

# A Scientific Review on the Ecology and Management of the Azalea Lace Bug *Stephanitis pyrioides* (Scott) (Tingidae: Hemiptera)<sup>1</sup>

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J. Entomol. Sci. 47(3): 247-263 (July 2012)

**Abstract** The azalea lace bug, *Stephanitis pyrioides* (Scott) (Tingidae: Hemiptera), is a major pest of azaleas (*Rhododendron* L. spp.). Since its introduction from Asia in the 1940s, the pest has spread considerably within and outside the US. It causes severe economic damage to azaleas and also attacks other ericaceous hosts. The widespread acceptance and cultivation of its preferred host plants, azaleas, in landscapes and home gardens prompted extensive research on *S. pyrioides* with respect to biology, damage and management. This review summarizes the work done on this pest and provides directions for future research.

**Key Words** azalea, lace bug, *Stephanitis pyrioides*, review, ecology, biology, management

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The genus *Stephanitis* Stål (Tingidae: Hemiptera) comprises over 60 species of lace bugs, many of which are pests of fruit and ornamental trees and shrubs in tropical and temperate regions of the world (Howard 2001). The azalea lace bug (*Stephanitis pyrioides* [Scott]), the Andromeda lace bug (*S. takeyai* Drake and Maa) and the rhododendron lace bug (*S. rhododendroni* Horváth) are the 3 species established in North America. Criteria for the identification of the 3 species are available (Bailey 1950, Dunbar 1974, Beshear et al. 1976, Stonedahl et al. 1992). A fourth species, *S. blatchleyi* Drake also has been reported (Froeschner 1988), but it was last collected in 1927 and is believed to be extinct (Drake 1925, Oliver et al. 1990).

Within the order Hemiptera, tingids are considered the most injurious to ornamental trees and shrubs (Johnson and Lyon 1991). All 3 *Stephanitis* species mentioned above are known to attack woody ornamentals, especially azaleas, rhododendrons and related plants of the family Ericaceae (Alverson et al. 1994, Schuh and Slater 1995). Under normal circumstances damage may be insignificant, but severe infestations have reportedly caused plant death (Froeschner 1995, Klingeman et al. 2000a), and they are considered major pests of ornamentals (Schultz and Shetlar 1994). Of the 3 species, the azalea lace bug occupies prominence in terms of spread and economic damage.

## Origin, Distribution and Spread of *S. pyrioides*

The azalea lace bug was first described by Scott (1874) as *Tingis globulifera*. Uhler and Mitzukuri (1896) listed it with the same name in a collection of Hemiptera of Japan

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<sup>1</sup>Received 22 November 2011; accepted for publication 16 January 2012.

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presented to the United States National Museum. Horváth (1905) renamed the bug as *Stephanitis azaleae*, and Oshanin (1908) changed the specific epithet to *pyrioides*. *Stephanitis pyrioides* was later a subject of study by several workers (Dickerson and Weiss 1917, Weiss 1918, Drake 1923, Blatchley 1926, White 1933, Bailey 1950, Gomez-Menor 1954, Stichel 1960, Shen et al. 1985). The common name 'azalea lace bug' was approved by the American Association of Economic Entomologists in 1942 (Muesebeck 1942) and by the Entomological Society of America in 1965 (Blickenstaff 1965). *Stephanitis pyrioides* is considered native to Japan but has spread through the movement of its host plants, most importantly azaleas (Mead 1967). The importance of the azalea lace bug has risen along with the increasing use and cultivation of azaleas in landscapes and home gardens (Neal and Schaefer 2000).

*Stephanitis pyrioides* was first reported in the United States in New Jersey (Weiss 1916) and spread to Pennsylvania and Washington, DC (Weiss and Headlee 1918, McAtee 1923). Since its introduction, *S. pyrioides* has been reported from different parts of the United States: New Jersey (Dickerson and Weiss 1917), Connecticut (Parshley 1922), New York (Drake 1923), Missouri (Froeschner 1944), New England (Bailey 1950) and Massachusetts (Bailey 1959). It also has been reported from other countries: Switzerland (Müller-Thurgau et al. 1917), Argentina (Blanchard 1926), Korea (Takeya 1932), China (Drake 1937), Taiwan (Takeya 1951), Morocco (Gomez-Menor 1954), England (Stichel 1960), New South Wales (Drake 1961), Japan (Takeya 1963) and Hong Kong (Lee and Winney 1981). *Stephanitis pyrioides* continues its spread to different states of the U.S. (Torres-Miller 1989, Nielsen 1997) as well as other parts of the world. More recently, Easton and Pun (1997) reported a new record of *S. pyrioides* in Macau, China. Other recent reports are from Italy (Bene and Pluot-Sigwalt 2005, Jucker et al. 2008), France (Streito 2006) and Greece (Kment 2007). In a review on alien Heteroptera species in Europe, an increased trend of introductions from North America to Europe is suggested, most importantly by way of transport of ornamental plants (Rabitsch 2008, 2010).

