

The Influence of Flowering Plants on Herbivore and Natural Enemy Abundance in Ornamental Landscapes

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ABSTRACT

Ornamental landscapes are diverse, perennial ecosystems. Habitat manipulation, a form of conservation biological control, is an ideal method of pest management for landscape systems. A field study was conducted to determine whether manipulating landscape habitats by adding flowering plants could reduce insect pest outbreaks. Incorporating flowering plants, coriander (*Coriandrum sativum*) and Shasta daisy (*Chrysanthemum* sp.), into a simulated landscape (plot) resulted in greater abundance of alternative prey and natural enemies. Survival of azalea lace bug (*Stephanitis pyrioides* (Scott)) on azaleas in plots with flowers was lower than in plots without flowers on most dates tested. Early season evaluation of azalea lace bug survival revealed no difference between plots with and without flowers. To determine whether the green lacewing predator, *Chrysoperla carnea*, could suppress azalea lace bug populations and whether flowers influenced the retention of green lacewings, augmentative release of lacewings was made onto azaleas with azalea lace bugs in plots with and without flowers. Lacewings reduced azalea lace bug populations in plots with and without flowers. Lacewings did not remain in plots with flowers any longer than in plots without flowers. High rates of lacewing disappearance from plots may be the result of dispersal, cannibalism, or intra-guild predation. This study suggests that augmentative release of green lacewings can effectively reduce azalea lace bug populations but these releases should be considered a short-term solution. Moreover, adding flowering plants to landscapes should reduce the likelihood of pest insect outbreaks. A better understanding of the interactions between the habitat, natural enemies, and herbivore is necessary to improve the likelihood of success of this habitat manipulation approach in ornamental systems.

Key Words: Azalea lace bug, *Chrysoperla carnea*, Conservation, Biological control, Habitat manipulation, Habitat complexity, Integrated pest management, Spiders

INTRODUCTION

Urban landscapes are highly complex ecosystems with many species of plants, pests, and beneficial organisms interacting in ways that are largely unknown (Shrewsbury 1996, Lozzia 1999, Balder et al. 2000, Raupp et al. 2001a and b). Home garden landscapes may contain more than 100 species or cultivars of plants and are

perennial ecosystems (Raupp et al. 1985). Despite these characteristics, natural enemies in managed landscapes are often scarce or absent (Hanks and Denno 1993, Shrewsbury 1996, Tooker and Hanks 2000). Many management practices associated with landscapes, such as the urbanization of communities (Hanks and Denno 1993, Tooker and Hanks 2000, Sperry et al. 2001) or the application of pesticides (Luck and Dahlsten 1975,

McClure 1977, Dreistadt and Dahlsten 1986, Clarke et al. 1992, Raupp et al. 2001a), have been found to disrupt ecological processes, especially those related to natural enemy–herbivore population dynamics, which can lead to insect pest outbreaks.

Habitat manipulation, a form of conservation biological control, is a relatively new science (Gurr et al. 2000, Landis et al. 2000). Understanding relationships among the vegetational texture of a habitat and its associated herbivores and natural enemies should help us to identify methods to manipulate habitats to restore ecological functionality and create more sustainable landscapes. For example, it has been found that more diverse and structurally complex landscapes support a greater diversity and abundance of natural enemies, especially generalist predators, resulting in reduced insect pest outbreaks compared to simpler landscapes (Hanks and Denno 1993, Shrewsbury 1996, Balder et al. 2000, Tooker and Hanks 2000). These studies suggest habitat manipulation to conserve natural enemies should be an effective method of pest management for ornamental landscapes.

