A New Invasive Species in Maryland: the Biology and Distribution of the Kudzu Bug, *Megacopta cribraria* (Fabricius) (Hemiptera: Plataspidae)

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ABSTRACT: The relaxation of trade restrictions in the 1960s and -70s led to an unintended exchange of invasive insect species as well as manufactured goods between the United States and its new trade partners. Consequently, the number of exotic insect pests accidently entering and taking up residence in the United States has increased dramatically over the past several decades. A recent arrival from Asia, the Kudzu Bug, *Megacopta cribraria* (Fabricius) (Hemiptera: Plataspidae), also known as the Bean Plataspid, Lablab Bug, and Globular Stink Bug, represents a family new to this continent. Although it belongs to the stink bug infraorder Pentatomomorpha, *M. cribraria* is the only member of the family Plataspidae currently known to occur in the New World. First reported in Georgia in 2009, *M. cribraria* has spread rapidly and was confirmed in eight Maryland counties in 2013. Initially regarded as a nuisance pest by home owners, *M. cribraria* has become a serious pest of soybeans (*Glycine max* [L.] Merr. [Fabaceae]), and potentially, of other leguminous crops (Fabaceae) in its introduced range. This article summarizes the known history, biology, identification, and movement of *M. cribraria* in the United States and Maryland to date, as well as environmentally responsible integrated pest management options.

INTRODUCTION

The first record of the Kudzu Bug, *Megacopta cribraria* (Fabricius) (Hemiptera: Plataspidae) in North America occurred in 2009 when it was discovered feeding on kudzu, *Pueraria montana* (Lour.) Merr. (Fabaceae), and congregating in large numbers on the exteriors of nearby homes and vehicles in nine counties in northeastern Georgia (Eger et al. 2010, Suiter et al. 2010). This true bug is a member of the family Plataspidae

and is native to the Indian subcontinent and Asia (Srinivasaperumal et al. 1992, Hua 2000). The exact date, location, and mode of entry into the United States are unknown (Zhang et al. 2012). However, it appears that the establishment of *M. cribraria* in the United States may have occurred as the introduction of a single female line (Jenkins et al. 2010, Ruberson et al. 2012). Specimens of the invasive pest were collected in October 2009 and submitted to the University of Georgia College of Agricultural and Environmental Science (UGA-CAES) Homeowner Insect and Weed Diagnostics Laboratory for identification. The plataspid was tentatively identified by Joseph E. Eger, Jr. (Research Scientist, Dow AgroSciences, Tampa, Florida), and identification was confirmed in November 2009 by David A. Rider (Professor, Department of Entomology, North Dakota State University, Fargo, North Dakota), Susan E. Halbert (Taxonomic Entomologist , Florida Department of Agriculture & Consumer Services, Gainesville, Florida), and Thomas J. Henry (Research Entomologist, United States Department of Agriculture - Agricultural Research Service - Systematic Entomology Laboratory (USDA-ARS-SEL), Washington, DC) (Eger et al. 2010, Jenkins et al. 2010, Suiter et al. 2010). Voucher specimens are on deposit in the Florida State Collection of Arthropods, Gainesville, Florida, and the United States National Museum of Natural History, Smithsonian Institution, Washington, DC (Suiter et al. 2010).

Froeschner (1984) concluded that no species of Plataspidae inhabited North America, so reports of *M. cribraria* from Georgia were a new United State record and the first known establishment of a species of Plataspidae in the Western Hemisphere. Over the next several weeks, specimen samples were sent in from eight additional north and central Georgia counties. *Megacopta cribraria* detections continued to increase rapidly, and by 2010, the insect was confirmed in dozens of Georgia counties, as well as limited distributions in Alabama, South Carolina, and North Carolina (Gardner et al. 2013b). Detections continued to expand and by 2013, *M. cribraria* had been confirmed in twelve southeastern states (Alabama, Delaware, Florida, Georgia, Kentucky, Louisiana, Maryland, Mississippi, North Carolina, South Carolina, Tennessee, and Virginia) and the District of Columbia. *Megacopta cribraria* was first detected in Maryland in five southern counties from mid-June to early July 2013: Anne Arundel, Calvert, Charles, Prince George's, and St. Mary's Counties (Leslie and Lamp 2013a). Two additional counties, Montgomery and Dorchester, were added by the end of August 2013. The Dorchester County detection is the first on the Maryland portion of the Delmarva Peninsula, although it had already been found on both the Delaware and Virginia sections (Leslie and Lamp 2013b).

Initially considered a nuisance pest like its distant cousin, the Brown Marmorated Stink Bug (*Halyomorpha halys* Stål [Hemiptera: Pentatomidae]), Del Pozo-Valdivia and Reisig (2013) showed that first-generation *M. cribraria* were able to feed exclusively on soybeans (*Glycine max* [L.] Merr. [Fabaceae]), reach maturity and reproduce. Until then, it was believed that feeding on kudzu vine was required for successful reproduction (Zhang et al. 2012). *Megacopta cribraria* is now considered a serious economic pest of soybeans that may be able to spread anywhere within the United States that soybeans are grown (Ruberson et al. 2012, Gardner et al. 2013b). With a confirmed rapid spread from nine counties in one state in 2009, to hundreds of counties in 12 states and the District of Columbia in only four years, *M. cribraria* has already established itself as an economic

pest of soybeans in the south, and may pose a threat to other leguminous crops (Fabaceae) (Gardner et al. 2013b).