### Biology and Life History

The biology and life history of *S. pyrioides* have been widely studied (White 1933, English and Turnipseed 1940, Drake and Ruhoff 1965, Mead 1967, Shen et al. 1985). The adult males are 2.8 - 3.3 mm and adult females 2.9 - 3.3 mm in length (Shen et al. 1985). Both male and female adults have transparent wings with lace-like patterns marked with brown patches. The wings are held flat over the dorsum. Adults are weak fliers, and flight occurs mostly due to exhaustion of food (Neal and Schaefer 2000) and sometimes on disturbance of the host plant. Adults showed remarkable longevity (up to 240 d) under optimal rearing conditions, and males lived longer than females. Courtship and mating behavior are not well described, but time for oviposition of a single egg was reported as 2 - 3 min (Dickerson and Weiss 1917). Adults do not diapause (Neal and Douglass 1988) and show cold hardiness (Neal 1985). Winter oviposition has been recorded (Nalepa and Baker 1994), but significantly higher oviposition was observed in June and July than in other months (Schultz 1993). Fecundity and oviposition rate were significantly increased by mating and also varied nonlinearly with temperature (Neal and Douglass 1988).

The eggs are the overwintering stage and are usually laid along the midrib or leaf margins on the underside of the leaves and covered with a dark brownish adhesive material that hardens to form a protective coating (Shen et al. 1985). The hard protective

coating (feculae) also has been described (Weiss and Boyd 1952). Eggs are white, oval or flask-shaped and 0.36 - 0.43 mm long and 0.16 - 0.23 mm wide with a bent neck. Noncleidoic nature of the eggs and the pervious and elastic nature of the chorion are demonstrated by the significant increase in egg width, breadth and weight during development (Neal and Bentz 1997).

Nymphs are colorless on hatching and turn black and spiny as they grow. Five nymphal instars are recorded, ranging in length from 0.1 - 1.8 mm. Wing pads can be seen after the fourth molt (Shen et al. 1985). Early instars are usually seen in groups, which later disperse to seek food (Drake and Ruhoff 1965). Eggs and nymphs of *S. pyrioides* have been studied and described (Dickerson and Weiss 1917, Maa 1957, Lee 1969, Shen et al. 1985, Hwang and Choi 1998). Herring and Ashlock (1971) developed keys to identify nymphs of *S. pyrioides* and other Hemiptera using structures such as trichobothria and dorsal abdominal scent glands. Shen et al. (1985) identified nymphal instars using the number of eye facets. Complete development time from egg to adult is approx. 1 month, and there are at least 4 generations per year (Sparks et al. 2002), with 3 broods being reported in a year (Dickerson and Weiss 1917, Barber and Weiss 1922, Weiss and Headlee 1918, Bailey 1951, Nakasuga 1994) as well as 4 (Neal and Douglass 1988, Braman et al. 1992a). Voltinism may be affected by plant stress (Neal 1985).

Development time for *S. pyrioides* was measured at different temperatures and locations (Neal and Douglass 1988, Braman et al. 1992a, Nakasuga 1994). Complete development took 22 d at 30°C to 97 d at 15°C, but was not successful at 33°C. Threshold temperatures and degree day accumulations for egg, nymphal and complete development also were determined (Braman et al. 1992a). Development of eggs and instars across temperatures has been reported to be nonlinear in the U.S. (Neal and Douglass 1988, Braman et al. 1992a) but linear over the range studied in Japan (Nakasuga 1994).

