Exploring the Spread of Brown Marmorated Stink Bug in New Jersey Through the Use of Crowdsourced Reports

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The brown marmorated stink bug (BMSB), *Halyomorpha halys* Stål (Hemiptera: Pentatomidae), is an insect native to China, Japan, and Korea that is an invasive pest of agricultural crops in the mid-Atlantic United States (Hoebeke and Carter 2003, Gonzales 2012). It was introduced around 1996 into Allentown, Pennsylvania, and since then has caused significant crop losses in multiple states and has expanded its range to 42 states (StopBMSB 2014, Leskey and Hamilton 2014). High populations in 2010 resulted in more than $37 million in losses to apples and vegetables in the mid-Atlantic region (USApple 2011, Rice et al. 2014). As a highly polyphagous pest, it is able to feed on a variety of non-agricultural plants in addition to numerous agricultural crops. This has given *Halyomorpha halys* an advantage by using the diverse landscape of the mid-Atlantic to its benefit.

Attics and garages provide a suitable location for several overwintering insects. The multicolored Asian lady beetle, *Harmonia axyridis* Pallas, and boxelder bugs, *Boisea trivittata* Say, are known to overwinter in homes (Crenshaw 2011). *Harmonia axyridis* was introduced into the United States as a biocontrol agent and has since become a homeowner pest. Large aggregations overwinter in houses starting in the fall, and annoy and sometimes cause allergic reactions in homeowners (Huelsman et al. 2002, Koch and Gavan 2008). *H. halys* does not bite or harm humans or pets and is not known to transmit disease to humans, so it does not pose a public health threat; however, it is a nuisance pest to homeowners because it can use houses and man-made structures as overwintering sites. When the photoperiod and temperature decrease in the fall, *H. halys* adults begin moving into overwintering sites, where they remain until late spring (Nielsen 2009). Periodically, *H. halys* will emerge in a homeowner's dwelling throughout the winter season. It can enter through any small openings, such as gaps in the outer frame of windows or doors. In some cases, *H. halys* can be found in extremely high numbers. One homeowner was able to document 26,205 individuals in his house over half a year (Inkley 2012). Large aggregations of *H. halys* such as this can pose problems for homeowners, as they can continuously emerge by the dozens or hundreds every day throughout the winter and early spring. It also overwinters in dead trees in forested areas (Lee et al. 2014), which can be a refuge for populations that can subsequently invade other nearby suitable locations.

Monitoring of *H. halys* has been conducted mostly in agricultural settings using baited pyramid traps, visual sampling, and blacklight traps (Leskey et al. 2012b). These traps are mainly in or close to soybean, vegetable, and fruit-producing farms. Currently, *H. halys* control involves frequent insecticide application, which has disrupted established IPM programs (Leskey et al. 2012a). New Jersey has been recording *H. halys* catches from blacklight traps throughout the state since 1999. All blacklight trap locations in New Jersey have been georeferenced and insect captures associated with each blacklight trap have been recorded (Holmstrom et al. 2001). At present, the data gathered from the blacklights are used to create weekly maps of the distribution of corn earworm, European corn borer, and *H. halys* catches so that New Jersey growers can be aware of the presence and buildup of these pests.

In the past 20 years, advancements in mapping technology and access to technologies that allow us to georeference our location have allowed for increased acquisition and accuracy of data. The ubiquity of the internet, cell phones, and wireless technology have led to increasing importance of mobile GIS as a mode of data acquisition. This has led to the increased interest in citizen science and crowdsourcing data. Citizen science projects are a form of gathering crowdsourced data, which refers to data gathered by a large network of people. A citizen scientist is "a volunteer who collects and/or processes data as part of a scientific enquiry" (Silverton 2009). Utilizing citizen science is a cost-effective tool that allows scientists to gather or analyze large amounts of data that would otherwise be impossible by the efforts of a single person. Citizen scientists participate as volunteers and are not compensated for this work, but oftentimes have a reason to contribute to the project. For example, avid birdwatchers have reported sightings to websites such as eBird, from which the collected data can be used to investigate conservation efforts (Sullivan et al. 2009). Goodchild (2007) remarks that what he terms "volunteered geographic information" has the potential to be a significant source of geographers' understanding of the surface of the earth. Crowdsourcing data through the use of non-professional scientists has the potential to be incredibly useful when collecting and examining data over a long time period and across a wide geographic range.

Utilization of crowdsourcing has been beneficial to the public and scientists in a multitude of ways. From the Sam Adams brewery asking the public for help with designing a beer to crowdfunding video games or new technologies on Kickstarter, the public has been shown to be a powerful tool. Cell phones and the internet have been vital in many of these endeavors. For example, after the earthquake in Haiti in 2010, crowdsourcing of text messages and the utilization of GPS coordinates uploaded by volunteers aided with disaster relief through the use of maps to guide personnel to people in need (Zook et al. 2010).

Citizen science and crowdsourcing have been prevalent in the sciences as well. Oftentimes in research studies, there is a large amount of data to process or an extensive geographic range to cover. This poses a problem for a single researcher or even a small team of researchers. One such project is the SETI@home distributed computing project, which has the goal of searching for extraterrestrial life by utilizing multiple computers to analyze radio frequencies. This project started in 1999 and now has millions of participants volunteering their computer power. Birdwatching is another example of a popular citizen science activity. The Audubon Society's Christmas Bird Count started in 1900 and has been a source of data used by scientists to look at variation in sightings or arrival dates of birds due to climate change.

The ordinary citizen's enthusiasm for insects is not as high as that for birds, but some of the more colorful and apparent insects have caught the public eye. The North American Butterfly Association's Butterfly Count Program has been used to monitor butterflies to better quantify their range and abundance (NABA 2015). Monarch migration has been monitored during the fall to overwintering sites (Howard and Davis 2009). The Cape May monitoring project is an example of an organization that monitors monarch migration along the Atlantic coast. Data for the periodical cicada, *Magicicada* spp., have been collected through the website www.magicicada.org and used to map distributions of the insect to detect range changes (Cooley 2015).