BIOLOGY AND DESCRIPTION

Megacopta cribraria (Figure 1) belongs to the order Hemiptera in the suborder Heteroptera, the true bugs, and is a member of the infraorder Pentatomomorpha, including stink bugs, shield bugs, and relatives. In its native range in Asia and India, it is reported to have up to three generations annually (Eger et al. 2010), but thus far has produced two generations annually in the southern United States (Zhang et al. 2012). *Megacopta cribraria* overwinters as an adult in cracks and crevices of buildings and structures, in leaf litter, and under the bark of trees located near host plants. In the United States, adults emerge in spring, form large mating aggregations, and begin laying first-generation eggs in April (Zhang et al. 2012), most frequently on kudzu vines (Figure 2). Adults are strong flyers, and there are three peak periods of adult flight activity: early spring (April/May) when overwintering adults first emerge, throughout the summer (June-August) when first-generation adults are active, and then in the fall (October) when second-generation adults mature. It is second generation adults that overwinter (Zhang et al. 2012), but it may be possible that *M. cribraria* can remain active all year in warmer climates (Thippeswamy and Rajagopal 1998, Eger et al. 2010). Both adult and nymphal populations display an edge effect, being found in greater numbers around the perimeters of fields where they are feeding, than in the interiors (Seiter et al. 2013b).

Figure 1. Kudzu Bug, *Megacopta cribraria* (Fabricius) (Hemiptera: Plataspidae), adults. Left: dorsal view; Right: anterodorsal view. (Image credits: Left: William O. Lamp; Right: Bill Johnson, Bill Johnson Nature Stock Photography, Inc. [by permission])

Female *M. cribraria* are reported capable of laying 26 to 274 eggs (Eger et al. 2010) in masses of about 20 eggs each, with a reported range of 16 to 28 per cluster (Zhang et al. 2012, Del Pozo-Valdivia and Reisig 2013, Gardner et al. 2013b), typically deposited in two parallel rows (Figure 3). Egg masses are usually located on new leaf growth in the upper canopy of kudzu, but also on the undersides of leaves and vines of older plants (Eger et al. 2010, Zhang et al. 2012, Seiter et al. 2013c). Females deposit small brown capsules containing the gut symbiotic γ-proteobacterium '*Candidatus* Ishikawaella

Figure 2. Kudzu, *Pueraria montana* (Lour.) Merr. (Fabaceae). Top: close-up; Bottom: vines overwhelming a tree. (Image credits: Alan W. Leslie)

Figure 3. Kudzu Bug eggs on a kudzu leaf. Top: freshly laid; Middle: older, but not yet hatched; Bottom: hatched and unhatched. (Image credits: Top and middle: Alan W. Leslie; Bottom: Bill Johnson)

Figure 4. Kudzu Bug nymphs. Top left, top right, middle left: early to mid-instars; Middle right: 4th or 5th (late) instar; Bottom: various instars on kudzu vine. (Image credits: Top left, top right, middle left: Bill Johnson; Middle right: Michael J. Raupp; Bottom: John Ruberson, Kansas State University, Bugwood.org)

capsulata' beneath each egg mass. The presence and genotype of the bacterial symbiont stored in the gut of the bug appears to play a significant role in determining suitable host plants for normal growth and development of *M. cribraria* (Jenkins et al. 2010, Ruberson et al. 2012). Eggs hatch in about one week and the newly emerged nymphs feed on the symbiotic bacteria, which enables them to survive on host plants such as kudzu, soybeans, peas, beans, and peanuts, and other legumes (Jenkins et al. 2010). Nymphs develop through five instars over a period of 4-6 weeks (Ruberson et al. 2012) (Figure 4). Newly hatched nymphs tend to aggregate near the egg mass, but the second and third instar nymphs begin to disperse from that location (Zhang et al. 2012). Nymphs reportedly cluster together when feeding, and are likely to be found in large numbers feeding around growing points and nodes of host plants (Seiter et al. 2013c). Reported estimates of development time from egg to adult vary widely (24 to 56 days), as do estimates of adult longevity (less than one week up to 11 weeks), depending on location, temperature, and other conditions (Eger et al. 2010, Ruberson et al. 2012, Zhang et al. 2012, Seiter et al. 2013c).

SPREAD

Megacopta cribraria are strong and rapid flyers as well as exceptional hitchhikers. Until 2012, expansion of its range appeared to have primarily been progressively outward movement of the leading edge of the infestation. However, in 2012, *M. cribraria* was detected in western Mississippi, nearly 320 km (198.8 mi) from the known western edge of its range in Alabama at that time. The site in Mississippi was adjacent to an east-west highway running through the states. Weather fronts and strong air currents were likely involved in long-range dispersal of adults to the east and northeast in 2011. Violent thunderstorms and tornadoes that year moved across the southern range of *M. cribraria* up the Mid-Atlantic coast (Ruberson et al. 2012, Gardner et al. 2013b). Adult *M. cribraria* have also been found 32 stories above ground in high-rise buildings in Atlanta, attesting to their flight capability. Other confirmed isolated pockets of infestation in 2012 that occurred in areas well removed from the existing range of *M. cribraria* were likely the result of hitchhiking, prevailing winds, and weather fronts. International trading partners of the United States have become concerned with potential invasion after the discovery by Honduran agricultural port inspectors of several live and dead *M. cribraria* in containerized shipments of blended cotton/polyester yarn from the United States. The shipments were rejected, and future such incidents could significantly impact export opportunities for the United States. The host range of *M. cribraria* will probably continue to expand as they disperse long distances, possibly along transportation routes in the northeastern and western United States (Medal et al. 2013).

IDENTIFICATION

Adults:

- Newly emerged adults are soft and whitish, but harden and darken within several hours
- Small: ~ 4-6 mm (~ 0.16-0.24 in) long and ~ 4.0 mm (~ 0.16 in) wide (similar size to a small lady beetle or pea)

- Squarish shape, wider at the scutellum (the posterior plate along the dorsal side of the thorax) than anteriorly (More common stink bugs have a shield-shaped body with a triangular-shaped scutellum.)
- Scutellum enlarged, covers the forewings and most of the abdomen, truncated with a flattened posterior end (a characteristic unique to this species when compared to other United States stink bugs)
- Mottled brown to olive-green in color; dorsal side covered with numerous, small dark punctures giving a speckled appearance.
- Females with a broad pale area laterally on the abdomen, venter black; males with limited pale area, venter black and hairy
- Emit a pungent odor when disturbed
- Most distinguishing characteristics: size; enlarged and truncated scutellum; 2-segmented tarsi

Eggs:

