Biol Invasions (2016) 18:3109–3116
DOI 10.1007/s10530-016-1217-z

INVASION NOTE

Citizen science and early detection of invasive species: phenology of first occurrences of *Halyomorpha halys* in Southern Europe

Lara Maistrello · Paride Dioli · Massimo Bariselli · Gian Lorenzo Mazzoli · Isabella Giacalone-Forini

Received: 21 June 2015 / Accepted: 30 June 2016 / Published online: 4 July 2016

Abstract Early detection of invasive alien species and the ability to track their spread are critical for undertaking appropriate management decisions. Citizen science surveys are potentially valuable tools for quickly obtaining information on biodiversity and species distributions. The Asian brown marmorated stink bug, *Halyomorpha halys*, is an invasive pest of agricultural crops and a dwelling nuisance. *Halyomorpha halys* was first recorded in Italy in 2012 in Emilia Romagna, one of the most important fruit producing regions of Europe. To rapidly obtain data on its distribution in the newly invaded area, a survey that combined citizen science and active search was set up using multimedia channels. Data concerning when, where and how the bugs were spotted were collected, together with photographs and specimens. The survey detected established breeding populations in different areas of Northern Italy and Southern Switzerland, indicating a potentially high risk for crop damage that extends beyond the territories of first detection. Furthermore, new data on *H. halys* phenology, host plants, voltinism and behaviour were obtained. The importance of citizen science in early detection of introduced pest species is highlighted. This paper also provides a picture-based key to recognize *H. halys* from similar pentatomids in the world.

Keywords Alien species · Brown marmorated stink bug · Distribution map · Introduced pest · Pentatomidae · Recognition keys

Electronic supplementary material The online version of this article (doi:10.1007/s10530-016-1217-z) contains supplementary material, which is available to authorized users.

L. Maistrello (✉)
Dipartimento di Scienze della Vita, Università di Modena e Reggio Emilia, Pad. Besta, Via G. Amendola 2, 42122 Reggio Emilia, Italy
e-mail: lara.maistrello@unimore.it

P. Dioli
Museo Civico di Storia Naturale, Milan, Italy

M. Bariselli · G. L. Mazzoli
Servizio Fitosanitario Regione Emilia Romagna, Bologna, Italy

I. Giacalone-Forini
Monte Carasso, Switzerland

Invasive alien species (IAS) are causing a multitude of negative effects on both natural and agricultural ecosystems, leading to serious economic losses and adverse environmental impacts (Simberloff et al. 2013). A recent case of IAS is the Brown Marmorated Stink Bug (BMSB) *Halyomorpha halys* (Stål, 1855) (Heteroptera: Pentatomidae) (Online Resource 3), an extremely polyphagous pest of many agricultural crops. BMSB is also known as a dwelling nuisance because of its massive overwintering aggregations inside buildings (Hoebeke and Carter 2003). Native to Asia, BMSB arrived in North America in the mid- to

late 1990s (Hoebeke and Carter 2003) and spread rapidly, causing millions of dollars of losses in fruit orchards. Its management consisting of season-long repeated insecticide treatments has disrupted previous IPM programs (Leskey et al. 2012a). In Europe, the first appearance occurred in Switzerland in 2004, followed by Liechtenstein, Germany, France, Hungary and Greece (Haye et al. 2015). In Italy the first BMSB specimen was captured in 2012 in the province of Modena (Emilia Romagna Region, Northern Italy), where an increasing problem with deformed pears (5–37 % damage at harvest) was initially attributed to mirid species (Heteroptera: Miridae). In northern Switzerland BMSB is univoltine and is mostly a household nuisance, only occasionally damaging vegetable gardens (Haye et al. 2014a). However, in Italy, there is a high concern that BMSB will not be limited to being a dwelling nuisance, because: (a) it was first detected in Emilia Romagna, one of the major European orchards, providing 25 % of the Italian fruit production and exporting fruits for 446 million Euro (Fanfani and Pieri 2012); (b) Emilia Romagna is a strategic, busy crossroads between continental Europe and Centre-Southern Italy; (c) the warmer climatic conditions could support bivoltinism. Together, these factors could favour a fast population increase and facilitate the spread all over the country and beyond, ultimately resulting in a potentially high impact of BMSB on the entire Italian/European agricultural production.

