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From Asian Curiosity to Eruptive American Pest: *Megacopta cribraria* (Hemiptera: Plataspidae) and Prospects for Its Biological Control

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ABSTRACT

The kudzu bug or bean plataspid, *Megacopta cribraria* (Fabricius), is native to Asia where it appears to be widely distributed (although the taxonomy is not entirely clear), but is infrequently a pest of legumes. This bug appeared in 2009 in the southeastern United States, where it is closely associated with kudzu, *Pueraria montana* Lour. [Merr.] variety *lobata* [Willd.] Maesen & S. Almeida. However, the insect has become a consistent economic pest of soybeans, *Glycine max* (L.) Merr., and some other leguminous crops in areas where large numbers can build in kudzu, in addition to being a considerable nuisance in urban landscapes where kudzu occurs. The insect has remarkable capacity for movement, and has spread rapidly from nine Georgia counties in 2009 to seven states in 2012. Despite being a nuisance in urban areas and a crop pest, high populations of the bug also reduce the biomass of kudzu, which is itself a seriously problematic invasive weed, complicating the status of *M. cribraria* in its expanded range. Extant predators and a pathogen in the US have been observed attacking kudzu bugs in the laboratory and field, but no parasitism of eggs or nymphs has been observed to date. A single record of parasitism of an adult kudzu bug by a tachinid fly is known from the US, but no other adult parasitism has been observed in the US or elsewhere. Extant enemies may eventually significantly reduce the bug's populations, but at present native enemies appear to be insufficient for the task, and exotic enemies from the kudzu bug's native range may offer the best possibility for effective biological control in the US. Based on the available literature, the best option for an importation biological control program appears to be the platygastrid egg parasitoid *Paratelenomus saccharalis* (Dodd) because of its apparent host specificity, intimate biological linkages with *M. cribraria*, and wide geographic distribution in the Eastern

Hemisphere. Other natural enemies may eventually emerge as good candidates for importation, but at present *P. saccharalis* appears to be most promising.

Keywords: Kudzu bug, Bean plataspid, Globular stink bug, biological control, invasive species

INTRODUCTION

The bean plataspid or kudzu bug, *Megacopta cribraria* (Fabricius), made its first known appearance in the Western Hemisphere in fall of 2009, when it was reported aggregating in large numbers on and around homes in urban areas of northern Georgia near Atlanta (see review of discovery in Suiter et al. 2010). These homes were associated with patches of kudzu, *Pueraria montana* var. *lobata* (Willd.) Maesen & S. Almeida, where large numbers of the bug were observed. The kudzu bug was initially identified by Dr. Joe Eger (Dow AgroSciences) following collections by Dr. Daniel Suiter (University of Georgia). Working with Drs. Eger and Suiter, Dr. Tracie Jenkins soon added a 2336 bp mitochondrial DNA (mtDNA) marker (GenBank # HQ444175) (Jenkins and Eaton 2011). This established a one-to-one correlation between morphology and DNA early in the history of this bugs invasion, and it established a genetic marker that could be used to track country of origin, port of entry, study maternal genetic diversity and evaluate genetic change over time. Because kudzu is so abundant in the region and it supports very large populations of *M. cribraria*, kudzu and the kudzu bug have generated a serious pest problem that includes high numbers of insects flying about and landing on homes and people. The malodorous bugs also produce a yellow substance when crushed that can stain cloth and wood, and nymphs, in particular, can cause welts and inflammation on skin. These issues, and the possible threat to soybeans in the region, triggered an effort to obtain biological information on the bug and its enemies in its native range. The purpose of this review is to summarize the information available on the insect in the US and in its native range relevant to its activity in North America and to provide current information on its status in North America and the prospects for biological control.

BIOLOGY OF *MEGACOPTA CRIBRARIA* AND PEST STATUS

We have chosen to consider the species occurring in the southeastern United States as *M*. *cribraria* although we recognize that there is some uncertainty in the identity of this species. Eger et al. (2010) reviewed the taxonomic history of *M*. *cribraria* and *Megacopta punctatissima* (Montandon) and indicated that the latter was considered to be a synonym of the former by Yang (1934). Both names continue to be used today, however, primarily in Japanese economic literature. We have examined specimens from Japan, China, and India and have been unable to find differences in morphology or genitalia. Specimens from the southeastern United States are variable in size and specimens resembling published photos of both species occur in this area. Jenkins et al. (2010) found that molecular characters for Georgia specimens are similar to those previously reported for *M. cribraria*. So for the present, we refer to our specimens as *M. cribraria* until studies are conducted to clarify the species relationships. The close genetic link to specimens from Japan suggests that our species may be *M*. *punctatissima* should this species be found to be distinct from *M*. *cribraria*.

Prior to 2009, *M. cribraria* was known only from Asia (Eger et al. 2010). It was originally described as *Cimex cribraria* by Fabricius with specimens from India in 1798. It has since been reported from various locales throughout Asia and the Indian subcontinent (although the very similar species *M. punctatissima* predominates in the main islands of Japan – Honshu, Shikoku, and Kyushu (Tomokuni et al. 1993)). *Megacopta cribraria* is the only member of its family (Plataspidae) in North or South America. However, a close relative, *Coptosoma xanthogramma*

(White), was detected in Hawaii in 1965 (believed to originate in the Philippines) and has since established there as a pest of legumes (Beardsley and Fluker 1967). The family Plataspidae belongs to the hemipteran superfamily Pentatomoidea (Schuh and Slater 1995), and outside of the Plataspidae, the genus *Megacopta* appears to be most closely allied with the family Scutelleridae and by further extension to the Pentatomidae (Schuh and Slater 1995; Li et al. 2005).

The origins of the *M. cribraria* established in the US are unclear. DNA was extracted from 269 individuals from across the spatial and temporal range of *M. cribraria* in the southeastern US. Polymerase chain reaction (PCR) was then used to amplify and sequence a 2336 bp mitochondrial fragment (Jenkins et al. 2010, Jenkins and Eaton 2011). All of these fragments analyzed to date are the same. Only one female line, designated GA1 (Jenkins and Eaton 2011) has been observed. While more lines may have been introduced, only one has so far been found from random sampling using this marker. Thus, at least for mtDNA, there appears to be a lack of genetic diversity in introduced *M. cribraria*, even as the bug rapidly moves into new territory. Furthermore, preliminary data comparing GA1 haplotypes with haplotypes collected from sites across Asia appear to indicate strong similarity with collections in Japan and South Korea (Jenkins, unpubl. data).