In regards to *H. halys* as a nuisance pest, citizens have been asked to report initial sightings of the insect in their dwellings so that the spread of the initial infestation could be tracked and monitored. By utilizing GIS (Geographic Information Systems) and mapping, we can get a better picture of how populations of *H. halys* are moving throughout the state of New Jersey and beyond. Since *H. halys* can overwinter in many different habitats, are highly polyphagous, and have a high rate of dispersion, it is useful to have visual representations of how populations are spreading and dispersing throughout the state. Utilizing mapping technology allows us to do this and analyze additional questions such as how landscape features affect population clustering and densities. Using the spatial context of data points, our understanding of the movement of *H. halys* can be better explained.

New Jersey has a large set of historical monitoring data of *H. halys* collected from blacklight traps throughout the state. Specimens were collected from traps starting in 1999; however, data from 2004 to the present day is used in the analysis because active monitoring was conducted in these years. In addition to the blacklight traps, our lab began documenting the date and location of positive confirmation of inquiries of *H. halys* in houses using the internet in 2004 (https://njaes.rutgers.edu/stinkbug/report.asp). This arose out of the need to track BMSB populations as they spread through New Jersey and the United States. A website (https://njaes.rutgers.edu/stinkbug/) was designed to act as a repository for reports and included descriptions of the insect to assist the public with identification.

A few studies have used mapping to describe crowdsourced data. Monarch migrations and cicada broods have been mapped using citizen scientist and crowdsourced data (Howard and Davis 2009, Cooley 2015). However, integrating crowdsourced data sets with other monitoring methods to examine an invasive pest insect has not been examined, to our knowledge. New Jersey has a highly diverse landscape and is separated into four major physiographic provinces (Valley and Ridge, Highlands, Piedmont, and Coastal Plain) that are ecologically similar in respect to the flora and fauna, and it is the most densely populated state in the United States (Lathrop 2005). This has given us a unique opportunity to look at a pest through the eyes of the public. Maps were created to visually display *H. halys* trap capture data and crowdsourced data throughout New Jersey from 2004 to the present day using ArcGIS, investigate the spatial context of the data points that may contribute to the differences between maps, and determine if there is any correlation between trap captures and the spread of the crowdsourced reports. These data and maps show that additional tools such as crowdsourcing data can be a positive supplement to traditional monitoring of insect populations.

Materials and Methods

The web-based crowdsourced reports. In 2004, a website was developed on the New Jersey Agricultural Experiment Station portal for the purpose of disseminating information about *H. halys* to the public. The website (http://njaes.rutgers.edu/stinkbug/) includes links to an extension fact sheet and instructions on how to identify *H. halys*, how to prevent or manage the insect in houses and agricultural fields, and serves as a reporting portal in which people can report a finding of *H. halys* in their house. The website initially provided an e-mail address as a means for people to ask questions about *H. halys* and send in pictures asking for help with identification. The lab's physical address was also provided in the case that citizens sent physical samples of the insects for verification. Information about the location and date of reports was logged into a spreadsheet. The goal of providing our e-mail and physical address was to track the spread of *H. halys* by asking for citizens throughout the United States to report the first sighting of *H. halys* on their property. They were asked to refrain from reporting in subsequent years to prevent duplication. In 2013, reports since 2004 were consolidated into a database maintained by the Bugwood network (http://www.bugwood.org/). The data collected included the date of observation, city, county, and state. Latitude and longitude were added while samples and reports were collected. Only the presence of *H. halys* was recorded; we did not ask for magnitude of infestation or the total number of *H. halys*. Collected data was verified as *H. halys* by experienced researchers through pictures or physical samples sent in the mail. Now, the website includes a form with which reporting homeowners can fill in their information. The requested information includes name, e-mail address, observation date, state, county, location description, and images of the insect.

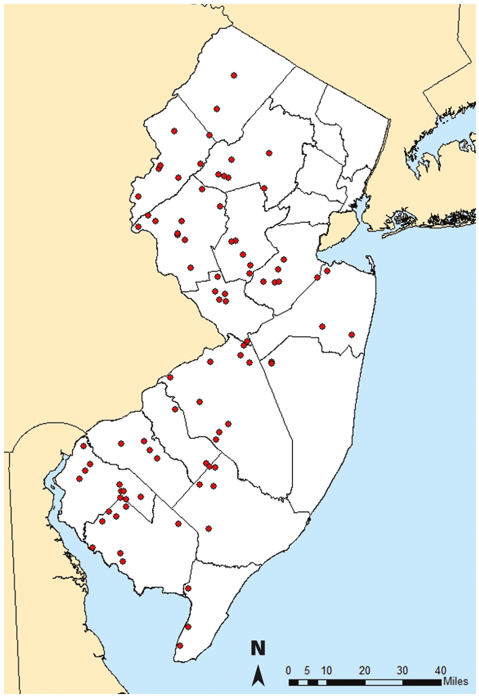

Fig. 1. The location of blacklight traps used in this study distributed throughout New Jersey from 2004-2015. Not all traps were deployed and active each year.

Table 1. The number of blacklight traps deployed and monitored by Rutgers Cooperative Extension in agricultural fields throughout New Jersey.