The addition of flowering plants to ornamental landscapes, a form of habitat manipulation, should favor natural enemies by providing additional refuges, favorable microclimates, and alternative food sources. To date, few, if any studies have explored this form of habitat manipulation in ornamental systems. The addition of flowering plants has been shown to increase natural enemy abundance and in some cases suppress insect pest populations in traditional agricultural systems (Harwood and Wratten 1992, Hickman and Wratten 1996, Patt et al. 1997a, Nicholls et al. 2000). Many predators and parasitoids require not only insect prey, but also alternative food sources such as nectar and pollen from flowering plants. The establishment and performance of beneficial insects is improved when certain flowers were interplanted within agroecosystems (Leius 1967, Syme 1975, Zandstra and Mootka 1978, Altieri and Whitcomb 1979, Altieri and Letourneau 1982, King and Olkowski 1991, Grossman and Quarles 1993, Landis et al. 2000). The increase in beneficial insect efficacy observed in cropping systems interplanted with flowers is due to the combined effects of increased survivorship, fecundity, retention and immigration (Altieri and Whitcomb 1979, Altieri and Letourneau 1982). While the nutrients from pollen and nectar support metabolism and gamete development for many insect predators and parasitoids, flowers also provide mating sites and alternative prey (Leius 1967, Altieri and Whitcomb 1979). Beneficial insect emigration from cropping systems interplanted with flowers may be minimized because additional alternative food sources (nectar, pollen, and alternative

prey) are available.

In our studies, we added flowers that were aesthetically pleasing and provided beneficial insects with nutrients, shelter, and alternative prey. Adding flowering plants could result in a significant reduction in pesticide use, furthering our goal of sustainable landscapes. Flowering plants are widely used in ornamental landscapes for aesthetic purposes so this method of pest management should be readily acceptable. Studies are necessary to optimize the use of flowering plants in conservation biological control. For example, not all flowering plant species have nectar and pollen that is readily accessible to natural enemies (Patt et al. 1997b) or they may attract different taxa of natural enemies, which may vary in their impact on herbivores. In addition, little is known about the dispersal and movement of natural enemies from a floral resource and therefore at what distance they may impact herbivore populations (Landis et al. 2000).

To evaluate the effect of incorporating flowering plants into landscapes on beneficial insect and herbivore population abundance we used the azalea, *Rhododendron* sp. and azalea lace bug, *Stephanitis pyrioides* (Scott) as our host plant-herbivore study system. We also supplemented the flowering plants by adding a generalist predator, the green lacewing (*Chrysoperla carnea* Stephens). We selected this study system for several reasons. A survey of more than 30,000 plants in ornamental landscapes found woody shrubs in the genus *Rhododendron* to be the most common (Raupp et al. 1985). An analysis of pest occurrence revealed that *Rhododendron* was one of the most pest prone genera, often with excess of 50% of the plants under pest attack (Raupp and Noland 1984), particularly among the group of rhododendrons commonly called azaleas. In the mid-Atlantic region of the U.S.A., the single most important insect pest of azaleas is the azalea lace bug (Raupp and Noland 1984). Low to moderate densities of azalea lace bug result in discoloration of foliage and high densities frequently kill plants. The most common control method for azalea lace bug is application of synthetic insecticides. A common pattern found in landscapes is that azaleas growing in structurally simple habitats (those with few plants) more frequently suffer from azalea lace bug outbreaks than azaleas growing in structurally complex habitats (those with many plants) (Trumble and Denno 1995, Shrewsbury and Raupp 2000). Shrewsbury (1996) found that generalist predator abundance was significantly greater in structurally complex landscapes than in structurally simple landscapes and that there were greater numbers of alternative prey in the complex habitats. These results indicated that the increased number of alternative prey in more complex habitats resulted in

greater numbers of predators in those habitats. This may explain the pattern found in azalea lace bug distribution and abundance in landscapes (Shrewsbury 1996). These results also suggest that habitat management practices that increase structural complexity, such as incorporating flowers into landscapes, should increase numbers of alternative prey and therefore natural enemy abundance resulting in reduced azalea lace bug densities.

The green lacewing, *C. carnea*, is a predator commonly associated with azalea lace bug in ornamental landscapes (Shrewsbury 1996). Augmentative releases of green lacewing larvae were able to significantly reduce azalea lace bug populations (70-97% mortality) in production nurseries (Shrewsbury and Smith-Fiola 2000). In addition, laboratory and field studies demonstrated that green lacewing adults and larvae could forage from a variety of flowers such as coriander and dill (Patt et al. 2003).

The overall objective of our study was to evaluate the effect of incorporating flowering plants into landscapes on natural enemy and herbivore population abundance. Specifically we tested the effects of flowering plants on: (a) the retention of green lacewings released onto azaleas with azalea lace bugs, (b) the ability of green lacewings to reduce azalea lace bug abundance; (c) natural enemy and alternative prey abundance; and (d) azalea lace bug survival. We hypothesized that: (i) augmented green lacewings would remain longer in plots with flowers than plots without flowers; (ii) azalea lace bug survival would be lower where lacewings were released; (iii) greater numbers of natural enemies and alternative prey would be found in plots with flowers than in plots without flowers; and (iv) azalea lace bug survival would be lower in plots with flowers than in plots without flowers.

