Invasive Species Compendium

Datasheets, maps, images, abstracts and full text on invasive species of the world

Halyomorpha halys

Pictures

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Picture	Title	Caption	Copyright
	Adult feeding	Brown marmorated stink bug (Halyomorpha halys); adult feeding on a cherry.	©CABI Switzerland - 2012
	Adults feeding	Adult brown marmorated stink bugs (Halyomorpha halys) feeding on cherries	©CABI Switzerland - 2012
	Egg mass	Egg mass of brown marmorated stink bug (Halyomorpha halys)	©CABI Switzerland - 2012
	Newly emerged nymphs	Brown marmorated stink bug (Halyomorpha halys); newly emerged nymphs around egg mass.	©CABI Switzerland - 2012
	Various nymphal instars	Various nymphal instars of the brown marmorated stink bug (Halyomorpha halys).	©CABI Switzerland - 2012
	Natural enemy	Natural enemy; parasitoid wasps (Trissolcus halyomorphae) parasitizing eggs of brown marmorated stink bug (Halyomorpha halys).	©CABI Switzerland - 2012

Identity

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Preferred Scientific Name

Halyomorpha halys (Stål)

Preferred Common Name

brown marmorated stink bug

Other Scientific Names

Halyomorpha brevis
Halyomorpha mista
Halyomorpha remota
Pentatoma halys Stål

International Common Names

English: yellow-brown marmorated stink bug, yellow-brown stink bug
French: punaise diabolique

Local Common Names

Germany: Marmorierte Baumwanze

English acronym

BMSB

EPPO code

HALYHA (Halyomorpha halys)

Summary of Invasiveness

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Following the accidental introduction and initial discovery of *H. halys* in Allentown, Pennsylvania, USA, this species has been detected in 41 states and the District of Columbia in the USA. Isolated populations also exist in Switzerland, France, Italy and Canada. Recent detections also have been reported in Germany and Liechtenstein. BMSB has become a major nuisance pest in the mid-Atlantic region and Pacific Northwest, USA, due to its overwintering behaviour of entering human-made structures in large numbers. BMSB also feeds on numerous tree fruits, vegetables, field crops, ornamental plants, and native vegetation in its native and invaded ranges. In the mid-Atlantic region, serious crop losses have been reported for apples, peaches, sweetcorn, peppers, tomatoes and row crops such as field maize and soyabeans since 2010. Crop damage has also been detected in other states recently including Oregon, Ohio, New York, North Carolina and Tennessee.

Taxonomic Tree

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Domain: Eukaryota
Kingdom: Metazoa
Phylum: Arthropoda
Subphylum: Uniramia
Class: Insecta
Order: Hemiptera
Suborder: Heteroptera
Family: Pentatomidae
Genus: Halyomorpha
Species: Halyomorpha halys

Notes on Taxonomy and Nomenclature

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Considerable confusion regarding the systematics of *Halyomorpha halys* has existed since its original description as *Pentatoma halys* by Stål in 1855 (Rider, 2005). Distant (1880, 1893, 1899) considered *H. halys* as a junior synonym of *H. picus* (Fabricius). Since then *H. halys* was determined to be distinct from *H. picus* and has been referred to as *H. mista, H. brevis*, and *H. remota* (Rider et al., 2002; Rider, 2005). Josifov and Kerzhner (1978) determined that only one species of *Halyomorpha, H. halys,* is present in eastern China, Japan and Korea and all references to *Halyomorpha* spp. from these locations are considered synonymous with *H. halys* (Rider et al., 2002). Common names in Asia include the yellow-brown stink bug and the brown marmorated stink bug, but the latter is the recognized common name in the USA or abbreviated as BMSB.

Description

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Although somewhat variable in size and coloration, adult specimens of *H. halys* range from 12 to 17 mm in length, and in humeral width of 7 to 10 mm. The common name brown marmorated stink bug is a reference to its generally brownish and marbled or mottled dorsal coloration, with dense punctation. Detailed redescriptions and diagnoses of adults are provided by Hoebeke and Carter (2003) and Wyniger and Kment (2010). Eggs are smooth and pale in colour, approximately 1.3 mm in diameter by 1.6 mm in length, and are laid in clusters of 20-30. The brightly coloured, black and reddish-orange first instars remain clustered about the egg mass after hatching and move away once moulting to second instars has occurred. There are five nymphal instars, which are described in Hoebeke and Carter (2003) with a key and illustrated with colour photos.

Distribution

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The brown marmorated stink bug, *H. halys*, is native to China, Japan, Korea and Taiwan (Hoebeke and Carter 2003; Lee et al., 2013a). The first USA populations were discovered in the mid-1990s in or near Allentown, Pennsylvania. In 2001, Karen Bernhardt with Penn State Cooperative Extension recognized that the insect invading homes was probably not native and sent a specimen to Richard Hoebeke at Cornell University who identified it as *H. halys* (Hoebeke and Carter, 2003). As of 2013, *H. halys* has been detected in 41 states and the District of Columbia in the USA though Colorado is still considered an unofficial find. In Delaware, Maryland, New Jersey, Pennsylvania, Virginia and West Virginia, *H. halys* has become a severe agricultural and nuisance pest, is considered an agricultural/nuisance pest in New York, North Carolina, Ohio and Tennessee, and a nuisance only pest in 10 additional states (Leskey and Hamilton, 2012).

Detections also have been reported in Hamilton, Ontario, Canada (Fogain and Graff, 2011), Switzerland (Wermelinger et al., 2008), Liechtenstein (Arnold, 2009), Germany (Heckmann, 2012), Italy (Pansa et al., 2013), France (Callot and Brua, 2013) and Hungary (Vétek et al., 2014).

Ecological niche modelling indicates that the area of invasion suitable for *H. halys* is quite extensive worldwide. *H. halys* could become established in northern Europe, north-eastern North America, portions of southern Australia and much of New Zealand, areas of South America (Uruguay, southern Brazil and northern Argentina) and parts of Africa (northern Angola and adjacent areas of Congo and Zambia) (Zhu et al., 2012).

Distribution Table

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Country	Distribution	Last Reported	Origin	First Reported	Invasive	References	Notes
ASIA							
China	Widespread		Native			CABI/EPPO, 2010; EPPO, 2013	
-Anhui	Present					EPPO, 2013; CABI/EPPO, 2010	
-Fujian	Present					EPPO, 2013; CABI/EPPO, 2010	
-Guangdong	Present					EPPO, 2013; CABI/EPPO, 2010	
-Guangxi	Present					EPPO, 2013; CABI/EPPO, 2010	
-Guizhou	Present					EPPO, 2013; CABI/EPPO, 2010	
-Hebei	Present					EPPO, 2013; CABI/EPPO, 2010	
-Heilongjiang	Present					EPPO, 2013; CABI/EPPO, 2010	
-Henan	Present					Song & Wang, 1993; CABI/EPPO, 2010; EPPO, 2013	
-Hubei	Present					EPPO, 2013; CABI/EPPO, 2010	
-Hunan	Present					EPPO, 2013; CABI/EPPO, 2010	
-Jiangsu	Present					EPPO, 2013; CABI/EPPO, 2010	
-Jiangxi	Present					EPPO, 2013; CABI/EPPO, 2010	
-Jilin	Present					EPPO, 2013; CABI/EPPO, 2010	
-Liaoning	Present					EPPO, 2013; CABI/EPPO, 2010	
-Nei Menggu	Present					EPPO, 2013; CABI/EPPO, 2010	
-Shaanxi	Present					EPPO, 2013; CABI/EPPO, 2010	
-Shandong	Present					EPPO, 2013	
-Shanxi	Present					EPPO, 2013; CABI/EPPO, 2010	
-Sichuan	Present					EPPO, 2013; CABI/EPPO, 2010	
-Tibet	Present					EPPO, 2013; CABI/EPPO, 2010	
-Yunnan	Present					EPPO, 2013; CABI/EPPO, 2010	
-Zhejiang	Present					EPPO, 2013; CABI/EPPO, 2010	
Japan	Present		Native			Goto et al., 2002; CABI/EPPO, 2010; EPPO, 2013	