Year	Number of traps
2004	72
2005	69
2006	69
2007	67
2008	65
2009	61
2010	64
2011	62
2012	60
2013	56
2014	53

Blacklight traps. Blacklight traps used to monitor insect pests have been in place on agricultural land throughout the state of New Jersey since the 1970s. These were used to track the spread and occurrences of agricultural pests and communicate management needs to growers. The numbers of traps that were in operation are listed for each of the years in which crowdsourced reports were collected (Table 1). A map of the full extent of the trap distribution in New Jersey is included (Fig. 1). Not all traps were active each year. Traps were checked twice weekly from April/May through October/November. The exact deployment, retrieval, and monitoring dates of particular traps varied between years. Data included the date of observation, trap location, latitude, longitude and number of *H. halys* found. Data from years 2004-present were used in the analysis.

***Halyomorpha halys* abundance/monitoring mapping.** The total abundance of *H. halys* in blacklight trap captures and the number of crowdsourced reports per year from 2004 to 2013 were plotted on a scatterplot. After plotting the scatterplot, examination of specific years was chosen to represent different periods of the invasion. The years 2007, 2009, 2010, and 2012 were investigated more closely with the creation of maps and analysis. The year 2007 was chosen to represent the rising population of *H. halys*, 2009 the highest number of crowdsourced reports, 2010 the highest number of trap captures, and 2012 the decrease in both trap captures and crowdsourced reports. The average number of *H. halys* captures per trap sample date and the total number of crowdsourced reports from each of these years were also plotted on a scatterplot. The data were mapped using ArcMap (ESRI 2014, ArcGIS Desktop, 10.2, Redlands, CA). Maps were created to display the number of *H. halys* from blacklight trap captures from 2007, 2009, 2010, and 2012. Maps were also created to display the number of crowdsourced reports from each of those years. Kernel density maps were made using the corresponding ArcMap toolbox to complement each of the maps of the crowdsourced reports. Maps of the crowdsourced reports in different

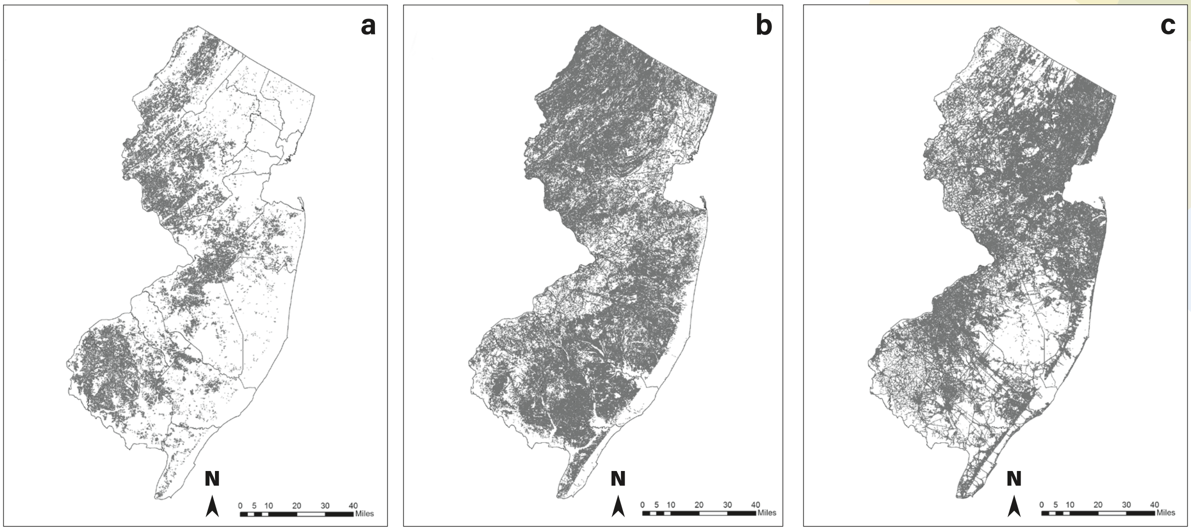

Fig. 2. Maps representing the agriculture(a), forest(b), and urban(c) land use/land cover types in New Jersey.

"seasons" (defined as intervals between the spring equinox, summer solstice, fall equinox, and winter solstice) were also created for all years.

Land use and density mapping of crowdsourced reports. Land use/land cover data were downloaded from the New Jersey Department of Environmental Protection website (http://www.nj.gov/dep/gis/). This data layer was created in 2007 for each of the 20 watershed management areas in New Jersey. The shapefiles for the 20 watershed management areas were merged using the Merge toolbox in ArcGIS. The TYPE07 categories of Agriculture, Forest, and Urban were extracted using the Clip toolbox. A buffer region of ¼ mile with all features dissolved was then added around all three land use shapefiles. In total, there were six shapefiles of land use: Agriculture, Forest, Urban, Agriculture + ¼ mile buffer, and Forest + ¼ mile buffer. Maps are provided in Fig. 2 to provide a sense of the distribution of agriculture, forest, and urban land use types. The number of crowdsourced reports for each reporting year was counted in each of these six land use shapefiles by using a spatial join of the land use data set and the crowdsourced data set.

Population data from the 2010 census for counties in New Jersey were downloaded from the New Jersey Office of Information Technology and the Office of Geographic Information Systems (https://njgin.state.nj.us/NJ_NJGINExplorer/DataDownloads.jsp), and the population in each county was displayed on a map (Fig. 3). The shapefile used for this was labeled "Counties of New Jersey, New Jersey State Plane NAD83." This data was used to calculate a relative number of crowdsourced reports per 100,000 people in each county for each year's reports. This was calculated using Raster Calculator utilizing the maps of the 2010 census data and the maps of the crowdsourced reports.

