

Short Communication

Initiation of a monitoring programme for early detection of *Halyomorpha halys* in Cyprus by using pheromone-baited traps and involving citizen scienceGábor Véték^{1,*}, Anthemis Melifronidou-Pantelidou², Despina Koukkoularidou² and Angeliki Martinou^{3,4,5}¹Department of Entomology, Institute of Plant Protection, Szent István University, Villányi út 29-43, H-1118 Budapest, Hungary²Plant Health and Marketing Standards of Agricultural Products Sector, Department of Agriculture, Ministry of Agriculture, Rural Development and Environment, Loukis Akritas Avenue, 1412 Nicosia, Cyprus³Laboratory of Vector Ecology and Applied Entomology, Joint Services Health Unit, British Forces Post Office 57, Royal Air Force Akrotiri, Cyprus⁴The Cyprus Institute, 20 Konstantinou Kavafi Street, 2121 Aglantzia, Cyprus⁵Enalia Physis, Akropoleos 2, 2101 Aglangia, CyprusAuthor e-mails: Vetek.Gabor@szie.hu (VG), amelifronidou@da.moa.gov.cy (AMP), dkoukkoularidou@da.moa.gov.cy (DK), A.martinou@cyi.ac.cy (AM)

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Citation: Véték G, Melifronidou-Pantelidou A, Koukkoularidou D, Martinou A (2021) Initiation of a monitoring programme for early detection of *Halyomorpha halys* in Cyprus by using pheromone-baited traps and involving citizen science. *Management of Biological Invasions* 12(2): 331–343, <https://doi.org/10.3391/mbi.2021.12.2.08>

Received: 1 July 2020**Accepted:** 7 August 2020**Published:** 5 October 2020**Handling editor:** Catherine Jarnevich**Copyright:** © Véték et al.

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Abstract

The invasive brown marmorated stink bug *Halyomorpha halys* is native to East Asia and was first detected in Switzerland, Europe in 2004. It is now widespread throughout continental Europe and has recently been reported on several islands in the Mediterranean Sea. In the Eastern Mediterranean, it has been recorded in Greece, Turkey and most probably Egypt, but there is no information regarding its occurrence in the Republic of Cyprus. Therefore, in September 2019, a survey at potential points of entry and arrivals was carried out by setting pheromone traps of the pest in the vicinity of airports, harbours as well as next to importers' trade warehouses in the country. This stink bug monitoring programme in September and October was completed with an awareness campaign, which consisted of the establishment of a citizen science initiative for the early warning of this alien pest by disseminating an alert letter titled "Bug Alert Cyprus" in English and Greek to various target groups. To the best of our knowledge, this is the first CS initiative in Cyprus focusing on the early detection of a polyphagous agricultural and nuisance pest. The lack of *H. halys* captured during the trapping period, and the absence of reports from citizens seem to indicate that *H. halys* had not reached this European island country up to January 2020. The methodology we applied and our further recommendations may foster further CS activities combined with targeted trappings to give an early warning and enable the detection of *H. halys* as effectively as possible on European islands as well as on other remote or isolated parts of the world not yet invaded by this pest.

Key words: brown marmorated stink bug, semiochemical-baited trap, public awareness, island country, biosecurity

Introduction

The brown marmorated stink bug (BMSB), *Halyomorpha halys* (Stål, 1855) (Hemiptera: Pentatomidae), is native to China, Korea, Taiwan, Japan, and Vietnam (Josifov and Kerzhner 1978; Rider et al. 2002). It has been introduced in North and South America (Hoebeke and Carter 2003; Faúndez and Rider 2017) as well as in Europe, where it was first detected in

2004, in Switzerland (Haye et al. 2014). *Halyomorpha halys* is an invasive polyphagous species, which is able to cause heavy feeding damage to many cultivated plants of major economic significance, such as apple, pear, peach, citrus fruits, hazelnut, tomato, pepper and sweet corn (Kuhar et al. 2012; Leskey et al. 2012; Bariselli et al. 2016; Vétek and Korányi 2017; Bosco et al. 2018; Musolin et al. 2018). Furthermore, once established, *H. halys* may also become a serious pest problem for homeowners and businesses in the autumn period due to its aggregatory behaviour, when the adult bugs invade man-made structures to overwinter inside protected environments (Hoebeke and Carter 2003; Haye et al. 2015; Leskey and Nielsen 2018).