Eger et al. (2010) provide an excellent overview of the life history of the insect, and their information is summarized here, with additional information derived from various sources. The common name applied to the bug in the region (“kudzu bug”) derives from the insect’s close association with kudzu, which is also noted in its original range in Asia. Circumstances in the southeastern US are ideal for *M. cribraria*, and unique for the US, in that kudzu, a perennial invasive weed pest native to Asia, is ubiquitous in the region, providing the bugs with their ideal host plant in abundance when they arrived. Kudzu bugs overwinter as adults clustered in sheltered areas (e.g., under loosened tree bark) in the vicinity of fall host plants (typically kudzu). Adults emerge from overwintering habitats in early spring and become very active, possibly looking for host plants and/or mates. The bugs are strong and rapid fliers and they become urban nuisances during the spring flight period in the US, especially in and around light-colored homes and structures. The large numbers of insects produced in kudzu (Zhang et al. 2012) and the strong flight ability of adults likely account for the rapid expansion of the kudzu bug's geographic range in the southeastern US, possibly aided by spring weather patterns producing active fronts that tend to move from west to east and northeast, corresponding with the most pronounced region of spread of the kudzu bug (Fig. 1).

Initial kudzu bug reproduction in the spring is synchronized with the emergence of buds in kudzu, the only perennial host known to support large numbers of *M. cribraria*, but eggs may be deposited on other potential host plants, such as wisteria (*Wisteria sinensis* (Sims)) and early-planted soybeans available at the same time, though not in the numbers observed on kudzu. Eggs are deposited largely on leaf nodes near the vine tips and, to a somewhat lesser extent, on bracts on kudzu vines, and on the undersides of kudzu leaves. An average of 16 eggs (Zhang et al. 2012) is deposited in two parallel rows, with fecal pellets containing symbionts placed beneath the egg mass. The symbionts play a key role in the dietary range of the bugs

(Hosokawa et al. 2006). Eggs hatch in 3-7 days, depending on temperature. The nymphs pass through five instars over a period of about 4-6 weeks. Adult longevity has been variously estimated at 2-5 days (Srinivasaperumal et al. 1992), 7 days (Aiyar 1913), and 23-64 days (Thippeswamy and Rajagopal 2005) in the spring and summer. Zhang et al. (2012) reported second generation adult longevity of 6-25 days in Georgia depending on host plant. Those tests were conducted at outdoor temperatures in a shaded area in July, while J.R. Ruberson observed adult longevity of 21-43 days in Georgia under laboratory conditions (25 ± 1°C; L:D 14:10) with snap bean pods (*Phaseolus vulgaris* L.) as food. Fecundity estimates are also rather wide: from 10-40 eggs (Aiyar 1913), 49-73 eggs (Srinivasaperumal et al. 1992), and 102-157 eggs (Thippeswamy and Rajagopal 2005) per female. Rearing conditions for these studies varied widely, confounding generalizations for the bugs currently in the US. For example, *M. cribraria* performed poorly in caged oviposition trials in Georgia (Zhang et al. 2012) suggesting that the bugs are sensitive to conditions that limit their movement or shade the plant.

After the first generation has completed development in kudzu or early-planted soybeans, many of the new adults move to other host plants, and can become serious pests of soybeans and other legumes. The second generation is passed in late summer primarily on kudzu (Zhang et al. 2012), soybeans (Greene et al. 2012) and some other legumes. The bugs appear to be bivoltine in the southeastern United States on kudzu (Zhang et al. 2012), which corresponds with phenology reported in China (2-3 generations annually: Li et al. 2001; Zhang and Yu 2005; Chen et al. 2009) and for *M. punctatissima* on kudzu in southern Japan (Takasu and Hirose 1986). Eggs on soybeans and other crop legumes are typically placed on stems and leaves, and hatched nymphs and adults feed chiefly on stems and, to a lesser extent, on leaves. Feeding on fruiting structures is highly unusual. Damage to plants appears to be a result of stress inflicted on the plant by high numbers of feeding bugs. Kudzu bugs can be rather non-discriminatory in their oviposition habits, as they have been reported to lay eggs on peaches, pecans, metal posts, plastic structures, and other plants and objects that are unlikely developmental hosts. However, when given a choice, they preferentially oviposit on kudzu and to a lesser extent on soybeans (Zhang et al. 2012). In that study, some eggs were also deposited on *Lespedeza hirta* (L.) Hornem., *L. cuneata* (Dum. Cours.), *Wisteria frutescens* (L.), *Vigna unguiculata* (L.), *Lablab purpureus* (L.), and *Robinia pseudoacacia* L., but development was only completed on kudzu and soybeans.

The taxonomic range of the bug's developmental hosts is poorly known. Defining the host range of *M. cribraria* is further complicated by the presence of gut symbionts that appear to play a significant role in shaping host plant suitability (Hosokawa et al. 2006; 2007). Srinivasaperumal et al. (1992) conducted a life table analysis for *M. cribraria* nymphs and adults on the plants *Sesbania grandiflora* (L.) and *Crossandra undulaefolia* Salisb., as well as cotton, *Gossypium hirsutum* L., and found that the bugs could develop successfully from egg hatch to adult on all three species. However, developmental time was prolonged, and adult size and fecundity were reduced for bugs that developed on cotton, suggesting that this is a less optimal host. It must be noted that Srinivasaperumal et al. (1992) inoculated the respective plants with *M. cribraria* eggs and did not observe oviposition on the tested plants. Thippeswamy and Rajagopal (2005) evaluated the life history of *M. cribraria* on soybean, field bean (*L. purpureus*), and redgram (or pigeon pea, *Cajanus cajan* (L.)) and found that although the bugs could readily oviposit and complete development on soybean and field bean, they failed to oviposit on redgram, although they congregated, fed on, and seriously damaged the plants.

