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REVIEW

Range expansion of the invasive brown marmorated stinkbug, *Halyomorpha halys*: an increasing threat to field, fruit and vegetable crops worldwide

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Abstract The brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae), has emerged as a harmful invasive insect pest in North America and Europe in the 1990s and 2000s, respectively. Native to eastern Asia, this highly polyphagous pest (>120 different host plants) is spreading rapidly worldwide, notably through human activities. The increasing global importance of the pest suggests that more coordinated actions are needed to slow its spread and mitigate negative effects in invaded areas. Prevention of large-scale outbreaks will require accurate identification and effective mitigation tools to be rapidly developed and widely implemented. In this short review, we update the current distribution of *H. halys*, discuss potential geographic range expansion based on passive and active dispersal and provide insight on the economic, environmental and social impact associated with *H. halys*.

Keywords Agricultural pest · Invasion scenarios · Distribution · Europe · Asia · North America

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Key message

- *Halyomorpha halys* has emerged as a harmful invasive insect pest in North America and Europe in the 1990s and 2000s.
- We updated the current distribution of *H. halys*, discuss potential geographic range expansion and provide insight on the economic, environmental and social impact associated with *H. halys*.
- Understanding the factors favouring establishment and mass outbreaks will be the key for effective control of *H. halys*.

Introduction

Native to eastern Asia, the brown marmorated stink bug (BMSB), *Halyomorpha halys* (Stål, 1855) (Hemiptera: Pentatomidae), has recently become one of the most harmful invasive insect pests in North America and Europe. In the US, this pest was first discovered in Allentown (Pennsylvania) in 1996, whereas the first records from Europe (Switzerland, Liechtenstein) date back to 2004 (Hoebeke and Carter 2003; Arnold 2009; Haye et al. 2014). Since its arrival in the US, *H. halys* has spread to 41 states

(Northeastern IPM Center 2014a) and into southern Ontario, Canada (Gariepy et al. 2014). Breeding populations in Europe were originally restricted to the Canton Zurich in Switzerland (Wermelinger et al. 2008), suggesting that its natural spread in the first years following the initial introduction was relatively slow. However, in recent years, it has been recorded in France, Italy, Germany, Liechtenstein, Hungary and Greece (Arnold 2009; Heckmann 2012; Callot and Brua 2013; Pansa et al. 2013; Maistrello et al. 2014; Vétek et al. 2014; Milonas and Partsinevelos 2014; Cesari et al. 2014). This pest is known to spread rapidly into new areas when moved through human activity and movement of goods, and thus, a continued spread, potentially throughout all climatically amenable locations, can be expected.

This highly polyphagous pest is known to feed on over 120 different host plants, including many economically important field, fruit and vegetable crops (Leskey et al. 2012a, b; Lee et al. 2013; Center 2014b; Haye et al. 2014b; ANSES 2014). Approximately 14 years after initial establishment in the US, *H. halys* has become one of the most significant pests in recent history, causing >$37 million in losses in the apple growing area of the Mid-Atlantic region (United States Apple Association 2010). Established in Europe for at least 10 years, *H. halys* is primarily considered an urban and household pest, and to date, only limited damage has been reported in agroecosystems (Sauer 2012). However, with recent spread into important fruit growing regions, the economic impact of *H. halys* is of increasing concern. Here, we update the available information on the current worldwide distribution of *H. halys* and discuss the threat to fruit production by the increasing spread of *H. halys.*

Current geographic distribution

Asia

The native range of *H. halys* comprises China, Japan and Korea (Hoebeke and Carter 2003) (Fig. 1). In China, *H. halys* is widely distributed throughout the temperate and subtropical regions of eastern China, including the provinces Anhui, Beijing, Fujian, Guangdong, Guangxi, Guizhou, Hebei, Heilongjiang, Henan, Hubei, Hunan, Jiangsu, Jiangxi, Jilin, Liaoning, Inner Mongolia, Shaanxi, Shandong, Shanxi, Sichuan, Taiwan, Xizang, Yunnan and Zhejiang (Rider et al. 2002; Yu and Zhang 2007; Zhu et al. 2012; Lee et al. 2013). In Japan, it occurs on the islands of Honshu, Shikoku and Kyushu, whereas in Hokkaido, it seems absent (Kobayashi et al. 1972; Watanabe 1980). *H. halys* is further found all across South Korea (Bae et al. 2008, 2009); however, its distribution in North Korea is unknown.