Halyomorpha halys is already widespread in continental Europe (Cianferoni et al. 2018; Claerebout et al. 2018), and there have been recent reports on several islands of the Mediterranean Sea, such as Sardinia (Dioli et al. 2016; Claerebout et al. 2018), Corsica (Kriticos et al. 2017; Claerebout et al. 2018), Sicily (Carapezza and Lo Verde 2017; Costi et al. 2017), Crete (Claerebout et al. 2018), Lesbos (Cianferoni et al. 2019) and Malta (Tassini and Mifsud 2019). In the case of many European islands, the early findings of *H. halys* in busy localities such as London and Teesport (Great Britain), Cagliari (Sardinia), Palermo (Sicily), Reykjavík and Keflavík (Iceland), and Birżebbuġa (Malta) were mostly considered to be related to the presence of important airports and/or seaports as potential points of entry of this pest (Malumphy 2014; Dioli et al. 2016; Carapezza and Lo Verde 2017; Claerebout et al. 2018; Tassini and Mifsud 2019). Individuals of the species might be carried accidentally as “hitchhikers” with cargo, inside various means of transport and other objects (Duthie 2012; Malumphy 2014; Kriticos et al. 2017; Maistrello et al. 2018). The association of *H. halys* with the high diversity of transported goods poses a severe risk to biosecurity. This concern is well indicated by, for example, the fact sheet disseminated by the Ministry for Primary Industries (MPI) of New Zealand, in which a dedicated “hotline” is also provided for the public for reporting any suspect stink bug finds to MPI (Biosecurity New Zealand 2018). Therefore, targeted surveys for this insect species at airports and harbours should be implemented to make early detection of *H. halys* as effective as possible.

Larnaca airport, Cyprus, is only a few kilometres from the main harbour and marina. The international flight connections from this airport are available to many cities of continental Europe, such as Athens, Basel, Belgrade, Bucharest, Budapest, Milan and Zurich (Hermes Airports 2020). These are locations where the presence of large populations of *H. halys* has already been observed (Ciceoi et al. 2017; Gariepy et al. 2015; Haye et al. 2014; Maistrello et al. 2018; Vétek et al. 2018; Vétek *personal observation*). Also the airport of Paphos, which can be found a few kilometres away from the city harbour popular with tourists, is available from several of these towns (Hermes Airports 2020). In the Mediterranean Basin, occurrences of considerable numbers of *H. halys* were reported not only from the urban

area of Athens (Greece), where there is the port of Piraeus, as early as 2014 (Garipey et al. 2015) but also from the region of Genoa, Italy (Maistrello et al. 2018), both having maritime trade connections with Limassol in Cyprus (Corres 2013).

Currently, *H. halys* is not regulated officially in Cyprus, and it is also absent from the European and Mediterranean Plant Protection Organization (EPPO) A2 list of pests recommended for regulation as quarantine pests (EPPO 2020), and as a result monitoring within EPPO member countries needs to rely on alternative detection methods such as research efforts or citizen science (CS) activities. Citizen science initiatives depend on non-professionals who undertake monitoring in a voluntary capacity (Dickinson and Bonney 2012). The contribution of citizens is considered crucial in biodiversity monitoring (Pocock et al. 2017b) as well as in the early detection and monitoring of pests (Maistrello et al. 2016; Pocock et al. 2017a) and vectors of pathogens such as mosquitoes (Palmer et al. 2017). It may also help alert the authorities or complement their efforts made to eradicate the harmful organisms.

