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Green Lacewings and Water Sprays for Azalea Lace Bug Control[1]

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Abstract

The azalea lace bug, *Stephanitis pyrioides*, is a serious pest of azaleas and rhododendrons which is often controlled by systemic insecticides. However, the efficacy of softer approaches such as biological control and water sprays against this pest on rhododendrons is unknown. Therefore, we tested the commercially available green lacewing predator, *Chrysoperla rufilabris*, and water sprays on lace bug infestation in one laboratory and four field trials. First, 2nd instar predator larvae were confirmed to consume lace bug nymphs and sometimes adults. Second, tapping predator larvae from hexcel units over dry leaves of potted rhododendrons and shaking loose eggs over wet leaves were reliable application methods. Third, predator larvae released onto potted rhododendrons lowered lace bug counts for two weeks. Fourth, after four bi-weekly applications, plants receiving egg cards or water-sprays had reduced lace bug counts and fewer damaged leaves than control plants. Fifth, landscape plants receiving the sequential combination of water spray followed by predator egg releases had 44 to 90% lower lace bug abundance and fewer damaged leaves than the control. After lace bugs were initially dislodged, hatching predators might have consumed hatching lace bugs.

Index words: biological control, *Chrysoperla rufilabris* (Burmeister), mechanical control, rhododendron, *Stephanitis pyrioides* (Scott).

Species used in this study: Azalea lace bug (*Stephanitis pyrioides* Scott), green lacewing (*Chrysoperla rufilabris* Burmeister), Rhododendron (*Rhododendron* spp.).

Significance to the Horticulture Industry

The azalea lace bug feeds on the leaves of azaleas and rhododendrons, causing unattractive leaf stippling that can prevent consumers from purchasing the plant. Augmentative releases of predators have reduced its abundance on azalea leaves (Shrewsbury and Smith-Fiola 2000), but no information is available on rhododendrons, which have larger leaves and sparser branch architecture. Therefore, we examined the efficacy of a commercially available green lacewing predator, *Chrysoperla rufilabris* on rhododendrons in four outdoor studies. Tapping predator larvae from hexcel units over dry leaves of potted rhododendrons, and shaking loose eggs over wet leaves were reliable application methods. In another study with potted rhododendrons approximately 0.6 m tall (2 ft), a single release of 10 predator larvae per plant reduced lace bugs for 1 to 2 weeks. Next, on large landscape rhododendrons in a garden, bi-weekly treatment with six predator egg cards (approx. 1000 eggs total) or 5 minutes of pressurized water spray on the underside of leaves suppressed lace bugs adults by 70% relative to untreated control plants or plants with releases of approximately 88 2nd instar predator larvae. Because predator releases and water sprays may only target certain life stages and not kill all of the pest, treatments would need to be repeated for longer-term suppression. A final trial combined water sprays to first dislodge lace bug nymphs and adults, and then apply egg cards so that hatching predators could later consume hatching lace bugs. This resulted in consistently lower lace bug abundance each week in treated plants compared to control plants, and 68% fewer adult lace bugs 5 weeks after the final treatment application. The combined water and egg treatment provided moderate control of lace bugs and damage among landscape rhododendrons where light infestation is acceptable.

Introduction

The azalea lace bug, *Stephanitis pyrioides* (Scott), feeds on the underside of azalea and rhododendron leaves, which causes stippling on the upper leaf side. While damage is at first aesthetic, a retail plant is unacceptable to consumers when 11% of its leaves have stippling on more than 2% of its leaf surface (Klingeman et al. 2000). Severe feeding reduces the chlorophyll content, photosynthesis, and growth of azaleas (Buntin et al. 1996, Klingeman et al. 2001). Native to Asia, this pest has been on the East Coast for over a century (Nair and Braman 2012). It was first detected in Washington State in 2008, and in Oregon in 2009 (Rosetta 2013). Systemic neonicotinoids or organophosphates provide long-term control of azalea lace bug (Baldson et al. 1993; Held and Parker 2011). However, managers are concerned about these insecticides affecting pollinators, as well as causing contamination of water supplies since some specimen gardens are next to streams or ponds. Therefore, our goal was to examine alternative controls that could be used near water-ways.

On the East Coast, some endemic natural enemies of azalea lace bugs include the parasitoid wasp *Anagrus*

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takeyanus Gordh (Baldson et al. 1996), predatory mirid *Stethonus japonicus* Schmacher (Henry et al. 1986), and spider *Anyphaena celer* (Hentz) (Shrewsbury and Raupp 2006). Effective endemic natural enemies have not yet been identified in Oregon (Flores 2016), but commercially purchased predators are available to managers. Releases of the green lacewing predator, *Chrysoperla carnea*, reduce azalea lace bugs on the East Coast, and predator releases are recommended following an insecticide application (Nair and Braman 2012). Releasing 10 lacewing larvae per potted azalea suppressed lace bugs by approximately 88% in a nursery (Shrewsbury & Smith-Fiola 2000) and releasing 5 larvae per potted azalea suppressed by approximately 42 to 54% in a field study (Shrewsbury et al. 2004). While transferring larvae by brush onto plants is precise for experimentation, a practical application method is needed for managers. Green lacewing larvae are often shipped in hexcel units where each predator is individually contained to prevent cannibalization. The fine mesh cover can be peeled incrementally off the hexcel unit, and hexcel tapped over plants to distribute the larvae. This tapping resulted in an impressive 97% reduction in lace bugs among azaleas in a commercial nursery (Shrewsbury and Smith-Fiola 2000).