Country	Distribution	Last Reported	Origin	First Reported	Invasive	References	Notes
-Honshu	Present		Native			CABI/EPPO, 2010; EPPO, 2013	
Korea, DPR	Present					EPPO, 2013	
Korea, Republic of	Present		Native			CABI/EPPO, 2010; EPPO, 2013	
Taiwan	Present		Native			CABI/EPPO, 2010; EPPO, 2013	
NORTH AMERICA							
Canada	Present		Introduced			CABI/EPPO, 2010; EPPO, 2013	
-Alberta	Absent, intercepted only					CABI/EPPO, 2010; EPPO, 2013	
-Ontario	Present					EPPO, 2013; Fogain & Graff, 2011	
-Quebec	Absent, intercepted only					Fogain & Graff, 2011	
USA	Widespread		Introduced			CABI/EPPO, 2010; EPPO, 2013	
-Alabama	Present, few occurrences					EPPO, 2013	
-Arizona	Present, few occurrences					EPPO, 2013	
-California	Present					EPPO, 2013; CABI/EPPO, 2010	
-Connecticut	Present					CABI/EPPO, 2010; EPPO, 2013	
-Delaware	Present		Introduced		Invasive	Oregon Department of Agriculture, 2005; CABI/EPPO, 2010; EPPO, 2013	
-District of Columbia	Present					EPPO, 2013	
-Florida	Absent, intercepted only					CABI/EPPO, 2010; EPPO, 2013	
-Georgia	Present, few occurrences					EPPO, 2013	
-Idaho	Present					CABI/EPPO, 2010; EPPO, 2013	
-Illinois	Present					CABI/EPPO, 2010; EPPO, 2013	
-Indiana	Present					CABI/EPPO, 2010; EPPO, 2013	
-Iowa	Present					CABI/EPPO, 2010; EPPO, 2013	
-Kansas	Present					Tindall et al., 2012; EPPO, 2013	
-Kentucky	Present					EPPO, 2013	
-Maine	Present					EPPO, 2013; CABI/EPPO, 2010	
-Maryland	Present		Introduced		Invasive	Oregon Department of Agriculture, 2005; CABI/EPPO, 2010; EPPO, 2013	
-Massachusetts	Present					EPPO, 2013; CABI/EPPO, 2010	
-Michigan	Restricted distribution					EPPO, 2013	
-Minnesota	Present					CABI/EPPO, 2010; EPPO, 2013	
-Mississippi	Present					CABI/EPPO, 2010; EPPO, 2013	
-Missouri	Present					EPPO, 2013	
-Montana	Present					CABI/EPPO, 2010; EPPO, 2013	
-Nebraska	Present, few occurrences					EPPO, 2013	
-Nevada	Present					CABI/EPPO, 2010; EPPO, 2013	
-New Hampshire	Present					EPPO, 2013	
-New Jersey	Present		Introduced		Invasive	Oregon Department of Agriculture, 2005; CABI/EPPO, 2010; EPPO, 2013	
-New Mexico	Present					EPPO, 2013	
-New York	Present					EPPO, 2013; CABI/EPPO, 2010	

Country	Distribution	Last Reported	Origin	First Reported	Invasive	References	Notes
-North Carolina	Present					EPPO, 2013	
-Ohio	Present					EPPO, 2013; CABI/EPPO, 2010	
-Oregon	Present, few occurrences		Introduced		Invasive	Oregon Department of Agriculture, 2005; CABI/EPPO, 2010; EPPO, 2013	
-Pennsylvania	Present, few occurrences		Introduced	mid 1990s		Hoebeke & Carter, 2003; Oregon Department of Agriculture, 2005; CABI/EPPO, 2010; EPPO, 2013	
-Rhode Island	Present					EPPO, 2013; CABI/EPPO, 2010	
-South Carolina	Present		Introduced		Invasive	Oregon Department of Agriculture, 2005; CABI/EPPO, 2010; EPPO, 2013	
-South Dakota	Present					CABI/EPPO, 2010; EPPO, 2013	
-Tennessee	Present					CABI/EPPO, 2010; EPPO, 2013	
-Texas	Present					EPPO, 2013	
-Utah	Present					CABI/EPPO, 2010; EPPO, 2013	
-Vermont	Present					EPPO, 2013	
-Virginia	Present					EPPO, 2013; CABI/EPPO, 2010	
-Washington	Present					CABI/EPPO, 2010; EPPO, 2013	
-West Virginia	Present		Introduced		Invasive	Oregon Department of Agriculture, 2005; CABI/EPPO, 2010; EPPO, 2013	
-Wisconsin	Present					CABI/EPPO, 2010; EPPO, 2013	
-Wyoming	Present					CABI/EPPO, 2010; EPPO, 2013	
EUROPE							
France	Present		Introduced			Callot & Brua, 2013; EPPO, 2013	
Germany	Restricted distribution					Heckmann, 2012; EPPO, 2013	Single specimen found.
Greece	Present					Milonas & Partsinevelos, 2014	
Hungary	Present					Vétek et al., 2014	
Italy	Present, few occurrences		Introduced			EPPO, 2013; Pansa et al., 2013	Emilia-Romagna, Lombardy, Piedmont
Liechtenstein	Present					Arnold, 2009; EPPO, 2013	Single specimen found.
Switzerland	Widespread		Introduced			CABI/EPPO, 2010; Wyniger & Kment, 2010; Haye & Wyniger, 2013; EPPO, 2013	
OCEANIA							
Guam	Present					Moore, 2014	
New Zealand	Absent, intercepted only					EPPO, 2013	

History of Introduction and Spread

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H. halys is native to China, Japan, Korea and Taiwan (Hoebeke and Carter 2003; Lee et al., 2013a). The first USA populations were discovered in the mid-1990s in or near Allentown, Pennsylvania. In 2001, Karen Bernhard with Penn State Cooperative Extension recognized that the insect invading homes was probably not native and sent a specimen to Richard Hoebeke at Cornell University who identified it as *H. halys* (Hoebeke and Carter, 2003). As of 2013, *H. halys* has been detected in 41 states and the District of Columbia in the USA, though Colorado is still considered an unofficial find. *H. halys* has become a severe agricultural and nuisance pest in Delaware, Maryland, New Jersey, Pennsylvania, Virginia and West Virginia, is considered an agricultural/nuisance pest in New York, North Carolina, Ohio and Tennessee, and a nuisance only pest in 10 additional states (Leskey and Hamilton 2012). Genetic studies of mitochondrial cytochrome c oxidase (CO) subunit II gene, COI and 12S ribosomal RNA gene have revealed that *H. halys* populations in the USA originated from a single introduction from the region of Beijing, China (Xu et al., 2013).

In Canada, interceptions of *H. halys* at various ports of entry across the country began in 1993 from countries including China, Japan, Korea and the USA, with reports of homeowner finds beginning in the Province of Ontario as of 2010 (Fogain and Graff, 2011) and established breeding populations in the field confirmed as of July 2012 (Fraser and Gariepy, unpublished). On the basis of molecular data and interception records it appears likely that *H. halys* in Canada is derived from the movement of established US populations (Gariepy et al., 2013).

