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Biological control of sentinel egg masses of the exotic invasive stink bug *Halyomorpha halys* (Stål) in Mid-Atlantic USA ornamental landscapes

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HIGHLIGHTS

- Sentinel egg masses were placed in plots comprised of native or exotic plants.
- Parasitism and predation rates were not affected by plot type or plant genus.
- Parasitism rates were higher in adjacent wooded sites than in experimental plots.
- Seven native and one exotic parasitoid species attacked sentinel egg masses.
- Parasitism and predation rates in experimental plots and wooded sites were low.

GRAPHICAL ABSTRACT

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ABSTRACT

Biological invasions have far reaching effects on native plant and arthropod communities. This study evaluated the effect of natural enemies on eggs of the exotic invasive brown marmorated stink bug *Halyomorpha halys* (Stål) in experimental plots comprising species pairs of 16 ornamental trees and shrub genera from either Eurasia or North America and in wooded areas adjacent to the plots. Sentinel egg masses were placed on leaves of *Acer*, *Cercis*, *Hydrangea*, and *Prunus* in the plots and in seven genera of trees and shrubs in adjacent woods. Overall, rates of parasitism and predation in experimental plots were low, accounting for only 3.8% and 4.4% of egg mortality, respectively. There were no significant differences in parasitism and predation rates between native or exotic plots or between plants of different genera. In 2015, predation was significantly higher in the experimental plots than in the wooded sites, but parasitism was significantly higher in the wooded sites. In the experimental plots, seven native and one exotic parasitoid species attacked sentinel egg masses. Six native parasitoid species attacked sentinel egg masses in the wooded sites. Parasitoids in the genus *Trissolcus* were more likely to attack egg masses in exotic plots than in native plots. There is no evidence that native natural enemies attacking eggs of the exotic BMSB were more prevalent in landscapes with native ornamental trees and shrubs than those with exotic trees and shrubs.

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1. Introduction

Urban landscapes often comprise mosaics of exotic and native plants. There is evidence that exotic plants reduce the abundance and species diversity of arthropod communities (Zeufle et al., 2008; Burghardt et al., 2010; Simao et al., 2010; Roberge and Stenbacka, 2014; Macedo-Veiga et al., 2016). However, the effects of exotic plants on the abundance and species diversity of native parasitoids and predators of herbivorous insects are largely unknown (Bezemer et al., 2014). In a two-year study comparing the attractiveness of native and exotic plants to natural enemies, many of the native perennials were more attractive to natural enemies than annual exotic plants due to their nectar and pollen resources (Fiedler and Landis, 2007a). Natural enemy abundance increased with increasing floral area, period of peak bloom, maximum flower height, and decreasing corolla width (Fiedler and Landis, 2007b). Simao et al. (2010) conducted a study in 32 5.25 m × 5.25 m mowed plots that were planted with seeds from 12 native herbaceous plants. In half of these plots, seeds of the invasive exotic Japanese stiltgrass *Microstegium vimineum* (Trin) A. Camus were also planted. In plots with the invasive grass, insect populations were significantly lower than in plots composed exclusively of native plants. However, the impact of the invasive grass was greater on natural enemy populations, resulting in a reduction of 61%, compared with a reduction of only 31% in populations of herbivorous insects (Simao et al., 2010). In contrast, Lescano and Farji-Brener (2011) determined that the abundance of ants was increased on exotic thistles compared with native plants due to higher population densities of aphids on these invasive plants.

The ability of natural enemies to find their native prey or hosts on exotic plants can be reduced if they fail to recognize visual and chemical cues emitted by the plant that provide information about the presence of their prey or hosts (Vet and Dicke, 1992). Spatial features of the landscape can also interfere with the searching behavior of natural enemies. In patches of habitat where native grass was surrounded by invasive grass, both the native herbivore and its parasitoid suffered high rates of extinction, but the rate of extinction of the parasitoid was three times higher than that of its host (Cronin and Haynes, 2004). The native butterfly *Pieris oleracea* Harris (Lepidoptera: Pieridae) was able to find refuge from parasitism on an exotic plant because overtopping vegetation prevented the parasitoid from finding its host (Herlihy et al., 2014).

The development and survival of parasitoids depends on the fitness of the host feeding on the plant. For example, the survival of the larval parasitoid *Cotesia glomerata* L. (Hymenoptera: Braconidae) and its host *Pieris brassicae* (L.) were much lower when *P. brassicae* was reared on an exotic plant than a native plant (Fortuna et al., 2012). Also, the parasitism rate of *C. glomerata* on *P. brassicae* larvae was higher on the native plant than on the exotic plant in field cage tests (Fortuna et al., 2013). In contrast, the survival of the pupal parasitoid *Pteromalus puparum* L. (Hymenoptera: Pteromalidae) was similar on *P. brassicae* reared on exotic and native plants (Fortuna et al., 2012).