In order to standardize the trap captures due to the varying number of traps per year and variation in the dates of trap deployment and retrieval, trap captures were calculated by county and tabulated as the number of *H. halys* per trap. A regression analysis was conducted to determine if the magnitude of trap capture values was correlated with the number of crowdsourced reports per 100,000 people per year for 2007,

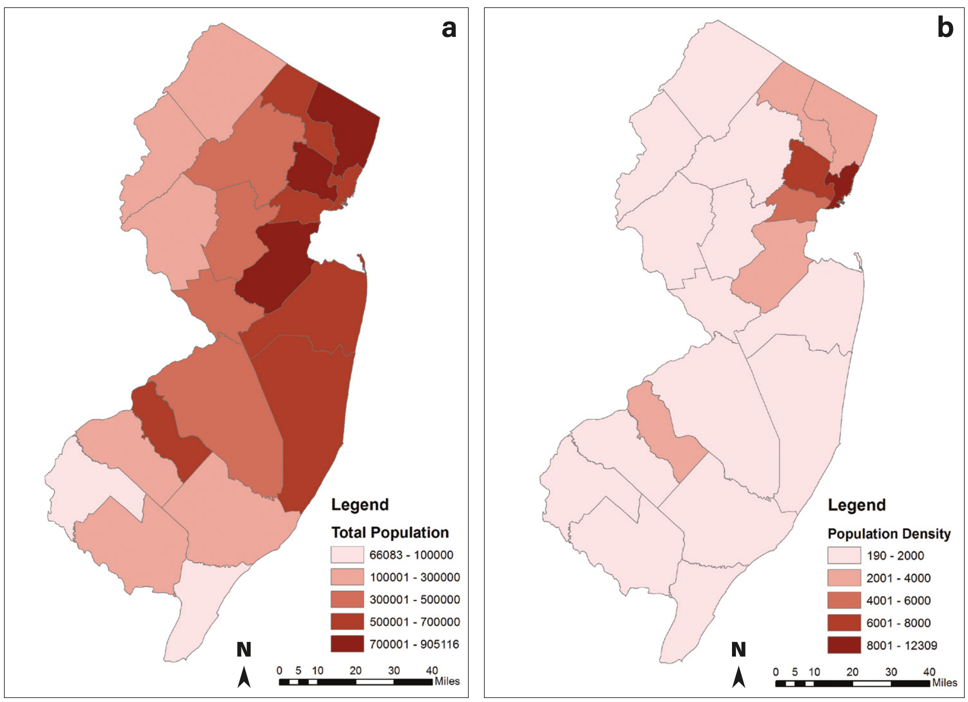

Fig. 3. The population(a) and population densities(b) of the counties in New Jersey.

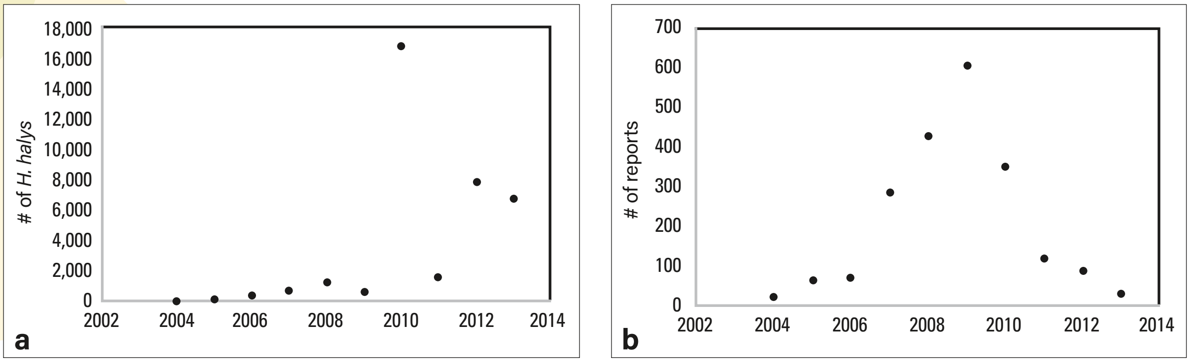

Fig. 4. The number of *H. halys* captures in blacklight traps deployed throughout agricultural fields in New Jersey(a) and the number of confirmed crowdsourced reports of *H. halys*(b).

2009, 2010, and 2012.

Results

The abundance of *H. halys* in blacklight trap captures was low starting in 2004, but gradually increased until it reached peak populations in 2010 (Fig. 4a). In subsequent years, populations were lower than in 2010, but still exhibited higher numbers in comparison to earlier years. The number of crowdsourced reports per year (Fig. 4b) also started low and increased steadily until 2009; in the following years, the number of reports decreased. Crowdsourced reports were higher in the beginning of the calendar year (January–March), then decreased until August/September, when reports increased (Fig. 5). The number of reports in November and December remained low. The trap captures, which were monitored from April or May through October or November, exhibited low numbers of *H. halys* captures from April through May, but high numbers in the months of July and August followed by a decrease until the traps were taken down in October or November.

The number of *H. halys* captures in blacklight traps indicated low populations early in the invasion, mostly centered on land in western New Jersey (Fig. 6). By 2009, there were high populations throughout the state of New Jersey that have remained established through the present day. The overlaid kernel density maps show red hot spots of high densities of reports versus the colder blue spots of low numbers or no reports (Fig. 7).