Europe

The first established population of *H. halys* in Europe was detected in Zurich, Switzerland, in 2007 (Wermelinger et al. 2008). At this time, individuals of *H. halys* were found within an area of 40 km^2, suggesting that it had already been present for much longer. This was later confirmed by a photograph of single individual which had been taken in May 2004 in the district Hottingen of Zurich (Haye et al. 2014). In the same year, a second specimen was caught in a light trap near Balzers, in southern Liechtenstein (Arnold 2009), which likely originated from the well-established Swiss population. Between 2007 and 2010, homeowner reports of *H. halys* in Zurich increased exponentially (Mueller et al. 2011), and by the end of 2013, it was present in 11 Cantons with large breeding populations observed in the cities of Zurich, Basel, Bern and Lugano (Haye et al. 2014b). In 2011, several individuals were found in residential homes in Central Athens in Greece, representing the most southern record of *H. halys* in Europe (Milonas and Partsinevelos 2014). In 2012, a single individual was reported from Konstanz in Germany (Heckmann 2012), but remarkably, breeding populations have yet to be reported from Germany. In France, *H. halys* was first detected in 2012 from the Alsace region, where several individuals were found near the botanical garden of Strasbourg and in the nearby city Schiltigheim (Callot and Brua 2013). A targeted search in September 2013 confirmed the presence of a large breeding population in a small park near the original detection site in Schiltigheim (Haye, unpublished). In addition, in autumn 2013, several specimens were found in the garden and buildings of the Natural History Museum (MNHN) of Paris and in Ile de France (Essonne) (Garrouste et al. 2014) suggesting that *H. halys* is already more widespread in France than initially thought. In Italy, the first individual was detected in September 2012 in the province of Modena (Maistrello et al. 2014). A public survey conducted in 2013 showed that *H. halys* is already widely distributed in northern Italy, including the territories of Emilia Romagna, Lombardy and Piedmont (Pansa et al. 2013; Maistrello et al. 2014; Cesari et al. 2014). In addition, by October 2013, adults and nymphs of BMSB were found in Budapest, Hungary (Vétek et al. 2014), which adds further evidence that *H. halys* has established across a broad area, and is likely more widespread in Europe than previously assumed (Fig. 1).

North America

United States Prior to its establishment, *H. halys* was occasionally intercepted in shipments arriving at ports. Two reports from 1973 to 1987 and 8 reports from 1989 to