In Europe BMSB was first officially reported from the canton of Zurich in Switzerland in 2007 (Wermelinger et al., 2008). However, later investigations showed that it was already present in Zurich in 2004 (Gariepy et al., 2013). In the same year, a single individual was found near Balzers in Liechtenstein, which probably originated from nearby founder populations in Zurich (Arnold, 2009). In Switzerland three haplotypes were found, which were not identical with haploytypes found in North America. The dominant haplotype in Switzerland was consistent with Asian samples collected in the Hebei and Beijing provinces; however, it was not the dominant haplotype in these regions. The remaining two haplotypes were unique to Switzerland and their origin in Asia remains unknown (Gariepy et al., 2013). Outside Switzerland, a single individual was found near Konstanz in southern Germany (Heckmann, 2012) and most recently breeding populations established in the Alsace region of France (Callot and Brua, 2013) and northern Italy (EPPO, 2013; Pansa et al., 2013).

Ecological niche modelling indicates that the area of invasion suitable for *H. halys* is quite extensive worldwide. *H. halys* could become established in northern Europe, north-eastern North America, portions of southern Australia and much of New Zealand, areas of South America (Uruguay, southern Brazil and northern Argentina) and parts of Africa (northern Angola and adjacent areas of Congo and Zambia) (Zhu et al., 2012).

Introductions

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Introduced to	Introduced from	Year	Reason	Introduced by	Established in wild through		References	Notes
					Natural reproduction	Continuous restocking		
Canada	North America	2010	Hitchhiker (pathway cause)		Yes		Fogain & Graff, 2011; Gariepy et al., 2013	Accidental introduction.
France		2012	Hitchhiker (pathway cause)		Yes		Callot & Brua, 2013	Accidental introduction.
Germany		2011	Hitchhiker (pathway cause)		No		Heckmann, 2012	Accidental introduction.
Italy		2012-2013	Hitchhiker (pathway cause)				Haye & Wyniger, 2013	Accidental introduction.
Liechtenstein	Switzerland	2007	Hitchhiker (pathway cause)		No		Arnold, 2009; Gariepy et al., 2013	Accidental introduction.
Switzerland		2007	Hitchhiker (pathway cause)		Yes		Gariepy et al., 2013; Wermelinger et al., 2008	Accidental introduction.
USA	China	2001	Hitchhiker (pathway cause)				Hoebeke & Carter, 2003; Xu et al., 2013	Specimens collected in 1998. Accidental introduction.

Risk of Introduction

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Most interceptions of *Halyomorpha* halys during quarantine inspections or surveys have been adults, and the entry pathways for eggs and nymphs are considered to be much lower risk (Holtz and Kamminga, 2010; Duthie et al., 2012; Gariepy et al., 2013). This is because adults have more interaction with inanimate objects, making use of various structures and materials for their winter aggregations. Immature stages are not present in aggregations and are more closely associated with host plant material. It is possible that egg masses and nymphs could be transported on fresh fruits, vegetables and nursery stock. However, eggs are sensitive to temperature and may not survive well under the cool temperatures that would be typical in produce shipments. Moreover, eggs typically hatch within a few days, and transport could potentially disrupt first-instar nymphs from feeding on the egg mass after emergence, causing increased mortality. Risk for introduction is slightly higher for second- through to fifth-instar nymphs on fresh host material, but the likelihood of survival and establishment is low on produce destined for market. Transport of nursery stock is a potential mechanism for the introduction of nymphs, but strict regulations governing transport and treatment of nursery plants greatly reduce this possibility for trans-oceanic, inter-state or long distance introductions (Duthie et al., 2012).

Although interceptions of individual *H. halys* are more common, aggregations clearly represent the biggest risk for establishment with multiple insects of both sexes represented. Transported aggregations by people relocating from the eastern to the western USA have been the source of potential introductions into the states of California, Washington and Idaho. Introduction pathways involving adults are most likely to occur with non-plant material and are associated with adults exhibiting aggregation behaviour. These adults are sexually immature, so the introduction of isolated individuals may represent relatively little risk compared to aggregations. In exporting countries that can be regarded as major source populations of *H. halys* including China, Korea, Japan and the USA, aggregations begin forming in August and September (Hoebeke and Carter, 2003; Hamilton, 2009). Interceptions of *H. halys* tend to increase during these times in quarantine inspections, and may correlate with transport of goods stored outside during these periods in the source country (Duthie et al., 2012). Individuals are more likely to be incidentally transported by personal items such as luggage, and aggregations are more likely to occur in larger cargos. Large items that have been left in place for extended periods of time while winter aggregations of *H. halys* are forming have the highest risk for harbouring aggregations. Ocean-going cargo containers or packing crates appear to be one of the most common pathways of introduction, and may have been responsible for the initial introduction of *H. halys* into the USA in the mid 1990s (Hoebeke and Carter, 2003; Hamilton, 2009). However, *H. halys* has also been intercepted from ship decks and other cargo including transported machinery, furniture and cars (Holtz and Kamminga, 2010; Duthie et al., 2012).

The risk of introduction of adults on produce or other plant material is considered low or moderate, but may have been the mechanism of introduction of *H. halys* into Switzerland (Wermelinger et al., 2008). However, transport packaging for plant materials, particularly if stored outside, are always a potential source of introduction. Once established, continental spread is likely to follow paths of human activity, including highways and railways. Cars, tractor-trailers, recreational vehicles and moving trucks are all known pathways of introduction over land. Deliberate introductions are unlikely as *H. halys* is regarded as a pest under every circumstance and has no known unintended uses.

Habitat List

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Category	Habitat	Presence	Status
Terrestrial-managed	Buildings	Principal habitat	Harmful (pest or invasive)
	Buildings	Principal habitat	Productive/non-natural
	Cultivated / agricultural land	Principal habitat	Harmful (pest or invasive)
	Cultivated / agricultural land	Principal habitat	Productive/non-natural
	Disturbed areas	Secondary/tolerated habitat	Productive/non-natural
	Managed forests, plantations and orchards	Principal habitat	Harmful (pest or invasive)
	Managed forests, plantations and orchards	Principal habitat	Productive/non-natural
	Rail / roadsides	Secondary/tolerated habitat	Productive/non-natural
	Urban / peri-urban areas	Principal habitat	Harmful (pest or invasive)
	Urban / peri-urban areas	Principal habitat	Productive/non-natural
Terrestrial-natural/semi-natural	Natural forests	Present, no further details	Natural

Hosts/Species Affected

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H. halys has over 100 reported host plants. It is widely considered to be an arboreal species and can frequently be found among woodlots. Such host plants are important for development as well as supporting populations, particularly during the initial spread into a region. In Canada for example, established populations of *H. halys* have only been recorded in the Province of Ontario. Homeowner finds have previously been identified in the City of Hamilton (Fogain and Graff, 2011) as well as the Greater Toronto Area, the City of Windsor, Newboro and Cedar Springs (Ontario) (Fraser and Gariepy, unpublished data). However, preliminary surveys confirmed an established breeding population in Hamilton, Ontario, as of July 2012 (Fraser and Gariepy, unpublished data). At present, these populations are localized along the top of the Niagara escarpment in urban/natural habitats within Hamilton, and have not yet been recorded in agricultural crops. Reproductive hosts from which *H. halys* eggs, nymphs and adults have been collected on in Ontario include: ash, buckthorn, catalpa, choke cherry, crabapple, dogwood, high bush cranberry, honeysuckle, lilac, linden, Manitoba maple, mulberry, rose, tree of heaven, walnut and wild grape (Gariepy et al., unpublished data).