Urban Issues: *Megacopta cribraria* was first noticed in the US because it appeared en masse on homes and property in close proximity to kudzu in the fall of 2009 (Suiter et al. 2010). This problem has recurred each spring and fall in the region, as the bugs actively move in the spring in search of food and reproductive resources prior to significant kudzu growth in the spring, and as they search for overwintering sites in the fall. The insects are nuisance pests in the urban environment, aggregating in great numbers on and around homes and other structures. The bugs are attracted to light-colored vertical surfaces, which provides an effective means of trapping them (Horn and Hanula 2011, Zhang et al. 2012), but also contributes to their aggregation on homes, other buildings, and vehicles, reinforcing their status as urban pests. Because *M. cribraria* are active fliers, they not only annoy people in open areas, but also readily enter homes and other buildings through open doors and windows. Annoyance can also be less benign. Bugs (especially nymphs) crushed against the skin can induce rashes (Fig. 2), and can stain surfaces when crushed against them. Risks of localized dermal rashes are likely minimal in and around structures, but these concerns are much greater for workers in soybeans or kudzu where nymphs can be abundant.

Crop-related Issues: In Asia, *M. cribraria* tends to be an occasional pest of legumes, but can be serious at times. Thippeswamy and Rajagopal (1998) found that yield of field bean (*L.*

purpureus) was reduced from 9-44% by increasing infestations of the kudzu bug, and the yield reduction was more pronounced when infestations occurred in the crop's vegetative stage than in the reproductive stage. Similar results were observed in soybeans in China, where 0.5-50% yield loss was reported (Wang et al. 1996), and in Japan where clear density-dependent effects on soybeans were documented (Kikuchi and Kobayashi 2010).

The very limited number of publications pertaining to this insect as a pest or to its management indicates that *M. cribraria* is not a consistently significant crop problem in its native range. This is not the case in the US, where bugs appear consistently in large numbers in soybean fields within the southeastern range of the pest. This is most likely due to the large number of bugs produced during the first generation in kudzu, which is abundant and widespread in the southeastern US. Some portion of this very large first generation of adults then migrates from kudzu to soybeans where the adults oviposit and their progeny complete development. However, observations from spring of 2012 indicated that overwintered bugs moved directly to early-planted soybeans (Phillip M. Roberts, University of Georgia, and Jeremy K. Greene, Clemson University, unpubl. data), bypassing kudzu entirely, and suggested that the wild host plant might not be necessary for the insect to propagate in a given region in the spring if sufficient suitable alternative hosts are present.

Studies conducted in 19 soybean fields in Georgia and South Carolina in 2010 and 2011 showed that kudzu bug populations reduced soybean yields in untreated fields from 0-47% (16 of the 19 fields suffered yield loss), with an average loss of 18% (Greene et al. 2012). Therefore, at least one application of a broad-spectrum insecticide will likely be required to reduce damage in infested soybeans in the US. An additional application of insecticide to soybeans would add a cost of $15-22 per hectare, as well as environmental costs of additional pesticides in the environment. The best chemical controls for the pest in China were found to be broad-spectrum insecticides, such as chlorpyrifos (Zhang and Yu 2005) and deltamethrin (Li et al. 2001), among others (Wu et al. 1992), all of which have significant non-target effects on the environment. A number of organic growers in northern Georgia have had snap bean crops severely damaged and, in some cases, destroyed by heavy populations of kudzu bugs (Ruberson, unpubl. data). Organic growers have very limited therapeutic options to control the insects. The economic losses of organic producers have not been calculated, but growers report that they are significant. As this invasive species continues to expand its range in the US, its adverse impact on soybeans and other cultivated legumes will continue to increase. However, the magnitude of the pest problems and extent of the insect's spread may be limited by the distribution and abundance of kudzu, because of the insect's close relationship with this host plant.

International Issues: In December, 2011, two dead kudzu bug adults were recovered by Honduran inspectors on the floor of a shipping container of fertile chicken eggs originating from Georgia. On 11 February 2012, Honduran inspectors identified seven dead kudzu bug adults in a containerized shipment of frozen chicken meat paste from Georgia. These interceptions prompted Honduran officials to halt acceptance of any agricultural products shipped from Alabama, Georgia, and South Carolina on 27 February 2012. Two days later, shipments from

North Carolina were included in this action. Within 48 hours of this action, Honduran officials accepted all shipments only after inspection of 100% of the containers.

The US Department of Agriculture Animal and Plant Health Inspection Service (USDA APHIS) worked with the University of Georgia and industry partners to develop and implement a standard operating protocol for loading containers to ensure freedom from kudzu bugs. The protocol centered on exclusion practices in loading and handling areas, visual inspections, and cleaning of containers before loading. The University of Georgia hosted representatives from nine Central American member countries of the Organismo Internacional Regional de Sanidad Agropecuaria (OIRSA) in April 2012 to provide current information about the bug, the risks it poses, and management options (e.g., http://southeastfarmpress.com/markets/kudzu-bug-now-interfering-southeast-exports?page=1; accessed 5 September 2012). Normal trade has resumed, but Honduras and several other Central American governments inspect double the number of shipping containers from countries/areas in which the kudzu bug is endemic than from areas in which the insect does not occur. There remains great concern about *M. cribraria* possibly invading and becoming established in Central America, and there is concern that these worries will spread to other US trading partners in the Americas and elsewhere, especially countries such as Brazil, with large acreages in soybeans and other legumes. These concerns are underscored with the interception of kudzu bugs by Honduran and Guatemalan inspectors on commercial passenger and cargo airlines originating from Atlanta, Georgia, and other international airports in infested areas.

***Beneficial Aspects*:** Although *M. cribraria* is a crop and urban pest in the southeastern US where kudzu occurs, the bugs are also having a beneficial effect by reducing kudzu growth. Zhang et al. (2012) found that the bugs feeding in kudzu led to a total biomass reduction of 32.5% during the first year of infestation, demonstrating that the bug can have a significant adverse effect on kudzu at the current high population levels found during initial invasion in a new area. Kudzu is considered one of the most serious invasive plants in regions where it occurs (Fig. 3), where it has been estimated to cover approximately 2.8 million ha (Blaustein 2001) and continues to expand. Grebner et al. (2011) estimated that recovering land infested by kudzu and planting it with pine trees could result in increased land expectation values of $3-4,000/ha at the end of a 30-year rotation, depending on the treatment methods used to eradicate kudzu. Effective biological control of kudzu would increase that value significantly by reducing or eliminating kudzu control costs. Importation biological control efforts have been directed at kudzu, but no releases have been made because of the generalized feeding range of kudzu herbivores that could lead to significant nontarget effects, most notably with soybeans, which are closely related to kudzu (Frye et al. 2007). *Megacopta cribraria* feeds on kudzu stems and most likely reduces the plant's capacity for growth by stressing the plant. Given the ability of the bug to disperse and locate patches of kudzu, there is potential for the insect to have a significant effect on scattered kudzu patches across many habitat types.