Accurate species identification is crucial to phytosanitary officers, IPM staff and farmers. At the same time, early detection and the ability to rapidly track the spread of IAS are essential to undertake decisions on their management. In the US, a 5 year delay between the likely date of first introduction of BMSB and the date of its correct identification (Hoebeke and Carter 2003) caused a delay in research and management efforts. Thus, the development of easy to use "universal keys" could allow for correct recognition of BMSB among similar stink bugs by non-specialists. Difficulties in tracking the real-time spread of IAS could be overcome with the involvement of many people by means of "citizen science" surveys (Scyphers et al. 2014). Citizen science data, if properly checked and verified by experts, are a potentially valuable source of information on biodiversity and species distribution (Crall et al. 2010).

The aim of this study was to verify the current distribution of BMSB and to obtain data on its phenology, host plants and voltinism, by combining active search and a multimedia citizen science survey.

After the first detection of BMSB in the Province of Modena (Magreta, 13 September 2012), which occurred during an insect collection for educational purposes, we launched an active search campaign in Northern Italy and Southern Switzerland. In the provinces of Modena and Reggio Emilia presence of BMSB was also checked during the weekly monitoring program (May–September 2013) for mirids performed by the local phytosanitary agencies in selected orchards. At the same time, a citizen science survey was initiated by: (a) encouraging the students of the University of Modena and Reggio Emilia (UNIMORE) Entomology classes and the personnel in Canton Ticino schools to actively search for the bug; (b) alerting professional and amateur entomologists/naturalists, using social networks and web forums; (c) alerting the phytosanitary services in Canton Ticino and Lombardy; (d) alerting UNIMORE personnel and general public through the UNIMORE website; (e) alerting farmers and general public through the Emilia Romagna Phytosanitary Service website and its extension magazine; (f) issuing a press-release, published in many newspapers and websites; (g) alerting the local municipalities and sanitary offices by means of extension flyers, published also in the respective websites; (h) organizing public conferences. In all cases, the public was invited to collect or take high quality photographs of any brown-grey marmorated bugs and to send them to the authors, together with details on the collection/sighting. All the records were collected in a database indicating: (a) when (date); (b) where (locality and street); (c) context of detection (open field = crops or uncultivated land; rural = isolated country farmhouses; country village = small residential area in the countryside; urban = cities); (d) place of detection (house/building, terrace, urban green, vegetable garden, crop, means of transport); (e) plant species, if the bug was found on plants; (f) how the bug was collected/detected (hand, photo, type of trap or sampling technique); (g) number and instar of the specimens observed/collected; (h) detector name and category (Researcher = investigator in University or other institution; Mus nat = Natural History Museums personnel; Ento/nat = entomologist/naturalist; Phytosan = phytosanitary services personnel; Student = university student; Cit = citizen not belonging to previous categories); (1) additional observations

if any. This work refers to data collected up to November 17, 2013.

As BMSB adults can be confused with similar European pentatomids, e.g. *Rhaphigaster nebulosa* Poda, *Troilus luridus* Fabricius, and *Arma custos* Fabricius, the records were validated by the authors as positive if *H. halys* was recognized when examining dead/alive specimens and/or digital pictures. Records were considered negative when related to other species or to cases where BMSB was actively searched for but never detected in the considered period. The positive records were categorized, obtaining the percentages of occurrence of BMSB according to: (a) the presence in different regions, in relation to the known bug biology (January–April = overwintering period, May–June = emergence from recovery sites and spread to host plants, July–August = reproductive period, September–November = movement to overwintering sites); (b) the presence in different contexts and places, for each region; (c) the size of the record (total number of individuals detected/record); (d) the method of detection and the category of the survey participants.