The list of host plants in Europe contains 51 species in 32 families, including many exotic and native plants. High densities of nymphs and adults were observed on *Catalpa bignonioides*, *Sorbus aucuparia*, *Cornus sanguinea*, *Fraxinus excelsior* and *Parthenocissus quinquefolia* (Haye et al., unpublished data).

Multiple host plants seem to be important for development and survival of *H. halys*. This species can complete its development entirely on paulownia (*Paulownia tomentosa*), tree of heaven (*Ailanthus altissima*), English holly and peach. More details on host plants and host plant utilization can be found at http://www.stopbmsb.org/where-is-bmsb/host-plants/ as well as http://www.halyomorphahalys.com, Panizzi (1997), Nielsen and Hamilton (2009b) and Lee et al. (2013a).

In Asia, *H. halys* is an occasional outbreak pest of tree fruit (Funayama, 2002). Damage to apples and pears in the USA was first detected in Allentown, Pennsylvania, and Pittstown, New Jersey (Nielsen and Hamilton, 2009a). In orchards where *H. halys* is established in the USA, it quickly becomes the predominant stink bug species and, unlike native stink bugs, is a season-long pest of tree fruit (Nielsen and Hamilton, 2009a; Leskey et al., 2012a). In particular, peaches, nectarines, apples and Asian pears are heavily attacked. Feeding injury causes depressed or sunken areas that may become cat-faced as fruit develops. Late season injury causes corky spots on the fruit. Feeding may also cause fruiting structures to abort prematurely. Similar damage occurs in fruiting vegetables such as tomatoes and peppers, although frequently later in the season. Feeding can cause failure of seeds to develop in crops such as maize or soyabean. There is frequently a distinct edge effect in crop plots as *H. halys* an aggregated dispersion and moves between crops or woodlots. In soyabeans, this can result in a 'stay green' effect where pods fail to senesce at the edges due to *H. halys* feeding injury.

Host Plants/Plants Affected

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Plant name	Context
Abelia grandiflora (Glossy abelia)	Other
Abelmoschus esculentus (okra)	Other
Acer campestre (field maple)	Other
Acer circinatum	Other
Acer japonicum (full-moon maple)	Wild host
Acer macrophyllum (broadleaf maple)	Other
Acer negundo (box elder)	Other
Acer palmatum (Japanese maple)	Other
Acer pensylvanicum (striped maple)	Other
Acer platanoides (Norway maple)	Other
Acer rubrum (red maple)	Other
Acer saccharinum (soft maple)	Other
Acer saccharum (sugar maple)	Wild host
Acer tegmentosum	Other
Aesculus glabra (Texas buckeye)	Other
Ailanthus altissima (tree-of-heaven)	Other
Amaranthus caudatus (Love-lies-bleeding)	Other
Amelanchier laevis (Allegheny serviceberry)	Other
Antirrhinum majus (snapdragon)	Other
Arctium minus (common burdock)	Other
Armoracia rusticana (horseradish)	Other
Asimina triloba (Pawpaw-apple)	Wild host
Basella alba (Malabar spinach)	Other
Betula nigra (river birch)	Other
Betula papyrifera (paper birch)	Other
Betula pendula (common silver birch)	Other
Brassica oleracea (cabbages, cauliflowers)	Other
Capsicum annuum (bell pepper)	Other
Caragana arborescens (Siberian pea-tree)	Other
Carpinus betulus (hornbeam)	Other
Carya illinoinensis (pecan)	Other
Carya ovata (shagbark hickory)	Other
Catalpa	Other
Celastrus orbiculatus (Asiatic bittersweet)	Other
Celosia	Other
Celosia argentea (celosia)	Other
Celtis (nettle tree)	Other
Celtis occidentalis (hackberry)	Other
Cephalanthus occidentalis (common buttonbush)	Other
Cercidiphyllum japonicum (katsura)	Other
Cercis canadensis (eastern redbud)	Wild host
Chenopodium (Goosefoot)	Wild host
Citrus	Other
Citrus junos (yuzu)	Main

Plant name	Context
Cladrastis kentukea (American yellowwood)	Other
Cornus (Dogwood)	Other
Cornus florida (Flowering dogwood)	Wild host
Cornus officinalis	Other
Cornus racemosa (gray dogwood)	Other
Cornus sericea (redosier dogwood)	Other
Corylus	Other
Crataegus laevigata	Other
Crataegus monogyna (hawthorn)	Wild host
Crataegus viridis	Other
Cucumis sativus (cucumber)	Other
Cucurbita pepo (ornamental gourd)	Other
Diospyros kaki (persimmon)	Main
Elaeagnus angustifolia (Russian olive)	Wild host
Elaeagnus umbellata (autumn olive)	Wild host
Ficus	Other
Ficus carica (fig)	Other
Forsythia suspensa	Other
Fraxinus americana (white ash)	Wild host
Fraxinus pennsylvanica (downy ash)	Wild host
Ginkgo biloba (kew tree)	Other
Gleditsia triacanthos (honey locust)	Other
Glycine max (soyabean)	Main
Hamamelis virginiana (Virginian witch-hazel)	Wild host
Helianthus (sunflower)	Other
Hibiscus rosa-sinensis (China-rose)	Other
Humulus lupulus (hop)	Other
Ilex aquifolium (holly)	Other
Juglans nigra (black walnut)	Wild host
Juniperus virginiana (eastern redcedar)	Other
Koelreuteria paniculata (golden rain tree)	Other
Lagerstroemia indica (Indian crape myrtle)	Other
Larix kaempferi (Japanese larch)	Other
Ligustrum sinense (Chinese privet)	Wild host
Liquidambar styraciflua (Sweet gum)	Other
Liriodendron tulipifera (tuliptree)	Wild host
Lonicera (honeysuckles)	Wild host
Lonicera tatarica (Tatarian honeysuckle)	Wild host
Lythrum salicaria (purple loosestrife)	Wild host
Magnolia grandiflora (Southern magnolia)	Other
Mahonia aquifolium (Oregongrape)	Wild host
Malus baccata (siberian crab apple)	Other
Malus domestica (apple)	Main
Malus zumi	Other
Mimosa (sensitive plants)	Other
Morus (mulberrytree)	Other

Plant name	Context
Morus alba (mora)	Other
Paulownia tomentosa (paulownia)	Wild host
Phalaenopsis	Other
Phaseolus (beans)	Other
Phaseolus lunatus (lima bean)	Other
Phaseolus vulgaris (common bean)	Other
Pisum sativum (pea)	Main
Prunus avium (sweet cherry)	Main
Prunus cerasifera (myrobalan plum)	Other
Prunus laurocerasus (cherry laurel)	Other
Prunus mume (Japanese apricot tree)	Other
Prunus persica (peach)	Main
Prunus serotina (black cherry)	Wild host
Prunus serrulata (Japanese flowering cherry)	Other
Prunus subhirtella (weeping Japanese cherry)	Other
Pyracantha (Firethorn)	Other
Pyrus (pears)	Other
Pyrus calleryana (bradford pear)	Other
Pyrus communis (European pear)	Other
Pyrus pyrifolia (Oriental pear tree)	Other
Quercus alba (white oak)	Other
Quercus coccinea (scarlet oak)	Other
Quercus robur (common oak)	Other
Quercus rubra (northern red oak)	Other
Rhamnus cathartica (buckthorn)	Wild host
Robinia pseudoacacia (black locust)	Wild host
Rosa canina (Dog rose)	Other
Rosa multiflora (Multiflora rose)	Wild host
Rosa rugosa (rugosa rose)	Other
Rubus (blackberry, raspberry)	Other
Rubus idaeus (raspberry)	Other
Rubus phoenicolasius	Other
Salix (willows)	Wild host
Sassafras albidum (common sassafras)	Wild host
Solanum lycopersicum (tomato)	Other
Solanum melongena (aubergine)	Other
Solanum nigrum (black nightshade)	Other
Sorbus americana (American mountainash)	Wild host
Sorbus aria (whitebeam)	Other
Spiraea	Other
Styrax japonica	Other
Syringa pekinensis	Other
Tilia americana (basswood)	Other
Tilia cordata (small-leaf lime)	Other
Tilia tomentosa (silver lime)	Other
Tsuga canadensis (eastern hemlock)	Wild host