SPREAD OF THE KUDZU BUG

It is anticipated that the problems and benefits delineated above will spread along with the kudzu bugs. Their movement from initial infestation areas has been rapid. Initially found in nine counties in northern Georgia in 2009, the kudzu bug has moved rapidly to cover a much larger area of the southeastern US (see Fig. 1). Also in 2010, the first reports of the kudzu bug attacking soybeans were recorded in Georgia and South Carolina. More widespread complaints about the bug in urban areas of northern Georgia were received in fall of 2010.

In 2011, the bug continued to move rapidly and was eventually reported in every county in South Carolina, numerous counties in North Carolina, and in Virginia (Fig. 1). In 2012, the insect has continued to spread, with bugs found in Florida and Tennessee, and throughout nearly all of Georgia.

MANAGEMENT

The serious economic and social concerns related to the kudzu bug justify efforts to suppress its populations in a variety of environments and over large areas. Data generated thus far indicate that broad-spectrum insecticides (organophosphates and pyrethroids) are effective against the bugs (e.g., Wang et al. 2004, Greene et al. 2012), but in sensitive areas, such as urban neighborhoods where kudzu is abundant, more environmentally benign approaches are needed, such as biological control. We address this topic below, focusing on natural enemies native to North America and then on enemies in the original range of the pest and their potential for use in classical biological control programs directed against the insect.

Role of Native Natural Enemies. Native natural enemies in North America have not yet demonstrated the capacity to significantly reduce populations of *M. cribraria,* based on the persistently large populations of the bugs present in kudzu and infested soybeans in epicenter areas three years after the infestations were first observed. Some native predators have been found to feed on adults and nymphs of *M. cribraria* in the laboratory and/or field (see Table 1). The predators *Geocoris uliginosus* (Say)*, Zelus* sp.*, Hippodamia convergens* Guérin-Méneville*,* and *Chrysoperla rufilabris* (Burmeister) have been observed feeding on nymphs in kudzu in the field (Table 1), offering promise of growing activity of native predators. The predatory pentatomid *Euthyrhynchus floridanus* (L.) was also observed attacking adult *M. cribraria* on beans, *Phaseolus vulgaris* L., in the garden of an organic grower (Cyndi Ball, in northern Georgia). The impact of these predators is presently unknown in kudzu or any other host plant, but all are generalists, as would be expected given the lack of Plataspids in the Americas, and these predators may have limited impact on the bug populations.

No egg parasitoids have been found to date in samples in Georgia. In 2010, 287 egg masses from four counties in northern Georgia (Burke, Clarke, Elbert, and Morgan) were collected by Ruberson, and none of them yielded parasitoids. Likewise, Zhang et al. (2012) placed all egg masses from their weekly samples of kudzu vines in rearing and found no egg parasitoids. In 2011, Ruberson collected 345 egg masses from five counties in northern and eastern Georgia(Bulloch, Burke, Clarke, Jasper, and Morgan), and no egg parasitoids were found. Laboratory evaluations conducted by Walker Jones (USDA-ARS) with several native egg parasitoids also suggest that native egg parasitoids may not readily accept *M. cribraria* eggs. Because *M. cribraria* is the sole member of the Family Plataspidae present in North America (Eger et al. 2010), there may be difficulties for egg parasitoids in North America to successfully parasitize the bug's eggs. Inability of extant egg parasitoids to successfully parasitize *M. cribraria* eggs is further supported by quarantine studies by Walker Jones in which *M. cribraria* eggs were exposed to several important egg parasitoids of Pentatomidae present in North America, including *Trissolcus basalis* (Wollaston) (Hymenoptera: Platygastridae (= Scelionidae)), which exhibits a very broad host range within the Pentatomidae (Johnson 1985). None of the parasitoids attacked eggs of *M. cribraria* or showed interest in them, suggesting that specific cues for the parasitoids may be lacking. Therefore, parasitism of eggs by extant species does not appear to be likely, at least in the near-term.

A single tachinid parasitoid was recently obtained from an adult *M. cribraria* collected on 2 April 2012 in Tifton, Tift County, Georgia by M. D. Toews. This is the first case of adult parasitism observed in hundreds of bugs collected and held, so it may represent a rare event, or the beginning of a novel relationship. The specimen was determined to be *Phasia robertsonii* (Townsend) by Dr. Norman Woodley (Systematic Entomology Laboratory, Smithsonian Institution). This native parasitoid has been reared from adult Miridae and Pentatomidae (Arnaud 1978; as *Alophorella pulverea* (Coquillet)), so it has a broad host range. No other parasitoids have been observed from eggs, nymphs or adults.

A single specimen of *M. cribraria* was found infected with the entomopathogenic fungus *Beauveria bassiana* (Balsamo) Vuillemin in kudzu in Georgia in 2010 (Zhang and Gardner, unpubl, data) and in soybeans in Tift County, Georgia in 2012 by Ruberson. No other pathogens have been observed.

Classical Biological Control Opportunities. There is relatively limited information about natural enemies of *M. cribraria* in its native range, perhaps due to its limited pest status in these regions. Among natural enemies in the bug's native range, there is particularly little information on predators and pathogens. Only three cases of predation have been recorded. In the first case, Ahmad and Moizuddin (1976) noted that fifth instars and adults of *M. cribraria* were attacked by Reduviids (identified as "*Reduviius* [sic] sp.") on lablab in Karachi, Pakistan, but that smaller nymphs were not attacked. They provided no quantitative or other data regarding the importance of the Reduviids, other than concluding that "Predators appear to have less importance [than egg parasitoids] in biological control programme" (p. 86). The second and third cases of predation were reported by Borah and Sarma (2009a), and are field observations of predation by a spider (the Oxyopid *Oxyopes shweta* Tikader) and a predatory bug (the Pyrrhocorid *Antilochus coqueberti* (F.)). Populations of the spider correlated positively and significantly with those of *M. cribraria*, whereas populations of the predatory bug were too low to assess. There are several reports of coccinellid predators of other Plataspids having significant effects on plataspid populations and exhibiting some prey specificity (see summary in Dejean et al. 2002). There are no such reports, however, for *M. cribraria*.