- Tiny, cylindrical-shaped, with an outward facing operculum ("lid") surrounded by short spiny projections
- White when first laid, turning pale pink/salmon soon after
- Typically laid in two, or occasionally three, parallel rows of about 20 eggs per cluster
- Most commonly found attached to tender leaf sheaths of new growth; also found on undersides of leaves and older growth
- Beneath the eggs are dark capsules containing symbiotic bacteria deposited by females

Nymphs:

- 5 instars, ranging from 1st instar at ~ 1 mm (~ 0.04 in) up to 5th instar ~ 4-5 mm (~ 0.16-0.20 in) in length; somewhat flattened; very hairy; color ranges from pale orange to green to brown
- 1st instars are reddish, soon turn light brown; aggregate near egg masses
- 2nd and 3rd instars are yellowish-green and disperse from the vicinity of egg masses
- 4th and 5th instars are greenish to greenish/brown with well-defined wing buds

HOST PLANTS

In its native range in Asia, *M. cribraria* is most commonly reported feeding on legumes (Fabaceae) such as kudzu, *Pueraria* DC. spp.; hyacinthbean, *Lablab purpureus* (L.) Sweet; dunchi fiber, *Sesbania bispinosa* (Jacq.) W. Wight; black gram, *Vigna mungo* (L.) Hepper; mung bean, *Vigna radiata* (L.) R. Wilczek; and soybean, as well as many other beans and peas, lespedeza, *Lespedeza* Michx. spp.; vetch, *Vicia* L. spp.; and wisteria, *Wisteria* Nutt. spp. (Eger et al. 2010). Additionally, in China it has been reported feeding on fruit trees including peach, *Prunus persica* (L.) Batsch (Rosaceae); plums, *Prunus* L. spp.; and jujube, *Ziziphus jujuba* Mill. (Rhamnaceae) (Wang et al. 1996, Li et al. 2001, Wang et al. 2004). An expanded list of Asian hosts compiled by Eger et al. (2010) reported more than 30 herbaceous and woody hosts used by *M. cribraria* and its closely related congener *M. punctatissima* (Montandon). Few reports of *M. cribraria* on non-leguminous hosts are given by more than one author and only adults were reported, so

they possibly do not survive and reproduce on these plants (Eger et al. 2010). Two exceptions to this observation are the non-legumes firecracker flower, *Crossandra infundibuliformis* (L.) Nees (Acanthaceae) and upland cotton, *Gossypium hirsutum* L. (Malvaceae), on which Srinivasaperumal et al. (1992) reported *M. cribraria* survived and reproduced, although female fecundity was lower and nymphs took longer to develop than on the leguminous host vegetable hummingbird, *Sesbania grandiflora* (L.) Poir.

In the United States, *M. cribraria* feeds primarily on kudzu, which was introduced from Japan and widely planted for erosion control throughout the South over the last century, but is now considered one of the most serious invasive plants in this nation (Zhang et al. 2012). However, *M. cribraria* has also become a serious pest on soybeans in several southern states where it has become established (Ruberson et al. 2012). It is believed that other legumes could join the list of host plants. Zhang et al. (2012) identified ten common forest legumes found in North America that supported survival of adult *M. cribraria*. These included: Kentucky yellowwood, *Cladrastis kentukea* (Dum. Cours.) Rudd; sericea lespedeza, *Lespedeza cuneata* (Dum. Cours.) G. Don; kudzu, *Pueraria montana* (Lour.) Merr. var. *lobata* (Willd.) Maesen & S. Almeida; hairy lespedeza, *Lespedeza hirta* (L.) Hornem.; silktree, *Albizia julibrissin* Durazz.; redcardinal, *Erythrina herbacea* L.; black locust, *Robinia pseudoacacia* L.; hyacinthbean; eastern redbud, *Cercis canadensis* L.; and blue wild indigo, *Baptisia australis* (L.) R. Br. Although egg-laying occurred on many of these potential hosts, adults only developed from eggs deposited on kudzu and soybeans. Gardner et al. (2013b) surveyed 33 plants species for potential host range of *M. cribraria* and identified another 16 plants not reported by Eger et al. (2010) or Zhang et al. (2012) on which the insect was observed. However, all life stages (eggs, nymphs, and adults) of *M. cribraria* were recorded on only two species – kudzu and soybean – the only confirmed reproductive hosts of *M. cribraria* in the United States to date. Medal et al. (2013) demonstrated in a no-choice caged feeding test that *M. cribraria* was able to develop reproductively on several leguminous crops. Best development occurred on kudzu and soybean (no significant difference), followed by pigeonpea, *Cajanus cajan* (L.) Millsp., then at significantly lower values on kidney bean, *Phaseolus vulgaris* L., Sieva bean, *Phaseolus lunatus* L., and cowpea, *Vigna unguiculata* (L.) Walp., indicating that *M. cribraria* may be able to expand its known reproductive host range in North America.

FEEDING DAMAGE and IMPACT

Megacopta cribraria is a piercing-sucking insect, and it removes sap from the vascular tissue of stems, petioles, leaves, and fruit of a wide variety of plants. Plant injury noted on soybeans in Asia includes leaf discoloration, deformation of fruiting structures such as pods, and reduction in seed size (Xing et al. 2006). *Megacopta cribraria* also produces honeydew, thereby providing a substrate for the growth of sooty mold that is thought to reduce photosynthesis (Xing et al. 2006, Zhang et al. 2012). A greenhouse study revealed that high densities of *M. cribraria* reduced yields and quality of field beans grown in pots (Thippeswamy and Rajagopal 1998). Thippeswamy and Rajagopal (2005) also reported that although *M. cribraria* will feed on leaves, stems, flowers, and pods of soybeans, they prefer tender new growth to older growth. They noted that white patches developed at feeding sites, and eventually turned brownish and coalesced into necrotic

areas. Shoots withered with heavy infestations and bean pods did not develop normally. Feeding on soybeans in the United States has led to reported reductions in crop yields of 1-50% (Wang et al. 1996), and nearly 60% in soybean field-cage experiments (Seiter et al. 2013b), indicating the potential for this bug to become a significant pest of soybean.