Crowdsourced reports from the different seasons appear to have a widespread distribution throughout the state. In 2007, a high number of reports was found in the central area of New Jersey in the fall, with fewer reports in the other seasons (Fig. 8a). In 2009, reports emerged from the same region, but were more evenly distributed throughout each season, although the number of reports

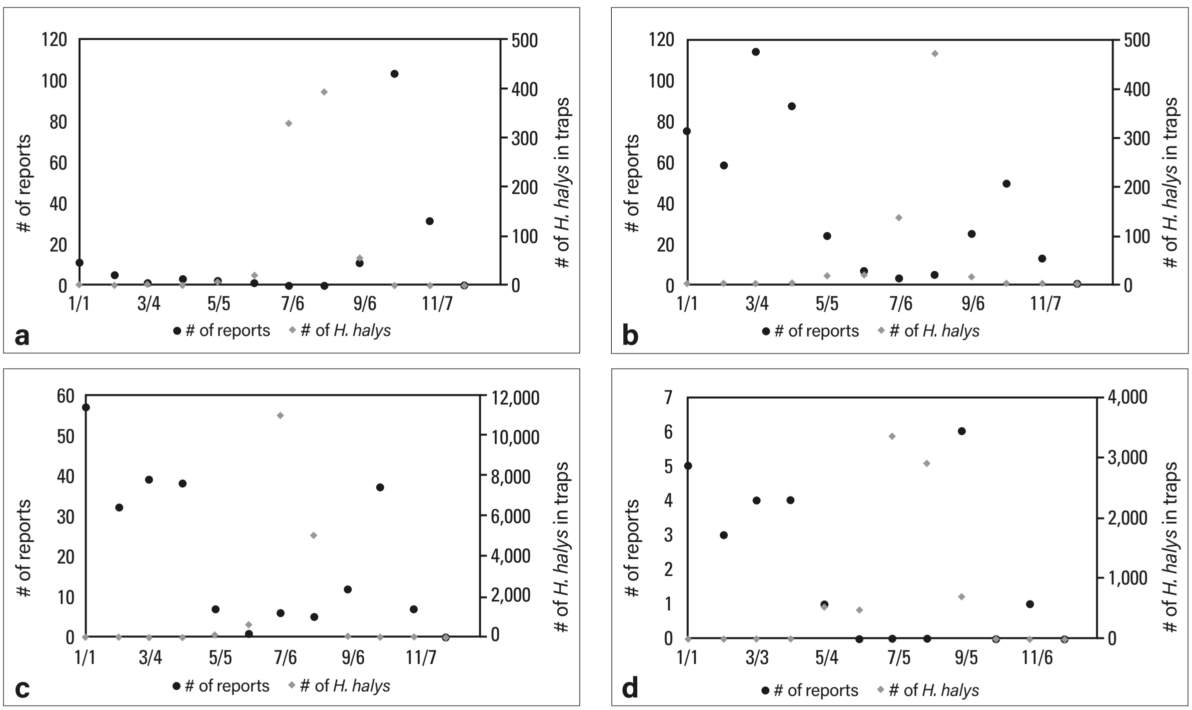

Fig. 5. The number of *H. halys* captures in blacklight traps and the number of reports of *H. halys* in crowdsourced reports for the years 2007(a), 2009(b), 2010(c), 2012(d).

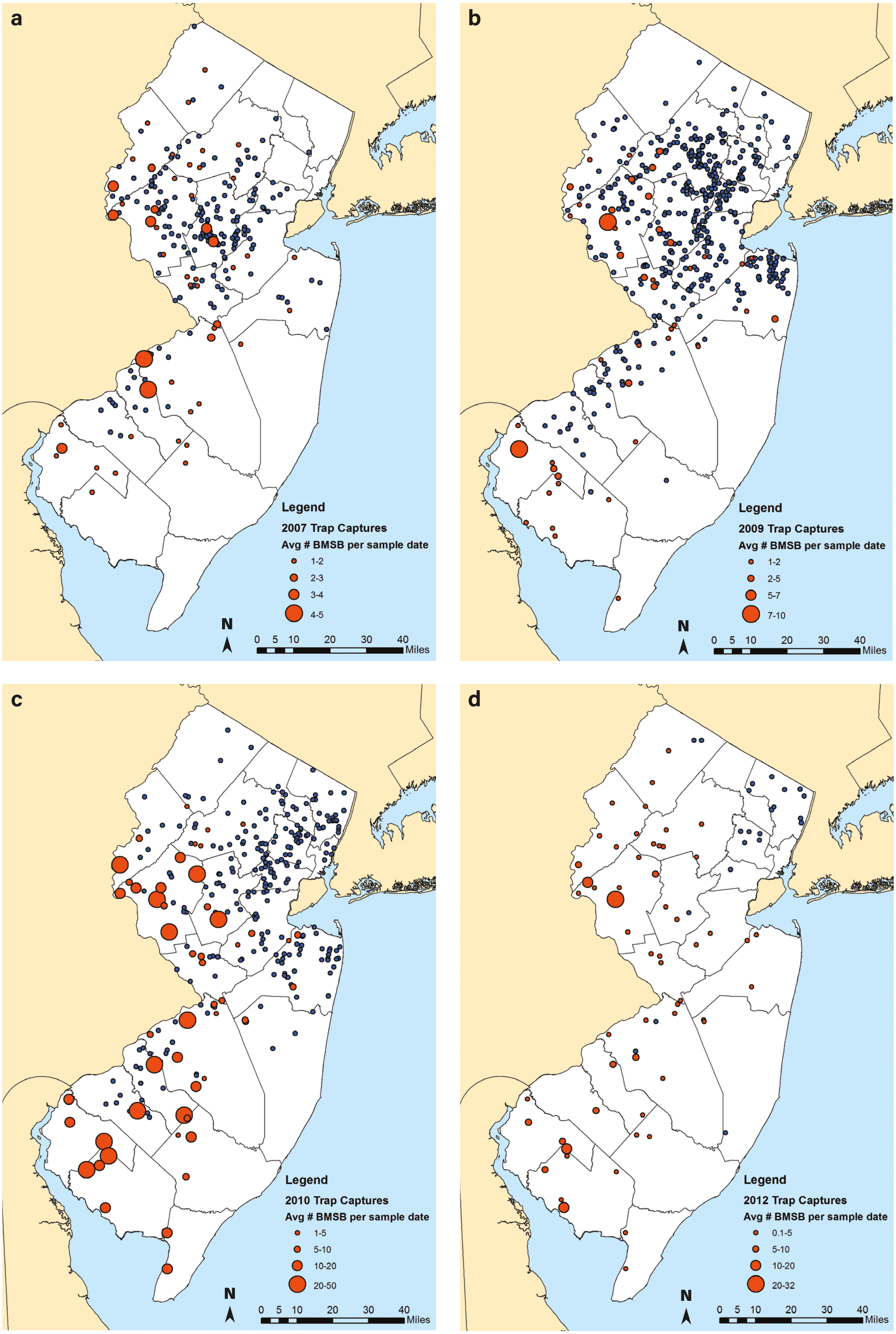

Fig. 6. New Jersey map of the number of *H. halys* caught in blacklight traps and crowdsourced reports in 2007(a), 2010(b), 2011(c), 2012(d).