Halyomorpha halys is currently one of the most invasive pests in the world and due to international trade and favourable biological features, its spread appears uncontrollable. The first detection of BMSB in Italy elicited a serious concern, as it occurred in Emilia Romagna, a region of primary importance in Europe for fruit and wine production (Fig. 3) (Fanfani and Pieri 2012). The timely activation of an investigation combining active search, performed by experts and purposely trained people (university students, entomologists and naturalists, phytosanitary services personnel) and the citizen science survey resulted in the first distribution map (Fig. 1) of BMSB and provided information on its biology in the newly invaded areas. Our survey consisted of 377 records collected between September 2012 and November 2013 in Northern Italy (87 % of all records), in Canton Ticino (10 %) and in Central and Southern Italy (3 %). A total of 200 records were positively validated as *H. halys*. The 177 negative records were misidentified native pentatomids, mainly *R. nebulosa* (15 % of negative records), and/or failure to detect BMSB during active search.

Halyomorpha halys can be easily confused with similar pentatomids in different parts of the world. In Europe, mottled brown-greyish stink bugs resembling BMSB include other phytophagous species, as well as predators of eggs and juvenile instars of plant pests, which are both potentially useful biological control agents. A correct recognition of the species and knowledge of their bio-ecology, are therefore crucial. Thus, we developed a photo-based identification key that allows for an accurate, quick recognition of *H. halys* adult and immature instars among pentatomids from all over the world (Online Resources 1, 2, 3), by means of a simplified dichotomy.

This study took advantage of the voluntary collaboration by many stakeholders who understood the potential threat of this introduced bug for Italian/European agriculture. Students were the major contributors to this survey (about 1/3 of records), followed by citizens (22 %), researchers (20 %), entomologists/naturalists (17 %), personnel of plant protection services (6 %) and museum personnel (2 %). Other phytosanitary relevant IAS similarly detected in Europe were *Leptoglossus occidentalis* (Hemiptera: Coreidae) (Taylor et al. 2001) and *Aromia bungii* (Coleoptera: Cerambycidae) (Burmeister et al. 2012). Our findings confirm that, when verified by competent taxonomy specialists, insect collection performed for educational purposes and/or by entomology amateurs can be crucial for the detection of allochthonous insects. Indeed, an increasing number of aliens are reported in dedicated web forums. We are aware that citizen science data are not reliable in yielding estimates of species distribution (Van Strien et al. 2013), since they are collected without a standardized protocol and explicit sampling design. However, these data are extremely useful for early detection of invasive pests and in tracking their spread in the initial introduction stages.

Our data are not necessarily exhaustive and possibly represent only a partial picture of the actual distribution of *H. halys* in Italy and Southern Switzerland. The compiled map (Fig. 1) shows three conspicuous apparently isolated nuclei. The most relevant, in terms of number and consistency of records, is centred in the province of Modena (Emilia Romagna, ER) (Online resource 5); the second is the area between Milan (Lombardy, LOM) and Bellinzona (Canton Ticino, TIC); the third is in Piedmont (PIE), where it was recorded also by Pansa et al. (2013). BMSB was detected mostly along main roads and/or railway lines like, in ER, the highway/railway connecting Centre-South Italy with continental