Plant name	Context
Ulmus americana (American elm)	Other
Ulmus parvifolia (lacebark elm)	Other
Ulmus procera (english elm)	Other
Vaccinium corymbosum (blueberry)	Other
Viburnum	Other
Vitis riparia (riverbank grape (USA))	Wild host
Vitis vinifera (grapevine)	Other
Zea mays (maize)	Other
Zea mays subsp. mays (sweetcorn)	Other
Ziziphus sativa	Main

Growth Stages

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Flowering stage, Fruiting stage, Vegetative growing stage

Symptoms

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Adults and nymphs cause feeding damage. On tree fruits, feeding injury causes depressed or sunken areas that may become 'cat-faced' as the fruit develops. Late season injury causes corky spots on the fruit. Feeding may also cause fruiting structures to abort prematurely. Similar damage occurs in fruiting vegetables such as tomatoes and peppers, although frequently later in the season. Feeding can cause failure of seeds to develop in crops such as maize or soyabean. There is frequently a distinct edge effect in crop plots as *H. halys* has an aggregated dispersion and moves between crops or woodlots. In soyabeans, this can result in a 'stay green' effect where pods fail to senesce at the edges due to *H. halys* feeding injury.

Symptoms List

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Sign	Life Stages	Type
Fruit		
abnormal shape		
discoloration		
external feeding		
lesions: scab or pitting		
Leaves		
external feeding		
necrotic areas		
Whole plant		
external feeding		

Biology and Ecology

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H. halys is a multivoltine species with up to five generations reported in southern China (Hoffman, 1931). In the mid-Atlantic region of the USA, it has one or two generations per year (Nielsen et al., 2008). In Switzerland *H. halys* has one generation per year (Haye et al., 2014). Non-reproductive adults overwinter and gradually emerge from overwintering sites beginning around March or April. There are few host plant resources available at this time and individuals are difficult to find in the field. Termination of diapause is probably driven by photoperiod (>14.75 h light per d (Yanagi and Hagihara 1980)); however, there is an interaction between photoperiod and temperature, and when the daylength threshold of *H. halys* has been reached, sexual development begins. This results in a delay between the initial adult dispersal from diapause and reproductive maturity, as females need an additional 148 DD prior to first oviposition (Nielsen et al., 2008). It is during this time period when the first movement to crops, specifically peaches, occurs. Hardwood trees and shrubs are also important early season hosts. Adults mate, with females being polyandrous, and eggs are oviposited in clusters on the underside of leaves in groups of 28 (Kawada and Kitamura, 1992). *H. halys* has five nymphal instars. Development from egg to adult takes 538 DD with a minimum temperature threshold of 14.14°C and a maximum temperature threshold of 35°C (Nielsen et al., 2008). At 30°C, this takes 32-35 days. *H. halys* can complete development on peaches, but more than 100 host plants including tree fruits, small fruits, vegetables, ornamentals and field crops (Leskey et al., 2012a) have been recorded.

Overwintering Ecology

H. halys is well-known for being a nuisance problem, as massive numbers of adults often invade human-made structures to overwinter inside protected environments (Inkley, 2012). This behaviour is generally uncommon among Pentatomidae and has been estimated to give *H. halys* an increased overwintering survivorship relative to other species such as *Nezara viridula* (Yanagi and Hagihara, 1980). Similar to other pentatomid species, *H. halys* will also overwinter in natural landscapes, at least in the mid-Atlantic region (Lee and Leskey, unpublished data). Overwintering *H. halys* were recovered from dry crevices in dead, standing trees with thick bark, particularly oak (*Quercus* spp.) and locust (*Robinia* spp.). For those trees with overwintering *H. halys* present, ~6 adults/tree were recovered when 20% of the total above-ground tree area was sampled.

Associations

H. halys is a vector of Paulownia witches' broom (Yuan, 1984).

Climate

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Climate	Status	Description	Remark
C - Temperate/Mesothermal climate	Preferred	Average temp. of coldest month > 0°C and < 18°C, mean warmest month > 10°C	
Cf - Warm temperate climate, wet all year	Preferred	Warm average temp. > 10°C, Cold average temp. > 0°C, wet all year	
Cs - Warm temperate climate with dry summer	Tolerated	Warm average temp. > 10°C, Cold average temp. > 0°C, dry summers	
Cw - Warm temperate climate with dry winter	Tolerated	Warm temperate climate with dry winter (Warm average temp. > 10°C, Cold average temp. > 0°C, dry winters)	

Natural Enemies

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Natural enemy	Type	Life stages	Specificity	References	Biological control in	Biological control on
Anastatus	Parasite	Eggs	not specific	Hou et al., 2009		
Anastatus mirabilis	Parasite	Eggs				
Anastatus pearsalli	Parasite	Eggs				
Anastatus reduvii	Parasite	Eggs				
Arilus cristatus	Predator	Adults/Nymphs				
Arma chinensis	Predator		not specific			
Astata bicolor	Predator	Nymphs				
Astata unicolor	Predator	Adults/Nymphs				
Astochia virgatipes	Predator					
Bicyrtes quadrifasciatus	Predator	Nymphs				
Bogosia	Parasite	Adults		Kawada & Kitamura, 1992		
Geocoris	Predator	Eggs/Nymphs				
Gryon japonicum	Parasite	Eggs	not specific			
Gryon obesum	Parasite					
Harmonia axyridis	Predator	Eggs				
Isyndus obscurus	Predator			Kawada & Kitamura, 1992; Oda et al., 1982		
Misumenops tricuspidatus	Predator		not specific	Qiu, 2007		
Ooencyrtus	Parasite	Eggs	not specific			
Ophiocordyceps nutans	Pathogen			Sasaki et al., 2012		
Orius	Predator	Eggs	not specific			
Telenomus podisi	Parasite	Eggs				

Natural enemy	Type	Life stages	Specificity	References	Biological control in	Biological control on
Trichopoda pennipes	Parasite	Adults/Nymphs				
Trissolcus brochymenae	Parasite	Eggs				
Trissolcus edessae	Parasite	Eggs				
Trissolcus euschisti	Parasite	Eggs				
Trissolcus flavipes	Parasite			Qiu et al., 2007; Qiu, 2007; Zhang et al., 1993		
Trissolcus itoi	Parasite		not specific	Arakawa & Namura, 2002		
Trissolcus japonicus	Parasite		to species	Kawada & Kitamura, 1992; Li & Liu, 2004; Talamas et al., 2013; Yang et al., 2009		
Trissolcus mitsukurii	Parasite		not specific	Arakawa & Namura, 2002		
Trissolcus thyantae	Parasite	Eggs				
Trissolcus utahensis	Parasite	Eggs				

