2, 6, 6, 6 and 10 individuals (5–25 % of the total individuals tested) from 2nd, 3rd, 4th, 5th instars and adult, respectively, that failed to grip the surface and climb up the experimental arenas. These individuals were excluded from the data analysis. There was a significant difference in the distance climbed by *H. halys* among the life stages tested ($F_{4,165}$=9.9669, P<0.0001) (Fig. 1b). Third and 4th instars showed significantly greater distance climbed compared with 2nd instars and adults in the study (P<0.05), while 5th instars were intermediate.

Direct Observations in the Field

There was a significant difference in the total walking distance of 3rd and 5th instars when their movements were observed in a grassy field for 30 min ($F_{1,32}$=7.2121, P= 0.0114) (Table 1). The 5th instars moved nearly two-fold greater distances compared with 3rd instars. A similar pattern was also observed for net walking distance calculated

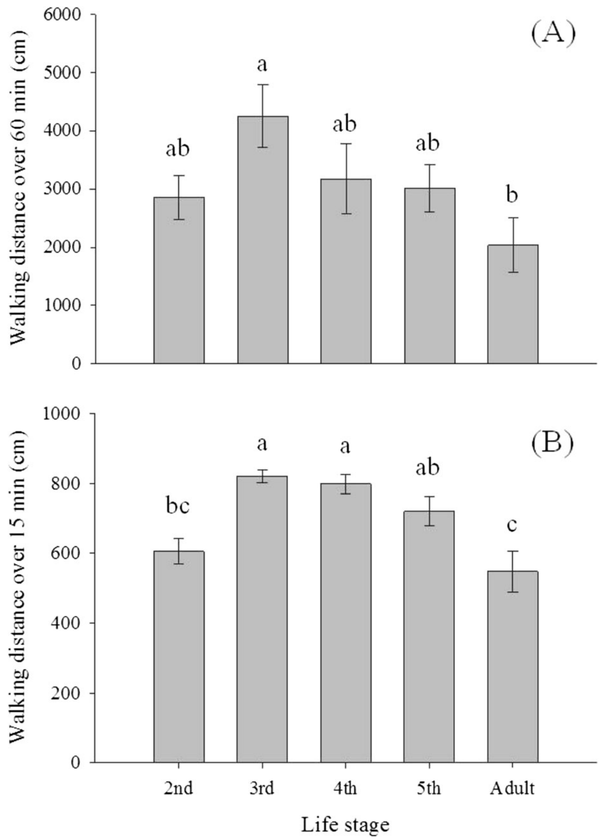

Fig. 1 Horizontal walking distance (mean±SE) of *Halyomorpha halys* nymphs and adults measured for 60 min in Petri-dish arenas (**a**). Vertical climbing distance (mean±SE) of *H. halys* measured for 15 min in plastic cylinder arenas (**b**). Bars with different letters are significantly different between life stages (Tukey's HSD, P<0.05)

Table 1 Walking capacity of the 3r and 5th instars of *Halyomorpah halys* observed on mowed grass

Measurement	Life stage		Statistic	*P*-value
	3rd instar	5th instar		
Total walking distance (cm)	121.70±23.35	233.58±42.28	$F_{1,32}$=7.2121	0.0114
Net walking distance[a] (cm)	93.84±20.43	193.06±37.71	$F_{1,30}$=8.7443	0.0060
Walking path straightness[b]	0.81±0.04	0.84±0.02	$F_{1,30}$=0.0517	0.8217

[a] Based on linear distance between start and end points

[b] Based on the ratio of net walking distance divided by total walking distance

as linear distance between start and finish points of the walking path ($F_{1,30}$=8.7443, P= 0.0060). However, the straightness of walking path was not significantly different between the two life stages ($F_{1,30}$=0.0517, P=0.8217). Grass surface temperature significantly affected the walking distances of *H. halys* ($F_{1,31}$=8.6983, P=0.0060) (Fig. 2). In general, individuals moved shorter distances when surface temperature was below 25 °C, whereas individuals started moving longer distances when ground temperature was over 25 °C. This temperature effect was consistent for both 3rd and 5th instars ($F_{1,31}$=0.1926, P=0.6638) (Fig. 2).