The two main objectives of our work were (1) to collect *H. halys* by using pheromone-baited traps provided it had been introduced and established in the vicinity of several potential points of entry and arrivals of Cyprus and (2) to increase public and stakeholder awareness of the risks of introduction of this stink bug species by using CS as a tool. Involvement of citizen scientists has been considered to be extremely useful for early detection of invasive pests (Maistrello et al. 2016). In the case of *H. halys*, both approaches (i.e., targeted trapping and the involvement of the public in data collection) have already proved to be suitable for obtaining data quickly, broadly and even relatively inexpensively on the occurrence of this particular pest (Haye et al. 2014; Maistrello et al. 2016; Véték et al. 2018; Tassini and Mifsud 2019).

Materials and methods

Trapping of Halyomorpha halys

Targeted trapping with eight Pherocon BMSB 24 week aggregation pheromone traps, provided by Trécé, Inc. (Adair, OK, USA), was carried out at four towns (Larnaca, Limassol, Nicosia and Paphos) in Cyprus in September–October 2019. The trapping sites were in the vicinity of airports (Larnaca and Paphos), city ports (Larnaca, Limassol and Paphos) and importers' trade warehouses (Nicosia). The sites were relatively close to entry or arrival points of commercial commodities and goods in international trade and transportation and/or of passengers arriving from many parts of Europe. Hence, they were considered as representative locations of potential introductions of *H. halys*. The two main goals of the trapping were: (1) to try to detect *H. halys* specimens recently and accidentally



Figure 1. Position of a Pherocon BMSB 24 week aggregation pheromone trap installed next to the port of Larnaca, Cyprus. Photo by G. Véték.

introduced inside planes or ships; (2) to try to capture specimens of potentially locally established *H. halys* populations originating from former introductions. Based on the results of various previous pheromone trapping studies (Morrison III et al. 2017b; Bosco et al. 2018; Murvanidze et al. 2018; Ak et al. 2019) the early/mid-autumn period was considered suitable for detecting *H. halys* if present at these locations.

The clear sticky cards (15.3 × 30.5 cm, STKY Dual Panel Adhesive Trap) with the lures were either secured to a wooden stake at a height of ca. 0.9 m above the ground (Figure 1) or hung horizontally on a tree branch or a fence with twist ties at a height of ca. 1.9 m. The traps were repeatedly inspected for *H. halys* captures until the end of the trapping period (Table 1).

Citizen science activities

As a first step in this part of the *H. halys* monitoring programme, an alert letter titled “Bug Alert Cyprus” was created in both English (see Supplementary material Appendix 1) and Greek. The aims were to raise awareness of the threats *H. halys* poses to the economy and human well-being and also to provide information that can help citizens identify this stink bug species and report its occurrence. The letter starts with highlighting the fact that the pest is already present in the Eastern Mediterranean and calls attention to the multifarious risks to the agricultural sector as well as citizens in urban environments once the pest establishes in a region. Then it provides an illustration of the adult bug with short notes about the “key” morphological characters which can be observed easily not only by entomologists but also by non-professionals. The simplified description of these features was primarily

Table 1. Sites and periods of trapping *H. halys* in Cyprus.

Location (No. of site)	Position of the trap and surrounding habitat	Coordinates of the trapping site	Trapping period (2019) (with the frequency of inspections)
Larnaca (1)	hung on a fence in a parking lot with poor vegetation, next to the airport facilities	34.8826°N, 33.6258°E	
Larnaca (2)	fixed to a wooden stake in an industrial area with poor vegetation, next to the port (Figure 1)	34.9328°N, 33.6410°E	13 Sept. – 30 Oct. (weekly)
Larnaca (3)	hung on an <i>Acacia</i> sp. ^a tree branch in a parking lot with poor vegetation, next to the port	34.9197°N, 33.6378°E	
Limassol (1) ^b	fixed to a wooden stake at the edge of a wetland, next to the port	34.6440°N, 33.0115°E	11 Sept. – 30 Oct. (weekly)
Limassol (2) ^b	fixed to a wooden stake at the edge of a wetland, next to the port and ca. 400 m away a citrus orchard	34.6439°N, 33.0036°E	11 Sept. – 30 Oct. (weekly)
Nicosia (1)	fixed to a wooden stake in the city, with poor vegetation in the area, very close to importers' warehouses	35.1849°N, 33.3931°E	27 Sept. – 1 Nov. (twice in Oct.)
Nicosia (2)	fixed to a wooden stake in the city, with poor vegetation in the area, very close to importers' warehouses	35.0923°N, 33.4208°E	27 Sept. – 1 Nov. (twice in Oct.)
Paphos	hung on an <i>Acacia</i> sp. tree branch in a parking lot with relatively dense vegetation (e.g., <i>Acacia</i> sp., <i>Hibiscus rosa-sinensis</i>) ^a , close to the port	34.7563°N, 32.4083°E	11–16 Sept. (once on the end date)