Morphology and ultrastructure of the female reproductive apparatus in *S. pyrioides* have been examined. In Tingidae, the 2 sac-like diverticula, the "pseudospermathecae," each at the base of a lateral oviduct, were previously considered to function as spermathecae. However ultrastructural studies and observations of sperm transit in the female reproductive tract suggested that these structures were not used for sperm storage but were more likely to be reproductive accessory glands (Marchini et al. 2010).

The occurrence of *S. pyrioides* along with its congener *S. takeyai* on azalea prompted investigation into the possibility of them crossmating and producing progeny. Reciprocal crosses between the species resulted in a unidirectional asymmetric sexual hybrid from *S. pyrioides* females and *S. takeyai* males, and the hybrids were confirmed by 2 physical methods (Neal and Oliver 1991).

## Damage

*Stephanitis pyrioides* adults and nymphs cause feeding injury as well as reduced rates of photosynthesis and transpiration (Buntin et al. 1996). They prefer to feed on older, mature leaves and avoid most tender leaves (Bailey 1951). Ishihara and Kawai (1981) reported that *S. pyrioides* feed by inserting their stylets through stomata on the abaxial leaf surface and removing the chlorophyll content from the upper palisade parenchyma. This depletion of chlorophyll results in reduced photosynthetic capacity of the leaves. Buntin et al. (1996) confirmed this observation and also reported that

females caused significantly more injury than males or nymphs. The feeding also increased stomatal resistance which affected gas exchange and transpiration. Depletion of chlorophyll leads to chlorosis, resulting in stippled or bleached appearance of the upper surface of leaves. Severely-damaged leaves may dry prematurely and abscise. These symptoms along with the presence of brown varnish-like excrement, as well as cast skins attached on the abaxial surfaces of leaves, can be used to identify lace bug damage (Johnson and Lyon 1991). Frass spot numbers are indicative of lace bug feeding and can serve as an index to quantify feeding and damage (Buntin et al. 1996). Females cause significantly more feeding injury per day than males, but overall amount of injury caused during lace bug lifetimes is similar for males and females (Klingeman et al. 2000a) because males live longer.

### Hosts and Range

Polyphagy is considered to be an ancestral character in the genus *Stephanitis*, and monophagous species are supposed to have developed later (Tsukada 1994). However, there are limited reports of *S. pyrioides* attacking hosts of plant families other than Ericaceae. One of the earliest descriptions of *S. pyrioides* was from azaleas (Horvath 1905). Most reports describe the occurrence of the lace bug on different species of *Rhododendron* or other members of the family Ericaceae. Drake and Ruhoff (1965) list the host plants of *S. pyrioides* as *Kalmia latifolia*, *Pieris ovalifolia*, *Rhododendron* spp. (*amoena*, *amurasaki*, *benigeri*, *calendulaceum*, *hinodegeri*, *hatsugeri*, *indica*, *kaempheri*, *ledifolia alba*, *mollis*, *mucronatum*, *obtusum amoenum*, *pontica*, *shirogeri*, *shibori*, *schilippenbachii*, *yedoense poukhanense* and *yodogawa*).

The genus *Rhododendron* L. comprises a large group of over 1000 species of woody ornamentals mostly known for their showy flowers (ARS, USDA 2011). Azaleas (*Rhododendron* sp.), native to North America, Europe as well as Asia (Scariot et al. 2007), comprise 2 of the 8 subgenera of the genus (Chamberlain and Rae 1990, Chamberlain et al. 1996) and are among the most widely cultivated ornamental and landscape plants (Raupp and Noland 1984). They are considered key plants in landscapes of the southeastern United States (Raupp et al. 1985). Breeding has resulted in thousands of azalea cultivars with diverse plant and floral characters (Galle 1987, Salley and Greer 1992) and they have been spread to different regions of the world by transport of plant material (Scariot et al. 2007). *Stephanitis pyrioides* is the major cosmopolitan tingid species attacking azaleas and causes severe economic damage to landscape and cultivated azaleas in most countries where they are grown (Shrewsbury and Smith-Fiola 2000, Klingeman et al. 2001b).