While prior studies are encouraging, the efficacy of predator release on rhododendrons is unknown, nor have releases been done with *Chrysoperla rufilabris* (Burmeister), another green lacewing species commonly available. While not known, predators may search differently and lace bug populations may thrive differently on rhododendrons with larger leathery leaves and sparser architecture compared to azaleas with small soft leaves with hairs and dense branch structure. Predators may have to search more on rhododendrons and be less effective. Thus, our studies released *C. rufilabris* on rhododendron plants. Study 1 confirmed the lace bug life stages consumed by 2nd instar *C. rufilabris* larvae, the stage that predator larvae are shipped. Study 2 evaluated the reliability of releasing predators by tapping larvae from a hexcel unit and shaking loose eggs over rhododendron plants. Lacewing eggs can be purchased loose in a container, or as egg cards which are convenient to use but vulnerable to ant predation. Study 3 tested the efficacy of releasing *C. rufilabris* larvae on reducing lace bug infestations on potted rhododendron plants. Study 4 tested the efficacy of predator releases on reducing lace bug infestations on large, established landscape plants by tapping larvae from a hexcel unit or by hanging egg cards, and the efficacy of pressurized water sprays. Water sprays are a non-toxic alternative to dislodge pests from plants, and have dislodged aphids from plants (Pinnock et al. 1974), and spider mites from post-harvest pears (Hansen et al. 2006).

Because multiple life stages of azalea lace bug were often concurrently observed in our field studies and others (Braman et al. 1992, Flores 2016, Neal and Douglass 1988), it became clear that longer-term management required targeting multiple stages. None of the treatments alone could target all lace bug stages. Lace bug eggs and adults are often predominant in the field by May/June. Azalea lace bug develops quickly through the nymphal stages in 2 weeks at 24 to 26 C (75.2-78.8 F), and lives 3 to 4 months as an adult (Braman et al. 1992, Neal and Douglass 1988). While Study 4 of this paper found that water sprays can dislodge nymphal and adult lace bugs, remaining lace bug eggs on leaves could take up to 2 weeks to hatch at 24 C (75.2 F) (Braman et al. 1992). Although small green lacewing larvae feed well on lace bug nymphs (Shrewsbury and Smith-Fiola 2000), we found in Study 1 of this paper that *C. rufilabris* may have difficulty consuming adult stages. Hence, our Study 5 combined water sprays with predator egg releases with the expectation that water sprays would first dislodge nymphs and adults from rhododendrons. Remaining lace bug eggs that hatch into small nymphs would then be attacked by predator larvae hatching from the egg card. In this manuscript, green lacewings are often referred to as predator, and azalea lace bugs as lace bugs.

Table 1. Average number and standard error (SE) of azalea lace bugs at various life stages consumed by one predatory *C. rufilabris* larvae in a Petri dish for 1 day.

Stage	No. lace bugs/dish	Ave. no. eaten ±SE	Ave. % eaten	N
3rd	6	5.06 ±0.47	84%	18
4th	7	4.71 ±0.70	67%	17
5th	5	3.30 ±0.41	66%	21
Adult	3-5	0.58 ±0.15	8%	26

Materials and Methods

Insects. Green lacewings, *C. rufilabris,* were purchased as eggs or 2nd instar larvae (Evergreen Growers, Portland, OR). Predator larvae were shipped in a hexcel unit, and eggs were either shipped loose in a jar filled with rice hulls, or glued on cardboard tags with approximately167 eggs per card. Predator larvae and eggs were stored at 10 C (50 F) until experimentation. Azalea lace bugs were obtained from a colony maintained by periodically adding wild-caught lace bugs from Benton Co. onto azalea and rhododendron plants enclosed in a vented cage (BugDorm 2400, Megaview Science Co., Ltd., Taiwan). The colony was maintained in a greenhouse at ambient light and temperature.

Study 1: Life stage predated. Feeding assays tested whether green lacewings predate on various life stages of lace bugs. One 2nd instar predator larva was placed in a 44 mm lockable Petri dish with moist filter paper with lace bugs: six 3rd instar, seven 4th instar, five 5th instar nymphs, or 3 to 5 adults. The 3rd instar lace bug develops quickly (Braman et al. 1992, Neal and Douglass 1988), which prevented us from using more in assays. Dishes were held at 21 C (69.8 F), 60% RH, and 16L:8D. After 1 day, the number of individuals that had their body contents removed were counted under the microscope. They could be distinguished from plump individuals that died naturally. Each lace bug life stage was replicated 17 to 26 times and tested in July 2015 (Table 1). Because this experiment was observational, only averages and standard errors were calculated.