^a *Acacia* spp. and *H. rosa-sinensis* are reported as hosts or among other affected plants of *H. halys* (Hamilton et al. 2018; CABI 2020).

^b The two traps in Limassol were installed in the Akrotiri Sovereign Base Area, UK.

based on information available on a professional website dedicated to this pest (Haye and Wyniger 2020) and on the work of Wyniger and Kment (2010). Then sites where the first individuals may be expected to arrive and thus should be paid specific attention (i.e., busy locations – see Introduction) are indicated in the letter. It is then emphasised that the insect, although being harmful for plant production and a severe nuisance for the public, does not pose a direct risk to human health as it only feeds on plant material. The last part of the alert letter shows the email account (bugalertcyprus@gmail.com) created to receive reports on observations of this or any “suspicious” bugs with features resembling those of *H. halys*. In addition to asking for data from the public on the place and date of their records, the citizen is also requested to take a digital image of the bug found to attach to the report, because this was considered to be essential for subsequent records verification by the authors who manage the email account.

To increase visibility of this CS initiative and to broaden the range of potential contributors, both the English and the Greek Bug Alert Cyprus letters were uploaded to several websites such as that of the Laboratory of Vector Ecology and Applied Entomology, Joint Services Health Unit, British Forces Cyprus, as outreach materials of Researching Invasive Species of Kýpros (RIS-Ký) and also as a reference in the Facebook group of RIS-Ký, on 17 September 2019. The Plant Health and Marketing Standards of Agricultural Products Sector of the Department of Agriculture under the Ministry of Agriculture, Rural Development and Environment (MARDE) of Cyprus also uploaded the Greek alert letter to their official website, and informed, by 31 October 2019, all of the 275 companies that were registered in the official Plant Health Registry of Cyprus. Furthermore, the information was sent to the plant health inspectors placed at the airport of Larnaca, and the ports of Larnaca and Limassol.