MATERIALS AND METHODS

Description of Study Sites

To evaluate the effect of incorporating flowering plants into landscapes on beneficial insects and herbivore population abundance, field studies were conducted in 1998 and 1999 at two Rutgers University research stations, the Horticultural Farm, New Brunswick, NJ (Lat. 40.5 N x Long. 74.4 W) and Cream Ridge Research Station, Cream Ridge, NJ (Lat. 40.2 N x 74.5 West) USA. In 1998, forty-four study plots, 4 m x 4 m in size, were set up (16 plots at the New Brunswick site and 28 plots at Cream Ridge) to simulate ornamental landscape beds. Three azaleas, *Rhododendron mucronatum* (cv. Delaware Valley White), approximately 0.35 m in

height and width were planted in a triangular pattern in the center of each of the 44 plots in early April. Plots were paired and flowering plants were added to 1 plot of each pair (22 plots received flowers). A circular flowerbed, 0.6 m in width, was established around the azaleas. One half of the bed was planted with coriander (Umbelliferae), *Coriandrum sativum*, seedlings (4-6 wk old) spaced 15 to 20 cm apart. The other half was planted with shasta daisy (Compositae), *Chrysanthemum* spp., seedlings (6-8 wk old) with a mixture of cultivars (*C. maximum x superbum* cv. Snow Lady, *C. maximum x superbum* cv. Little Princess, and *C. superbum* (*Leucanthemum*) cv. Marconi) spaced 25 to 30 cm apart. Flower seedlings were planted from 18 to 29 May. These plants were selected because they were known to have floral architectures that attract natural enemies (Patt et al. 2003) and to have a long flowering period. To maintain peak flowering in beds, additional coriander seedlings were planted on 8 July and shasta daisies were dead-headed as needed.

All plots were established and maintained using standard cultural practices. Soil amendments and nutrient applications were based on soil test results. The dominant soil type was Freehold sandy loam at the Cream Ridge Research Station and Sassafras sandy loam at the Horticultural Farm. Aluminum sulphate [(NH₄)₂SO₄] (Dragon Chemical Corp. VA) was incorporated into the study beds to obtain a pH of approximately 5.0. At planting of azaleas and flowers, super phosphate [Ca(H₂PO₄)₂] (Southern States Coop, VA) (label rate) and peat moss (Annapolis Valley Peat Moss Co. Canada) (7.5 – 10 cm thick) were incorporated into the beds. Flowers were fertilized with Miracle Gro (15-30-15) and azaleas with Mir-acid (30-10-10) (The Scotts Company, OH) at monthly intervals. Study plots were overhead irrigated and received approx. 2.5 cm of water per week, taking rainfall into account. All plots were hand weeded to maintain less than 5% weed cover. Areas of study plots without plant material were covered with a 5 to 7.5 cm layer of bark mulch.

For the 1999 field season, coriander and shasta daisy plants were allowed to over-winter from 1998 in the flowerbeds. New growth began in late April to early May. In late May, plants were removed or seedlings added to flower beds to maintain a similar density as in 1998. Cultural practices for flowers and azaleas were the same as described for 1998.

Experimental Design

In 1998, a 2x2 factorial design with two levels of flowers (with flowers and without flowers), two levels of green lacewing predators (with predators released and without predators released), and blocking (by location)

was used to conduct experiments. This design resulted in 11 blocks, each with 4 treatments that consisted of azaleas in plots: (1) with flowers, with lacewings released; (2) with flowers, without lacewings released; (3) without flowers, with lacewings released; and (4) without flowers, without lacewings released (control). In 1999, the same plots were used but the green lacewing treatment was eliminated and only the flower treatment was evaluated. This resulted in 22 blocks each with two treatments that consisted of azaleas in plots with flowers, and without flowers.