PEST STATUS

Megacopta cribraria is considered an urban nuisance as well as a significant agricultural pest. The insect was first reported by worried homeowners who found thousands of bugs aggregating on the sides of their homes in autumn. The pest is particularly attracted to white and light-colored surfaces, vehicles, and structures, and may be more commonly found on sunlit southern and eastern exposures of buildings (Horn and Hanula 2011). When handled, adults can produce an offensive odor, and both adults and nymphs may produce a yellow stain when crushed. Nymphs in particular may cause a rash or welts on the skin of sensitive individuals (Ruberson et al. 2012).

THE SPREAD OF *M. CRIBRARIA* IN MARYLAND

It was anticipated that *M. cribraria* would appear in Maryland during the spring and summer of 2013. In 2012, the distribution of *M. cribraria* in its introduced range had reached as far north as central Virginia, and projections of the expansion of the insect's range for 2013 placed it within Maryland (Ruberson et al. 2012). Concerned that *M. cribraria* could become a pest of Maryland agriculture, the University of Maryland (UMD) Lamp Entomology Lab initiated a two-part survey to provide for early detection of the pest within state borders, and to determine the geographical extent of its spread within the state. We sampled kudzu across the state, and established the Maryland Kudzu Bug Survey website (http://mdkudzubug.org/) to enlist the public's aid in monitoring and reporting both suspected detections of *M. cribraria* and the locations of kudzu patches growing within the state. Independently, entomologists with the Smithsonian Institution, the United States National Park Service, the United States Army, and the United States Department of Agriculture - Agricultural Research Service also conducted examinations of kudzu patches in Maryland and the District of Columbia, which led to additional detections and records that have been combined with those of UMD for this report.

METHODS

Forty-five kudzu patches were sampled across nine Maryland counties and the District of Columbia from June to October 2013 (Figure 5). UMD researchers gave particular emphasis to sampling kudzu patches within southern counties, as we believed the insect would appear there first, as it moved north from neighboring Virginia. Sampling was done by visually inspecting leaves and vines for insects and their egg masses, as well as by beating vines with handheld nets. Specimens were either preserved in 85% ethanol or frozen before being pinned or mounted on points.

We also wanted to monitor whether the insect would switch from its primary host of kudzu to feeding and reproducing on soybeans. To do this, we planted and monitored

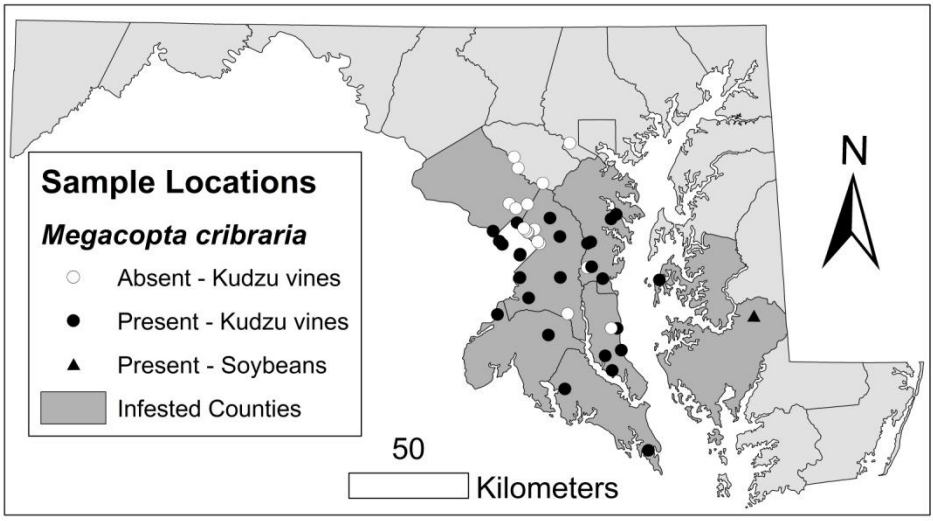

Figure 5. Map of *M. cribraria* sampling sites in Maryland and the District of Columbia, 2013. Forty-five kudzu patches were sampled for *M. cribraria* (indicated by white and black circles). Twenty-eight kudzu patches contained *M. cribraria* (indicated by black circles) across seven counties, plus the District of Columbia. At this scale, pairs of points showing distinct patches with kudzu bugs are overlapping in Montgomery and Prince George's Counties, and the District of Columbia. *Megacopta cribraria* was also reported from a single soybean field in Dorchester County.

edible soybeans (edamame var. Midori Giant), which are a variety of soybean that is particularly attractive to *M. cribraria*. Edamame soybeans were planted at five University of Maryland research farms (Research & Education Centers [REC]): Western Maryland REC (Keedysville, Washington County), Central Maryland REC-Beltsville (Prince George's County), Central Maryland REC-Upper Marlboro (Prince George's County), Wye REC (Queenstown, Queen Anne's County), Lower Eastern Shore REC (Salisbury, Wicomico County) and one plot in St. Mary's County through cooperation with the county extension office. Edamame soybean plants were sampled throughout the summer visually and by sweeping with handheld nets. In addition, we sampled any other soybean plants adjacent to these plots, as well as soybean fields adjacent to kudzu patches that were sampled. We also coordinated our efforts to monitor for *M. cribraria* with other UMD researchers sampling soybean fields for insect pests.

Finally, as Maryland is the new northern limit of the spread of this insect, we sought to determine whether the insects would be able to successfully overwinter as adults and persist in the following year, or if the colder climate would increase mortality and therefore keep populations low the following year. To do this, we examined overwintering sites adjacent to kudzu patches in search of dormant adults, following the senescence of kudzu vines and the onset of cold weather. Later in November,

examination of kudzu patches in Maryland and the District of Columbia led to additional records, followed by more collections and observations of bugs in hibernation.