Mark-Release-Recapture Study

In general, recapture rates of *H. halys* were high, ranging 19–82 % throughout the studies (Table 2). Most recaptures occurred within 12 h after releasing marked nymphs; only <4 % were recaptured thereafter until the end of 24 h observation period in all experiments. When *H. halys* were released at 5 m from the traps, >50 % of individuals were recaptured for both instars. The recapture rate of the 5th instar was significantly higher than the 4th instar (χ^2=14.301, *d.f.*=1, P=0.0002). When *H. halys* were released at 20 m from the traps, the recapture rates were 27 and 51 % for the 4th and 5th instars, respectively (χ^2=50.581, *d.f.*=1, P<0.0001). Recapture rates were significantly higher when insects were released at 5 m away from the traps compared

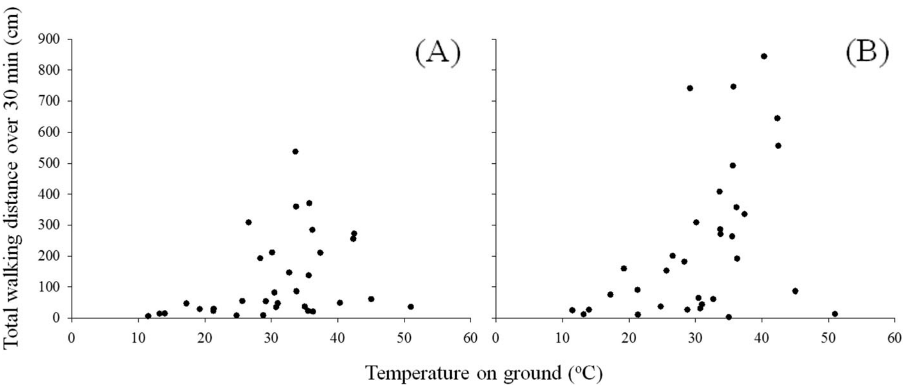

Fig. 2 Total walking distance of 3rd (**a**) and 5th (**b**) instar *Halyomorpha halys* across temperatures measured at grass surface for 30 min in a mowed plot

with 20 m for both 4th (χ^2=56.128, *d.f.*=1, P<0.0001) and 5th (χ^2=23.794, *d.f.*=1, P<0.0001) instars (Table 2). In the 5-m experimental plot, both instars were first recaptured in the traps within 2 h after release (Fig. 3a). In the 20-m plot, 4th and 5th instars were first recaptured within 5 and 4 h, respectively (Fig. 3b). Patterns of changes in recapture numbers were not significantly different over time between the two instars in the 5-m plot ($F_{11,120}$=0.5274, P=0.8816) and the 20-m plot ($F_{11,72}$=0.7087, P=0.7263).

Wild *H. halys* nymphs (i.e. unmarked individuals) were also consistently attracted to the baited pyramid traps during the study (Fig. 4). The captures of wild nymphs increased over time during the study period with some decreases at the end of 12-h observations in the 5-m plot ($F_{12,259}$=12.2750, P<0.0001) and the 20-m plot ($F_{12,155}$= 19.7977, P<0.0001). In both plots, 90 % of wild nymphs were captured during the last 6 h of the 12-h observation period.

Discussion

The brown marmorated stink bug, *Halyomorpha halys*, is a polyphagous pest with strong flight capacity (Lee et al. 2013a; Wiman et al. 2014). In general, stink bugs disperse among host plants in pursuit of developing fruiting structures of cultivated and wild plants over the season (Panizzi 1997; McPherson and McPherson 2000). Indeed, it has been reported that *H. halys* often disperse among a wide range of host plants (Wang and Wang 1988; Fujisawa 2001) as hosts vary in suitability and acceptability (Oda et al. 1980; Zhang et al. 1993). Feeding on multiple hosts also increases development and fitness of *H. halys* (Funayama 2002; Acebes-Dora A, personal communication). Active dispersal by adults has been observed season-long, resulting in crop injury with strong edge effects in multiple commodities at regional scales (Leskey et al. 2012a, b) as reported with other stink bug species (Tillman et al. 2009; Reeves et al. 2010).

In addition to dispersal by adults, it is critical to understand dispersal capacity and behavior of *H. halys* nymphs in order to develop integrated management programs as both adults and nymphs are damaging to specialty and row crops. There have been several studies that have examined dispersal capacity and behavior of herbivorous (Panizzi et al. 1980; Schumann and Todd 1982; Tillman et al. 2009) and predaceous (Waddill and Shepard 1975; Sant'Ana et al. 1997; Torres et al. 2002) pentatomids. In soybean fields, nymphs of *Nezara viridula* (L.), *Piezodorus guildinii* (Westwood)

Table 2 Recapture rates of *Halyomorpha halys* in the mark-release-recapture study using pyramid traps baited with olfactory attracts

Distance to trap	Trial date	Life stage	
		4th instar	5th instar
5 m	July 23	40 %	57 %
	July 30	69 %	82 %
	Total	54 %	69 %
20 m	August 7	19 %	41 %
	August 14	34 %	62 %
	Total	27 %	51 %