### Host Plant Resistance

The differences in susceptibility of various *Rhododendron* species and cultivars to *S. pyrioides* have been noted and studied by several workers. The levels of resistance are reported to show a continuous distribution from susceptible to highly resistant within deciduous azalea (*Rhododendron*: sect. *Pentanthera*: subseries *Luteum*) (Chappell and Robacker 2006). In an evaluation of the deciduous *Rhododendron* species, *R. albamense* Rehder, *R. austrinum* (Small) Rehder, *R. calendulaceum* (Michaux) Torrey, *R. canescens* (Michaux) Sweet and *R. prunifolium* (Small) Millais were less suitable for adult feeding, oviposition, and nymphal development of *S. pyrioides* than the evergreen *R. mucronatum* variety 'Delaware Valley White'. However, all 5

species supported adult activity and oviposition in no-choice and free-choice tests (Braman and Pendley 1992). A study comparing 20 azalea cultivars revealed lowest acceptance, as measured by significantly reduced oviposition and leaf injury, on 'Macrantha' (Schultz 1993). Another study evaluated the susceptibility of 17 deciduous and 1 evergreen *Rhododendron* species and cultivars to *S. pyrioides*. *Rhododendron canescens* and *R. periclymenoides* (Michaux) Shinnery were the most resistant species, followed by *R. prunifolium* (Wang et al. 1998). Plant physical characters like bloom color and abaxial leaf texture could not be correlated with host plant acceptance by *S. pyrioides* (Schultz 1993).

Several possible mechanisms of resistance in azaleas to *S. pyrioides* have been investigated, such as epicuticular waxes (Balsdon et al. 1995, Wang et al. 1998, 1999, Chappell and Robacker 2006), leaf pubescence (Schultz 1993, Wang et al. 1998), stomatal characters (Kirker et al. 2008) and leaf moisture content (Wang et al. 1998). It is likely that multiple mechanisms contribute to observed resistance. Resistant and susceptible deciduous cultivars differ in components of the leaf-surface lipids, identified as *n*-alkanes and triterpenoids, and these had significant correlations with *S. pyrioides* behavior as measured by oviposition, egg and nymphal development, nymphal survivorship and leaf area damaged. Seasonal variations in their proportions also were observed. Susceptible deciduous genotypes had the largest proportions of  $\alpha$ -amyirin,  $\beta$ -amyirin, and *n*-nonacosane, whereas, resistant genotypes were high in ursolic acid, *n*-hentriacontane, and *n*-nonacosane (Wang et al. 1999). In another study, the insect feeding and/or oviposition deterrent triterpenoid components  $\alpha$ - and  $\beta$ -amyirin were present in lower levels in susceptible cultivars (Balsdon et al. 1995). Leaf wax extracts from resistant genotypes applied to susceptible ones resulted in resistance to both feeding and oviposition by *S. pyrioides* in the treated susceptible genotypes, and wax extracts from susceptible genotypes applied on resistant ones caused susceptibility, indicating that leaf wax has a definite role in lace bug resistance in azaleas (Clark 2000, Chappell et al. 2004, Chappell and Robacker 2005, 2006, Chappell 2007).

Leaf water content and leaf pubescence, though significantly different among azalea varieties, did not appear to be significantly correlated with azalea lace bug performance and therefore, could not be related to lace bug resistance in most azalea taxa with the exception of *R. canescens* which had extremely high trichome density and was highly resistant to azalea lace bug feeding (Wang et al. 1998). Likewise, in another study stomatal characters of 33 azalea cultivars were compared with their preference by *S. pyrioides* and, although stomata size differed significantly among the cultivars, they could not be correlated to *S. pyrioides* feeding preference (Kirker et al. 2008). The possible role of chemical cues on the plant surface cannot be ignored, and most studies that examine structural defenses in azaleas mention the possibility that defensive compounds also are involved in resistance (Balsdon et al. 1995, Wang et al. 1998, Kirker et al. 2008). Azalea lace bug resistance in azaleas may likely involve leaf physical and chemical composition combined with antibiosis, indicated by lower growth rate and survivorship of adults and nymphs, and reduced feeding and plant damage by *S. pyrioides* (Wang et al. 1998).