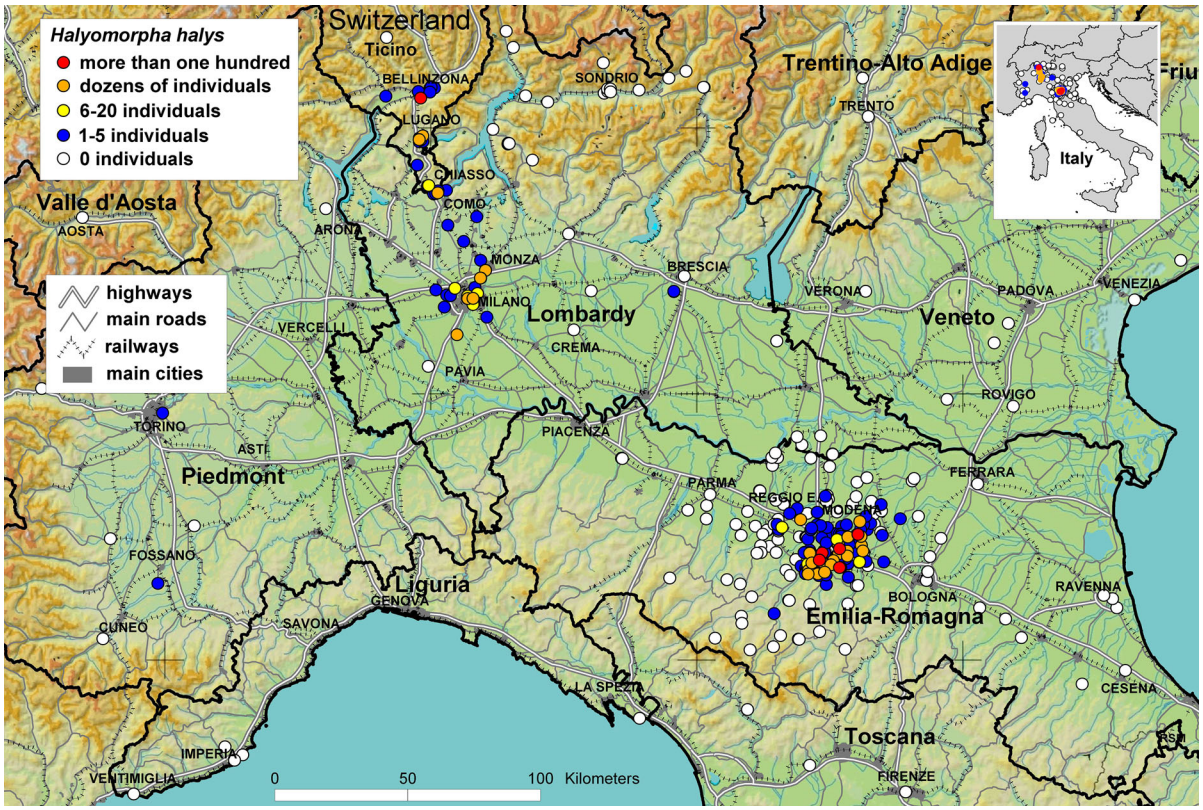

Fig. 1 Map of Northern Italy and Southern Switzerland representing the distribution of *Halyomorpha halys* according to our survey (*dots*). *Dot colours* represent the size of each record (number of specimens detected). *Coloured dots* positive records; *white dots* negative records, represented by cases of detection of pentatomids other than *H. halys* or by cases where BMSB was actively searched but never detected in the considered period

Europe, and, in LOM, the lines connecting Italy to Switzerland, where BMSB has been established for 10 years (Haye et al. 2015). The possibility that *H. halys* colonization is facilitated by "hitchhiking" was directly verified in our study by detecting it inside cars and in train stations (Table 1). A strong association with urban development and railroads occurred also in the initial establishment and dispersal of BMSB in the US (Wallner et al. 2014).

The likelihood that the population in the LOM-TIC nucleus derives, at least in part, from the Swiss one, is confirmed by the genetic analysis of specimens collected during this survey (Cesari et al. 2015). Considering the actual presence of monovoltine BMSB population in central Europe, (Haye et al. 2014a), our records and the records from Greece represent (Milonas and Partsinevelos 2014), one of the most southern points of the distribution range for the European continent.

The number and size of our records (Fig. 1; Online resource 5) indicate established breeding populations of low-moderate population levels in the described areas. Combining the data on occurrence relative to season (Fig. 2) with the occurrence related to the context, region and place of detection (Table 1) and the biological observations on individuals reared in semi-field conditions, it is possible to summarize the phenology of *H. halys* in the investigated areas. During autumn the bugs aggregate inside buildings to overwinter; in April–May they disperse onto host plants and mate until August, developing through two annual generations; immature individuals are detected until mid October. These findings are in agreement with the described biology of the species in the warmer US states (Leskey et al. 2012b). In our study BMSB was mainly detected in urban and country village settings (Table 1; Online resource 5) and most of the records occurred in autumn (with cases of hundreds of

Table 1 Number of records of *Halyomorpha halys* detected for each context, in each region (*ER* Emilia Romagna, *LOM* lombardy, *TIC* Ticino), according to the place of detection