Arthropod Taxa and Abundance

In 1998, to determine the influence of flowering plants on arthropod taxa and abundance, sampling was conducted four times (9 and 16 June; 1 and 14 July) during the season on azaleas, coriander, and shasta daisy using a standardized beat sampling technique. "Beating" consisted of holding a funnel sampling unit (30 cm diameter funnel with a mason jar at base containing 70% ethanol) under the plant and hitting or "beating" branches 6 times with a wooden dowel to knock arthropods from the plant into the funnel. A soft bristle paintbrush was used to brush arthropods into the mason jar. To sample azaleas, each of the three azaleas per study plot were sampled once (six beats per azalea) into a single jar (pooled sample). In study plots containing flowers, shasta daisy and coriander were each sampled at three locations per flower bed. Each flower species resulted in one sample (pooled sample). Samples were returned to the laboratory where they were later examined to determine taxa (to family level), abundance, and trophic level of all arthropods collected. Data were also collected on flower phenology to determine whether arthropod abundance was influenced by flower phenology. Phenology was monitored for each flower species in each bed at dates near the time arthropods were sampled (9 and 17 June; 1, 11, and 28 July). To quantify flower phenology, two 30 cm x 60 cm areas of the flower beds were randomly selected. Measurements were recorded on the mean number of flowers in full bloom.

In 1999, arthropods were sampled on 15 June on azaleas using the beating method and samples were sorted and identified as described for 1998. Data were also taken on flower phenology on 14 June as described above. A severe drought made it impossible to effectively continue the study for the remainder of the 1999 field season.

Azalea Lace Bug Survival

In 1998, azaleas were newly planted and free of azalea

lace bugs. To determine the impact of flowering plants on azalea lace bug survival, cohorts of known numbers of azalea lace bugs were put on each of the three azaleas in study plots with flowers and plots without flowers. Azalea lace bug survival studies were repeated four times throughout the season (24 June; 7, 10, and 23 July). The number and life stage of azalea lace bug used to infest azaleas varied between dates due to differences in availability of field populations. Cohort infestations were as follows: on 24 June, each of the three azaleas in each study plot was infested with 20 azalea lace bug nymphs (plot total = 60); on 7 July and 10 July, 50 azalea lace bug nymphs (plot total = 150); on 23 July, 50 azalea lace bug adults (plot total = 150). Azalea lace bug survival was monitored daily by visually inspecting plants until 50% of all azalea lace bug cohorts became extinct.

In 1999 azalea plants had natural infestations of azalea lace bugs. Therefore, azalea lace bug survival study methods were altered from 1998 methods. On 7 June, pre-counts were taken of azalea lace bug on azaleas in each of the study plots. Since pre-counts indicated that azalea lace bug abundance was variable among the study plots, on 9 June azalea lace bug densities on azaleas were adjusted so that all plots in each treatment had equal numbers of azalea lace bugs. In plots with high densities of azalea lace bugs all but 23 azalea lace bugs were removed. In plots that had low azalea lace bug densities, azalea lace bugs were added to equal 23 azalea lace bugs per plot. This resulted in all plots with equal numbers of azalea lace bugs. Post-counts of the number of azalea lace bugs per plot were taken on 14 June. Comparisons were made between flower and no flower plots of the number of azalea lace bugs that naturally infested azaleas (7 June) and post-counts (14 June). A covariance analysis of pre (the covariate) and post-counts was also performed.

Predation by Green Lacewing Predators

In 1998, to determine whether the presence of flowering plants affected the retention of green lacewings and the ability of green lacewings to reduce azalea lace bug abundance, known numbers of 2nd instar lacewing larvae were released onto azaleas (5 lacewings / azalea) in the 11 plots with flowers and the 11 plots without flowers. Lacewing larvae were purchased from Rincon Vitova, CA. Releases were performed to coincide with two of the azalea lace bug survival studies (24 June and 10 July). Azaleas and flowers were visually monitored for the presence of green lacewings on day 7 and day 4 post release of 24 June and 10 July, respectively. Azalea lace bugs were monitored as described above.