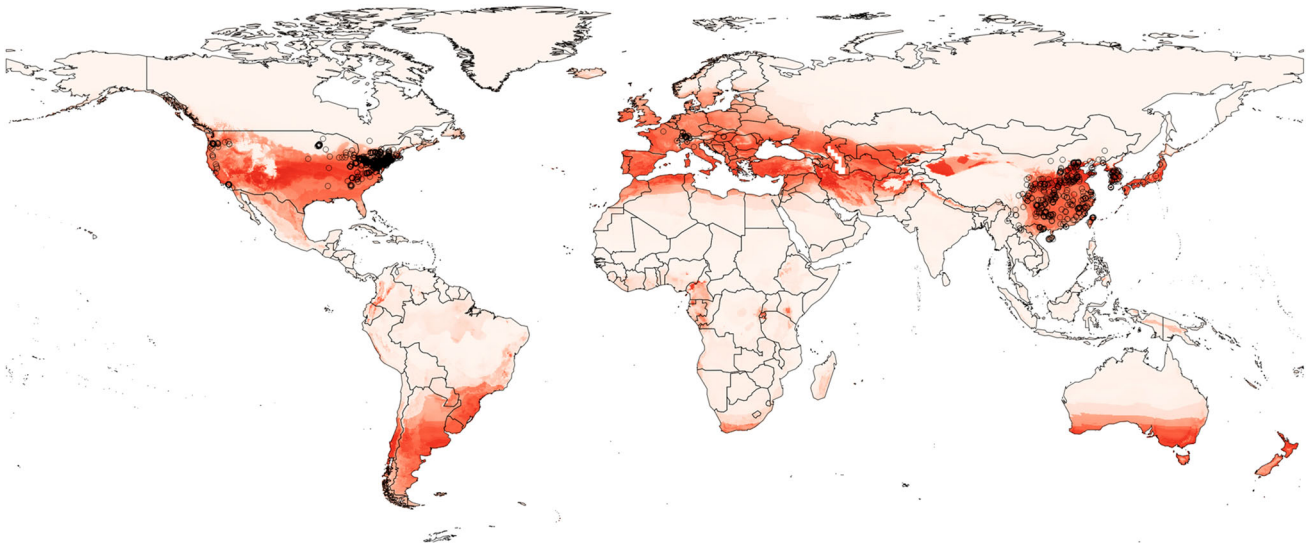

Fig. 1 Current world distribution of *Halyomorpha halys* (*circles*) and bioclimatic model (Maxent software, http://www.cs.princeton.edu/~schapire/maxent/) based on distribution data in Asia. *Dark colour* represents high habitat suitability; *light colour* indicates low suitability (Rossi and Streito, unpublished). Background map from http://www.naturalearthdata.com

1998 of specimens in shipping containers, aircraft, and soil associated with vehicles were mentioned by Hoebeke and Carter (2003). The first confirmed identification of *H. halys* from an established field population in North America was made in 2001 from specimens collected in the city of Allentown in eastern Pennsylvania (Hoebeke and Carter 2003). The introduction that led to establishment probably occurred some years earlier in the mid-1990s (Hamilton 2009), and other collections of this insect had been reported as early as 1996. A specialist with Pennsylvania State Cooperative Extension received numerous homeowner reports of a "new" insect pest invading homes during the fall months, recognized that it might be exotic, and sent specimens for identification to R. Hoebeke at Cornell University (Hoebeke and Carter 2003). By fall of 2002, the invader was known to be present within a 200 square mile area (United States Apple Association 2010) in at least six counties in Pennsylvania and two in New Jersey (Hoebeke 2002). It was first found in the adjacent states of New Jersey in 1999, New York in 2002 and Delaware in 2004; then continued to move progressively to other states along the east coast. Limited finds or populations began to be reported in central, southern and western states including Mississippi, Ohio, Oregon and California. Populations increased annually since first detection in 2003–2004 in Maryland and West Virginia, and in 2009, serious economic injury to peach, apple and Asian pear was widely reported. By 2010, *H. halys* had emerged as a severe pest of fruit and other crops across the Mid-Atlantic States region. On the west coast of the USA, *H. halys* was first reported in a storage unit California in 2002 and in a standard trap designed to detect wood-boring beetles in Portland, Oregon in 2004. Established populations were found soon afterwards in Portland. By 2010, the Oregon population had grown to encompass an area from Corvallis, Oregon to Vancouver, Washington. In California, established populations of *H. halys* were first seen in the Los Angeles area in 2006 and in Sacramento in the Central Valley in 2013 (CDFA Plant Health & Pest Prevention Services, unpublished database). As of March 2015, *H. halys* had been found in 42 states of the U.S. (Fig. 1); of these, 8 states reported the insect to be only an urban nuisance pest, while 15 states on both coasts reported significant or serious agricultural damage in addition to its nuisance status (Northeastern IPM Center 2014c).

Canada *Halyomorpha halys* was first recognized in Canada in the Province of British Columbia in 1993 when a specimen was intercepted in a shipment originating from Asia. Although there were additional interceptions across the country following this first arrival, establishment of this pest was not suspected until 2010 when homeowner reports of overwintered *H. halys* adults began in Hamilton, Ontario (Fogain and Graff 2011). Breeding populations were officially confirmed in 2012 in the Greater Toronto and Hamilton Areas of Ontario when eggs, nymphs, and adult *H. halys* were found in the field (Gariepy et al. 2014). *H. halys* is currently considered a minor nuisance pest in these areas, as it has been found primarily on wild hosts in urban areas, with some damage reported on home garden plants and ornamentals (H. Fraser, personal communication). However, evidence suggests continued spread of *H. halys*

to additional locations in southern Ontario, including major fruit growing regions such as the Niagara Peninsula (Gariepy et al. 2014). Although populations of *H. halys* have yet to be found feeding on agricultural crops in southern Ontario, trapping and monitoring programmes have detected the presence of adult *H. halys* in fruit orchards in these areas (Gariepy, Fraser & Scott-Dupree, unpublished). To date, there is no evidence of establishment of *H. halys* in other Canadian Provinces; however, the risk of establishment outside of Ontario is high, given the ease with which *H. halys* is both actively and passively transported based on human activity.