RESULTS

The earliest recorded individuals were collected on 11 June 2013 from a kudzu patch in Anne Arundel County. By the end of summer, *M. cribraria* had been detected within 28 kudzu patches across seven Maryland counties, plus the District of Columbia. Some kudzu patches sampled earlier in the season did not have *M. cribraria*, but became colonized by the insect later in the summer. Populations within the re-sampled sites increased through the summer. A single dispersing adult was detected at the Beltsville Agricultural Research Center, Prince George's County, away from kudzu vines on 20 August 2013. Total individuals collected per site ranged from one to 48, and the mean sex ratio among adults was significantly skewed towards males at 1.28:1 (male:female, $\chi 2 = 4.24$, df = 1, P = 0.04), supporting earlier observations by Zhang et al. (2012) and Seiter et al. (2013c) of an overall sex bias towards males.

No life stages of *M. cribraria* were detected in soybeans over the summer through our sampling. One record of the insect on soybeans was submitted to us by a crop consultant, who found two adult insects in a soybean field in Hurlock, Maryland (Dorchester County). We calculated the distance from each kudzu patch sampled to the nearest fields used for soybean production using ArcGIS (Esri, Redlands, California) and USGS land use and land cover dataset (USDA-NASS 2013) (Figure 6). We compared the mean distance to the nearest soybean field for kudzu patches with and without *M. cribraria* using a t-test after log (x+1) transforming distances to satisfy assumptions of normal distribution. Kudzu patches from the District of Columbia were excluded from the analysis. This analysis showed that on average, kudzu vines infested with *M. cribraria* were closer to soybean fields than kudzu vines that did not have *M. cribraria* present (t = 1.99, df = 38.8, P = 0.054).

By the end of 2013, *M. cribraria* had been confirmed in eight Maryland counties, plus the District of Columbia (Figure 5). We noted the Davidsonville site (Anne Arundel County) had by far the largest kudzu infestation and *M. cribraria* were very abundant on 14 October 2013, with several hundred bugs easily observed. Examination of potential hibernation sites on 1 January 2014 proved positive, with bugs hiding under leaf litter in depressions at the base of an isolated oak (*Quercus* L. sp.[Fagaceae]), and under bark of a dead standing pine (*Pinus* L. sp. [Pinaceae]), not far from kudzu vines. One month later, however, after two severe hard freezing events (6-8 January 2014 and 22-24 January 2014, lows -12 to -15°C [10 to 5°F]) all 20 of the bugs collected at the base of the oak were found dead. At the Sherwood (Talbot County) site, only one of four overwintering bugs was found alive after the hard freezes. No live bugs (four fragmented cadavers) were found at the Oxon Hill (Prince George's County) site, though it was difficult to locate suitable hibernation sites where bugs may have concentrated. We suspect that if bugs located themselves in deep crevices and under cover, winter survival would be possible.

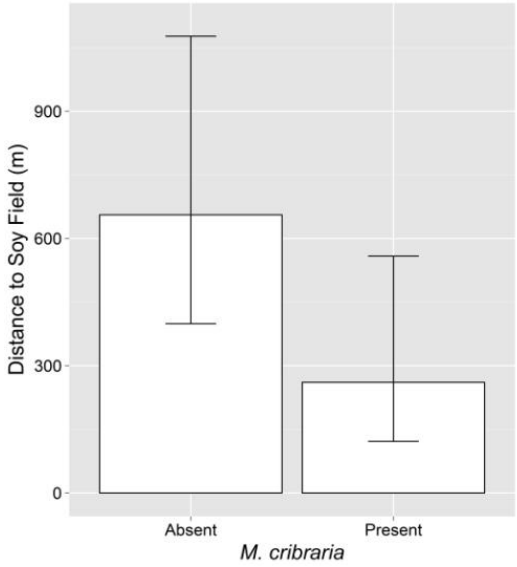

Figure 6. The mean distance from kudzu patches sampled to the nearest soybean field. Kudzu patches with *M. cribraria* (N = 28) were significantly closer to soybean fields than patches that did not have *M. cribraria* (N = 17). Error bars show 95% confidence interval.

We review these occurrences and use specimen label data to substantiate records of this newly arrived invasive insect. Specimens are deposited in the United States National Museum of Natural History, Smithsonian Institution, Washington, D.C., the collection of the Maryland Department of Agriculture, Annapolis, and the insect museum of the Department of Entomology at the University of Maryland, College Park. Where available, specimen label data below are quoted verbatim, with commas inserted for clarity; breaks between labels are separated by a backslash. The number of specimens bearing those data follow in parentheses; A = adult (unsexed); M = male; F = female; N = nymph.

District of Columbia Records

"DISTRICT OF COLUMBIA: NW Washington, Palisades area near Fletcher's Cove, 38°55'01"N, 77°05'55"W, 28 July 2013 \ On foliage of *Pueraria* at roadside; colls. W. E. Steiner & J. M. Swearingen" (1F); "DISTRICT OF COLUMBIA: SE Washington, Anacostia Park, 38°52'05"N, 76°59'50"W, 7 September 2013 \ Beaten from foliage and vines of *Pueraria* at open roadside; colls. W. E. Steiner & J. M. Swearingen" (3M, 8F); "DISTRICT OF COLUMBIA: SE Washington, Hillsdale area along Howard Road, 38°51'52"N, 76°59'53"W, 28 July 2013 \ On foliage and vines of *Pueraria* at roadside; colls. W. E. Steiner & J. M. Swearingen" (3M, 2F); District of Columbia, report from D. Weber: 38°54'19"N, 77° 05'02"W, 19 Aug 2013: Light infestation of kudzu bug on

riverside patch of kudzu; adults only observed, along with brown marmorated stink bug. Kudzu which is long-established on riverside mostly on southwest side of Capital Crescent Bike-Hike trail just south and west of C&O Canal, on NPS land. Just upstream of Three Sisters (islands) in Potomac River. Kudzu is now overgrown in places with porcelain vine and feral hop vines. In other areas it is still thriving and in full bloom.