Notes on Natural Enemies

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Among hymenopterous natural enemies, a number of egg parasitoids have been recorded in Asia including the generalist parasitoids *Anastatus* spp. (Eupelmidae) (Kawada and Kitamura, 1992; Arakawa and Namura, 2002; Hou et al., 2009) and *Ooencyrtus* spp. (Encyrtidae) (Kawada and Kitamura, 1992; Arakawa and Namura, 2002; Qiu 2007). A pteromalid, *Acroclisoides* sp., has been reported (Qiu, 2007) but it is probably a hyperparasitoid, as it has been documented from other pentatomids. More common and more host-specific are telenomines (Platygastridae) in the genus *Trissolcus,* including *T. japonicus* (= *T. halyomorphae*) (Kawada and Kitamura, 1992; Li and Liu, 2004; Talamas et al., 2013; Yang et al., 2009), *T. flavipes* (Zhang et al., 1993; Qiu, 2007; Qiu et al., 2007)*, T. mitsukurii* and *T. itoi* (Arakawa and Namura, 2002). The platygastrids *Gryon japonicum* (Noda, 1990) and *G. obesum* (Buffington, unpublished data) also have been recorded. A tachinid fly, *Bogosia* sp., is known to attack adult *H. halys* (Kawada and Kitamura 1992). No nymphal parasitoids are known. The highest levels of parasitism, ranging from 63 to 85%, have been attributed to *Trissolcus* (Zhang et al., 1993; Qiu, 2007; Yang et al., 2009) and to *Anastatus* (Hou et al., 2009). Predatory arthropods reported in Asia include the pentatomid *Arma chinensis,* the asilid *Astochia virgatipes,* an anthocorid, *Orius sp.,* and the thomisid spiders *Misumena tricuspidata* [*Misumenops tricuspidatus*] (Qiu, 2007) and *Isyndus obscurus* (Oda et al., 1982; Kawada and Kitamura, 1992). Several other reports mention the entomopathogen *Ophiocordyceps nutans* (Sasaki et al., 2012) and the intestinal virus of *Plautia stali* (Nakashima et al., 1998). In North America, commonly found predators of eggs, nymphs and adults have also been reported in the Anthocoridae, Geocoridae, Reduviidae, Asilidae, Chrysopidae and Melyridae. In crop and ornamental plots surveyed in Maryland, *Ooencyrtus* sp. and *Telenomus podisi* were among the most commonly found species emerging from *H. halys* eggs in soyabean, maize and vegetable plots, while *Anastatus reduvii* and *A. pearsalli* were commonly found on ornamental plants, but were absent or rare in maize and soyabean plots (Hooks, unpublished data). In apple orchards surveyed in Pennsylvania, *T. podisi* was the most common species found to attack *H. halys* egg masses (Biddinger, unpublished data). In Delaware, successful parasitism by *Trissolcus brochymenae, T. euschisti, T. edessae* and *Anastatus spp*. of sentinel *H. halys* egg masses on *Paulownia* was typically low (<1-3%). Parasitism of adult *H. halys* by tachinid flies in Pennsylvania and Delaware averaged 1-5% (but with up to 20% in some locations) and a negligible emergence rate (Biddinger, unpublished data; Hoelmer, unpublished data). In North America, commonly found predators of eggs, nymphs and adults have also been reported in the Anthocoridae, Geocoridae, Reduviidae, Asilidae, Chrysopidae and Melyridae.

The impact of natural enemies on *H. halys* populations in Europe is unknown, but laboratory tests with common European pentatomid egg parasitoids, e.g. *Trissolcus semistriatus*, *Trissolcus flavipes* and *Telenomus chloropus* suggest that *H. halys* is not a suitable host (Haye and Gariepy, unpublished data).

Means of Movement and Dispersal

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H. halys has a strong capacity to disperse at landscape levels throughout most periods of its lifetime. In laboratory studies where *H. halys* adults were tethered to a flight mill, wild populations flew on average 2 km over a day (Wiman et al., 2013). Where free flight of *H. halys* was directly observed and tracked in field studies, the mean flight speed was 3 m/s along a straight line from take-off to landing (Lee et al., 2013b). Adult flight activity also occurs at night as adults seek out mates or alternate food resources. Black light traps are good monitoring tools for landscape-level movement of *H. halys*. Because a lot of activity occurs at night, adults that are dispersing for new resources (food or mates) may be caught in the trap. This method has demonstrated a 75% annual increase in *H. halys'* population size in New Jersey from 2004 to 2011. Although activity changes throughout the year, a large peak in flight activity occurs at 685 DD14.17 (Nielsen et al., 2013). Nymphs also actively disperse to host plants. For nymphs, although the first instars tend to remain aggregated around the egg mass, later instars show a strong capacity to disperse in the laboratory and field. In the laboratory, the older instars were capable of climbing 6-8 m in 15 min. In the field, the third and fifth instars walked on average 1.3 and 2.6 m over 30 minutes on a grassy surface (Lee and Leskey, unpublished data).

Pathway Causes

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Cause	Notes	Long Distance	Local	References
Agriculture	Deliberate dispersal during search for host plant resources. Moves between agricultural crops throug	Yes	Yes	Nielsen et al., 2013; Wiman et al., 2013b
Disturbance	Association with distrurbed habitat and population hot spots.		Yes	
Forestry	Deliberate dispersal during search for overwintering sites.	Yes	Yes	
Hitchhiker	Frequently occurs due to H. halys seeking sheltered overwintering sites.	Yes	Yes	Hoebeke & Carter, 2003
Self-propelled	Deliberate dispersal to seek host plants or overwintering sites.	Yes	Yes	Wiman et al., 2013b

Pathway Vectors

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Vector	Notes	Long Distance	Local	References
Aircraft	Accidentally transported by aircraft.	Yes	Yes	
Bulk freight/cargo	Frequently can occur accidentally due to H. halys seeking sheltered overwintering sites.	Yes	Yes	Hoebeke & Carter, 2003
Clothing/footwear and possessions	Wintering adults are often found in clothing and other possessions that may be transported.	Yes	Yes	
Containers and packaging (non-wood)	Frequently can occur accidentally due to H. halys seeking sheltered overwintering sites.	Yes	Yes	
Land vehicles	Adults found in vehicles, especially when seeking shelter in the autumn.	Yes	Yes	
Luggage (incl. sailors' sea chests)	Overwintering adults are sometimes found in clothing or other possessions in luggage and transported	Yes	Yes	

Plant Trade

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Plant parts liable to carry the pest in trade/transport	Pest stages	Borne internally	Borne externally	Visibility of pest or symptoms
Bark	adults	No		Pest or symptoms usually visible to the naked eye
Leaves	adults; eggs; nymphs	No	Yes	Pest or symptoms usually visible to the naked eye

Plant parts not known to carry the pest in trade/transport
Bulbs, Tubers, Corms, Rhizomes
Flowers, Inflorescences, Cones, Calyx
Fruits (inc. pods)
Growing medium accompanying plants
Roots
Seedlings, Micropropagated plants
Stems (above ground), Shoots, Trunks, Branches
True seeds (inc. grain)
Wood

Wood Packaging

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Wood Packaging liable to carry the pest in trade/transport	Timber type	Used as packing
Solid wood packing material with bark	cardboard, plywood boards	Yes

Impact Summary

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Category	Impact
Cultural/amenity	Negative
Economic/livelihood	Negative
Environment (generally)	Negative
Human health	Negative

Impact

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In 2008-2009, increasing *H. halys* populations in the mid-Atlantic region of the USA caused late-season problems to tree fruit (Leskey and Hamilton, 2010a) though *H. halys* was not a widely recognized pest until late in the 2010 season. To date, *H. halys* has been recorded in many important USA agricultural production regions. *H. halys* distribution has continued to spread in the USA and has recently been recorded in orchard crop production regions in Oregon (Wiman et al., 2013) and could spread to other major production regions of similar crops throughout much of North America (Zhu et al., 2012). Susceptible crops in the USA where the bug is present are worth >$40 billion (NASS, 2013).