Many morphological traits associated with azalea leaves are strongly influenced by environmental conditions (Kirker et al. 2008), and these influences may be reflected in the host preferences shown by the lace bugs. Greater damage has been observed by *S. pyrioides* on azaleas growing in sunny, exposed habitats as opposed to those growing in shaded locations (Felt and Bromley 1931, White 1933, Raupp

1984), which may be due to stress-induced changes in nutritional physiology. Shaded plants were better hosts to *S. pyrioides* and could tolerate infestations better than those exposed to sun (Bentz 2003). Conversely, lace bugs in shaded habitats may show lower survival than in exposed areas due to action of natural enemies (Trumbule et al. 1995). Studies examining these 2 situations showed that lace bugs may move to sunny habitats (thermal refuge) when faced with natural enemy pressure, and overall survival may be greater but actual performance reduced (Trumbule and Denno 1995, Lepping 2004). When natural enemies were excluded, lace bugs preferred to feed and oviposit on shaded plants than sun-grown plants, and lace bug fitness was higher on shaded plants (Trumbule and Denno 1995). However, studies on *S. pyrioides* population dynamics in containerized azaleas found that there were no significant differences among *S. pyrioides* oviposition, eclosion and stippling damage under various sun and shade levels (Kintz 1997, Kintz and Alverson 1999). The differential thermal environments created by shading also were found to influence lace bug development and survival (Lepping 2004). *Stephanitis pyrioides* mortality was seen to be higher in complex landscapes containing both plant as well as arthropod diversity (Raupp et al. 2001, Raupp and Shrewsbury 2005, Raupp et al. 2010).

Nitrate:ammonium ratios applied to azaleas appeared to influence *S. pyrioides* feeding and damage in *R. austrinum*. *Stephanitis pyrioides* damage was found to decrease with ammonium and increase with the nitrate concentrations in test plants. These observations may indicate an influence of N form on synthesis of certain epicuticular lipids (Clark 2000). Performance of *S. pyrioides* did not appear related to supplemental nitrogen fertilization to host plants (Casey and Raupp 1999a, b), although the lace bugs showed a preference for plants with elevated nitrogen levels. Lace bug fitness also did not differ on azaleas receiving high and low application rates of water (Trumbule and Denno 1995). Application of plant growth regulators appeared to affect development of *S. pyrioides*, where changes were suggested to be related to azalea growth and nutritional quality (Coffelt and Schultz 1988).

### Management of *S. pyrioides*

Some of the earliest reports on managing azalea lace bug populations mention the use of whale oil soap (Weiss 1918) and white oil in combination with rotenone (as powdered derris root) (English and Turnipseed 1940). Chemical control using insecticides was common in earlier years following the introduction and establishment of *S. pyrioides* in the U.S. (Streu 1975). Insecticides used included thimet (Schread 1959), dimethoate and phosphamidon (Schread 1960). Dimethoate soil treatments were widely used for seasonal control of *S. pyrioides* populations (Johnson 1960, Schread 1968). Chemicals found effective for lace bug control include acephate, dimethoate, carbaryl, malathion, cyfluthrin and bifenthrin (Buss and Short 2001, Sparks et al. 2002, Cranshaw 2004, Buss and Turner 2006, Gyeltshen and Hodges 2009). In one study, the synthetic pyrethroids deltamethrin and cyfluthrin provided significantly better control than azadirachtin (Coffelt 1994). Acephate proved to be more cost-effective and persistent in suppression of *S. pyrioides* compared with dimethoate, bendiocarb, cyfluthrin, abamectin, azadirachtin, insecticidal soap and horticultural oil (Balsdon et al. 1993). Comparison of gas exchange measurements in azaleas treated with insecticides used to control *S. pyrioides* showed that acephate did not affect whole-plant gas exchange, whereas, insecticidal soap caused short-term reductions in gas exchange as well as carbon use efficiency (Klingeman et al. 2000c). Systemic insecticides

like imidacloprid have been used successfully to control infestations (Balsdon et al. 1993, Hommes and Westhoff 2004). Early spraying of plants prevents further generations from developing because nymphs are more susceptible to pesticides than adults (Neal and Schaefer 2000, Sparks 2000). Various soil-applied neonicotinoid insecticides were evaluated for speed of translocation and residual longevity in control of azalea lace bugs, and dinotefuran, thiamethoxam, imidacloprid and clothianidin suppressed lace bugs and improved plant appearance (Held and Parker 2011).

The determination of azalea lace bug feeding-injury potential is critical to the development of decision-making guidelines (Klingeman 1998, Klingeman et al. 2000a). Attempts to define a "tally threshold value" for assessing *S. pyrioides* feeding injury prompted a survey which revealed that 6 - 10% damage is acceptable to consumers and using aesthetic injury levels to determine treatment thresholds can significantly help in limiting urban pesticide use (Klingeman et al. 2000b, 2001a, b). Comparison of gas exchange parameters like net photosynthesis and growth in lace bug damaged and undamaged plants also showed that azaleas were tolerant of lace bug feeding injury levels above the aesthetic threshold (Klingeman et al. 2000d).