Maryland Records Listed by County

Anne Arundel County: "MD: Anne Arundel Co., AA-2 Mt. Zion Marlboro Rd, on *Pueraria montana*, 38.820992, -76.649826, 11-Jun-2013, A. Leslie & V. Johnson" (2A, 9M, 2F, 1 egg cluster); "MD: Anne Arundel Co., AA-2 Mt. Zion Marlboro Rd, on *Pueraria montana*, 38.820992, -76.649826, 1-Jul-2013, A. Leslie & V. Johnson" (1M, 2F); "MD: Anne Arundel Co., AA-3 Rt 2, on *Pueraria montana*, 38.775990, -76.596191, 1-Jul-2013, A. Leslie & V. Johnson" (1A); "MD: Anne Arundel Co., AA-4 MD 214 at Patuxent River, on *Pueraria montana*, 38.908596, -76.669449, 15-Aug-2013, A. Leslie & V. Johnson" (2M, 2F); "MD: Anne Arundel Co., AA-5 Epping Forest Rd, on *Pueraria montana*, 39.000404, -76.554153, 15-Aug-2013, A. Leslie & V. Johnson" (4M, 1F); "MARYLAND: A. Ardl. Co., Annapolis, at Epping Forest Clubhouse on Severn River, 39°01'0"N, 76°31'44"W, 2 November 2013 \ On *Pueraria* vines at forest edge; B. B. Pagac, W. E. Steiner, J. M. Swearingen, et al. collectors" (11M, 9F); "MARYLAND: Anne Arundel County, 2 km WSW Davidsonville, 38°54'50"N, 76°39'13"W, 14 October 2013, on *Pueraria*, roadside \ Colls. G. L. Williams, W. E. Steiner, J. M. Swearingen, E. L. Nakash, W. M. Johnson, R. H. Dabill" (17M, 10F, 20N, 2 egg clusters); same data except "38°54'49.5"N, 76°39'15"W, 1 January 2014 \ Under leaf litter at base of pin oak, open turf area; Colls. W. E. Steiner & J. M. Swearingen" (19M, 14F); same data except "38°54'48"N, 76°39'13"W \ Under loose bark of dead standing loblolly (*Pinus taeda*) in edge of mixed forest tract" (2M, 5F); same data except "38°54'49.5"N, 76°39'15"W, 1 February 2014, Under leaf litter at base of pin oak, open turf area (specimen found dead) \ W. E. Steiner, J. M. Swearingen, E. L. Nakash Collectors" (13M, 7F); MARYLAND: A.Ardl. Co., Annapolis, at Epping Forest Road X Old Epping Forest Road 39°0'12.672"N, 76°33'7.923"W, 7 November 2013, On *Pueraria* vines, at Roadside, B. B. Pagac (1M, 1F, 1N).

Calvert County:"MD: Calvert Co., CA-1 Gray's Rd, on *Pueraria montana*, 38.486931, -76.585854, 1-Jul-2013, A. Leslie & V. Johnson" (2M, 3F); "MD: Calvert Co., CA-2 Broomes Island Rd, on *Pueraria montana*, 38.432125, -76.552147, 1-Jul-2013, A. Leslie & V. Johnson" (1M, 0F); "MD: Calvert Co., CA-3 Wilson Rd & Dunn Rd, on *Pueraria montana*, 38.432125, -76.552147, 1-Jul-2013, A. Leslie & V. Johnson" (1M, 3F, 1 egg cluster); "MARYLAND: Calvert Co., Scientists Cliffs, 38°30'29"N, 76°30'27"W, 4 August 2013 \ Swept from foliage and vines of *Pueraria* above sand beach; colls. W. E. Steiner, J. M. Swearingen, B. S. & S. E. Dixon" (11M, 2F, 6N).

Charles County: "MD: Charles Co., CH-1 Fenwick Rd, on *Pueraria montana*, 38.64190, -77.10698, 3-Jul-2013, A. Leslie & V. Johnson" (1F); "MD: Charles Co.,

CH-2 Rt 5/ LaPlata Rd, on *Pueraria montana*, 38.564766, -76.859825, 3-Jul-2013, A. Leslie & V. Johnson" (1A, 4F).

Dorchester County: "MD: Dorchester Co., DO-1 Soybeans, on *Glycine max*, Hurlock, MD, 20-Aug-2013, L. McConnell" (1M, 1F).

Montgomery County: "MARYLAND: Montg. Co., SE of Glen Echo, 38°57'15"N, 77°07'42"W, 27 July 2013 \ On foliage and vines *Pueraria* at roadside; colls. W. E. Steiner & J. M. Swearingen" (1M, 6F); same data except "2 November 2013 \ On foliage and vines *Pueraria* at roadside; colls. W. E. Steiner, J. M. Swearingen, S. I. Morita" (11M, 5F, 8N); "MARYLAND: Montg. Co., Takoma Park, 38°59'12"N, 77°0'42"W, 28 July 2013 \ Beaten from foliage *Pueraria* at edge of open field; colls. W. E. Steiner & J. M. Swearingen" (1M, 1F); same data except "16 August 2013 \ coll. W. E. Steiner" (2M, 5F); same data except "13 October 2013 \ Beaten from foliage *Pueraria* at edge of open field; colls. W. E. Steiner, J. M. Swearingen, W. M. Johnson, R. H. Dabill" (2M, 1F, 1N); Montgomery Co. MD report from D. Weber: 38°57'16"N 77°07'42"W, 19 August 2013: Light infestation of kudzu bug with adults mainly on leaf axils and one nymph observed on large patch of kudzu on south side of MacArthur Boulevard. Large patch of kudzu between MacArthur Boulevard and Clara Barton Parkway (NPS land near Chesapeake & Ohio Canal National Historic Park), near Brookmont section, Cabin John, Montgomery Co. MD. Established patch growing over tall trees.