Only a single pathogen has been reported attacking *M. cribraria* in its native range. Borah and Dutta (2002) reported natural infections of *M. cribrarium* (= *M. cribraria*) nymphs and adults in Assam, India, by the entomopathogenic fungus *B. bassiana*. They verified pathogenicity by fulfilling Koch's postulates on bugs (Borah and Dutta 2002; Borah and Sarma 2009b). Levels of infection were 31% in November 1997 and 19% in November 1998.

The bulk of the available information on natural enemies in the native range is focused on egg parasitoids. This bias may reflect the ease of sampling and of making observations rather than the actual relative importance of natural enemy guilds or taxa. However, no nymphal or adult parasitoids have been reported in the literature, suggesting that such enemies may be rare or non-existent in the native distribution.

Among egg parasitoids, the Platygastridae and Encyrtidae are the most important, although Aphelinidae have also been reported. For example, the aphelinid parasitoid *Encarsiella* (=*Dirphys*) *boswelli* (Girault) has a southern Australasian and tropical Indian and African distribution, and has been reared from the plataspids *Brachyplatys vahlii* (F.) in Malaysia, *M. cribraria* in India, and *Coptosoma*/*Brachyplatys* sp. in Zaire (Polaszek and Hayat 1990; 1992). However, there are no data regarding rates of parasitism by this species in the field, and the species appears to be uncommon, based on *Megacopta* parasitoid surveys in India, China, and elsewhere.

More common are the Platygastrids and Encyrtids, which are commonly observed attacking eggs of *M. cribraria* within the bug's native range. In China, Zhang et al. (2003) observed parasitism of *M. cribraria* eggs in soybeans by the Encyrtid *Ooencyrtus* sp. and the Platygastrid *Trissolcus* sp. (possibly *Paratelenomus saccharalis* (Dodd)), with *Ooencyrtus* sp. dominating parasitism of eggs of the initial bug generation in soybeans (accounting for 61% of parasitism in Jiangsu Province). Wu et al. (2006) observed both *Ooencyrtus nezarae* Ishii and *P. saccharalis* (as *Asolcus minor*) parasitizing eggs of *M. cribraria* in Fuzhou, China, from May to October in soybeans. As was the case with Zhang et al. (2003), *O. nezarae* was the dominant parasitoid reported by Wu et al. (2006), and overall egg parasitism levels ranged from 22.4 to 76.9%. Wall (1928; 1931) observed parasitism of *M. cribraria* eggs (and two other plataspid species) in Guangdong Province, China, by *P. saccharalis* in cultivated beans from late June to mid-August, accounting for about 51% parasitism of all eggs collected. Although *O. nezarae* can exhibit high parasitism rates, it is a generalist parasitoid of heteropteran eggs – attacking Plataspidae, Pentatomidae, and Alydidae – and is also a facultative hyperparasitoid (Takasu and Hirose 1991).

Egg parasitism for *M. punctatissima* in Japan can be quite high (43-100%), with parasitism by *P. saccharalis* dominating early in the season and *O. nezarae* becoming the dominant parasitoid later in the season (Takasu and Hirose 1986). Ahmad and Moizuddin (1976) reported a species of *Trissolcus* attacking eggs of *M. cribraria* in Pakistan, but provided no information on rates of parasitism in the field. Srinivasaperumal et al. (1992) conducted a life table analysis on *S. grandiflora*, *C. undulaefolia*, and cotton and observed parasitism of artificially placed eggs on all three crops, ranging from 4.3 to 20.6% from May to July in southern India. All egg parasitism was attributed to *P. saccharalis* (as *Archiphanurus*).

The parasitoid selected for proposed releases in the US is *P. saccharalis* for three reasons. First, its ecology has been studied in Japan, so there is a good body of knowledge already in place. Second, the parasitoid appears to be highly host specific, with the only known hosts being several species in the family Plataspidae. Third, the parasitoid has a wide geographic distribution in the Eastern Hemisphere, which should facilitate locating a strain or strains that is/are adapted to climatic conditions in the invaded region. We overview each of these issues below.

Paratelenomus saccharalis Ecology. As noted above, *P. saccharalis* has been recorded parasitizing eggs of *Megacopta/Coptosoma* species in various studies throughout Asia. Studies in Japan and elsewhere have demonstrated a close spatial and temporal synchrony between the parasitoid and its host. *Paratelenomus saccharalis* is a primary and solitary endoparasitoid of eggs of *M. cribraria* and *M. punctatissima* in Asia (Johnson 1996). Parasitism rates in the spring are relatively high (up to 80%), but rates in late summer are much reduced, possibly due to facultative hyperparasitism by the competing egg parasitoid *O. nezarae* (Takasu and Hirose 1991).

Parasitoid developmental time from oviposition to adult emergence varied from 11.7 ± 1.03 d at 30˚C to 24.8 ± 0.66 d at 20˚C for a parasitoid population from Fukuoka, Japan, with an estimated thermal requirement of 208.3 degree days (base 12°C) (Takagi and Murakami 1997). Survival across these same temperatures ranged from 58.6% at 30˚C to 96% at 20˚C. Takagi and Murakami (1997) also calculated the lower developmental threshold to be 11.8˚C, and estimated a thermal requirement of 208.3 degree days (base 12°C) from egg to adult emergence. On this basis, they estimated that approximately four generations of the parasitoid could occur from 1 July to 31 August in the region of Fukuoka, Japan.

Wall (1928) noted that parasitoids were most successful parasitizing young eggs ("…it is only in the last third of the embryonic development of the host… that the parasitoid is unable to parasitize the host egg"; p. 234). An inverse relationship between host age and suitability is typical for egg parasitoids (e.g., Pak 1986).