from the summer remained low (Fig. 8b). In 2010, the overall number of reports was lower, with most reported in spring, fall, and winter, from areas closer to the urban centers of New York and Philadelphia (Fig. 8c). In 2012, there were very few reports, and they were clustered in northeastern New Jersey (Fig. 8d).

Almost all reports were from land cover that is considered "urban" land use. Land use classifications were determined by photo-interpreters' examination of aerial photography by the NJDEP. The number of crowdsourced reports in areas considered to be in forested or agricultural areas was low, but when looking at a larger coverage

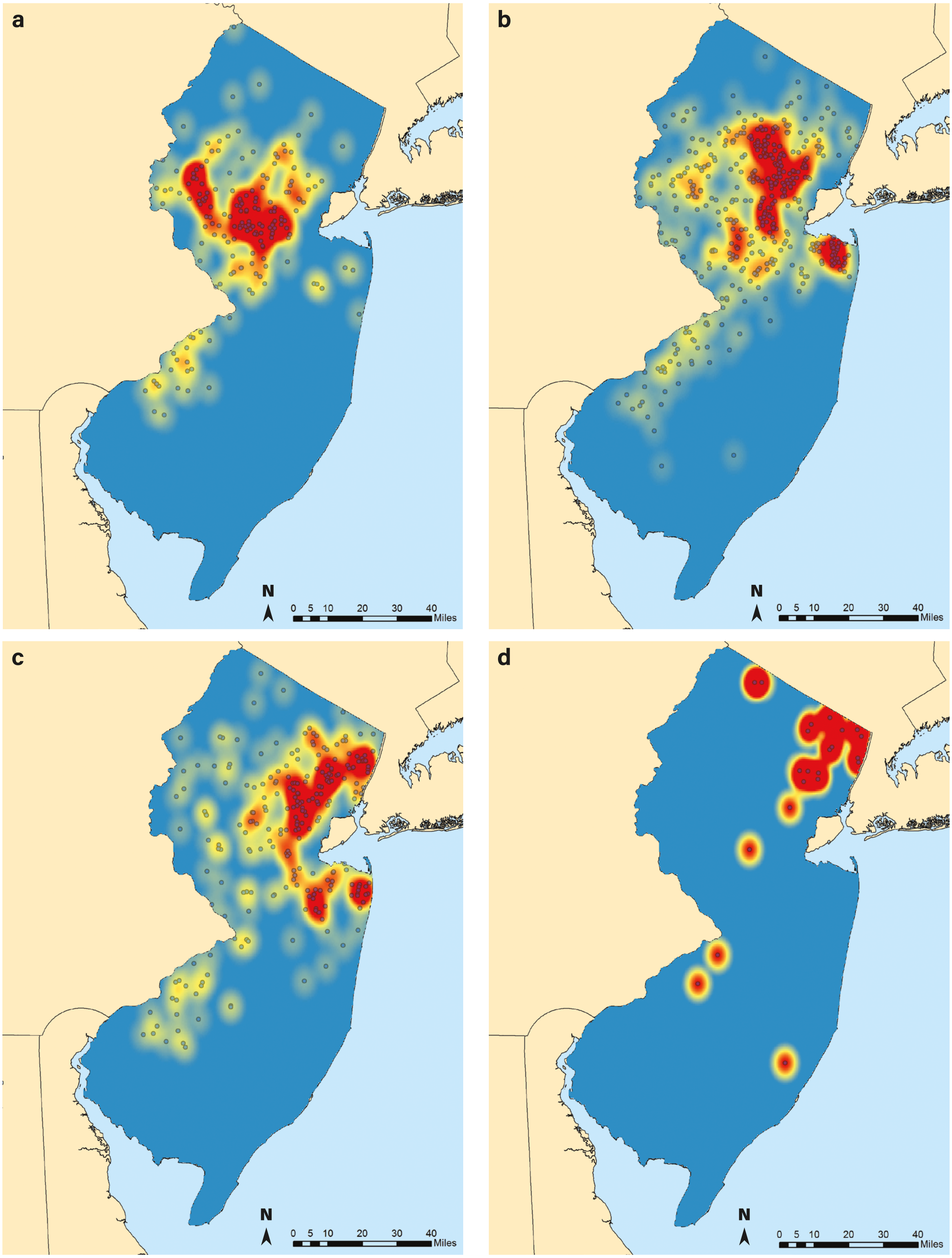

Fig. 7. Maps representing kernel density of the crowdsourced reports of *H. halys* in New Jersey in 2007(a), 2009(b), 2010(c), 2012(d). Blue colors represent areas with low kernel density and red areas represent areas with high kernel density.