Prince George's County: "MD: Prince George's Co., PG-8 Danville Rd & Floral Park Rd, on *Pueraria montana*, 38.704197, -76.956207, 1-Jul-2013, A. Leslie & V. Johnson" (1A, 2M, 1F); "MD: Prince George's Co., PG-2 210/Livingston Rd, on *Pueraria montana*, 38.780685, -76.998177, 3-Jul-2013, A. Leslie & V. Johnson" (1M); "MD: Prince George's Co., PG-4 USDA field Hubble Dr, on *Pueraria montana*, 39.003872, -76.851456, 6-Aug-2013, A. Leslie & V. Johnson" (2M, 1F); "MD: Prince George's Co., PG-1 Rosaryville St. Pk., on *Pueraria montana*, 38.781174, -76.802147, 15-Aug-2013, A. Leslie & V. Johnson" (3M, 4F); "MD: Prince George's Co., PG-13 Rt 193 and Locust Dale Dr, on *Pueraria montana*, 39.934299, -76.803947, 15-Aug-2013, A. Leslie & V. Johnson" (6M, 6F); "Prince George's Co. MD: Beltsville, 39°01'37.35"N 76°55'41.26"W, Single flying bug near greenhouse near 3rd Drive, USDA ARS Beltsville Agricultural Research Center. G. Cabrera Walsh [collector], 20 Aug 2013" (1A); "MD: Prince George's Co., PG-4 USDA field Hubble Dr, on *Pueraria montana*, 39.003872, -76.851456, 21-Aug-2013, A. Leslie & V. Johnson" (1M, 1F); "MARYLAND: Pr. Geo. Co., Oxon Hill, 38°46'48"N, 76°59'54"W, 7 September 2013 \ Swept from foliage and vines of *Pueraria* along creek channel; Colls. W. E. Steiner & J. M. Swearingen" (9M, 4F); same data except "2 February 2014 \ On ground under matted leaf litter and vines of *Pueraria* on bank along creek channel (specimens found dead) \ W. E. Steiner, J. M. Swearingen, E. L. Nakash Collectors" (2M, 2F in gelatin capsule); Prince Georges Co. MD, report from D. Weber: 39°00'16"N 76°05'07"W 16 August 2013: W of intersection of Soil Conservation Road and Hubble Road. Large kudzu patch SW of soybean field. Several patches of light infestation with a few nymphs.

Saint Mary's County: "MD: Saint Mary's Co., StM-1 St. Peter Clavers Rd, on *Pueraria montana*, 38.131466, -76.379257, 3-Jul-2013, A. Leslie & V. Johnson" (1A, 3M, 4F, 2N); "MD: Saint Mary's Co., StM-2 Hurry Rd, on *Pueraria montana*, 38.3630229 N, -76.7807563 W, 23-Aug-2013, A. Leslie & V. Johnson" (2M, 5F).

Talbot County: "MARYLAND: Talbot Co., Sherwood, 38°46'13"N, 76°19'14"W, 18 August 2013, Swept from foliage of *Pueraria* at roadside; colls. W. E. Steiner & J. M. Swearingen" (3M, 1F); same data except "27 September 2013" (6M, 2F, 40N); same data except "12 October 2013 \ colls. W. E. Steiner, J. M. Swearingen, W. M. Johnson, R. H. Dabill" (8M, 10F, 12N); same data except "1 February 2014 \ On ground under matted leaf litter and *Plantago* rosette, edge of patch *Pueraria* at roadside \ W. E. Steiner, J. M. Swearingen, E. L. Nakash collectors" (1M); same data except "(specimen found dead)" (3M).

DISCUSSION

Our surveys have documented the first instances of *M. cribraria* in Maryland, and have tracked its spread through the summer of 2013. Bugs were found at 28 of 45 of the sampled patches of kudzu vines, and seemed to be more abundant in southern counties. *Megacopta cribraria* was not found north of Annapolis, indicating the current northern limit of the invasion. South of this apparent border, there were many sites that never had any *M. cribraria*, which may reflect its recent arrival. Kudzu patches that did have *M. cribraria* were significantly closer to soybean fields than patches that did not have *M. cribraria*, which may indicate that *M. cribraria* may favorably colonize kudzu vine patches in more rural areas. This effect may be mediated by the availability of other host plants within the rural landscape that the insect can feed on, such as wisteria and redbud. Kudzu patches in more urban areas may also be subject to active eradication efforts to avoid encroachment onto private property, and therefore may be smaller. Patch size was not a factor that was measured during this survey, but may be considered in the future. Identifying dispersal limits of the insect may be useful for predicting the northern limits of its spread, especially as it enters landscapes where kudzu vines are less prevalent.

There were no reports of *M. cribraria* causing damage to soybean crops in Maryland in 2013, possibly because of low densities as it becomes established in the state. In Georgia, *M. cribraria* was detected moving into soybean fields from the end of June through mid-July, and nymphs typically appeared at the sensitive pod-filling stages (Suiter et al. 2010). We did not see high abundances of *M. cribraria* on kudzu vines until late summer and early fall, which may have precluded the insects from moving onto soybeans. The usual harvest time for soybeans in Maryland is mid-October to mid-November, which puts the dates of peak abundance of *M. cribraria* in 2013 outside of the growing season for Maryland soybeans, as soybean plants were already senescing at this time (USDA-NASS 2010). If this pattern of abundance continues into following years, the population of insects on kudzu vines may never build up to levels that would spill over into soybeans. However, if populations increase faster in future years as a result of previous establishment in Maryland, *M. cribraria* may build up on kudzu vines earlier and begin to disperse into soybeans during sensitive growth stages.

Since first being detected in 2009, *M. cribraria* has continued to increase its range northward every year (Ruberson et al. 2012). For 2014, we expect *M. cribraria* to continue its spread throughout Maryland east of the Blue Ridge Mountains, and possibly cross the Pennsylvania border. Winter mortality may play a role in the continued spread of the insect throughout Maryland, and preliminary observations of overwintering sites suggest that for winter 2013-14, survival may be low. Further surveys for the emerging adult insects will be needed for the coming spring 2014 to accurately assess persistence of adult insects through the overwintering stage. Few kudzu vine patches were discovered on Maryland's Eastern Shore, which made surveying for the insect in 2013 difficult. The most efficient way of detecting the insect on the Eastern Shore may be through education of farmers and crop consultants to recognize the new invasive species, and to report sightings to researchers.