Statistical Analysis

An analysis of variance (ANOVA) was used to determine the influence of incorporating flowering plants into study plots on arthropod abundance and azalea lace bug survival (Proc Mixed, SAS Institute 1999). Relationships between flower phenology and arthropods were determined by regression analysis (Proc Reg, SAS Institute 1999). An analysis of covariance was used to determine whether azalea lace bug pre-count densities influenced azalea lace bug survival in 1999 (Proc ANCOVA, SAS Institute 1999). A factorial analysis was used to determine the influence of flowers and green lacewing releases on azalea lace bug survival (Proc GLM, SAS Institute 1999). To determine whether data met the assumptions of ANOVA, homogeneity of variances and normality were examined using Proc Univariate and plotting residuals (SAS Institute 1999). Data that did not meet the assumptions of normality were \log_{10} transformed. Data are presented as untransformed means \pm SEM. Differences between individual means were examined by a least significant difference (LSD) or Bonferonni test (Proc GLM, SAS Institute 1999, Zar 1999). All analysis incorporated a blocking term unless stated differently. Differences were considered significant at $P < 0.05$.

RESULTS

Arthropod Taxa and Abundance

Statistical comparisons of overall arthropod abundance on azaleas, coriander, and shasta daisy between flower and no flower plots could not be made since the number of samples varied between treatments. Plots with flowers had greater numbers of samples per sampling period (1/plant species = 3 samples) than plots without flowers (1/plant species = 1 sample). However, comparisons could be made of arthropod abundance on azaleas between treatment plots. In 1998, alternative prey abundance on azaleas in plots with flowers did not significantly differ from plots without flowers at any of the four sampling times (9 June: $F = 0.08$; $df = 1,19$; $P = 0.781$; 16 June: $F = 2.80$; $df = 1,21$; $P = 0.109$; 1 July: $F = 3.85$; $df = 1,21$; $P = 0.063$; 14 July: $F = 0.03$; $df = 1,21$; $P = 0.863$) (Table 1). Similarly, natural enemy abundance did not differ significantly on azaleas between flower and no flower plots (9 June: $F = 1.19$; $df = 1,17$; $P = 0.795$; 16 June: $F = 0.80$; $df = 1,14$; $P = 0.207$; 1 July: $F = 3.25$; $df = 1,13$; $P = 0.373$; 14 July: $F = 1.08$; $df = 1,15$; $P = 0.704$) (Table 2). In 1999, alternative prey were significantly more abundant on azaleas in plots with flowers than

without flowers ($F = 3.97$; $df = 1,37$; $P = 0.054$) (Figure 1). However, natural enemy abundance did not differ on azaleas between flower and no flower plots ($F = 0.83$; $df = 1,32$; $P = 0.368$) (Figure 1).

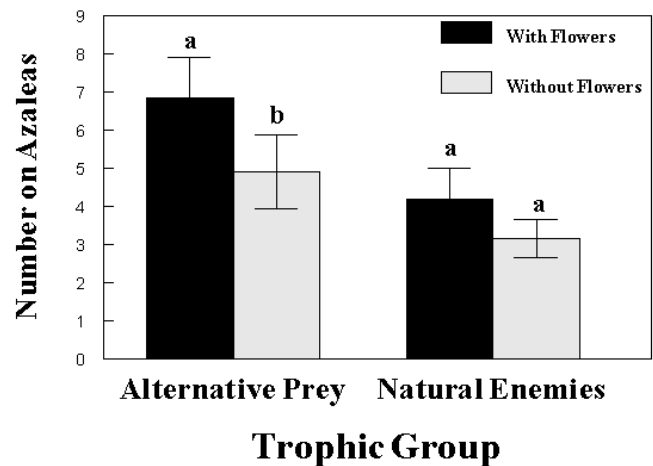


Figure 1. Mean number (\pm SEM) of alternative prey and natural enemies on azaleas sampled 15 June 1999 in plots with flowers and without flowers. Bars with the same letter are not statistically different within each trophic group ($P < 0.05$).

The five most abundant natural enemy families in 1998, as determined by calculating means of natural enemy families summed over the season, were Salticidae (Araneae), Therididae (Araneae), Anyphaenidae (Araneae), Cantharidae (Coleoptera), and Coccinellidae (Coleoptera). Salticids were significantly ($F = 4.39$; $df = 1,21$; $P = 0.0561$) more abundant on azaleas in plots without flowers than in plots with flowers (Table 3). Statistical analysis could not be performed on other natural enemy families between azaleas because data did not meet the assumption of homogeneity of variances even with a log transformation. Abundance of natural enemies in each family on each of the flower species and on azaleas in plots with and without flowers is presented in Table 3. Cantharids appeared to be most abundant on coriander while coccinellids were most abundant on shasta daisies. Anyphaenid spiders only occurred on azaleas, not on either flower species.