	Rural						Open field						Country village						Urban					
	ER	LOM	TIC	PIE	Tot rural	% Rural	ER	LOM	TIC	PIE	Tot open field	% Open field	ER	LOM	TIC	PIE	Tot c. village	% c. village	ER	LOM	TIC	PIE	Tot urban	% Urban
House/ building	1				1	**0.5**					0	**0**	58	2	2		62	**31.0**	31	5	14	1	51	**25.5**
Farmhouse	18				18	**9**					0	**0**					0	**0**					0	**0**
House terrace					0	**0**					0	**0**	3				3	**1.5**	5	7	5		17	**8.5**
Urban green					0	**0**					0	**0**	3	2		1	6	**3.0**	2	9	4		15	**7.5**
Garden/ vegetable garden	5				5	**2.5**					0	**0**	6				6	**3.0**	2		4		6	**3.0**
Field crop					0	**0**	4	1	1		6	**3.0**					0	**0**					0	**0**
Train station					0	**0**					0	**0**					0	**0**	1	1			2	**1**
Car	1				1	**0.5**					0	**0**					0	**0**	1				1	**0.5**
Total	25				25		4	1	1		6		70	4	2	1	77		42	22	27	1	92	
% Total	**12.5**	**0**		**0**	**0**		**12.5**	**2.0**	**0.5**		**0.5**	**0.00**		**3.0**	**35.0**	**2.0**		**1.0**	**0.5**		**38.5**	**21.0**	**11.0**		**13.5**	**0.5**		**46.0**

The columns and the row in bold indicate the percentages calculated over the total number of positive validated records (200)

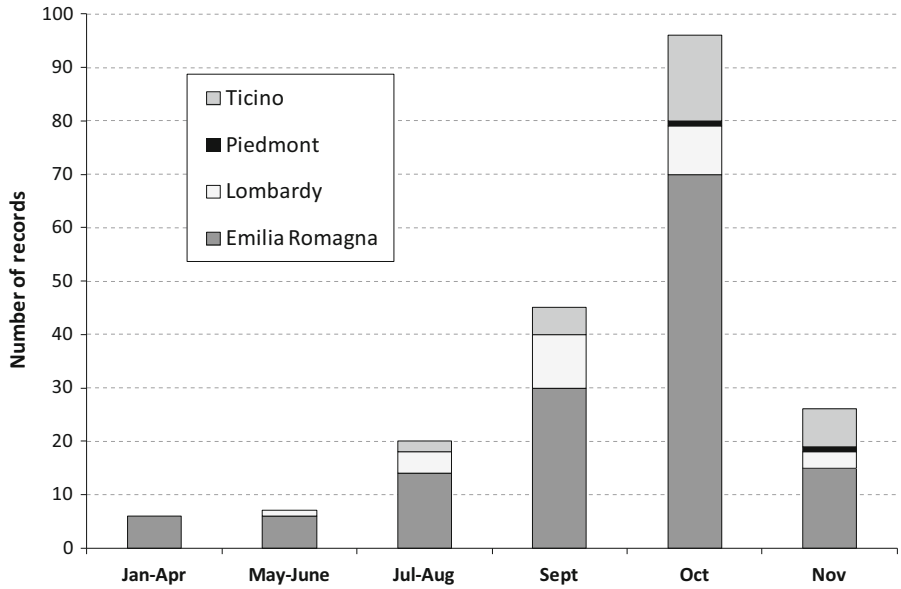

Fig. 2 Number of *Halyomorpha halys* records detected in the different regions, according to the bug biology

individuals: red dots, Fig. 1; Online resource 5) in buildings facing green areas, indicating proximity between host plants and the shelters chosen to overwinter. In urban settings the bugs were frequently found on balcony plants, especially on the highest floors (even the 10th floor). These observations indicate that: (a) autumn is the most favourable period to collect data on BMSB presence, because adult bugs are easily noticed inside buildings in any setting, (b) even the smallest green area in a city can host BMSB; (c) these bugs, already known to prefer the higher parts of plants (Leskey et al. 2012b), are able to fly higher than 25 m. These findings should be taken into account when designing a detection campaign for *H. halys* presence and the association with a citizen science survey could save time and energy.