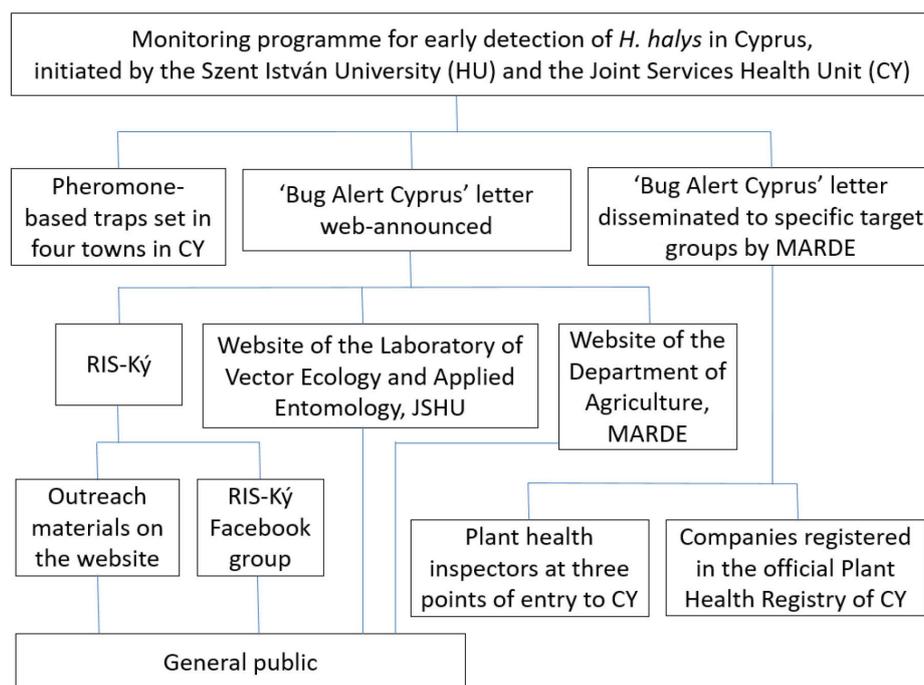


Figure 2. The monitoring programme, as set up in autumn 2019, including the network of citizens involved in the CS initiative to detect *H. halys* in Cyprus.

Results

Trapping with the aggregation pheromone traps resulted in no *H. halys* captures at the studied locations in Cyprus in September–October 2019. A few individuals of two other stink bug (Pentatomidae) species were captured in Larnaca: *Acrosternum millierei* (Mulsant & Rey, 1866), airport, 17 September 2019 (1 ♀); port, same date (2 ♂); port, 1 October 2019 (1 ♀); and *Graphosoma semipunctatum* (Fabricius, 1775), port, 23 September 2019 (2 ♂). Both species are known to occur in Cyprus (Aukema and Rieger 2006). Voucher specimens of these two species have been deposited in the Hemiptera Collection of the Hungarian Natural History Museum, Budapest.

As a result of our citizen science initiative a broad network comprising representatives of various sectors and the public could have been informed about the target pest with the objective to reveal its occurrence in Cyprus (Figure 2). However, up to 20 January 2020, no feedback from the members of either target groups arrived in the email account created to receive information on the occurrence of this pest, neither there were records of *H. halys* reported via the RIS-Ký Facebook group.

Discussion

Halyomorpha halys poses a severe threat to biosecurity all over the world. Since its introduction in continental Europe, it has been spreading rapidly and unstoppably (Haye et al. 2015; Cianferoni et al. 2018; Claerebout et al. 2018). Its hiding behaviour, as it is seeking shelter in dark places (Toyama et al. 2011), largely facilitates hitchhiking (Maistrello et al. 2018), which

makes this pest a notorious invader. Moreover, besides human-mediated dispersal, *H. halys* adults have a substantial flight capacity (Lee and Leskey 2015; Wiman et al. 2015), which may also contribute to the quick colonisation of contiguous land areas. However, as shown by previous flight mill assays, the average distance travelled per flight (i.e., without stopping for a rest) for *H. halys* was not more than 1 km, and it never reached 15 km (Wiman et al. 2015). The latter suggests that the risk of invasion of islands by active spread of *H. halys* adults considerably decreases with increasing distance from the continental coastal area. Therefore, islands located relatively far from the mainland should not be considered as threatened by flying immigrants of the pest. This is also the case with Cyprus, which is isolated from the surrounding mainland by more than 50 km. However, the accidental introduction of *H. halys* remains a real threat for islands all over the world as indicated by several interceptions (Harris 2010; Moore 2014; Vandervoet et al. 2019). This has recently resulted in monitoring activities for the early detection of this species by applying pheromone-baited traps throughout a large area, including high-risk locations for *H. halys* entry (Tassini and Mifsud 2019; Vandervoet et al. 2019). This method may help reveal the occurrence of alien *H. halys* both on the mainland (Ak et al. 2019) and, more specifically, near the entry points of imported goods on an island (Tassini and Mifsud 2019). However, covering the most risky point-of-entry sites fully and throughout the year with traps in order to make early detection as effective as possible would be rather expensive due to the high number of traps needed. It would also be time-consuming and labour-intensive for the personnel to be applied and trained for managing the traps continuously. Moreover, a recent study by Kirkpatrick et al. (2019) showed that the estimated maximum dispersive distance for *H. halys* adults was only 130 m when using pheromone-baited clear sticky traps set in an open position in the field devoid of host plants. This anticipates the need for setting many traps to reach a rational coverage of the high-risk locations. All these suggest that although trapping at potential entry points may be a good tool for early detection of *H. halys*, the use of pheromone-baited traps alone seems to have several concerns, including the considerable costs and efforts to be invested and the multifarious effects of the environment and landscape that may modify captures of the traps. In our study, the timing of trapping (September–October) was deemed to be suitable for the detection of still active individuals either recently and unintentionally introduced (e.g., with cargo or by travellers) or originating from small locally established populations under the detection threshold of local citizens. The lack of *H. halys* captured over the course of our study may, therefore, reflect the real absence of the pest at the sites of observation. However, as indicated above, the limited number as well as the potentially suboptimal position of the traps might also have affected the results. In order to increase the effectiveness of pheromone-based