We tested the hypothesis that native natural enemies would be more abundant in urban landscapes composed of native plants than in those composed of exotic plants by placing sentinel egg masses of the exotic invasive brown marmorated stink bug (BMSB) *Halyomorpha halys* (Stål) (Hemiptera: Pentatomidae) on plants in experimental plots composed exclusively of either native or exotic ornamental trees and shrubs. This study is one part of a replicated experiment testing the hypothesis that native natural enemies will be more abundant and diverse in habitats comprising native than exotic woody ornamental landscape plants (MHG, unpublished).

BMSB was first discovered in the United States in 1996 in Allentown, PA (Hoebeke and Carter, 2003). It is an extremely polyphagous pest of agricultural crops and ornamental plants (Hoebeke and Carter, 2003; Leskey et al., 2012a, 2012b; Rice et al., 2014; Wallner et al., 2014; Xu et al., 2014). Adults have been found feeding on over 100 ornamental trees and shrubs (Bergmann et al., 2016a). A survey of ornamental trees and shrubs identified 88 species used by all life stages of BMSB, including species of *Acer* and *Cercis* (Bergmann et al., 2016b). A survey of trees and shrubs in a commercial nursery found that species of lilac and maple (*Syringa*, *Acer*; Sapindales: Sapindaceae), redbud (*Cercis*; Fabales: Fabaceae), London plane tree (*Platanus*; Proteales: Platanaceae), and ornamental cherry (*Prunus*; Rosales: Rosaceae) were most commonly used by BMSB adults (USDA APHIS PPQ, 2010).

Sentinel BMSB egg masses were placed on plants from three genera, *Acer*, *Cercis*, *Prunus*, that were most frequently used by BMSB (USDA APHIS PPQ, 2010). In addition, sentinel egg masses were placed on *Hydrangea*, a very common plant in yards and gardens. The effect of natural enemies on BMSB eggs in native and exotic plots was evaluated by comparing the proportion of eggs attacked by parasitoids and predators for each plant genus in both native and exotic plots. We also compared the rates of parasitism and predation on egg masses in the experimental plots with egg masses placed in adjacent wooded areas.

We evaluated the species composition of native parasitoids attacking BMSB eggs in exotic and native plots and in wooded areas adjacent to the experimental plots to determine if habitat influenced the parasitoid species complex. Previous studies have found that *Telenomus podisi* Ashmead (Hymenoptera: Scelionidae) is the predominant parasitoid in vegetable crops and *Trissolcus* spp. are dominant in wooded habitats bordering those crops (Talamas et al., 2015; Herlihy et al., 2016). In a study conducted in ornamental tree nurseries in Maryland, *Anastatus* spp. (Hymenoptera: Eupelmidae) were the predominant parasitoids attacking BMSB egg masses (Jones et al., 2014). In Georgia, *Anastatus* spp. attacked native stink bug eggs in woodland habitats, but not in crops, and *T. podisi* was the predominant parasitoid species in both crops and woodland habitats (Tillman, 2016).

In addition, we collected parasitoids that were attending BMSB egg masses. Studies have shown that scelionid parasitoids of pentatomids defend egg masses they have attacked from other parasitoids (Austin et al., 2005). For instance, the parasitoid *Trissolcus basalis* (Wollaston) (Hymenoptera: Scelionidae) frequently remains on the egg mass after oviposition, patrols the egg mass, and aggressively defends the egg mass against intruders (Field, 1998; Field et al., 1998).

2. Materials and methods

2.1. Locality

We performed the experiment at the United States National Arboretum (USNA) in Northeast Washington, D.C., USA (38° 54′ 36.84″ N 76° 58′ 3.14″ W) in U.S.D.A. plant hardiness zone 7a (avg. annual minimum temperature of −17.8 to −15 °C). The USNA is uniquely suited for urban study: it is located within a large city, is itself a model urban landscape, and contains hundreds of examples of exotic and native congeners of popular urban landscape plants, including many of those in our experiment. Hence many herbivores and natural enemies capable of colonizing the experiment are found in the surrounding landscape, as they are in real-world urban residential plots.

2.2. Plants

Plots were planted with woody species commonly used as ornamental trees and shrubs in urban landscapes. We included only