Considering the 33 recorded plant species on which BMSB was detected, (Online Resource 4), 7 are new, compared to available literature (Lee et al. 2013; USDA-NIFA SCRI 2016; Haye et al. 2015), further increasing the host range of this extremely polyphagous bug. New hosts include ornamentals (*Ageratum houstonianum* vs. *nana*, *Myosotis* sp., *Calycanthus* sp., *Broussonetia papyrifera)* and 3 species typically grown in vegetable gardens (*Ocimum basilicum, Thymus* sp., *Capsicum chinense*). Also, we report the first European case of an open field crop infestation by BMSB. This infestation occurred in mid October 2013 on soybean in Canton Ticino (Switzerland), where despite an estimated presence of 500 individuals/ha, no significant yield loss was reported. In addition, BMSB was occasionally detected in ER in vineyards at harvest and in pear/peach orchards during monitoring for other pests, and in PIE on nectarines after last harvest (Pansa et al. 2013). The detection of BMSB in field crops without a specific monitoring program is alarming, especially taking into account that 35 % of the total positive records occurred in the countryside villages surrounded by high value orchards and vineyards in a region of great agricultural relevance such as ER (Fig. 3). BMSB was never detected during the field monitoring program for mirids in 2013, but this is misleading, as BMSB is a typically arboreal species, easier to catch using tree-beating rather than sweep nets as are used for mirid sampling (Nielsen and Hamilton 2009).

The likelihood that *H. halys* could become a crop pest in Europe, as well as in the US, depends on factors such as voltinism, type and range of host plants, biotic potential and possibility to overcome geographical barriers. According to the pest risk assessment performed for France (Haye et al. 2014b), the risk of invasion with negative impact on crops is high. Our findings indicate that south of the Alps, BMSB has established breeding populations that can rapidly spread due to bivoltinism, passive transportation and an increased host range. Thus there is a concrete risk that it could become a serious agricultural pest in