monitoring for at-border early detection of *H. halys*, optimisation of the number and arrangement of traps by considering all the related costs but also the benefits of the potential early detection in the area of airports and harbours may be recommended. The trapping period should not necessarily be season-long but could also be optimised as set for that time of the year when the chance of capturing active *H. halys* adults can be considered relatively high (e.g., between late summer and mid-autumn in Europe).

The involvement of CS as an additional tool for observing *H. halys* completed our study. Although this method has already been proved to be suitable for detecting and following the range expansion of this pest quickly and broadly (Haye et al. 2014; Maistrello et al. 2016; Véték et al. 2018), it is difficult to predict how effective CS initiatives will be. On one hand, the communication channels and methods of information dissemination should be defined adequately so that data requests can reach the target groups effectively. However, even in this case the amount of replies and data received from the targeted citizens will largely depend on their motivation, enthusiasm and willingness to contribute and report observations. In our programme, the Bug Alert Cyprus letter, also available online, was created by adding eye-catching photos of the pest, a simple key for identification and a concise text (see Appendix 1), as recommended tactics (Tweddle et al. 2012), to attract the members of each target group (Figure 2). Timing of dissemination of information on the pest among plant health inspectors working at the airport of Larnaca, and the ports of Larnaca and Limassol, as well as the general public and the companies was considered optimal, because autumn has been indicated as the most favorable period to collect data on *H. halys* presence, i.e., when adult bugs are easy to notice within and on the wall of human-made structures (Hoebeke and Carter 2003; Maistrello et al. 2016, 2018). Even more, the informed citizens might have been expected to report the observation of overwintering *H. halys* individuals, which do not respond to the pheromone-baited traps reliably (Morrison III et al. 2017a), occurring anywhere in Cyprus. The fact that there was no feedback either on the platforms where the alert letter was web-announced or from groups specifically targeted by MARDE may confirm what could be assumed on the basis of the negative trapping results that *H. halys* was indeed absent in Cyprus by January 2020, or, if supposed to be present, has not yet reached the level of citizens' concern. However, the real number of citizens reached by our campaign (which has not been tracked) and the willingness to report should also be taken into account. For example, in spite of the considerable efforts made to obtain data through a wide variety of channels in a CS initiative to reveal *H. halys* occurrence in Romania, the response rate did not reach 0.2% (Ciceoi et al. 2017). The means of raising public awareness of the stink bug issue may be recommended, also in the case of this study initiated in Cyprus, to be further expanded by, for example, face-to-face presentations and conversations to

increase commitment of volunteers as well as of stakeholders by explaining the goals of the CS initiative. Personal interactions may significantly improve the motivation of participants to provide feedback as they can better understand the social purposes of the project (Tweddle et al. 2012; Cappa et al. 2016; Ciceoi et al. 2017), and this may result in a more effective monitoring program of this pest in Cyprus.