Study 2: Predator application. The application efficiency of tapping predator larvae from a hexcel unit was tested on two cultivars of rhododendron plants: 'Anna Rose Whitney' in 4 L (#1) and 19 L (#5) pots, and 'Purple Jem' in 4 L (#1) pots. Plants were 30.5 to 45.7 cm (12 to 18 in) and 61 cm (24 in) tall in #1 and #5 pots, respectively. 'Anna Rose Whitney' has large leaves whereas 'Purple Jem' has small leaves with dense foliage. Fifteen or 30 larvae were tapped per plant about 15 cm (6 in) above plants in 4 L and 19 L (#1 and #5) pots, respectively. Any predator larvae that that did not fall on foliage were counted on the cardboard collar fitted around the trunk of a plant extending to the pot rim, or the white sheet below. Five replicates were tested for each cultivar and size in August 2015. For analysis, an ANOVA compared the proportion of predator larvae landing on the three treatments (SAS 2016).

The application efficiency of shaking predator eggs was tested on dry or wet rhododendron plants. Six potted rhododendrons from a single cultivar (not recorded) were used (11 L or 3# pots). Three plants were dry, and three were sprayed with water beforehand. Fifty eggs were shaken over each collared plant over a white sheet in August 2015. Eggs that did not land on the foliage were counted on the collar or white sheet. A t-test compared the proportion of eggs landing on dry or wet leaves.

Study 3: Potted rhododendron. The efficacy of lacewing larvae on reducing lace bug populations was tested on rhododendron plants in hoop houses of a commercial nursery in Yamhill Co., Oregon. Rhododendron plants were in 11 L (3#) pots and 61 cm (24 in) tall. On Aug. 21, 2014, ten 2nd instar predator larvae were transferred to each plant via a camel hair brush (Shrewsbury and Smith-Fiola 2000). No predators were transferred onto control plants. Each treatment was replicated in 6 plants. Both treatments were tested in each cultivar, this included two 'Lee's Dark Purple', two 'Cunningham's White', and eight 'Anna Rose Whitney' plants, all cultivars with large leaves. Control and treated plants were 10 m apart to prevent any cross-movement of predators. To assist the grower with general biological control, 2 g methyl salicylate lures (PredaLure, AgBio, Westminister, Colorado) were hung on plants. Methyl salicylate has attracted various predators and parasitoids into agricultural crops (Lee 2010, Kaplan 2012). While this may have increased predation on lace bugs, this volatile chemical was present in each of the four hoop houses.

Prior to larval release, each plant was visually inspected using 1.75X Opti-visors (BioQuip, Rancho Dominguez, California) to count nymphal and adult lace bugs. Plants were assigned such that treated and control plants started with similar lace bug densities, and their infested leaves were tagged. Because accurate nymphal counting required a microscope at 6 to 15 X and leaf removal affected plant appearance, a limited number of 'infested' leaves, selected by visual inspection for obvious lace bug damage was collected weekly. On week 1, previously tagged leaves plus two additional infested leaves per plant were collected. On weeks 2, 3, 4, and 6, three infested leaves per plant were collected.

For analyses, lace bug counts from leaves were averaged per leaf per plant; each leaf was the observational unit and each plant was the experimental unit. Response variables were the number of nymphs, adults, or nymphs + adults, and tested in three separate models. To confirm that initial lace bug densities were equivalent among treatments, counts at week 0 were compared between treatments. Next, counts from weeks 1 to 6 were analyzed in a repeated measures model with treatment, week, and treatment by week interaction as fixed effects, each plant as the random subject effect, with autoregressive correlation. Because treatment by week interactions were significant, the two treatments were compared each week by lsmeans comparisons. These and analyses for Studies 4 and 5 used a generalized linear mixed model with the appropriate distribution (normal, lognormal, Poisson), Proc Glimmix in SAS 9.3 (SAS 2016).

Study 4: Landscape rhododendron sole treatment. Here, one treatment type (sole treatment) was applied repeatedly per plant. The efficacy of green lacewing releases and water sprays were tested on landscape rhododendrons in a private garden in Washington Co., Oregon, that did not use insecticides. Plants were approximately 2 m tall and 2 m wide, and received either: 1) 6 predator egg cards (approx. 1000 eggs total), 2) predator larvae tapped from 4 hexcel rows which is 1/5 of the hexcel unit (approx. 88 larvae total), 3) a 5 min pressurized water spray on the underside of leaves, or 4) nothing as the control. For pressurized water sprays, a CO_2 backpack sprayer (R & D Sprayers, Opelousas, Louisiana) sprayed 2 L distilled water per plant at 38 PSI (2.67 kg/cm^2) (XR 8002 VS TeeJet Technologies, Glendale Heights, Illinois). Treatments were initiated July 21, 2016 on 5 plants per treatment, and repeated every 2 weeks into the end of August. Selected plants were of different cultivars since it was not possible to block by cultivar; instead, all plants were pre-checked to have an adequate infestation where lace bugs were found on most sampled leaves. Plants were spaced at least 5 m apart. Previously, azalea plants spaced 1.5 m apart showed differences with releases of another lacewing species, *C. carnea* (Shrewsbury and Smith-Fiola 2000), so 5 m was considered sufficient.