Potential geographic distribution

Bioclimatic modelling based on distribution data in Asia and climate data hosted in CliMond (Kriticos et al. 2012) suggested that the most favourable conditions for establishment of *H. halys* exist in the Mediterranean countries of Europe and the middle East, the northern parts of Algeria, parts of western Africa (northern Cameroon), the west coast of the United States and eastern North America, central Chile, northeastern Argentina, Uruguay and southern Brazil (Zhu et al. 2012; Fig. 1). Additional favourable regions include important fruit-producing areas such as the south island of New Zealand and southern Africa (Zhu et al. 2012).

With the rise in global trade, the movement of goods between countries, and the shelter-seeking behaviour exhibited by *H. halys*, the opportunity exists for the establishment and spread of this pest outside of the currently documented and predicted range.

Invasion scenarios/pathways of movement/entry

In addition to the documented establishment of *H. halys* discussed above, individual *H. halys* has been intercepted in shipments by phytosanitary officials in a number of countries including Australia (Walker 2009), New Zealand (Duthie 2012), and Germany (Freers 2012). Intercepted specimens are reported to have arrived in shipments originating from China, Hong Kong, Japan, Korea and the US. From 2000 to 2014 (after *H. halys* was already established in North America), USDA-APHIS recorded 128 interceptions of *H. halys* at US ports. A notable increase in the number of US interceptions occurred during 2010–2013. The majority (98) were associated with maritime cargo. Many of the finds were in shipments that originated from countries within the native range of *H. halys*, but interceptions were also made in cargo arriving from other ports around the world in regions where it is not known to be established (USDA-APHIS United States Deptartment Agriculture 2002). It is likely that specimens (alive or dead) have arrived in additional locations worldwide, but have gone unreported.

Pathways of movement for *H. halys* have been well documented (see Hoebeke and Carter 2003; Duthie 2012), and include movement of specimens on inanimate objects as stowaways in cargo, packing crates, aircraft, machinery, vehicles and personal luggage—all of which are more likely when *H. halys* begins to aggregate for overwintering (Hoebeke and Carter 2003; Hamilton 2009; Duthie 2012). Studies on the population genetics of established *H. halys* in North America strongly suggest that the invasion consists of one dominant haplotype originating in the Beijing/Hebei regions of China (Gariepy et al. 2014; Xu et al. 2014). Further, the Canadian population is likely derived from movement of the already-established population in north eastern USA (Gariepy et al. 2014). However, new samples from western U.S. states (California, Oregon and Washington) collected in 2013 were found to include additional haplotypes not found in any of the specimens analysed by Xu et al. (2014), suggesting that further introductions may have occurred in the U.S. (Hoelmer, unpublished). The invasion in Europe was initially restricted to Switzerland, but reports of establishment in France, Italy, Hungary and Greece have recently surfaced (Callot and Brua 2013; Pansa et al. 2013; Maistrello et al. 2014; Vétek et al. 2014; Milonas and Partsinevelos 2014). Until 2012, the Swiss population consisted of three haplotypes, one of which was consistent with specimens from China, and two which were unique and have yet to be matched to Asian populations (Gariepy et al. 2014). Initially, none of the haplotypes in the Swiss samples were shared with the North American samples, indicating that the invasions were separate and distinct events (Gariepy et al. 2014). However, additional collections in 2013 in the Alsace region of France (Strasbourg and Schiltigheim) and in southern Switzerland (Lugano, Canton Ticino) revealed the presence of low levels of an additional haplotype in Europe, which is consistent with the dominant haplotype (H1) in North America (Gariepy and Haye, unpublished). Recently, the same haplotype was also found in Italy (Cesari et al. 2014), suggesting that additional introductions are ongoing and that the haplotype diversity is likely to change over time as new invasion events occur from different locations where the pest is either native or introduced. The occurrence of the H1 haplotype in Europe could represent the introduction of specimens from North America, or from the same Asian locality as those that established in North America. Haplotype analysis of the samples from Hungary, Greece and Italy may shed some light on the continued introduction and/or spread of *H. halys* within Europe. From a regulatory standpoint, continued genetic analysis of *H. halys* populations in newly invaded areas is important as it may help identify pathways of entry and movement or

spread of the pest from points of introduction. Further, the integration of molecular approaches that target nuclear genes (e.g. microsatellite markers) in the population genetic analysis of *H. halys* could provide additional information on the genetic structure of founding populations, their spread and admixture from multiple introductions (see Ciosi et al. 2008; Lawson Handley et al. 2011).