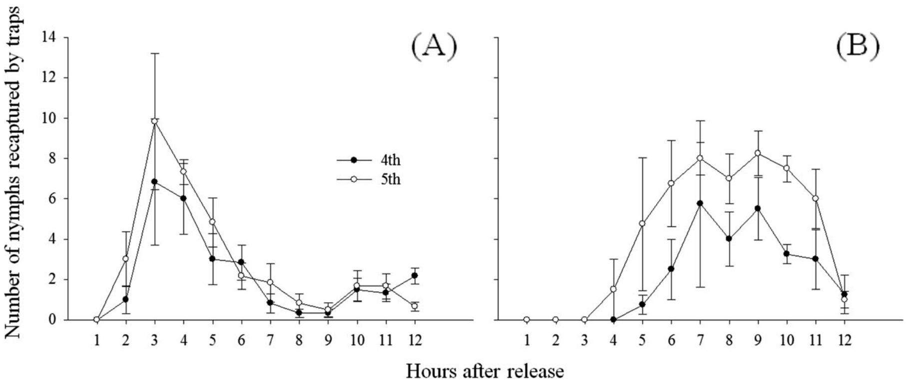

Fig. 3 Number of marked *Halyomorpha halys* nymphs (mean±SE) recaptured in the pheromone-baited traps over 12 h when marked nymphs were released at 5 m (**a**) and 20 m (**b**) from the traps in a mowed plot

(Panizzi et al. 1980) and *Podisus maculiventris* (Say) (Waddill and Shepard 1975) dispersed more frequently along rows rather than across rows. Dispersal by later instars (e.g. 4th and 5th) of *N. viridula* and *P. guildinii* was more pronounced compared with younger instars (e.g. 2nd and 3rd) (Panizzi et al. 1980; Schumann and Todd 1982). In peanut-cotton farmscapes, spatiotemporal analyses demonstrated that *N. viridula* and *Euschistus servus* (Say) nymphs that developed in peanuts dispersed into cotton (Tillman et al. 2009). This type of information can be useful in developing site- and crop-specific management strategies, particularly when nymphs may be likely to leave one host plant or crop and move on to another.

Laboratory trials of this study demonstrate that *H. halys* nymphs (i.e. 2nd through 5th instars) have strong walking capacity on horizontal and vertical surfaces. Because insects were confined in smaller experimental arenas and tested on smooth plastic or glass surfaces, the absolute distances might not necessarily represent those to which *H. halys* may disperse in the field. Also, the laboratory condition would have affected natural willingness of *H. halys* to disperse. With this caveat, the results of this study demonstrate that nymphs have locomotor ability which may exceed adult's in certain environments. In both horizontal and vertical walking arenas, all nymphal stages of *H. halys* showed equivalent or significantly greater distances moved compared to adults.

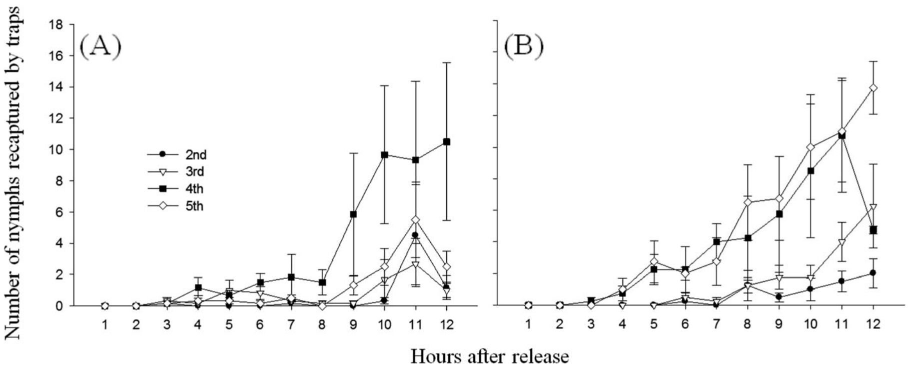

Fig. 4 Number of unmarked *Halyomorpha halys* nymphs (i.e. wild populations) (mean±SE) captured in the pheromone-baited traps over 12 h in the 5-m (**a**) and 20-m (**b**) distance experiments

Indeed, laboratory trials to study insect walking have been proven to be useful to measure treatment effects such as insecticides or insect response to given stimuli, and compare the walking behaviors and capacities. For example, Shambaugh (1969) used a rotating rod system to measure the effect of DDT on the walking ability of the cockroach, *Nauphoeta cinerea* (Oliv.). Combinations of wind tunnel and servosphere were used to describe the olfactory orientation and walking behavior of Colorado potato beetle, *Leptinotarsa decemlineata* (Say) (Thiery and Visser 1986) and its pentatomid predator, *Perillus bioculatus* (Fabricius) (Loon et al. 2000).