Sampling occurred from week 0 to week 8 on September 8, 2016. Two types of sampling were done. First, weekly samples of 5 to 20 'infested' leaves were removed per plant, depending on leaf size and plant canopy density. On weeks 0 and 2, five infested leaves were removed per 'water' plant before and after water sprays to assess lace bug removal. On other weeks, leaves were removed only after water sprays. In the lab, nymphs and adults on leaves were counted under the microscope while labelling each leaf. Then, frass from the same leaves were washed off with warm water to count eggs at 20X. Lastly, the leaf area was measured with a leaf area meter (LI-3000, LI-COR, Lincoln, Nebraska). Because this sampling focused only on damaged leaves, a second sample involved visually examining 40 'random' leaves per plant at the end of the experiment. We counted the number of live adults per leaf. Since dead lace bugs remain on leaves, lace bugs were determined to be alive if they moved when poked. We recorded whether the leaf topside was either 'visibly damaged', or 'not damaged'. Visibly damaged leaves resembled leaves with 2 to 50% of the leaf area injured as illustrated by Klingeman et al. (2000, see Fig. 1); this level of

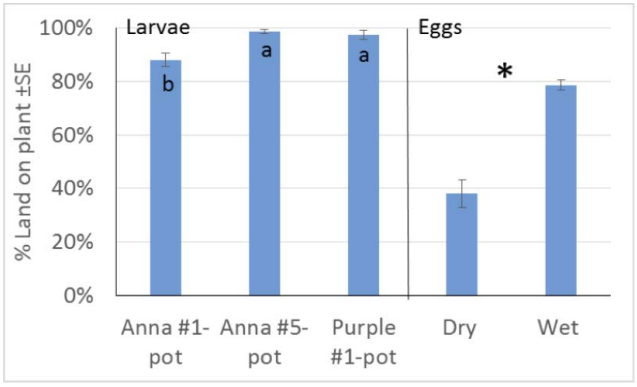

Fig. 1. Container study: Average percent and standard error (SE) of green lacewing larvae and eggs that land on two rhododendron cultivars in either 4 L (#1) or 19 L (#5) pots, or on rhododendrons in 11 L (#3) pots with wet or dry leaves. Different letters denote a significant difference by Tukey HSD, and asterisk by t-test.

damage was recognized by consumer, managers and growers.

The first analysis tested whether spraying a leaf with water removed lace bugs and only included data from water-sprayed plants. Counts of nymphs, adults, nymphs + adults on weeks 0 and 2 were compared before and after a water spray with each infested leaf as the experimental unit. Treatment was a fixed effect, and the week sprayed combined with the plant the leaf was taken from was a random effect. The remaining analyses compared all four treatments together. Lace bug counts from 'infested' leaves were standardized by leaf area (cm^2) with each plant as the experimental unit. The second analyses confirmed that initial lace bug densities were similar among treatments. Lace bug counts at week 0, including pre-water-sprayed leaves, were compared among treatments. Third, counts from weeks 1 to 8 were analyzed in a repeated measures model with treatment, week, and treatment by week interaction as fixed effects, plant as the random subject effect, with autoregressive correlation. Fourth, 'random' leaves at the end of the experiment were compared. Adult counts were averaged per leaf or the proportion of visibly damaged leaves were compared by treatment with each plant as the experimental unit. Proportional data fit a binomial distribution in the model.

Study 5: Landscape rhododendron dual treatment. Here, two control measures were applied together per plant (dual treatment). The efficacy of water sprays followed by predator egg releases was tested on landscape rhododendrons in the same garden. Plants were either sprayed with pressurized water and then received 6 egg cards, or not treated with water or egg cards as the control. Because plants were of different cultivars and some were taller than 2 m, the area under 2 m was treated and flagged for weekly sampling. Treatments were initiated on July 21, 2017 on 5 plants per treatment, and treatments were repeated on August 4, and August 17.

Sampling occurred weekly starting 3 weeks prior to the study, and from weeks 0 to 6, with a break in sampling until week 9 on September 18, 2017. Prior to the experiment, 5 'infested' leaves were collected per plant per week, and counted for eggs, nymphs and adults. Starting at week 0, 10 'infested' leaves were collected per plant, and counted for eggs, nymphs, and adults, and measured for leaf area in the lab. In Study 5, leaves were collected before water sprays were applied. Collecting dry leaves prevented us from including lace bugs already dead in the field in our counts. On weeks when sprays were not done, weeks 1, 3, 5, 6 and 9, 40 'random' leaf samples were also visually checked per plant for live adults, and rated for damage as in Study 4.

For 'infested' leaf samples, the number of eggs, nymphs, adults, and nymphs + adults were counted on a per leaf basis or divided by leaf area with each plant as the experimental unit. To confirm that initial lace bug densities were not different among treatments, counts per leaf for the three weeks preceding the experiment were compared between treatments, and counts per leaf area at week 0 were compared between treatments. Next, counts from weeks 1 to 9 were analyzed in a repeated measures model with treatment, week, and treatment by week interaction as fixed effects, each plant as the random subject effect, with autoregressive correlation. For 'random' leaf samples, adult counts per leaf and proportion of visibly damaged leaves were tabulated with plant as the experimental unit. These counts or proportions were analyzed with a similar repeated measures model with appropriate distributions. While treatment by week interactions were not significant, control and water treatments were compared each week by t-test for discussion purposes.