Economic and environmental impact worldwide

Halyomorpha halys causes injury to plants by inserting their feeding stylets into plant fruiting bodies, which are often the marketable portion of commercial crops. Feeding may result in scarring, faded sunken areas, deformed fruits, seeds or pods, white spongy areas on the surface of fruits and tissue damage internally visible as discoloured flesh (Leskey et al. 2009; Leskey et al. 2014; Kuhar et al. 2012; Nielsen and Hamilton 2009; Rice et al. 2014). In addition to reducing the quality of marketable produce, feeding injury can reduce fruit set and subsequent yield by aborting flower buds and young fruiting bodies. Feeding on nuts (such as hazelnuts) increases the incidence of empty shells (Hedstrom et al. 2014).

Although a wide variety of host plants have been recorded, for many, it remains unknown whether they are actually "true" hosts, supporting oviposition and nymphal development, or just plants *H. halys* had been observed to feed on (McPherson and McPherson 2000). The host range of *H. halys* includes many economically important crops such as larger tree fruits (e.g. *Malus domestica* (apple), *Pyrus communis* (pear), *P. persica* (peach), *Prunus armeniaca* (apricot), *P. avium* (cherry), *P. domestica* (plum), *Citrus* spp., *Morus* spp.), small fruits (e.g. *Rubus idaeus* (raspberry), *Corylus* spp. (hazelnuts); *Vitis vinifera* (grapevine)), vegetables (*Lycopersicon esculentum* (tomato), *Capsicum* spp. (peppers), *Helianthus annuus* (sunflower)), field crops: *Glycine max* (soybean), *Phaseolus vulgaris* (common bean), *Zea mays* (maize), and a number of forest and ornamental trees and shrubs (e.g. *Acer* spp., *Fraxinus excelsior*, *Paulownia tomentosa*, *Ailanthus altissima*, *Buddleia davidii*, *Cupressus* spp., *Hibiscus* spp., *Lonicera* spp., *Rosa rugosa*, *Salix* spp.) (Leskey et al. 2012, 2014; Lee et al. 2013; Northeastern IPM Center 2014c; Rice et al. 2014; Haye et al. 2014b). Host species are found in many different plant families, both Angiosperm and Gymnosperm. In Switzerland, more than 50 hosts plants have been recorded (Haye et al. 2014b), which include many exotic as well as native plants. *Halyomorpha halys* prefers to feed upon reproductive structures, particularly unripe berries, and may be present for only a short time on a given plant (Northeastern IPM Center 2014c). Nymphs and adults move readily between host plants according to whichever species is currently most suitable in the area. Adults are strong dispersers and can quickly colonize new hosts (Wiman et al. 2014). A few hosts, such as the princess tree (*Paulownia tomentosa*), tree of heaven (*Ailanthus altissima*), English holly (*Ilex aquifolium*) and peach (*Pyrus persica*), are attractive throughout the season and support complete development from egg to adult (Leskey et al. 2014).

In Asia, *H. halys* is an occasional outbreak pest of tree fruit, such as Asian pear (*Pyrus* spp.), persimmons (*Diospyros*), and tangerines (*Citrus* × *tangerina*) (Funayama 2002), and vegetables (Fukuoka et al. 2002). In North America, a far greater range of commercially important crops are impacted (Leskey et al. 2012). Where it is established in North American orchards, *H. halys* is the predominant stink bug species and, unlike native stink bug species, it is a season-long pest of tree fruit, especially peaches, nectarines, apples and Asian pears (Nielsen and Hamilton 2009; Leskey et al. 2012a, b; Rice et al. 2014). It is capable of causing high levels of economic damage, and some growers have experienced near-total crop losses (Leskey et al. 2012). In response, the use of broad spectrum-insecticides, especially pyrethroids, has increased greatly, which has disrupted existing integrated pest management (IPM) programmes and caused outbreaks of secondary pests such as mites, aphids and scale (Leskey et al. 2012). In some cases, the number of insecticide treatments has increased four-fold since the introduction of *H. halys* (Leskey et al. 2012). In wine grapes, there are indications that *H. halys* feeding in grape clusters during harvest may taint grape juice and affect wine quality (Mohekar et al. 2013; Tomasino et al. 2013a, b). *Halyomorpha halys* also causes significant injury to a wide range of vegetable crops, and losses in okra (*Abelmoschus esculentus*) exceeding 40 % due to *H. halys* damage have been reported. Apart from okra, heavy infestations have been observed in green beans (*Phaseolus vulgar*is), pepper (*Capiscum annuum*) and eggplant (*Solanum melongena*) (Kuhar et al. 2012).