Direct observations of this study provide practical measurements on dispersal capacity and behavior of *H. halys* nymphs in the field. In the laboratory settings described above, there was no significant difference in the walking distances among 3rd through 5th instars; however, 5th instars showed ca. two-fold greater walking distances compared with 3rd instars in grassy field plots. In addition, temperature affected walking distances of the two nymphal instars tested across different times of the day. For both instars, shorter bouts of movement were common at surface temperatures below 25 °C, whereas individuals showed longer walking distances, e.g. >3 m per 30 min above 25 °C. It was not quantitatively documented but some individuals seemed to try to escape from direct sunlight by moving beneath the grass and closer to the ground to reach shaded areas, especially when the temperature was >40 °C. Adults were not included in direct observation trials because adult readily initiated flight when released on the ground (Lee D-H, personal observation) and are likely to use flight to make initial dispersal to escape or move to favorable locations. In the experimental grassy field, we did not see measurable directionality of *H. halys* movement. However, the mark-release-recapture trials of this study confirmed that *H. halys* nymphs strongly responded to the aggregation pheromone-based stimuli in a similar environmental setting (see below).

Mark-release-recapture (MRR) studies have been utilized for various insects but low recapture rates can affect the quality of the data collected (Hagler and Jackson 2001). In this study, *H. halys* nymphs were successfully recaptured by pyramid traps baited with olfactory stimuli (i.e. *H. halys* aggregation pheromone plus a synergist). Indeed, strong dispersal capacity of nymphs, coupled with their response to the olfactory stimuli, yielded up to a 60 % recapture rate within 12 h, during which insects walked >20 m on the grassy ground. In the MRR study, marked nymphs were released from plastic containers without food or water, which may have encouraged initial dispersal by insects during the early hours of the experiment. However, wild *H. halys* nymphs (i.e. unmarked individuals) also were consistently captured in the traps across all trials, especially in those traps located near the surrounding woodlot: the nearest distance between traps and woodlot was ~20 m. Therefore, the olfactory stimuli can attract *H. halys* nymphs present on wild host plants to disperse across areas devoid of resources to reach the pheromone stimuli. That is, *H. halys* nymphs are likely to make active, directed dispersals when attractive stimuli are detected and overriding stimuli, including food resources, at the nymph's current location. Similar patterns were observed when apple trees were baited with higher doses of the same stimuli at the orchard border to develop attract-and-kill systems for *H. halys* (Leskey et al. unpublished data). Therefore, further studies are warranted to evaluate potential of attract-and-kill strategies for *H. halys* by baiting perimeter row trees or plants with the olfactory stimuli (e.g. Prokopy et al. 2003; Leskey et al. 2008; Wright et al.

2012) and applying site-specific insecticide applications targeting aggregated *H. halys* populations.

H. halys is a global invader with established populations throughout the U.S., Canada and Europe (Hoebeke and Carter 2003; Wermelinger et al. 2008; Fogain and Graff 2011). In particular, this invasive species has caused significant crop losses in specialty and row crops in the mid-Atlantic region of the U.S, changing management practices by affected growers. In tree fruit in particular, recent insecticide programs using broad-spectrum materials with increased frequency (e.g. up to four-fold applications) (Leskey et al. 2012b) have caused severe disruption to agroecosystems leading to secondary pest outbreaks (Leskey et al. 2012a). To mitigate the severe agricultural crop losses incurred by multiple life stages of *H. halys*, it is desired to develop precision management regimes in time and space. Toward this goal, it is crucial to evaluate dispersal capacity and behaviors of damaging populations as a foundation to develop spatially precise management programs. The results of this study indicate that *H. halys* nymphs have strong walking capacity that can be readily translated into within-farm dispersal toward more favorable stimuli such aggregation pheromone or more suitable host plants (e.g. trap crops). Therefore, further studies are warranted to determine seasonal movement patterns of nymphal populations at larger spatial scales and its implications towards site-specific management programs.

Acknowledgments We thank Cameron Scorza, John Cullum, and Samuel Nathan Brandt for excellent technical support. We thank Clarissa Mathews and Haroun Hallack for allowing us to conduct mark-release-recapture studies at Redbud Farm in Inwood, WV. This work was supported in part by USDA-NIFA OREI # 2012-51300-20097 award. Mention of trade names or commercial products in this publication is solely for the purpose of providing specific information and does not imply recommendation or endorsement by the U.S. Department of Agriculture.

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