Results and Discussion

Study 1: Life stage predated. The feeding assay confirmed that 2nd instar green lacewing larvae, *C. rufilabris,* consume azalea lace bugs at the 3rd, 4th and 5th instar, and adult stage (Table 1). The predator consumed on average fewer lace bug nymphs when given larger instars, the predator may have gotten more satiated with larger nymphs. Previously, 2nd instar *C. rufilabris* had only been confirmed to feed on 4th and 5th instar lace bugs in a laboratory functional response study (Stewart et al. 2002). Adult lace bugs do not appear as suitable for 2nd instar predators since less than one was eaten in a day in our study, and 11 out of the 24 predators tested fed on the adult in a confined arena. In the field, predation may be even lower since adult lace bugs have been observed to drop off the plant to elude predators (Robin Rosetta, personal observations).

Study 2: Predator application. Tapping predatory *C. rufilabris* larvae from a hexcel unit resulted in 88 to 99% of the larvae landing on the rhododendron plant (Fig. 1). Landing rates were 9 to 10% lower on Anna Rose Whitney in #1 pots than in #5 pots or Purple Jem in #1 pots (ANOVA $F_{2,14} = 10.6$, $P = 0.0022$). This suggests that with larger-leaved Anna Rose Whitney rhododendrons, predators are more likely to land on larger than smaller potted plants possibly due to a thicker canopy. Among small potted plants, predators are more likely to land on Purple Jem with smaller leaves and denser canopy than on Anna Rose Whitney with large leaves. Shaking loose predator

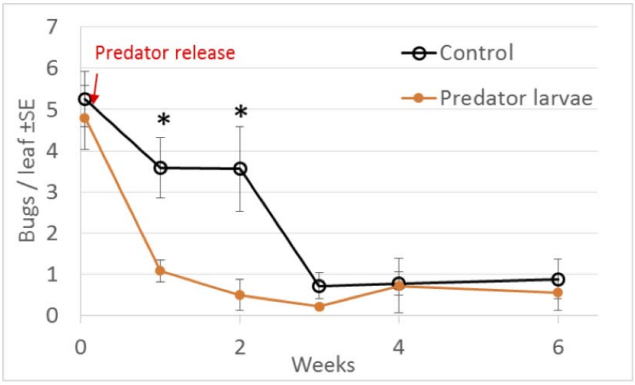

Fig. 2. Container study: Average number and standard error (SE) of azalea lace bug nymphs + adults per leaf on rhododendrons. Asterisks indicate a significant difference between treatments for the given week as affected by the addition of green lacewing larvae (predator).

eggs over wet leaves resulted in 79% landing on the plant, which was twice the rate on dry leaves (Fig. 1, t-test df = 4, P = 0.0019). Two hours later after leaves dried, eggs were still observed to stick to the foliage.

Study 3: Potted rhododendron. For simplicity, results are reported as nymphs + adults and only reported separately if outcomes differed. All differences mentioned are statistically significant unless otherwise noted.

To our knowledge, this is the first demonstration that releases of *C. rufilabris* larvae reduce lace bugs in whole-plant trials, as well as on rhododendrons. Starting densities of lace bugs on assigned plants were similar before treatments were applied at week 0 (Fig. 2; $F_{1,10} = 0.33$, P = 0.581). Later, rhododendrons that had 10 predator larvae added per plant had a lower number of lace bug nymphs + adults on infested leaves compared to controls. A treatment by time interaction occurred, treatment effects were short-term (next paragraph), with a 70 to 86% reduction 1 to 2 weeks after predator release. No differences were observed 3 to 6 weeks after release. Both predator and control treatments had low lace bug counts by week 3 which may have been due to naturally occurring predation, or normal mortality among lace bugs during fall.

A short-term impact is expected since released predator larvae would have pupated, stopped feeding, and potentially fly away as an adult. Our released species, *C. rufilabris*, can develop from 1st instar to pupa in just 8 to 10 days on high quality foods in the laboratory (Cohen and Smith 1998). Adult *C. rufilabris* are not predaceous and feed on nectar and pollen. Adults of another species, *C. carnea,* migrate before they lay eggs (Duelli 1980). Trials with *C. carnea* in azaleas reduced lace bug densities 4 to 7 days post-release, and the authors commented that season-long control would require multiple releases and integration with other tactics (Shrewsbury and Smith-Fiola 2000, Shrewsbury et al. 2004).

Study 4: Landscape rhododendron sole treatment. First, pre- and post-water spray comparisons confirmed that water sprays dislodged azalea lace bugs. Leaves that were sprayed with water on the underside had 71% fewer lace bug nymphs + adults than unsprayed leaves ($F_{1,82} = 57.4$, P < 0.0001). Unsprayed leaves had on average 5.20 ±1.85

Table 2. Statistical results from predatory *C. rufilabris* releases and water sprays on azalea lace bug counts and damage to rhododendron plants.