IPM approaches have been also attempted for azalea lace bug management. A study comparing IPM with traditional pest control approaches in landscapes found that pesticide volume was reduced by an average of 85.3% at test sites compared with preprogram levels. (Stewart et al. 2002c). IPM practices also reduced overall cost of plant care without compromising aesthetic quality of the landscape (Smith and Raupp 1986). In a comparison of different management strategies, whereas traditional management using pesticide applications effectively suppressed azalea lace bug and produced a high-quality landscape, resistant plant-based management was most effective in managing *S. pyrioides*. Targeted management using horticultural oils alone resulted in intermediate levels of *S. pyrioides* populations (Braman et al. 2000). The importance of *S. pyrioides* as an introduced pest and the widespread popularity of its hosts, azaleas, have prompted several investigations using the 'azalea and azalea lace bug system' as a representative of urban landscapes (Hellman et al. 1982, Holmes and Davidson 1984). Use of diverse vegetation in landscape designs was found to be an effective strategy for improving the sustainability of urban landscapes and reducing use of pesticides (Raupp and Shrewsbury 2005, Raupp et al. 2010). Studies on various components of vegetational texture in the landscapes revealed that the best habitat predictors of lace bug abundance were structural complexity and light exposure (Shrewsbury and Raupp 2000). Addition of flowering plants and other nonhost vegetation to landscapes lowered *S. pyrioides* survival due to increased abundance of alternative prey and natural enemies (Leddy 1996, Shrewsbury et al. 2004). Overall, the collective effects of top-down and bottom-up forces determined abundance of herbivores like *S. pyrioides* in diverse urban landscapes (Shrewsbury and Raupp 2006). Habitat manipulation by using mixed vegetation and proper care of azaleas by preventing water deficit minimized *S. pyrioides* infestations (Trumbule and Denno 1995). Groundcover and container position manipulations in nursery beds showed that *S. pyrioides* had an overall lower abundance on plants in wood mulch plots above-ground containers (Waterworth 2005). Information gained from habitat manipulation studies is helpful in designing low-input and sustainable landscapes (Trumbule 1989, Shrewsbury and Raupp 2000).

The widespread use of chemical insecticides have raised concerns among homeowners and gardeners and has prompted testing of safer methods like the use of botanicals and other natural materials for lace bug control. Screening of essential oils

from different plants for bioactivity against *S. pyrioides*, using serial-time mortality bioassays, showed that 1% emulsions derived from oil of *Pelargonium*, *Cinnamomum*, *Hedychium* and *Tagetes* caused higher mortality in the treated lace bugs than malathion-DMSO emulsions (Sampson et al. 2009). Essential oils from *Juniperus saltuaria* and *J. squamata* var. *fargesii* also were found to have insecticidal activity against *S. pyrioides* (Wedge et al. 2009). The essential oil of *Eupatorium capillifolium* (dog-fennel) showed a linear dose response of adult *S. pyrioides* mortality to increasing oil concentration (Tabanca et al. 2010). Although azadirachtin is recommended for lace bug control (Hale 2011, Dreistadt and Perry 2006), it is not found to be as effective as chemicals (Coffelt 1994).

Insecticidal soaps and horticultural oils have been used against *S. pyrioides* with variable results (White 1933, Braman et al. 1992b, Klingeman et al. 2000c, Stewart et al. 2002c). However, being considered less hazardous and of shorter persistence than chemical insecticides, they are often integrated into pest management programs (Miller 1989, Davidson et al. 1990). The safety aspect prompts homeowners and landscapers to consider using these materials even though the control offered is not as effective as with chemical insecticides (Balsdon et al. 1993). Repeated applications of insecticidal soap, horticultural oil and neem oil are effective against mild infestations of *S. pyrioides* (Braman et al. 1992b, Sparks et al. 2002).