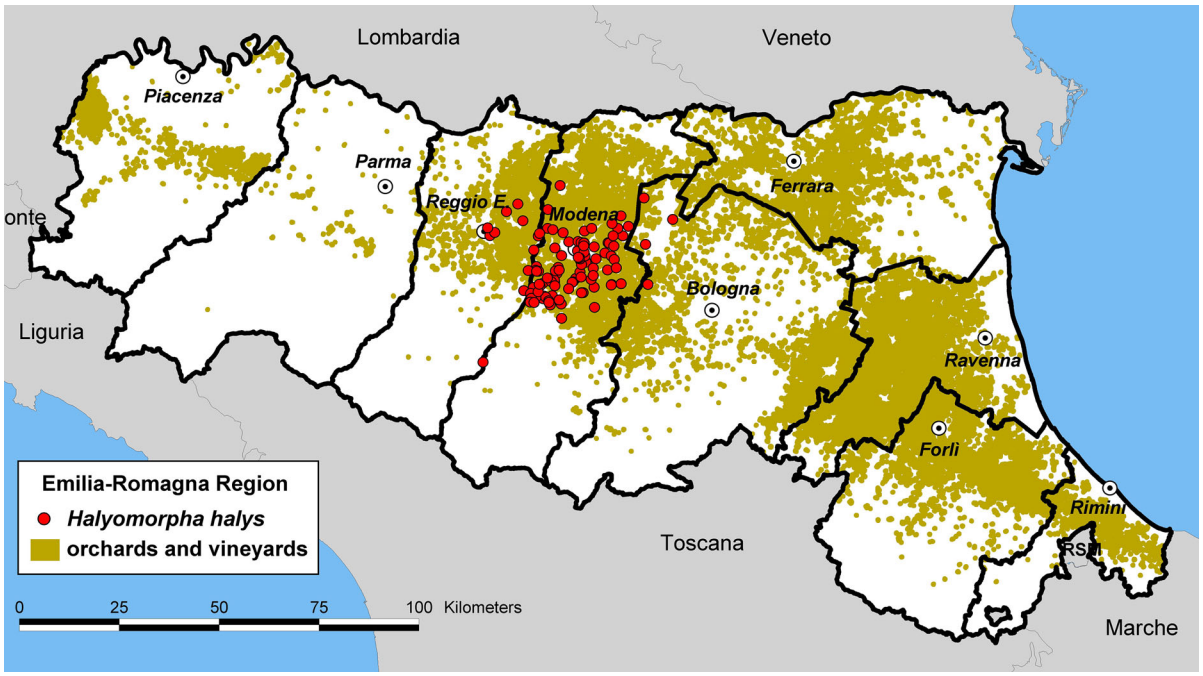

Fig. 3 Map of Emilia Romagna region (Northern Italy) representing the detection sites of *Halyomorpha halys* (*red dots*) and, in *brownish green*, the distribution and amount (in hectares) of the cultivated crops mostly threatened by this alien species (fruit orchards and grapevine)

Southern Europe and along the Mediterranean basin. In Italy, the results of this study led to the development of a specific field monitoring program for *H. halys* that is currently being performed in ER and other regions, together with a detailed study on the biology and the potential of native antagonists. The citizen science survey is still active, producing real-time data on BMSB spread and acting as an alert system for other regions. The methods used for this survey could serve as a functional example for other introduced species. Moreover, the obtained information and the provided identification keys can be used to spot and track the spread of the invasive pest *H. halys* all over the world.

Acknowledgments Part of this research was supported by a Grant, ''Innovative tools and protocols for monitoring and sustainable control of the alien stink bug *Halyomorpha halys*, a new phytosanitary threat, and of other harmful heteropterans for the fruit crops of the territory of Modena'' (2013.065) from Fondazione Cassa di Risparmio di Modena. Very special thanks to the most important "sentinels" of BMSB, the entomology students of UNIMORE, in particular S. Berselli (first detector). We are grateful to the Phytosanitary Services of Modena and Reggio Emilia for field monitoring, and to the following people/groups: M. Malmusi, R. Poloni, M. Po (Gruppo Modenese Scienze Naturali); A. Piglia, M. Spiller, C. Piani, F. Capitani F. Luthi Barbieri, M. Norbiato and A. Girodo (www.naturamediterraneo.com); L. Mola, G. Bianchi (www.entomologiitaliani.net), G. Mariani, S. Turolo, C. Azara, G.P. Spina, A. Reggiani; M. Aberhalden, L. Pollini Paltrinieri F. Rampazzi, N. Schoenenberger (Museo Cantonale Storia Naturale, Lugano); M. Colombo, I. Rigamonti, R. Regalin (UNIMI, DeFENS); F. Rigato, M. Pavesi, A. Sabbadini (Museo Civico di Storia Naturale, MI); M. Valle, P. Pantini (Museo Scienze Naturali "E. Caffi", BG); M. Boriani, A. Taddei (Ersaf Lombardia), M. Salvetti (Fondazione Fojanini di Studi Superiori, SO); I. Ansaloni, G. Bosi, R. Guidetti, L. Lombroso, F. Masino, L. Rebecchi, M. Mandrioli (UNIMORE), R. Ferrari, L. Boriani (CAA Crevalcore); the elementary school of Monte Carasso (Canton Ticino); L. Colombi (Servizio Fitosanitario Canton Ticino). The authors are grateful to Dr C. Costa and Dr K. E. Wells for English editing and to the reviewers for valuable suggestions and revision of the manuscript.

References

Burmeister EG, Hendrich L, Balke M (2012) Der Asiatische moschusbock *Aromia bungii* (Faldermann, 1835)—erstfund für Deutschland (Coleoptera: Cerambycidae). Nachr Bayer Entomol 61:29–31

Cesari M, Maistrello L, Ganzerli F et al (2015) A pest alien invasion in progress: potential pathways of origin of the brown marmorated stink bug *Halyomorpha halys* populations in Italy. J Pest Sci 88:1–7. doi:10.1007/s10340-014-0634-y

Crall AW, Newman GJ, Jarnevich CS et al (2010) Improving and integrating data on invasive species collected by citizen scientists. Biol Invasions 12:3419–3428. doi:10.1007/s10530-010-9740-9