Experiment	Leaves	Response variable	Effect variable(s)	ndf, ddf	F	P
3 - Potted rhododendron	Infested	Nymphs + adults /leaf	Treatment	1,10	7.97	0.0181
			Week	4,40	6.35	0.0005
			Treat. by wk	4,40	4.16	0.0066
4 - Landscape rhododendron sole treatment	Infested	Eggs /cm^2	Treatment	3,16	3.11	0.056
			Week	7,112	3.80	0.001
			Treat. by wk	21,112	0.78	0.783
	Infested	Nymphs /cm^2	Treatment	3,16	0.75	0.540
			Week	7,112	9.3	<.0001
			Treat. by wk	21,112	1.38	0.146
	Infested	Adults /cm^2	Treatment	3,16	3.04	0.0596
			Week	7,112	7.87	<.0001
			Treat. by wk	21,112	1.45	0.112
	Random	Adults /leaf	Treatment	3,16	4.25	0.0218
	Random	Prop. leaves damaged	Treatment	3,16	4.29	0.0211
5 - Landscape rhododendron dual treatment	Infested	Eggs /cm^2	Treatment	1,8	19.3	0.0023
			Week	6,48	3.22	0.0098
			Treat. by wk	6,48	0.37	0.895
	Infested	Nymphs /cm^2	Treatment	1,8	0.17	0.687
			Week	5,27	7.27	0.0002
			Treat. by wk	4,27	0.27	0.896
	Infested	Adults /cm^2	Treatment	1,8	5.6	0.046
			Week	6,40	14.3	<.0001
			Treat. by wk	6,40	1.4	0.228
	Random	Adults /cm^2	Treatment	1,8	8.95	0.0173
			Week	4,32	4.15	0.0081
			Treat. by wk	4,32	0.55	0.698
	Random	Prop. leaves damaged	Treatment	1,8	10.6	0.0117
			Week	4,32	2.68	0.0491
			Treat. by wk	4,32	2.01	0.117

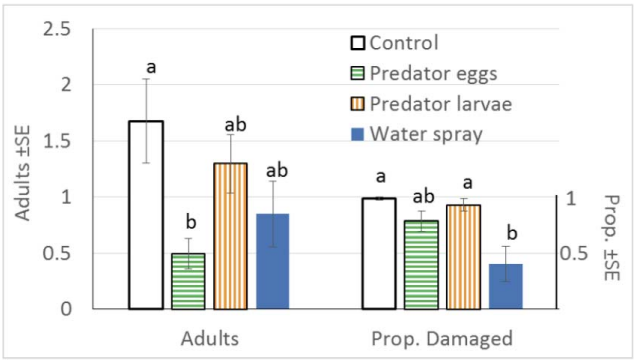

Fig. 3. Landscape study: Average number and standard error (SE) of azalea lace bug adults and proportion of visibly damaged leaves among randomly sampled leaves from rhododendron plants at week 8. Different letters denote significant difference by Tukey HSD as affected by the addition of green lacewing eggs or larvae (predator) or water spray.

lace bugs per leaf, and sprayed leaves had 1.53 ±0.53 per leaf.

Starting densities of lace bugs appeared similar before treatments were applied at week 0. Specifically, the number of eggs, and nymphs + adults per leaf area on 'infested' leaves did not differ (eggs $F_{3,16} = 1.48$, $P = 0.258$; nymphs + adults $F_{3,16} = 0.51$, $P = 0.683$). From weeks 1 to 8, 'infested' leaves had a marginally significant difference in egg and adult counts between treatments ($P < 0.06$), but not nymph counts (Table 2); counts were standardized per leaf area.

Lastly, treatments had a noticeable impact on 'random' leaves sampled at 8 weeks after four bi-weekly applications (Table 2). Plants with predator eggs had 70% fewer adults per leaf than control plants, and plants with water spray had 59% fewer leaves visibly damaged than control plants (Fig. 3). These results suggest that treatments impacted the overall plant based on random leaf samples. However, there were marginal impacts on the infested leaves suggesting that treatments partially remedied the most afflicted plant parts. Since results with water sprays and predator egg releases were encouraging, they were studied in combination the following year.

Study 5: Landscape rhododendron dual treatment. When a water + predator egg treatment was applied bi-weekly three times, a consistent decrease in azalea lace bug counts and damage was observed from both 'infested' and 'random' sampled leaves starting 1 week after the first