The phenology of flowering plants changed over time. The mean (\pm SEM) number of coriander and shasta daisy plants in full bloom were as follows: 1998 – 9 June: coriander 0.2 (0.1), daisy 0.5 (0.1); 17 June: coriander 6.1 (0.1), daisy 2.6 (0.3); 1 July: coriander 61.8 (5.4), daisy 10.8 (0.8); 11 July: coriander 27.9

Table 1. Mean (SEM) number of alternate prey on azaleas, coriander, and shasta daisy on four sampling dates in 1998 in plots with flowers and without flowers

Date	Treatment	Azalea ¹	Coriander	Shasta Daisy	Plot Total
June 9	Flowers	18.8 (3.0)a	8.5 (1.1)	7.4 (1.3)	34.7
	No Flowers	17.5 (2.4)a	--	--	17.5
June 16	Flowers	8.8 (1.2)a	7.0 (1.1)	4.9 (0.8)	20.7
	No Flowers	10.7 (1.1)a	--	--	10.7
July 1	Flowers	7.3 (1.2)a	12.5 (1.6)	4.5 (0.8)	24.3
	No Flowers	5.3 (0.7)a	--	--	5.3
July 14	Flowers	6.4 (0.9)a	16.9 (2.9)	4.6 (0.6)	27.9
	No Flowers	6.2 (0.8)a	--	--	6.2

¹Numbers on azaleas with the same letter are not significantly different between treatments within a date ($P < 0.05$).

Table 2. Mean (SEM) number of natural enemies on azaleas, coriander, and Shasta daisy on four sampling dates in 1998 in plots with flowers and without flowers.

Date	Treatment	Azalea ¹	Coriander	Shasta Daisy	Plot Total
June 9	Flowers	2.9 (0.5)a	1.9 (0.6)	1.4 (0.2)	6.2
	No Flowers	2.9 (0.4)a	--	--	2.9
June 16	Flowers	2.4 (0.5)a	2.6 (0.7)	1.5 (0.3)	6.5
	No Flowers	3.3 (0.6)a	--	--	3.3
July 1	Flowers	2.4 (0.4)a	4.0 (0.6)	2.3 (0.6)	8.7
	No Flowers	2.1 (0.4)a	--	--	2.1
July 14	Flowers	2.3 (0.3)a	2.9 (0.5)	2.4 (0.4)	8.3
	No Flowers	2.5 (0.3)a	--	--	2.5

¹Numbers on azaleas with the same letter are not significantly different between treatments within a date ($P < 0.05$).

Table 3. Mean (SEM) number of the five most abundant natural enemy families summed across all sampling dates in 1998 on azaleas, coriander, and Shasta daisy in plots with flowers and without flowers.

Family	Treatment	Azalea ¹	Coriander	Shasta Daisy	Plot Total
Salticidae	Flowers	1.4 (0.2)a	1.4 (0.4)	1.1 (0.1)	3.9
	No Flowers	2.2 (0.3)b	--	--	2.2
Therididae	Flowers	1.3 (0.2)	1.0 (0)	1.1 (0.1)	3.4
	No Flowers	1.6 (0.3)	--	--	1.6
Anyphaenidae	Flowers	2.7 (1.7)	0 (0)	0 (0)	2.7
	No Flowers	1.8 (0.4)	--	--	1.8
Cantharidae	Flowers	2.3 (0.5)	2.7 (0.7)	1.1 (0.1)	6.1
	No Flowers	1.0 (0)	--	--	1.0
Coccinellidae	Flowers	1.3 (0.3)	1.3 (0.3)	1.7 (0.7)	4.3
	No Flowers	1.8 (0.4)	--	--	1.8

¹Number of Salticidae on azaleas were significantly different between treatments ($P < 0.05$). Other families did not meet the assumption of homogeneity and could not be statistically compared.