Several field crop species are also colonized by *H. halys*, including sweet corn and soybeans (Kuhar et al. 2012). There is some evidence that stink bug populations may accumulate in wheat fields (*Triticum aestivum*), cotton (*Gossypium hirsutum*), hops (*Humulus lupulus*), sorghum (*Sorghum bicolor*) and sunflower (*Helianthus annuus*) (Rice et al. 2014). Ornamentals raised in nurseries are also fed upon and impacted by *H. halys*, in some cases via feeding directly through the bark. Members of the genera *Acer*, *Ailanthus*, *Catalpa*, *Cercis*, *Ilex*, *Magnolia*, *Malus*, *Mimosa*, *Morus*, *Paulownia*, *Platanus*, *Prunus* and *Syringa* appear to be highly attractive to *H. halys* (Northeastern IPM Center 2014c). Olives (*Olea europaea*), pistachios (*Pistacia vera*), almonds (*Prunus dulcis*), walnuts (*Juglans*

spp.) and *Citrus* have not yet experienced large populations of *H. halys* but are potentially at risk (Northeastern IPM Center 2014c).

In Zurich (the initial entry point of *H. halys* in Europe), homeowners have observed increased damage to backyard fruit and vegetable gardens over the years, and Wermelinger et al. (2008) reported heavy infestation of ornamental plants. A single report of economic crop damage has been recorded in Switzerland, where *H. halys* was found feeding on pepper crops grown in plastic tunnels in the Canton Aargau (Sauer 2012). To date, damage in commercial fruit orchards has only been observed in Italy, where *H. halys* was detected in 2012 (Maistrello et al. 2014). Damage occurred particularly in organic fruit orchards and on trees located close to man-made structures and residences, where the bugs are likely to overwinter. Currently, there are no control measures applied against the pest in Europe. However, with the current spread into new fruit-growing areas, the situation may change in the near future.

No direct, negative environmental impacts are known, e.g. competition with native wildlife or damage to wild plants. However, several types of indirect damage can be considered. In addition to the disruption of existing biocontrol programmes and integrated pest management practices, the risk of insecticide resistance increases with greater use of pesticides. A second indirect effect could be the disruption of the balance between indigenous Pentatomoidea and their associated egg parasitoids. In Europe, laboratory tests have shown that native egg parasitoids of Pentatomoidea in the family Scelionidae [*Trissolcus flavipes* (Thomson 1860); *Trissolcus semistriatus* (Nees 1834); *Trissolcus scutellaris* (Thomson 1861); *Telenomus chloropus* (Thomson 1861)] frequently attack the eggs of *H. halys*, but are unable to complete their development (Haye, unpublished data). Exposure of sentinel egg masses confirmed that indigenous egg parasitoids also attack *H. halys* in the field. These results suggest that although native egg parasitoids recognize *H. halys* as a potential host and display all behaviours associated with oviposition, they are unable to recognize that this host is unsuitable for development of their offspring. If the abundance of *H. halys* is growing in Europe as expected, this insect could have an indirect, negative impact on populations of native parasitoids by virtue of the fact that *H. halys* eggs act as a dead-end host. In the long run, this may result in increased population levels of native pentatomids due to lower natural enemy pressure. The potential for *H. halys* to act as an evolutionary trap for native parasitoids has also been suggested with *Telenomus podisi* (Hymenoptera: Scelionidae) in North America (Abram et al. 2009).