The absence of reports of observations by informed plant health inspectors working at the borders seems to confirm that *H. halys* has not reached the country, or at least it has not been intercepted yet. However, not only plant health inspectors, but also further border inspectors and operators should be informed about the pest and involved in the detection program for early warning. The reason for this is that *H. halys* can be introduced in the island, more likely, within inanimate objects (e.g., containers, vehicles, machinery) as adults, independently of plants and planting material. By having suitable crevices and being stored outside, these objects can provide good shelter both for single individuals or for overwintering aggregations (Duthie 2012). It is also noteworthy that “Vehicles, aircraft, vessels and associated transport equipment” and “Machinery and mechanical appliances, electrical equipment and parts” represented the most important imported/arrived commodity sections in total value in Cyprus, 2019 (Toumbaki 2019). Although the absence of interceptions cannot be taken as evidence of absence of the pest on the pathway due to several reasons (Duthie 2012), a recent study in New Zealand highlighted the significance of calling the attention of border inspectors to this particular species. In this case, the number of at-border interceptions was shown to have increased dramatically since 2013 when *H. halys* was added to the border monitoring survey list (Vandervoet et al. 2019). A similar official action may be recommended to take in the case of Cypriot airports and ports to reduce the risk that hitchhiker individuals of the pest remain undetected. During inspection, special attention should be paid to any transported goods and other objects imported or arriving from locations where there are known, established and mass populations of *H. halys* (e.g., Athens in Greece, Genoa in Italy, or Zurich in Switzerland) and, in general, to products from those countries which are the main sources of supply of goods to Cyprus, such as Greece and Italy (Toumbaki 2019). The use of biosecurity detector canines, which have been shown to have promising potential to locate concealed stink bug individuals (Lee et al. 2014; Moser et al. 2020), may also be considered in future inspections in order to reveal the presence of *H. halys* at borders before it enters and establishes on an uninvaded island.

To the best of our knowledge, our study is the first CS initiative in Cyprus focusing on the early detection of a highly polyphagous agricultural and nuisance pest. This work represents a combined monitoring approach in which the use of pheromone-based traps was completed with the

establishment of a network of citizens with the main objectives of detecting the invasive alien brown marmorated stink bug and raising citizens' awareness of the risks posed by this pest. This study aimed to reveal the occurrence of this species on an island country with the combined efforts described, and may serve as an example for initiating similar activities to help early warning and foster rapid response. Such activities can contribute to the maintenance of biosecurity of isolated environments all over the world.

Acknowledgements

The authors would like to thank Trécé, Inc. (Adair, OK, USA) for providing the Pherocon BMSB 24 week aggregation pheromone traps for this study. Special thanks are due to Dávid Rédei (Nankai University, China) for the identification of the stink bug species captured over the course of this study, the personnel of JSHU for technical assistance, as well as to Dmitry Musolin (Saint Petersburg State Forest Technical University, Russia), Mária Höhn (Szent István University, Hungary), Carl-Johan Nordberg (Wallenius Wilhelmsen Ocean, Sweden) and Balázs Károlyi (IBM Cloud Video, Hungary) for valuable consultations, and Siobhan Edney (UK Centre for Ecology & Hydrology) for a linguistic review. The authors also thank the two anonymous reviewers whose comments have improved this manuscript.

Funding Declaration

This research was supported by the COST Action 'Increasing understanding of alien species through citizen science' (ALIEN-CSI) CA17122 by providing financial support for Gábor Véték to conduct the research in Cyprus. This research was also supported by the Hungarian Ministry for Innovation and Technology within the framework of the Higher Education Institutional Excellence Program (NFKFIH-1159-6/2019) in the scope of plant breeding and plant protection research of Szent István University, and the NKTH 2017-2.3.3-TÉT-VN-2017-00006 research project by supporting Gábor Véték in the preparation of the article.

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Supplementary material

The following supplementary material is available for this article:

Appendix 1. The English version of the “Bug Alert Cyprus” letter disseminated in autumn 2019. This material is available as part of online article from:

http://www.reabic.net/journals/mbi/2021/Supplements/MBI_2021_Vetek_etal_SupplementaryMaterial.pdf