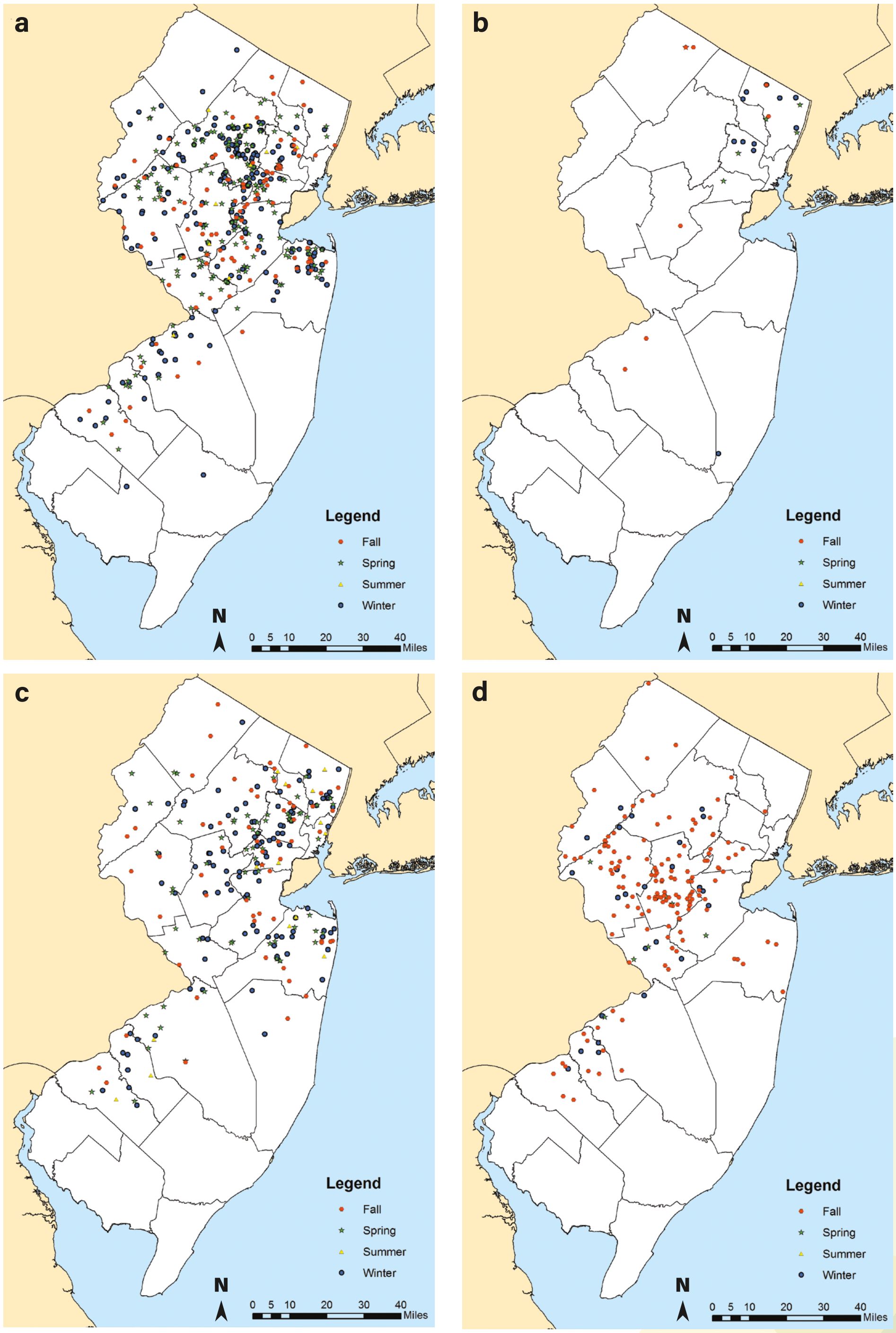

Fig 8. Maps of the number of crowdsourced reports of *H. halys* by season in 2007(a), 2009(b), 2010(c), and 2012(d).

area within a ¼ mile buffer region around the land use classes, many more reports were found (Table 2). Greater than 90% of all reports per year were found within the ¼ mile buffer around forested land use, with the exception of the three reports in 2013.

The regression analysis revealed significant correlation between the number of *H. halys* in blacklight trap captures and the number of crowdsourced reports as partitioned by county in the earlier years of the infestation (2007 and 2009) (Fig. 9a, b). However, there was a decrease in correlation in the number of *H. halys* in traps and the crowdsourced reports as the trend was not significantly significant in 2010 and 2012 ($p > 0.05$, Fig. 9c, d).

Discussion

The invasion of the brown marmorated stink bug has allowed us a great opportunity to look at the spread of a pest species through a different lens. The initial invasion of *H. halys* originated from the area around Allentown, Pennsylvania, just 20 miles west of the New Jersey border. Through our trapping efforts, detection of the pest in western New Jersey was very useful, as the spread of *H. halys* indicated that management techniques should be implemented on farms throughout the region. Maps of the crowdsourced data indicate a similar pattern, with low populations of *H. halys* in the western part of the state in the early years of the invasion. As the years progressed, *H. halys* was able to establish itself throughout the state. This was apparent in both the blacklight trap data and the crowdsourced data. By 2009, there were hundreds of reports from homeowners reporting *H. halys* in their dwellings. In subsequent years, there was a drop-off in the number of reports, possibly due to fewer novel infestations, lower media coverage, or homeowners becoming accustomed to the presence of *H. halys*.

The majority of homeowner reports were received from fall through the spring. Very few reports were received during the summer. This was most likely due to the fact that during that time, the stink bugs had left inhabited structures, used as overwintering sites, and were out in areas where they could feed and reproduce. Although the number of reports was low at that time, the blacklight trap captures were continuously high each year during the summer. Even though trapping was not conducted in the late fall, winter, and early spring, numbers indicate that although *H. halys* is still present in the region during these seasons, its presence in agricultural fields does not reach peak levels until the months of July and August.