Takasu and Hirose (1986) found that parasitism of *M. punctatissima* eggs by *P. saccharalis* (as *A. minor*) increased quickly after bug oviposition began in kudzu (end of May) in Fukuoka, Japan, and within two weeks reached levels of 57-81% from mid-June through early July, when the parasitoid *O. nezarae* became more prevalent. Similarly, the parasitoid was found in close temporal association with *C. cribrarium* (=*M. cribraria*) in the spring in India (Rajmohan and Narendran 2001). There may be differences in parasitoid efficacy among host plants. Takasu and Hirose (1985) reported that eggs of *M. punctatissima* were only parasitized by *O. nezarae* in soybeans, although *P. saccharalis* occurred in the same area. Similarly, Hirose et al. (1996) noted little parasitism of *M. punctatissima* by *P. saccharalis* (as *Paratelenomus minor*) in soybeans, but the very high levels of parasitism by *O. nezarae* in soybeans, coupled with the comparable numbers of adult females of the two parasitoid species trapped in the crop, may indicate that *O. nezarae* is able to outcompete *P. saccharalis*.

Although *P. saccharalis* is bisexual throughout its Australasian and Asian range, Bin and Colazza (1986) reported that the population found in Italy was thelytokous, was active in July and August, and that parasitism ranged from 4.5 to 34.2% during this period (averaged over three years).

<u>Paratelenomus saccharalis</u> <u>Host Specificity</u>. There are no records in the literature of *P. saccharalis* being reared from any hosts besides selected plataspid species (e.g., Johnson 1996). Johnson (1996) reported the parasitoid's known hosts from museum specimens and the literature as the Plataspids *Brachyplatys subaeneus* Westwood in China (citing Wall 1928; 1931), *Megacopta* (=*Coptosoma*) *cribrarium* (F.) in China, and *M. punctatissimum* in Japan. Bin and Colazza (1986) reported rearing the parasitoid (identified as *Archiphanurus graeffei* (Kieffer)) from the sole known Italian Plataspid, *Coptosoma scutellatum* (Geoffroy), on a wild legume host (*Ononis spinosa* L.). Hirose et al. (1996) collected egg masses of four species of hemipterans in soybeans, but *P. saccharalis* was reared only from eggs of *M. punctatissimum*, in stark contrast with *O. nezarae*, which was reared from eggs of all four species. The lack of records for any hosts besides Plataspids suggests that the parasitoids may be restricted to hosts in this bug family. There are no known plataspid species in the Americas; therefore, there is a significant phylogenetic gap between *M. cribraria* and other Pentatomoids present in North America that may also be reflected in the host range of the parasitoid. Evaluations of the parasitoid to date in quarantine in the US further indicate the parasitoid has no interest in a variety of pentatomoid and other Hemipterans found in North America. The lack of any successful parasitism in quarantine studies supports the literature on specificity.

Paratelenomus saccharalis Geographic Distribution. The parasitoid *P. saccharalis* is widely distributed throughout the Eastern Hemisphere. The Geographic Biodiversity Information Biofacility (GBIF) provides 275 georeferenced records for the parasitoid (http://es.mirror.gbif.org/species/16198853, accessed 1 May 2012) demonstrating the wide geographic distribution of the parasitoid based on museum specimens. The parasitoid has been collected throughout the Australasian region, India, and Western and Central Europe. It has also been collected in the Middle East and Africa. This distribution corresponds with that of members of the Family Plataspidae.

CONCLUSIONS

The kudzu bug or bean plataspid, *Megacopta cribraria*, is rapidly spreading in the southeastern United States, where it is closely associated with kudzu, but can also infest soybeans and some other legumes. In addition to causing economic damage to soybeans, the bugs have become a considerable nuisance in urban landscapes where kudzu occurs. The insect has a remarkable capacity for movement and has spread from nine Georgia counties in 2009 to seven states in 2012. Although a nuisance in urban areas and a crop pest, the bug also reduces biomass of kudzu, which is itself a seriously problematic invasive weed, complicating the status of *M. cribraria* in its expanded range. Native natural enemies have been observed attacking kudzu bugs in the laboratory and field, and might eventually reduce their populations, but at present native enemies appear to be insufficient for the task. Therefore, exotic enemies from the kudzu bug's native range may offer the best possibility for effective biological control in the US. Based on available literature, the best option for an importation biological control program appears to be the platygastrid egg parasitoid *Paratelenomus saccharalis* because of its apparent host specificity, intimate biological linkages with *M. cribraria*, and wide geographic distribution in the Eastern Hemisphere. Other natural enemies may eventually emerge as good candidates for importation, but at present *P. saccharalis* appears to be the most promising.

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References

Ahmad I, Moizuddin M (1976) Biological control measures of bean plataspids (Heteroptera: Pentatomoidea) in Pakistan. Proc Entomol Soc Karachi Volume unknown (6): 85-86

Aiyar TVR (1913) On the life history of *Coptosoma cribraria*, Fabr. Journal, Bombay Natural History Society 22: 412-414

Arnaud PH, Jr (1978) A host-parasite catalog of North American Tachinidae (Diptera). Misc Publ. 1319. USDA Science and Education Administration, Washington DC

Beardsley JW, Jr, Fluker S (1967) *Coptosoma xanthogramma* (White), (Hemiptera: Plataspidae) a new pest of legumes in Hawaii. Proc Haw Entomol Soc 19: 367-372

Bin F, Colazza S (1986) Egg parasitoids, Hym. *Scelionidae* and *Encyrtidae*, associated with Hemiptera Plataspidae. In: Trichogramma and Other Egg Parasites, 2nd Internatl. Symp., Guangzhou, China. Ed. INRA, Paris, 1988

Blaustein RJ (2001) Kudzu's invasion into Southern United States life and culture. In: McNeeley, JA (ed.) The Great Reshuffling: Human Dimensions of Invasive Species. IUCN, Switzerland and Cambridge, UK, The World Conservation Union, pp 55-62.