It is currently unclear whether *M. cribraria* will become an established pest of soybean crops in Maryland. However, the status of *M. cribraria* as a potential pest of soybeans and other legumes in Maryland needs to be monitored, and future research on this insect in Maryland should focus on the timing of development and number of generations produced within Maryland's climate, and possible interactions with other pests of soybeans. The phenology of kudzu vines and the planting schedule for soybeans may differ enough from the southern range to prohibit multiple generations of the insect from developing within a single year. Now that populations of the insect have been located in Maryland, demographic studies can be conducted to determine timing of generations on the kudzu vine host. If *M. cribraria* does become a pest of soybeans in Maryland, it may interact with another invasive insect pest, the Brown Marmorated Stink Bug, which has also become established in Maryland. Future studies may determine whether there are any interactions between the combined feeding of the two insects on soybean plants, and how timing of movement into soybean fields may differ between the two species.

CONTROL/MANAGEMENT

Mechanical/Physical Control:
There are no confirmed reports of *M. cribraria* invading buildings in Maryland to date. To reduce the likelihood of invasion, host plant material, such as kudzu or wisteria, growing near buildings may be removed or cut back. However, *M. cribraria* may readily fly over from host plants growing near, but not on, the affected property. Should they become a problem in or on homes, physical barriers such as caulking openings or cracks and screening over larger openings to prevent entry is preferable to using chemical pesticides indoors. See Sargent et al. (2011) for a full description of mechanical/physical control methods for excluding invasive Brown Marmorated Stink Bugs from homes, which will work as well for *M. cribraria*.

Biological Control:
In its native range, predators of *M. cribraria* include an unidentified assassin bug (Hemiptera: Reduviidae) (Ahmad and Moizuddin 1976); *Oxyopes shweta* Tikader (Araneae: Oxyopidae) – a lynx spider; and *Antilochus coqueberti* (Fabricius) (Hemiptera: Pyrrhocoridae) (Borah and Sarma 2009) – a red bug. In the invaded range in North America, predators of *M. cribraria* include *Geocoris uliginosus* (Say) (Hemiptera:

Geocoridae) – a big-eyed bug; *Zelus* Fabricius spp. and *Sinea* Amyot & Serville spp. (Hemiptera: Reduviidae) – both assassin bugs; *Nabis roseipennis* (Reuter) (Hemiptera: Nabidae) – a damsel bug; *Hippodamia convergens* Guérin-Méneville (Coleoptera: Coccinellidae) – Convergent Lady Beetle; *Chrysoperla rufilabris* (Burmeister) (Neuroptera: Chrysopidae) – a green lacewing; *Euthyrhynchus floridanus* (Linnaeus) (Hemiptera: Pentatomidae) – a stink bug (Ruberson et al. 2012); and in 2013, an adult *M. cribraria* was observed and photographed being devoured by a crab spider, *Xysticus* C. L. Koch sp. (Araneae: Thomisidae), in Anne Arundel County, Maryland (Figure 7).

Figure 7. Natural predator. *M. cribraria* being devoured by a crab spider, *Xysticus* C. L. Koch sp. (Araneae: Thomisidae). (Image credit: Bill Johnson)

Throughout its native range in Asia, *M. cribraria* is attacked by several species of parasitoid wasps (Hymenoptera: Platygastridae and Encyrtidae) and rates of egg parasitism can exceed 75% (Ruberson et al. 2012). The platygastrid, *Paratelenomus saccharalis* (Dodd) was under consideration for importation and release in the United States owing to its specificity, broad geographic distribution, and well-known biology (Ruberson et al. 2012). However, the recent discovery of *P. saccharalis* in Georgia likely has obviated this plan (Gardner et al. 2013a). In Georgia, the generalist *Phasia robertsonii* (Townsend) (Diptera: Tachinidae) was reared from a single specimen of *M. cribraria*. Golec et al. (2013) discovered the larvae of another tachinid fly, *Strongygaster triangulifera* (Loew), developing in the abdomen near the reproductive structures of adult male and female *M. cribraria* that had been field collected in Alabama. The larvae caused tissue damage proximate to the reproductive structures in both sexes. The fungal entomopathogen *Beauveria bassiana* (Bals. -Criv.) Vuill. (Cordycipitaceae) has been observed infecting and killing *M. cribraria* in both Asia and North America (Borah and Sarma 2009, Eger et al. 2010, Ruberson et al. 2012). Developing biological control options as part of an overall management program for *M. cribraria* appears promising at this time.

Chemical Control:
A number of pesticides, including pyrethroids, pyrethroid-neonicotinoid mixes, dinotefuran, and indoxacarb, have proven effective in controlling fall aggregations of *M. cribraria* adults when applied to exterior building surfaces (Seiter et al. 2013a). The material chosen should be labeled for structural use, and application should be made when it is sunny and cool, before the bugs become active. Rain and direct sunlight will degrade the chemicals, so reapplication may be necessary if an infestation is severe. These bugs generally do not enter homes and the decision to apply insecticide should be carefully weighed.

The current scouting recommendations for Kudzu Bugs in Georgia, South Carolina, and North Carolina is to use a 38 cm (15 in) diameter sweep net to sample the entire field (minimum 100 sweeps), with a treatment threshold of an average of a single immature insect per sweep. Research conducted in 2010 and 2011 in Georgia and South Carolina for insecticide efficacy on soybeans for control of *M. cribraria* may be accessed on the kudzubug.org website at http://www.kudzubug.org/grower.html (UG-CISEH 2014).

Monitoring/Reporting:
The goal of the Maryland Kudzu Bug Survey is to provide early detection of *M. cribraria* in Maryland and to help farmers and homeowners prepare for this potential pest. The public is asked to help by accessing the website at www.mdkudzubug.org to report:

- The location of any kudzu patches growing in Maryland and associated *M. cribraria*
- Suspected *M. cribraria* in soybeans
- Large aggregations of *M. cribraria* on the sides of structures in the fall before overwintering

Visit the UMD website for updates on our research in Maryland, and for more information on *M. cribraria* in the southern United States, visit www.kudzubug.org.

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