(4.0), daisy 8.7 (0.7); 28 July: coriander 9.0 (1.0), daisy 1.7 (0.3); 1999 – 14 June: coriander 57.0 (5.9), daisy 7 (1.0). As expected, early in the season the number of flowers in full bloom was quite low, with an increase towards mid-summer, followed by a decrease later in the summer. The number of flowers in full bloom in June of 1999 was greater than the number of flowers in full bloom at the same time period in 1998. A regression analysis of 1998 seasonal data determined flower phenology did not significantly influence alternative prey abundance ($R^2 = 0.0075$; $F = 0.65$; $df = 1,86$; $P = 0.423$). However, there was a slight, but significant, effect of flower phenology on natural enemy abundance ($R^2 = 0.0445$; $F = 4.00$; $df = 1,86$; $P = 0.048$). Natural enemy abundance increased as the number of flowers in full bloom increased.

Azalea Lace Bug Survival

Following introduction of azalea lace bug cohorts, survival was significantly lower on azaleas in study plots with flowers than in plots without flowers on three of the four dates sampled in 1998 (24 June: $F = 1.38$; $df = 1,8$; $P = 0.274$; 7 July: $F = 4.90$; $df = 1,21$; $P = 0.038$; 10 July: $F = 4.73$; $df = 1,10$; $P = 0.055$; 23 July: $F = 6.23$; $df = 1,21$; $P = 0.021$) (Figure 2). Early in the season (24 June), when the number of flowers in full bloom was low, azalea lace bug survival did not differ between treatments. However, later in the season, when greater numbers of flowers were blooming and numbers of natural enemies in plots with flowers were greater, azalea lace bug survival was lower in plots with flowers.

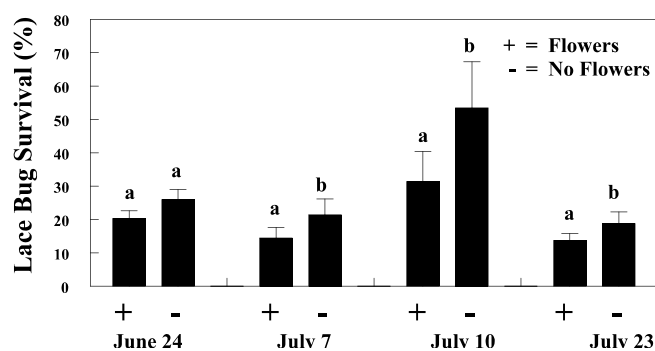


Figure 2. Mean (\pm SEM) azalea lace bug survival (%) following introduction of azalea lace bug cohorts on azaleas in plots with flowers and without flowers on four sampling dates in 1998. Bars with the same letter are not statistically different ($P < 0.05$).

In June 1999, there was no significant effect of flowers on the abundance of azalea lace bugs that naturally infested azaleas in plots with flowers and without flowers ($F = 3.21$; $df = 1,21$; $P = 0.088$). Five days after azalea lace bug populations were equalized on study plants, there was no significant difference in azalea lace bug survival on azaleas in plots with flowers compared to plots without flowers ($F = 0.10$; $df = 1,21$; $P = 0.753$). In the covariance analysis, there was no significant pre-count (covariate) by flower treatment interaction or main effect of flowers (Figure 3). However, there was a significant ($P = 0.003$) and positive main effect of pre-count on azalea lace bug survival (pre-count*treatment: $F = 0.53$; $df = 1,27$; $P = 0.474$; treatment: $F = 0.18$; $df = 1,24$; $P = 0.678$; pre-count: $F = 15.65$; $df = 1,39$; $P = 0.0003$) such that high pre-counts increased azalea lace bug survival (Figure 3).

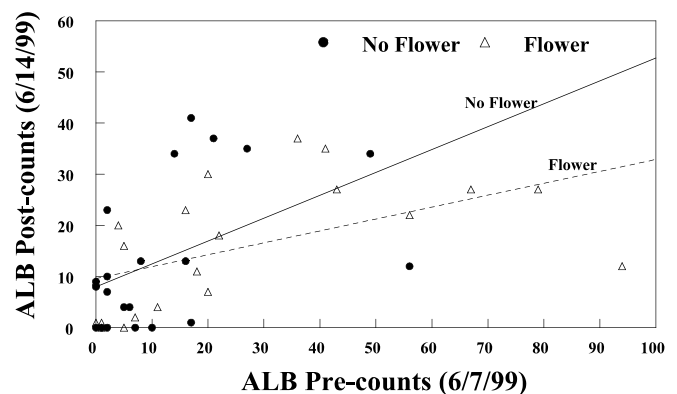


Figure 3. Relationship between number of azalea lace bug that naturally infested azaleas (pre-counts) and the number of azalea lace bug surviving on azaleas (post-counts) five days after equalization of azalea lace bug densities in June 1999.