### Biological Control

Natural enemies reported to attack *S. pyrioides* include the mymarid egg parasitoid *Anagrus takeyanus* Gordh (Braman et al. 1992a, Balsdon et al. 1993, 1996); the Japanese mirid *Stethoconus japonicus* Schumacher (Henry et al. 1986); the mirids *Rhinocapsus vanduzeei* Uhler and *Dicyphus rhododendri* Dolling (Braman and Beshear 1994), the green lacewings *Chrysoperla carnea* (Stephens) (Shrewsbury and Smith-Fiola 2000) and *C. rufilabris* (Burmeister) (Stewart et al. 2002a), and various spiders (Shrewsbury et al. 2004).

Spiders are usually the most abundant predatory arthropod on azaleas (Stewart et al. 2002b, c, Shrewsbury and Raupp 2006). The predatory mirid *S. japonicus* native to Japan, was first reported in the Western Hemisphere based on specimens collected from Maryland (Henry et al. 1986). It was described as an adventive, obligate predator of *Stephanitis* lace bugs with good biocontrol potential. Late hatch of *S. japonicus* eggs results in synchrony with the second generation of *S. pyrioides* which may also indicate that voltinism is regulated by host water potential (Neal et al. 1991). This also allows escape from pesticides used against the first generation of the host (Neal and Haldemann 1992); however, it is effective only with high populations of its host *S. pyrioides* (Neal and Schaefer 2000).

*Anagrus takeyanus*, collected from *S. pyrioides* eggs, was reported as a natural enemy of *S. pyrioides* in Georgia (Braman et al. 1992a). It was described earlier from *Stephanitis takeyai* (Tsukada 1992) and also believed to be introduced along with it because *Stephanitis* lace bugs were not commonly parasitized in America at the time (Gordh and Dunbar 1977). Development of *A. takeyanus* in *S. pyrioides* eggs has been studied, and the parasitoid was reported to have potential as a biocontrol agent (Balsdon et al. 1996). Parasitism by *A. takeyanus* was not seen to be affected by chemicals insecticides (Balsdon et al. 1993).

Green lacewings are voracious predators in landscape situations where they are found in association with and preying on a variety of arthropods including *S. pyrioides*



(Ehler and Kinsey 1995, Shrewsbury and Smith-Fiola 2000). They are popular because they fulfill most of the essential requirements for an effective biological control agent (Daane and Yokota 1997) and are also easily available from commercial suppliers (Olkowski et al. 1992, Hunter 1997). *Chrysoperla rufilabris* is reported to be the better adapted and dominant species in the southeastern U.S. as compared with *C. carnea* (Tauber and Tauber 1983, Dinkins et al. 1994, Smith et al. 1995). It also was found to be suitable for augmentative release to control *S. pyrioides* (Stewart et al. 2002a). Although not entirely successful, integration of *C. carnea* with azalea lace bug management programs also was found to be feasible (Shrewsbury and Smith-Fiola 2000, Shrewsbury et al. 2004). A high-throughput and inexpensive procedure for documentation of lace bug predation by green lacewings in the field, using analysis of gut contents of the predators, has been described (Rinehart and Boyd 2006). Nymphs of *S. pyrioides* are more susceptible to predation due to their limited mobility (Lepping and Shrewsbury 2004).

### Chemistry of Exudates

Nymphs and adults of many genera of lace bugs are known to secrete fluid droplets from specialized setae on their abdomen and antennae (Livingstone 1978) which were later described as phenolic acetogenins (Millar 2005). These compounds are reported to have a possible role in defense against predation and parasitization (Oliver et al. 1990, Mason et al. 1991) and alarm pheromone systems (Aldrich et al. 1991) because, although lace bug nymphs are seen in groups (Drake and Ruhoff 1965), they are usually free of predators and parasites (Sheeley and Yonke 1977). The secretions also possess bactericidal, fungicidal and nematocidal properties (Neal et al. 1995). Some of the acetogenins secreted by *Stephanitis* nymphs are potent prostaglandin H synthase inhibitors (Jurenka et al. 1989).

The individual species of the genus *Stephanitis* are chemotaxonomically distinct and are characterized by the oxidation states of the secreted compounds in their setal exudates. Some of the phenolic acetogenins in these exudates have been isolated, identified, and synthesized from 3 species of *Stephanitis* (Oliver et al. 1985, 1987, 1988).

### Summary

The azalea lace bug has been one of the most important problems affecting azaleas since its introduction. Although many aspects of its life history and ecology have been studied in great detail over the past century, the pest continues to offer scope for research. Future studies should be directed toward integrated pest management, biological control and host plant resistance.

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