Fanfani R, Pieri R (2012) Il sistema agro-alimentare dell'Emilia-Romagna. Rapporto 2011. Maggioli Editore, Rimini

Haye T, Abdallah S, Gariepy T, Wyniger D (2014a) Phenology, life table analysis and temperature requirements of the invasive brown marmorated stink bug, *Halyomorpha halys*, in Europe. J Pest Sci 87:407–418

Haye T, Hoelmer KA, Rossi J, Streito J (2014b) Avis de l'ANSES/Rapport d'expertise collective: Analyse de risque phytosanitaire express *Halyomorpha halys*—la punaise diabolique

Haye T, Gariepy T, Hoelmer K et al (2015) Range expansion of the invasive brown marmorated stinkbug, *Halyomorpha halys*: an increasing threat to field, fruit and vegetable crops worldwide. J Pest Sci. doi:10.1007/s10340-015-0670-2

Hoebeke ER, Carter ME (2003) *Halyomorpha halys* (Stål) (Heteroptera: Pentatomidae): a polyphagous plant pest from Asia newly detected in North America. Proc Entomol Soc Wash 105:225–237

Lee D-H, Short BD, Joseph SV et al (2013) Review of the biology, ecology, and management of *Halyomorpha halys*(Hemiptera: Pentatomidae) in China, Japan, and the Republic of Korea. Environ Entomol 42:627–641. doi:10.1603/EN13006

Leskey TC, Short BD, Butler BR, Wright SE (2012a) Impact of the invasive brown marmorated stink bug, *Halyomorpha halys* (Stål), in Mid-Atlantic tree fruit orchards in the United States: case studies of Commercial Management. Psyche J Entomol. doi:10.1155/2012/535062

Leskey TC, Wright SE, Short BD, Khrimian A (2012b) Development of behaviorally-based monitoring tools for the brown marmorated stink bug (Heteroptera: Pentatomidae) in commercial tree fruit orchards. J Entomol Sci 47:76–85

Milonas PG, Partsinevelos GK (2014) First report of brown marmorated stink bug *Halyomorpha halys* Stål (Hemiptera: Pentatomidae) in Greece. EPPO Bull 44:183–186. doi:10.1111/epp.12129

Nielsen AL, Hamilton GC (2009) Life History of the Invasive Species *Halyomorpha halys* (Hemiptera: Pentatomidae) in Northeastern United States. Ann Entomol Soc Am 102:608–616. doi:10.1603/008.102.0405

Pansa MG, Tavella L, Asteggiano L et al (2013) Primo ritrovamento di *Halyomorpha halys* nei pescheti piemontesi. Inf Agrar 69(37):60–61

Scyphers SB, Powers SP, Akins JL et al (2014) The role of citizens in detecting and responding to a rapid marine invasion. Conserv Lett. doi:10.1111/conl.12127

Simberloff D, Martin J-L, Genovesi P et al (2013) Impacts of biological invasions: what's what and the way forward. Trends Ecol Evol 28:58–66. doi:10.1016/j.tree.2012.07.013

Taylor SJ, Tescari G, Villa M (2001) A nearctic pest of pinaceae accidentally introduced into Europe: *Leptoglossus occidentalis* (Heteroptera: Coreidae) in northern Italy. Entomol News 112:101–103

USDA-NIFA SCRI (2016) Stop BMSB. Biology, ecology, and management of brown marmorated stink bug in specialty crop. In: Stop BMSB. http://www.stopbmsb.org. Accessed 17 Jan 2016

Van Strien AJ, Van Swaay CAM, Termaat T (2013) Opportunistic citizen science data of animal species produce reliable estimates of distribution trends if analysed with occupancy models. J Appl Ecol 50:1450–1458. doi:10.1111/1365-2664.12158

Wallner AM, Hamilton GC, Nielsen AL et al (2014) Landscape factors facilitating the invasive dynamics and distribution of the brown marmorated stink bug, *Halyomorpha halys* (Hemiptera: Pentatomidae), after arrival in the United States. PLoS ONE 9:e95691. doi:10.1371/journal.pone.0095691