Social impact

In addition to its status as an agricultural pest, brown marmorated stink bug has become well-known as a nuisance pest, as adults often invade human-made structures—sometimes in very large numbers—to overwinter inside protected environments (Watanabe et al. 1994; Hoebeke and Carter 2003; Hamilton 2009; Inkley 2012). In addition to the general aversion of having insects in one's home, stink bugs also produce a distinctive, unpleasant odour, which results from the bug's defence chemicals. Inkley (2012) reported that in a single farm house in rural Maryland, 26,205 adults were collected between January and June 2011. Since 2004, the website of Rutgers University (http://njaes.rutgers.edu/stinkbug/) received nearly 10,000 homeowner reports of *H. halys*. The University of Pennsylvania datasheet on *H. halys* (Jacobs and Bernhard 2009) has been accessed more than 600,000 times between 2008 and 2012 (according to Jacobs, in Leskey et al. 2012a). To date, the situation in Europe has been less severe than in North America. Although established in Switzerland for at least 9 years, *H. halys* is primarily considered an urban and household pest. Between 2007 and 2010, homeowner reports of *H. halys* in Zurich increased exponentially (Mueller et al. 2011) and complaints from hotel owners about mass invasions of adults have been reported. It is very likely that these nuisance problems will occur wherever *H. halys* is introduced.

Halyomorpha halys does not attack humans, animals or goods. However, humans may come into contact with *H. halys* particularly in autumn and winter (September to March), after adults have moved into houses for overwintering. Exposure likely occurs through debris of dead insects in house dust or direct contact when removing live *H. halys* from their homes. Large aggregations of *H. halys* can block ventilation ducts and intakes, and particles may be aerosolized and distributed throughout the house. In addition, adults release chemical defence compounds, a mix of tridecane, 5-ethyl-2(5H)-furanone, and (E)-2-decenal, from their scent glands when threatened (Solomon et al. 2013). In the US, allergic reaction to *H. halys* is suspected after patients visiting allergy clinics described worsening of rhinitis and conjunctivitis after exposure to the insects (Mertz et al. 2012). Clinical tests confirmed that *H. halys* is a novel, clinically significant indoor allergen which could play an important role in allergic disease in the US in the near future. A similar scenario seems to be possible in European cities, where *H. halys* is an increasing nuisance problem, e.g. Basel and Zurich. Concern has also been raised in the dairy industry regarding whether or not *H. halys* secretions in silage fed to lactating cows are transferred into the milk. However, these concerns appear to be

unwarranted based on recent research by Baldwin et al. (2014) who demonstrated that the ensiling process and/or rumen metabolism prevent contamination of the milk by *H. halys* secretions.

Conclusions

It is likely that we will continue to see new worldwide invasions of *H. halys* in the coming years due to increased global trade and the aggregation and shelter-seeking behaviours of this pest. Recently, a new combination of semiochemicals that is attractive season-long to *H. halys* was identified and became commercially available, which provides researchers, scouts and growers with a new tool for detection and monitoring of the invasive pest (Weber et al. 2014). Pheromone traps near major transport hubs, which pose the highest invasion risks, may allow the early detection of new introductions. In addition, generating more genetic data on invasive *H. halys* populations can provide insight regarding the source areas and routes of invasion, as well as determining whether some populations are more successful than others in terms of establishment and spread in an invaded range. Dogs trained to sniff *H. halys* may help phytosanitary officials in detecting 'hidden' *H. halys* adults in cargo arriving at airports and harbours (Northeastern IPM Center 2014c). Although new technologies may allow the earlier detection of *H. halys*, our experience in Europe and North America has shown that by the time adults are detected in houses and in the environment, a significant population already exists in the invaded countries and its spread into other areas of the country by human transportation would be difficult to prevent. In addition, the risk that adults remain undetected, particularly when they arrive within large shipment containers, remains very high. As a pest of global concern, particularly in fruit- and vegetable-growing regions, it will nevertheless be important to continue to monitor the movement, spread and establishment of this pest as new, effective detection and control measures may become available in the near future. Understanding the factors favouring establishment and mass outbreaks, such as the one that occurred in the US in 2010, will be the key for effective control of *H. halys*. Further, the identification and monitoring of production areas that are at a high risk of infestation may allow early intervention and crop protection.

Author contribution statement

TH, TG, KH, JPR, JCS, XT, and ND wrote the manuscript. All authors edited the manuscript and approved the final version.

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