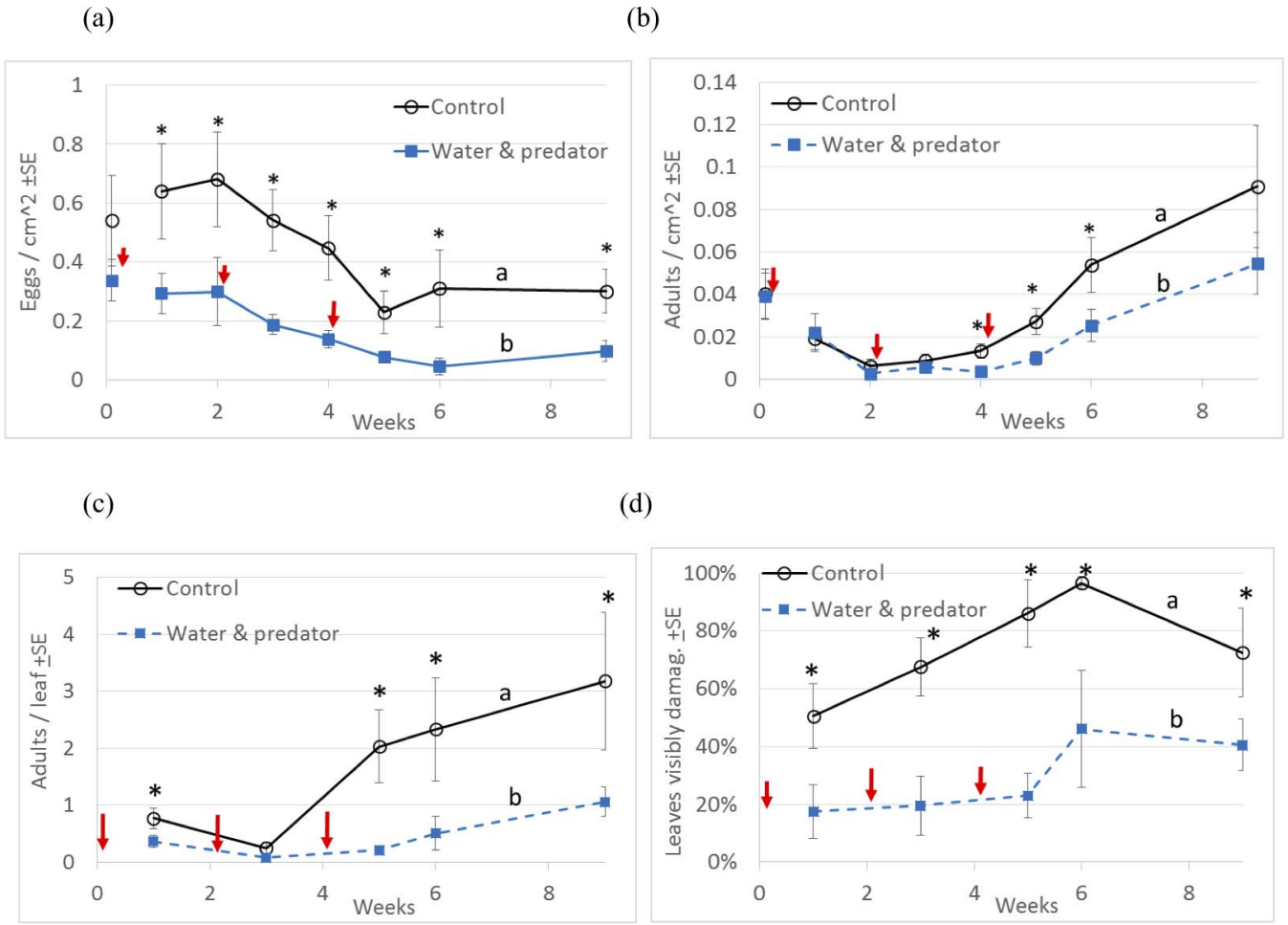

Fig. 4. Average number and standard error (SE) of azalea lace bug eggs (a), and adults per leaf area (b) among infested leaves. Average number of adults per leaf (c) and percent of visibly damaged leaves (d) among randomly sampled leaves. Red arrow indicates when treatments were applied. Different letters denote a significant difference overall during weeks 1-9, and asterisks denote a difference for the given week as affected by water spray plus the addition of green lacewing eggs (predator).

application. First, starting lace bug densities did not differ for 3 weeks prior to the experiment with counts standardized per leaf (eggs $F_{1,28} = 0.723$, $P = 0.402$, nymphs + adults $F_{1,27} = 0.252$, $P = 0.620$), nor at week 0 with lace bug counts standardized per leaf area (Fig. 4a,b; eggs $F_{1,8} = 0.36$, $P = 0.566$, nymphs + adults $F_{1,8} = 0.001$, $P = 0.993$). Later among 'infested' leaves, fewer lace bug eggs and adults were found in treated plants than controls (Table 2, Fig. 4a,b). Among 'random' leaves, fewer adults and visibly damaged leaves were found in treated plants than controls (Table 2, Fig. 4c,d). Treated plants had 44 to 90% fewer lace bugs than control plants at various weeks. A 44 to 68% difference still appeared by week 9, which was 5 weeks after the last application.

Our studies demonstrate that *C. rufilabris* can suppress azalea lace bugs in rhododendrons, and water sprays can dislodge nymphal and adult lace bugs. Ideally, treatments should be targeted when lace bug nymphs have recently hatched in spring and mid-summer. This requires detailed monitoring to detect the presence of small nymphs. Treatments may be most effective in spring if overwintering lace bug eggs hatch synchronously into nymphs, and predators suppress populations at the start of the growing season. In our final trial, the combined water + predator egg treatment showed a reduction 5 weeks after the last treatment. Also, treated plants had consistently lower lace bug counts on both 'infested' and 'random' leaves, and lower visible leaf damage each week. These control methods might be appropriate when there is some tolerance for lace bugs, such as in landscapes. When there is little tolerance for pest damage, these control measures would need to be integrated with other measures to provide season-long control, and water sprays might be set-up in the irrigation system if possible to dislodge lace bugs without labor input.