Borah BK, Dutta SK (2002) Entomogenous fungus, *Beauveria bassiana* (Balsamo) Vuillemin: a natural biocontrol agent against *Megacopta cribrarium* (Fab.). Insect Environ 8:7-8

Borah BK, Sarma KK (2009a) Seasonal incidence of negro bug, *Megacopta cribrarium* (Fab.) on pigeonpea. Insect Environ 14:147-149

Borah BK, Sarma KK (2009b) Pathogenicity of entomopathogenous fungus, *Beauveria bassiana* (Balsamo) Vuillemin on *Megacopta cribrarium* (Fab.): a sucking pest of pigeonpea. Insect Environ 14:159-160

Chen Q, Wang JL, Guo SJ, Bai HX, Zhuo XN (2009) Studies on the biological characteristics of *Megacopta cribraria* (Fabricius). J Henan Agr Sci 4:88-90

Dejean A, Orivel J, Gibernau M (2002) Specialized predation on plataspid heteropterans in a coccinellid beetle: adaptive behavior and responses of prey attended or not by ants. Behav Ecol 13:154-159

Eger JE, Jr, Ames LM, Suiter DR, Jenkins TM, Rider DA, Halbert SE (2010) Occurrence of the Old World bug *Megacopta cribraria* (Fabricius) (Heteroptera: Plataspidae) in Georgia: a serious home invader and potential legume pest. Insecta Mundi 0121: 1-11

Frye MJ, Hough-Goldstein J, Sun J-H (2007) Biology and preliminary host range assessment of two potential kudzu biological control agents. Environ Entomol 36:1430-1440

Grebner DL, Ezell AW,Prevost JD, Gaddis DA (2011) Kudzu control and impact on monetary returns to non-industrial private landowners in Mississippi. J Sustain For 30:204-223

Greene JK, Roberts PM, Gardner WA, Reay-Jones F, Seiter N (2012) Kudzu Bug Identification and Control in Soybeans. United Soybean Board, Chesterfield, MO. 10 pages

Hirose Y, Takasu K, Takagi, M (1996) Egg parasitoids of phytophagous bugs in soybean: mobile natural enemies as naturally occurring biological control agents of mobile pests. Biol Contr 7:84-94

Horn S, Hanula JL (2011) Influence of trap color on collection of the recently-introduced bean plataspid, *Megacopta cribraria* (Hemiptera: Plataspidae). J Entomol Sci 46:85-87

Hosokawa T, Kikuchi Y, Nikoh N, Shimada M, Fukatsu T (2006) Strict host-symbiont cospeciation and reductive genome evolution in insect gut bacteria. PLoS Biol 4:1841-1851

Hosokawa T, Kikuchi Y, Shimada M, Fukatsu T (2007) Obligate symbionts involved in pest status of host insect. Proc Royal Soc B: Biol Sci 274:1979-1984

Jenkins TM, Suiter D, Eger J, Ames L, Buntin D, Eaton T (2010) The preliminary genetics of an invasive true bug from the Old World: implications for the New World. J Entomol Sci 45:1-2

Jenkins TM, Eaton TD (2011) Population genetic baseline of the first plataspid stink bug symbiosis (Hemiptera: Heteroptera: Plataspidae) reported ij North America. Insects 2:264-272

Johnson NF (1985) Systematics of New World *Trissolcus* (Hymenoptera: Scelionidae) species related to *T. basalis*. *Can Entomol* 117:431–45

Johnson NF (1996) Revision of World species of *Paratelenomus* Dodd (Hymenoptera: Scelionidae). Can Entomol 128:273-291

Kikuchi A, Kobayashi H (2010) Effect of Injury by Adult *Megacopta punctatissima* (Montandon) (Hemiptera: Plataspidae) on the Growth of Soybean during the Vegetative Stage of Growth. Jpn J Appl Entomol Zool 54:37–43 (in Japanese with English summary)

Li H-M, Deng R-Q, Wang J-W, Chen Z-Y, Jia F-L, Wang XZ (2005) A preliminary phylogeny of the Pentatomomorpha (Hemiptera: Heteroptera) based on nuclear 18s rDNA and mitochondrial DNA sequences. Mol Phylog Evol 37:313-326

Li YH, Pan ZS, Zhang JP, Li WS (2001) Observation of biology and behavior of *Megacopta cribraria* (Fabricius). Plant Prot Technol Ext 21(7): 11-12 (in Chinese)

Pak, GA (1986) Behavioural variations among strains of *Trichogramma* spp. A review of the literature on host-age selection. J Appl Entomol 101:55-64

Polaszek A, Hayat M (1990) *Dirphys boswelli* (Hymenoptera: Aphelinidae) an egg parasitoid of Plataspidae (Heteroptera). J Nat Hist 24:1-5

Polaszek A, Hayat M (1992) A revision of the genera *Dirphys* Howard and *Encarsiella* Hayat (Hymenoptera: Aphelinidae). Syst Entomol 17:181-197

Rajmohan K, Narendran TC (2001). Parasitoid complex of *Coptosoma cribrarium* (Fabricius) (Plataspididae [sic]: Hemiptera). Insect Environ 6:163

Schuh RT, Slater JA (1995). True bugs of the world. Cornell University Press, Ithaca, NY.

Srinivasaperumal S, Samuthiravelu P, Muthukrishnan J (1992) Host plant preference and life tale of *Megacopta cribraria* (Fab.) (Hemiptera: Plataspidae). Proc Indian Nat Science Acad B58 (6):333-340

Suiter DR, Eger JE Jr., Gardner WA, Kemerait RC, All JN, Roberts PM, Greene JK, Ames LM, Buntin GD, Jenkins TM, Douce GK (2010) Discovery and distribution of *Megacopta cribraria* (Hemiptera: Heteroptera: Plataspidae) in northeast Georgia. J Integrat Pest Manag 1(1): 1-4

Takagi M, Murakami K (1997) Effect of temperature on development of *Paratelenomus saccharalis* (Hymenoptera: Scelionidae), an egg parasitoid of *Megacopta punctatissimum* (Hemiptera: Plataspidae). Appl Entomol Zool 32:659-660

Takasu K, Hirose Y (1985). Seasonal egg parasitism of phytophagous stink bugs in a soybean field in Fukuoka. Proc Assoc Plant Prot Kyushu 31: 127-131 (in Japanese with English summary)

Takasu K, Hirose Y (1986). Kudzu-vine community as a breeding site of *Ooencyrtus nezarae* Ishii (Hymenoptera: Encyrtidae), an egg parasitoid of bugs attacking soybean. Jpn J Appl Entomol Zool 30:302-304 (In Japanese with English summary)

Takasu K, Hirose Y (1991) The parasitoid *Ooencyrtus nezarae* (Hymenoptera: Encyrtidae) prefers hosts parasitized by conspecifics over unparasitized hosts. Oecologia 87:319-323

Thippeswamy C, Rajagopal BK (1998) Assessment of losses caused by the lablab bug, *Coptosoma cribraria* Fabricius (Heteroptera: Plataspidae) to the field bean, *Lablab purpureus* var. *lignosus Medikus*. Karnataka J Agric Sci 11:941-946