Nuisance impacts are especially problematic in rural areas, and have been reported in many urban and metropolitan regions. In the autumn, *H. halys* moves to structures, often by the thousands, generating numerous complaints (Inkley, 2012). Similar to the impacts on commercial growers, homeowners are also experiencing damage to backyard fruit and vegetable gardens.

H. halys attacks tree fruit (Nielsen and Hamilton, 2009a; Leskey et al., 2012a), small fruit, vegetables (Kuhar et al., 2012a), tree nuts (Hedstrom et al., 2013), ornamentals (Martinson et al., 2013) and row crops (Nielsen et al., 2011; Owens et al., 2013). In tree fruit, economic damage due to *H. halys* has resulted in increased production inputs and secondary pest outbreaks (Leskey et al., 2012a). In some cases, up to four-fold more pesticides were applied in affected fruit orchards (Leskey et al., 2012a). An outbreak in 2010 in the mid-Atlantic region resulted in >$37 million losses to apple alone and some stone fruit growers lost 90% of their crop (Leskey and Hamilton, 2010 a, b). Even unnoticeable populations in tree fruit may cause significant crop losses of up to 25% (Nielsen and Hamilton, 2009a). Tuncer and Ecevit (1997) and Tuncer et al. (2005) found that indigenous stink bugs in Turkey cause up to 3% direct crop loss to hazelnut. Should a similar scenario unfold in nut production areas in the USA, this may result in $200 million losses to tree nuts annually. Vegetables most at risk are sweetcorn, peppers, tomato, okra, aubergine, asparagus, cucurbits, crucifers and edible beans. Damage exceeding 50% is common under heavy infestations. With the exception of early sweetcorn, which may be damaged in early July, most vegetable crops are attacked from late July to September (Kuhar et al., 2012a). Taint and contamination of harvested fruit may also be an issue, particularly for small fruit and grapes. In wine made from *H. halys*-contaminated grapes, trans-2-decenal was the main taint compound (Mohekar et al., 2013) associated with *H. halys*. In some cases taint from stink bugs is transient and does not survive the fermentation/bottling process (Fiola 2012). Nevertheless, wines containing certain levels of this compound were perceived to be inferior compared to uncontaminated wines (Tomasino et al., 2013a, b). *H. halys* has been successfully removed from clusters just before harvest in order to prevent 'stink bug taint' (Pfeiffer et al., 2012).

To date only a single incidence of economic damage on pepper crops has been reported in Europe from the Canton Aargau in Switzerland (Sauer, 2012).

Social Impact

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Large numbers of *H. halys* can become a nuisance when they seek shelter in houses during autumn and winter months.

Risk and Impact Factors

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Impact mechanisms

- Causes allergic responses
- Competition - monopolizing resources
- Herbivory/grazing/browsing
- Pest and disease transmission

Impact outcomes

- Changed gene pool/ selective loss of genotypes
- Damages animal/plant products
- Host damage
- Negatively impacts agriculture
- Negatively impacts livelihoods
- Negatively impacts trade/international relations

Reduced amenity values

Invasiveness

Benefits from human association (i.e. it is a human commensal)
Capable of securing and ingesting a wide range of food
Gregarious
Has a broad native range
Has high reproductive potential
Highly mobile locally
Is a habitat generalist
Proved invasive outside its native range
Tolerant of shade

Likelihood of entry/control

Difficult to identify/detect as a commodity contaminant
Difficult/costly to control
Highly likely to be transported internationally accidentally

Detection and Inspection

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H. halys adults can be detected throughout the active growing season using blacklight traps and baited pheromone traps and nymphal populations can be detected with pheromone traps. However, each trap has limitations. Blacklight traps are attractive from early spring through September with reduced attractiveness as adults begin seeking overwintering sites. Baited pheromone trap effectiveness depends on the lure deployed. The use of methyl (2*E*,4*E*,6*Z*)-decatrienoate only provides late season adult attractivess, whereas the use of (3*S*,6*S*,7*R*,10*S*)-10,11-epoxy-1-bisabolen-3-ol and (3*R*,6*S*,7*R*,10*S*)-10,11-epoxy-1-bisabolen-3-ol alone or in combination with methyl (2*E*,4*E*,6*Z*)-decatrienoate provides season-long adult attractiveness.

In cropping systems, *H. halys* adults and nymphs can be detected through the use of timed visual counts, whole plant inspections, beat sheets counts and sweep netting. Timed visual counts are effective in field maize, nursery, nut, tree fruit and vegetable crops. Whole plant inspections are possible in various vegetables, field and sweetcorn by inspecting a specified number of plants per field or through the use of counts per linear foot of row. Beat sheet counts can be employed in nursery, nut and tree fruit; however, they are discouraged in nuts and tree fruit after thinning or June drop has occurred due to the potential removal of fruit. Sweep netting can be used in soyabeans but should be confined to field borders.

H. halys adults seek concealed, cool, tight and dry locations to overwinter. Because of this overwintering behaviour and need for specific microhabitats, many suitable sites can be generated by human-made materials and used by this insect as an overwintering sites such as inside cardboard boxes, other shipping containers and luggage, between wooden boards, within layers of folded tarps, and within machinery motors and vehicles. Thus, inspection for *H. halys* in shipments of goods from areas where it is present will require thorough visual inspections.

Similarities to Other Species/Conditions

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The superficial similarity in colour and overall appearance of *H. halys* to a number of other pentatomids requires that accurate identifications be based on sound morphological characters. This is particularly true for species that are found in the same habitats or utilize the same host plants, or which exhibit similar aggregation and overwintering behaviours. *Rhaphigaster nebulosa* is a prime example of a common European species often misidentified as *H. halys* because of its similar appearance, habitat preference and behaviour. Although adult *H. halys* present among invasive populations in Europe and North America are rather uniform in appearance, notable colour variations exist among different geographic populations in China (Hoelmer, unpublished observations of museum specimens). For North America, Hoebeke and Carter (2003) discuss possible confusion of adult *H. halys* with species of *Brochymena* in tribe Halyini and *Euschistus, Holcostethus* and *Thyanta* among members of tribe Pentatomini. For each genus, they give appropriate diagnostic characters distinguishing species from *H. halys*. Paiero et al. (2013) can also be used to distinguish *H. halys* from similar North American species. Wyniger and Kment (2010) provide an excellent dichotomous key, well illustrated with colour photographs, to distinguish *H. halys* from a number of native European pentatomids in the subfamily Asopine genera *Arma, Picromerus, Pinthaeus* and *Troilus* and the Pentatomine subfamily genera *Carpocapsis, Dolycoris, Holcostethus, Peribalus, Pentatoma* and *Rhaphigaster*, that are similar in appearance to *H. halys*.