The majority of the homeowner reports were found to be reported from what is classified as urban land. Urban land did not encompass all of the reports, most likely due to land use changes since the 2007 land use survey was conducted. There were a lower number of reports from

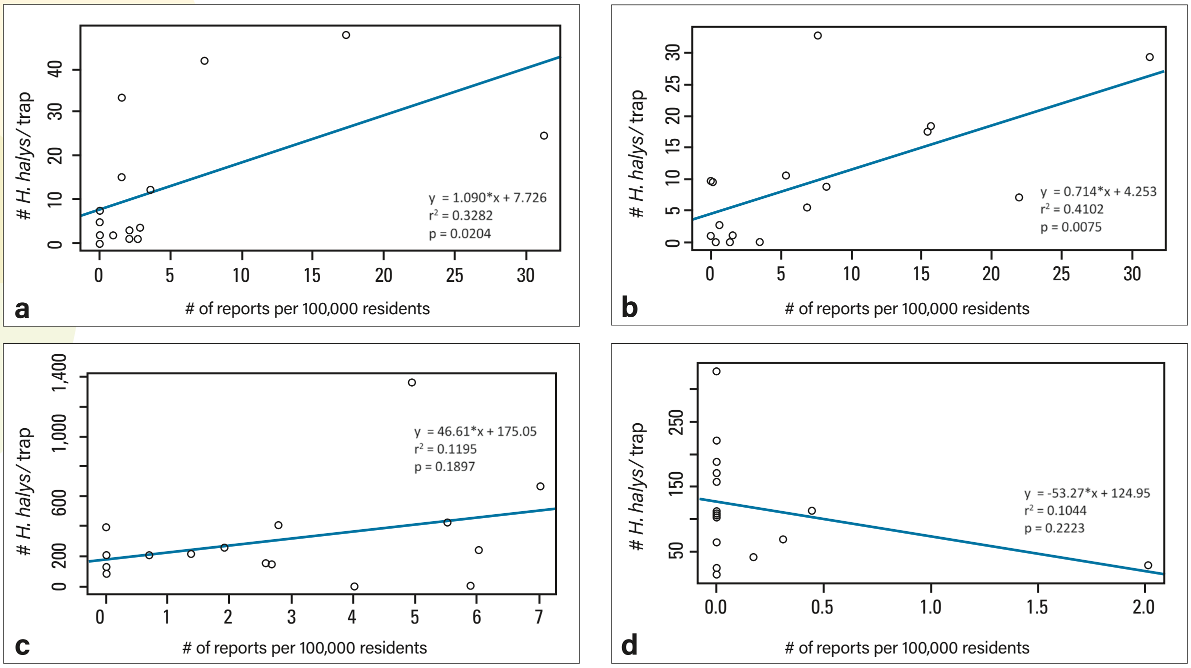

Fig. 9. Linear regression of the number of crowdsourced reports per county and the number of *H. halys* captured per county in 2007(a), 2009(b), 2010(c), and 2012(d).

agricultural and forested lands. However, when a ¼-mile buffer was created around the forested land, the majority of reports occurred within that area. A ¼-mile buffer around the agricultural land yielded additional reports as well, but not to the magnitude seen for forested land. This suggests that many of the *H. halys* adults are emigrating from forests into homes rather than from agricultural land, supporting Lee (2014), which found overwintering adults in dead trees. It is also possible that there is not as much urban development around agricultural lands in New Jersey than there is around forested land.

Although a relationship was seen between crowdsourced reports and trap captures in 2007 and 2009, there was a noted decrease in the relationship in 2010 and 2012, after the earlier years of infestation. This may be attributed to a decreased interest in reporting. Although the blacklight traps were located predominantly in western

Table 2. The number of reports that were found in agricultural land, forested land, and urban land or within a ¼ mile buffer within agricultural and forested land.

Year	Agriculture	Forest	Urban	Ag + ¼ mile buffer	Forest + ¼ mile buffer	Total # of reports
2006	3	6	34	27	42	43
2007	3	17	168	95	179	188
2008	6	16	300	134	305	322
2009	9	21	440	175	451	470
2010	3	7	238	66	217	248
2011	0	8	50	17	52	58
2012	1	2	21	6	23	24
2013	0	0	3	0	0	3

agricultural areas of the state, the data is indicative of the movement of the *H. halys* population in the state of New Jersey as it spread throughout the state and encompassed additional counties that did not include any trapping. The crowdsourced data perhaps showed this trend in the data more clearly and could be a helpful monitoring tool that could supplement traditional trapping methods.

There are some inherent problems with crowdsourced data. By nature, it is not collected by professional research scientists, and is therefore prone to having some inaccuracies due to misidentifications. This was mitigated by the confirmation that a homeowner had in fact found *H. halys* through the use of pictures or physical samples. There is also the issue of the wane in public interest. In the initial phases of the invasion, homeowners were unfamiliar with a new insect invading their homes, and were eager to find out what it was and how to get rid of it. Now, almost 20 years after the initial invasion, most homeowners in the region are very familiar with the brown marmorated stink bug, either through news channels or the internet. In fact, Google trends indicate a peak of searches starting at the end of 2010, when large numbers of *H. halys* were invading homes (https://www.google.com/trends/explore#q=stink%20bug). At this point, homeowners may not be eager enough to report their sightings, or have yielded to the bug. When and if there is another surge in populations, it would be interesting to see how the trend in reporting changes, and if there is another flood of interest. Crowdsourcing data from the public has yielded a data set that would have otherwise been difficult to acquire due to the length of time and the wide geographic spread of the reports. Investigating the presence of *H. halys* in homeowners' dwellings over the course of the past decade would have taken a researcher or a team a large amount of coordination, time, and money. With coordinated and planned data collection and increased education and outreach, crowdsourced reports such as these have the potential to serve as an essential tool for improved integrated pest management (IPM).

Acknowledgments

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