Thippeswamy C, Rajagopal BK (2005) Life history of lablab bug, *Coptosoma cribraria* Fabricius (Heteroptera: Plataspidae) on field bean, *Lablab purpureus* var. *lignosus Medikus*. Karnataka J Agric Sci 18:39-43

Tomokuni M, Yasunaga T, Takai M, Yamashita I, Kawamura M, Kawasawa T (1993) A field guide to Japanese bugs.-Terrestrial Heteropterans. Zenkoku Noson Kyikyu Kyokai Publishing Co., Ltd., Tokyo, Japan

Wall RE (1928) A comparative study of a chalcid egg parasite in three species of Plataspidinae. Lingnan Sci J 6:231-239

Wall RE (1931) *Dissolcus tetartus* Crawford, a scelionid egg parasite of Plataspidinae in China. Lingnan Sci J 9:381-382

Wang HS, Zhang CS, Yu DP (2004) Preliminary studies on occurrence and control technology of *Megacopta cribraria* (Fabricius). China Plant Prot 24(8):45 (in Chinese)

Wang ZX, Wang HD, Chen GH (1996) Occurrence and control of *Megacopta cribraria* (Fabricius) on soybean. Plant Prot 1996: 7-9

Wu MX, Wu Z-Q, Hua S-M (2006) A preliminary study of some biological characters of globular stink bug, *Megacopta cribraria* and its two egg parasitoids. J Fujian Agric For Univ (Natural Science Edition) 35:147-50

Wu YQ, Zhang XM, Hua AQ, Chen JF (1992) Observation of the biological characteristics and control of *Megacopta cribraria* (Fabricius). Insect Knowl 29:272-274

Zhang CS, Yu DP (2005) Occurrence and control of *Megacopta cribraria* (Fabricius). Chinese Countryside Well-off Technol 1:35

Zhang Y, Hanula JL, Horn S (2012) The biology and preliminary host range of *Megacopta cribraria* (Heteroptera: Plataspidae) and its impact on kudzu growth. Environ Entomol 41:40-50

Zhang Y-T, Du X-G, Dong M, Shei W (2003) A preliminary investigation of egg parasitoids of *Megacopta cribraria* in soybean fields. Entomol Knowl 40:443-445 (In Chinese)

Table 1. Predators observed feeding on *M. cribraria* in Georgia (observations by Ruberson, Eger, Olson, Cyndi Ball; 2010 to 2012)

Species	Family	Stage attacked	Where observed
Euthyrhynchus floridanus adult	Pentatomidae	Adult	Field
Nabis roseipennis (Reuter) adult	Nabidae	Nymph	Lab
Geocoris uliginosus adult	Geocoridae	Nymph	Lab, Field
Geocoris punctipes adult	Geocoridae	Nymph	Lab
Zelus sp. adult	Reduviidae	Nymph	Field
Sinea sp. adult	Reduviidae	Nymph, adult	Lab
Hippodamia convergens adult	Coccinellidae	Nymph	Lab, Field
Hippodamia convergens larva	Coccinellidae	Nymph	Lab
Chrysoperla rufilabris larva	Chrysopidae	Nymph	Lab, Field

Figure Captions

Fig. 1. Distribution and spread of *Megacopta cribraria* from 2009-2012 in the southeastern United States (prepared by Wayne A. Gardner, University of Georgia; July 2012).

Fig. 2. Dermatitis induced by nymphal *M. cribraria* being crushed between boots and socks while working in infested soybeans (photo courtesy of Michael D. Toews, University of Georgia).

Fig. 3. Documented distribution of kudzu, *Pueraria montana* var. *lobata*, in the United States, September 2012. Map produced by EDDMapS, 2012. Early Detection & Distribution Mapping System. The University of Georgia - Center for Invasive Species and Ecosystem Health. Available online at http://www.eddmaps.org/distribution/uscounty.cfm?sub=2425; last accessed September 20, 2012.

Fig. 1

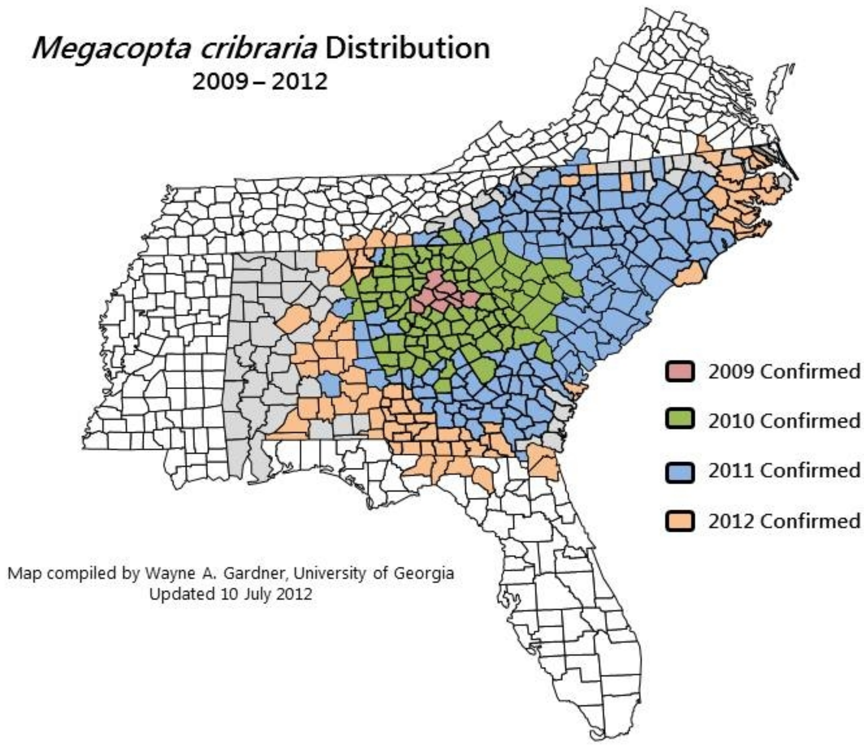
Megacopta cribraria Distribution
2009 – 2012
2009 Confirmed
2010 Confirmed
2011 Confirmed
2012 Confirmed
Map compiled by Wayne A. Gardner, University of Georgia
Updated 10 July 2012

Fig. 2

Fig. 3.