Prevention and Control

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Susceptible Crops

Soyabean. Research has revealed three *H. halys* characteristics that are allowing for development of better management practices in soyabean: *H. halys* tends to invade soyabean fields during the R4 plant growth stage (fully elongated pods) to R6 (fully developed seed) and does the most crop injury by feeding on developing seed during R5; feeding injury is similar to that caused by native stink bug species; and populations typically infest only field edges, especially those bordering maize fields, woody edges or farm structures. While still under development, tentative thresholds are 1-2 *H. halys*/row foot, or 5 per 15 sweep-net sweeps. Scouting field edges is recommended during R4-R6 and making field edge-only treatments if populations exceed tentative thresholds. Several insecticides provide control, and a single field edge-only treatment is effective, if applied at the right time.

Maize. H. halys populations are highest (>3 per ear) during ear formation, the milk (R3) and soft dough (R3-R4) stages. Populations are typically highest within 12 m of field edges and decrease significantly toward the centres of fields. The highest populations are in maize fields bordering woods, followed by alfalfa, buildings and sorghum with the fewest in fields adjacent to open areas. Economic thresholds are under development.

Vegetables. Research shows that the vegetables most at risk to *H. halys* damage are sweetcorn, most varieties of pepper, tomato, okra, aubergine and edible beans. Plants are typically attacked in late summer when fruiting structures are present. Several foliar-applied insecticides provide effective control including pyrethroids (i.e., bifenthrin, permethrin and fenpropathrin); neonicotinoids (dinotefuran) and acephate (on peppers) (Kuhar et al., 2012 b, c, d, e). Neonicotinoids applied as a soil drench or via drip chemigation provide control for up to 14 days after treatment in vegetables such as pepper and tomato.

Tree fruit. H. halys adults can move into orchards at any time. Stone fruit, particularly peaches and nectarines are vulnerable in the early season, but the majority of fruit injury to pome fruit occurs later in the season. It takes several weeks for feeding injury on apple to appear; injury close to harvest can be expressed after harvest in cold storage. Issues with PHI (pre-harvest intervals) in mixed apple blocks severely restrict the availability of most insecticides used for control in the USA. Effective control can be achieved with applications of neonicotinoids and pyrethroids (Leskey et al., 2012b). Field and laboratory assays indicate that residual activity is limited. In general, damage in orchard crops has been mitigated by increases in insecticide applications against *H. halys* (Leskey et al., 2012a). This practice can disrupt IPM programmes, causing outbreaks of secondary pests such as European red mites, woolly apple aphids and San Jose scale. In general, overwintered *H. halys* populations are easier to kill with insecticide applications than the new generation adults present later in the season.

Biological Control

The egg parasitoid *Anastatus* has been mass-reared in the laboratory for experimental field trials in China (Hou et al., 2009) but is not yet widely applied. The role of indigenous natural enemies, primarily invertebrate predators and hymenopterous parasitoids, in the control of *H. halys* in crops, orchards and ornamentals surveyed in North America in Maryland, Delaware and Pennsylvania is highly variable. In Maryland, predators contributed ~40-70% of *H. halys* egg mortality found in some maize and soyabean plots, respectively. In Pennsylvania orchards, an estimated 25% of *H. halys* egg mortality is due to predation by Coccinellidae, particularly *Harmonia axyridis*, and earwigs (Forficulidae). In addition, late *H. halys* instars comprise the majority of nest provisioning by sand wasps (Crabronidae), up to 96% of discovered nests in orchards (Biddinger, unpublished data). Thus, species composition and attack rates of *H. halys* egg masses by native egg parasitoids appear to be highly variable depending on the crop or ecosystem studied. On the basis of the considerably higher rates of parasitism reported for *Trissolcus* spp*.* in Asia, these species are currently being evaluated in quarantine facilities in the USA as candidate agents for possible field releases.

Monitoring and Surveillance

Black light traps have been used to track *H. halys* activity in Japan (e.g., Moriya et al., 1987) and New Jersey. Relative pest pressure and spread of *H. halys* throughout New Jersey have been successfully tracked and documented using a network of black lights (Nielsen et al., 2013). In addition, baited black pyramid traps can be used to monitor *H. halys* (Leskey et al., 2012a). Khrimian et al. (2008) confirmed that the aggregation pheromone of *Plautia stali*, methyl (2*E*,4*E*,6*Z*)-decatrienoate (Sugie et al., 1996), is cross-attractive to *H. halys*, as reported in Asia (Tada et al., 2001a, b). However, adults are reliably attracted only late in the season, though nymphs are attracted season-long. In addition, the aggregation pheromone has been identified for *H. halys* and includes (3*S*,6*S*,7*R*,10*S*)-10,11-epoxy-1-bisabolen-3-ol and (3*R*,6*S*,7*R*,10*S*)-10,11-epoxy-1-bisabolen-3-ol (Zhang et al., 2013). These stimuli can be used in combination with pyramid-style traps to monitor presence, abundance and seasonal activity of *H. halys*.

Gaps in Knowledge/Research Needs

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Host use patterns and preferences and related movement of *H. halys* need to be elucidated during the period between dispersal from overwintering sites and invasion into cultivated crops. Some wild host plant species, particularly hardwood trees, could play a key role in supporting overwintered and new generation *H. halys* populations. However, little is known regarding host plant selection factors, including specific visual, olfactory and host quality cues, host plant preferences including wild and cultivated throughout the season and movement patterns at landscape levels. A greater understanding of these factors will provide many opportunities to manage *H. halys* as their temporal movement patterns and associated at-risk crops would be known.

The impact of abiotic conditions on population dynamics of *H. halys* during the active growing season and the overwintering period is poorly understood. In the USA, populations have fluctuated dramatically from year to year in areas in the mid-Atlantic with well-established populations since 2010, but key factors promoting or reducing survivorship remain unknown.

Similarly, the overall impact of native natural enemies on *H. halys* populations in invaded regions is also poorly understood. Although there are some climatic models predicting where *H. halys* can become established, more precise models could be used to better predict where *H. halys* poses a significant risk to agriculture. Furthermore, the taxonomy of many natural enemies, particularly *Trissolcus* spp., is presently in a confused state; efforts are presently underway to resolve not only East Asian species, but also provide updated identification tools for native North American species.

Dispersal capacity of adults and nymphs is not well established. The impact of factors such a mating status, age and feeding state on behaviour and dispersal are not known. How adult *H. halys* select overwintering sites is unknown. *H. halys* will overwinter in human-made structures and in dead, standing trees in forests, but how *H. halys* selects particular locations and why the density of adults at particular locations varies greatly is unknown.

Attractants for *H. halys* are available including methyl (2*E*,4*E*,6*Z*)-decatrienoate and its aggregation pheromone. However, optimal dose, distance of response at a particular concentration, physiological status of adults and nymphs that respond to olfactory stimuli are all factors that still require further study. Furthermore, why adults are responsive to methyl (2*E*,4*E*,6*Z*)-decatrienoate in the late summer while nymphs respond season-long is unknown. Similarly, the distance of response to light traps is unknown.

Management tools have been developed but revolve around the use of a select number of materials applied frequently. This level of use may not be sustainable due to outbreaks of secondary pests, impacts on natural enemies and pollinators, and the increasing potential for the development of resistance. Effective tools are also not available to organic growers. The development of economic thresholds and new classes of insecticides, resistance monitoring programs, and the use of trap, barrier and repellent crops need further investigation.

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Links to Websites

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Website	URL	Comment
Stop BMSB	www.stopbmsb.org	Biology, ecology and management of brown marmorated stink bug in speciality crops.
Northeastern IPM Center: Brown marmorated stink bug IPM working group	http://www.northeastipm.org/working-groups/bmsb-working-group/	
Die Marmorierte Baumwanze, Halyomorpha halys	http://www.halyomorphahalys.com	Biology, ecology and current distribution of brown marmorated stink bug in Europe.

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