Literature Cited

Balsdon, J.A., S.K. Braman, A.F. Pendley, and K.E. Espelie. 1993. Potential for integration of chemical and natural enemy suppression of azalea lace bug (Heteroptera: Tingidae). J. Environ. Hort. 11: 153–156.

Balsdon, J. A., S. K. Braman and K. E. Espelie. 1996. Biology and ecology of *Anagrus takeyanus* (Hymenoptera: Mymaridae), an egg parasitoid of the azalea lace bug (Heteroptera: Tingidae). Environ. Entomol. 25: 383–389.

Braman, S.K., A.F. Pendley, B. Sparks, and W.G. Hudson. 1992. Thermal requirements for development, population trends, and parasitism of azalea lace bug (Heteroptera: Tingidae). J. Econ. Entomol. 85: 870–877.

Buntin, G.D., S.K. Braman, D.A. Gilbertz, and D.V. Phillips. 1996. Chlorosis, photosynthesis, and transpiration of azalea leaves after azalea lace bug (Heteroptera: Tingidae) feeding injury. J. Econ. Entomol. 89: 990–995.

Cohen, A.C., and L.K. Smith. 1998. A new concept in artificial diets for *Chrysoperla rufilabris*: The efficacy of solid diets. Biol. Control 13: 49–54.

Duelli, P. 1980. Preovipository migration flights in the green lacewing, *Chrysopa carnea* (Planipennia, Chrysopidae). Behaviorural Ecology and Sociobiology 7: 239–246.

Flores, M. 2016. Phenology, host-plant resistance, and biological control of *Stephanitis pyrioides*. MS Thesis. Oregon State University, Corvallis, OR. 112 pp.

Hansen, J.D., M.L. Heidt, L.G. Neven, E.A. Mielke, J. Bai, P.M. Chen, and R.A. Spotts. 2006. Effect of high-pressure hot-water washing treatment on fruit quality, insects, and disease in apples and pears. Postharvest Biology and Technology 40: 221–229.

Held, D.W., and S. Parker. 2011. Efficacy of soil applied neonicotinoid insecticides against the azalea lace bug, *Stephanitis pyrioides*, in the landscape. Florida Entomologist 94: 599–607.

Kaplan, I. 2012. Attracting carnivorous arthropods with plant volatiles: The future of biocontrol or playing with fire? Biological Control 60: 77–89.

Klingeman, W.E., S.K. Braman, and G.D. Buntin. 2000. Evaluating grower, landscape manager, and consumer perceptions of azalea lace bug (Heteroptera: Tingidae) feeding injury. J. Econ. Entomol. 93: 141–148.

Klingeman, W.E., S.K. Braman, and G.D. Buntin. 2001. Azalea growth in response to azalea lace bug (Heteroptera: Tingidae) feeding. J. Econ. Entomol. 94: 129–137.

Lee, J.C. 2010. Effect of methyl salicylate-based lures on beneficial and pest arthropods in strawberry. Environ. Entomol. 39: 653–660.

Nair, S., and S.K. Braman. 2012. Integration of insecticides with the natural enemy *Chrysoperla carnea* (Stephens) for management of azalea lace bug (Hemiptera: Tingidae). J. Entomol. Sci. 47: 278–281.

Neal, J.W., and L.W. Douglass. 1988. Development, oviposition rate, longevity, and voltinism of *Stephanitis pyrioides* (Heteroptera: Tingidae), an adventive pest of azalea, at 3 temperatures. Environ. Entomol. 17: 827–831.

Pinnock, D.E., R.J. Brand, J.E. Milstead, and N.F. Coe. 1974. Suppression of populations of *Aphis gossypii* and *A. spiraecola* by soap sprays. J. Econ. Entomol. 67: 783–784.

Rosetta, R. 2013. Azalea lace bug: Biology and management in commercial nurseries and landscapes. Oregon State University Extension Service EM 9066: July 2013.

SAS Institute Inc. 2016. SAS 9.3. Cary, NC, USA.

Shrewsbury, P.M., J.H. Lashomb, J.M. Patts, and R.A. Casagrande. 2004. The influence of flowering plants on herbivore and natural enemy abundance in ornamental landscapes. Intern. J. Ecol. and Environ. Sci. 30: 23–33.

Shrewsbury, P.M., and M.J. Raupp. 2000. Evaluation of components of vegetational texture for predicting azalea lace bug, *Stephanitis pyrioides* (Heteroptera: Tingidae), abundance in managed landscapes. Environ. Entomol. 29: 919–926.

Shrewsbury, P.M., and D.C. Smith-Fiola. 2000. Evaluation of green lacewings for suppressing azalea lace bug populations in nurseries. J. Environ. Hortic. 18: 207–211.

Stewart, C.D., S.K. Braman, and A.F. Pendley. 2002. Functional response of the azalea plant bug (Heteroptera: Miridae) and a green lacewing *Chrysoperla rufilabris* (Neuroptera: Chrysopidae), two predators of the azalea lace bug (Heteroptera: Tingidae). Environ. Entomol. 31: 1184–1190.