Predation by Green Lacewing Predator

There was no significant interaction between flower treatment and green lacewing treatment on either date (24 June: $F = 0.90$; $df = 1,24$; $P = 0.354$; or 10 July: $F = 1.96$; $df = 1,30$; $P = 0.172$) (Figure 4). There also was no significant main effect of flower treatment on both dates (24 June: $F = 0.46$; $df = 1,24$; $P = 0.506$; or 10 July: $F = 2.73$; $df = 1,30$; $P = 0.109$). However, there was a main effect of green lacewing treatment on both dates (24 June: $F = 7.75$; $df = 1,24$; $P = 0.01$; and 10 July: $F = 4.98$; $df = 1,30$; $P = 0.033$). The data for lace bug survival on 24 June show that the presence of flowers

did not significantly reduce azalea lace bug populations compared to controls (no flowers or lacewings). However, release of green lacewings in the absence of flowers did significantly reduce azalea lace bug populations. Green lacewing releases in combination with flowers did not reduce azalea lace bug populations any more than lacewing releases alone (Figure 4). In July, the presence of flowers alone significantly reduced azalea lace bug survival compared to the control, unlike the study conducted in June. Other results of the 10 July study were similar to the 24 June study with lacewings significantly reducing azalea lace bug survival, but no synergistic effect of combining lacewings and flowers (Figure 4).

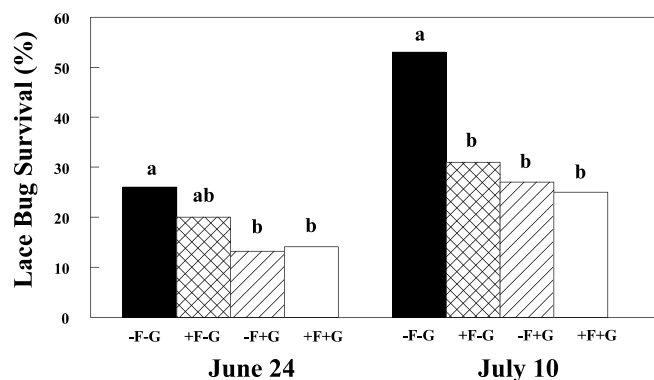


Figure 4. Mean percentage (\pm SEM) azalea lace bug survival on azaleas in plots with flowers (+F) and without flowers (-F), each with or without green lacewing predators (+G and -G, respectively) released on two dates in 1998. Bars with the same letter are not statistically different within each date ($P < 0.05$).

The presence of flowers had no impact on the retention of green lacewings augmented onto azaleas in the study plots. Seven days after lacewings were released for the 24 June study, 3% were recovered from the plots with flowers and 0.75% from plots without flowers. Four days after lacewings were released for the 10 July study, 7% were recovered from the plots with flowers and 7% from the plots without flowers.

DISCUSSION

Overall, our studies in simulated ornamental landscape beds showed a positive effect of adding flowers on natural enemy abundance and a negative effect on

azalea lace bug survival. Our results are consistent with other studies examining the impact of habitat manipulations on natural enemies and herbivores. In a recent review of studies on habitat manipulation, Gurr et al. (2000) found that of 19 studies the effects of habitat manipulation on natural enemies were beneficial in all but two cases. Additionally, of 22 studies that examined the impact of habitat manipulation on natural enemies and on herbivores simultaneously, 19 of 22 demonstrated a beneficial effect on natural enemies, and 15 of 22 demonstrated that the increases in natural enemies resulted in a reduction in herbivores (Gurr et al. 2000). Of the studies reviewed none were in ornamental systems and only a few involved the addition of flowering plants as the habitat manipulation.

Adding flowering plants increased the overall abundance of alternative prey and natural enemies in our study plots compared to plots without flowers. In addition, this habitat manipulation resulted in lower azalea lace bug survival on three of the four dates evaluated in 1998. These results support other studies conducted in established ornamental landscapes that found alternative prey and generalist predators, especially spiders, were more abundant on azaleas in structurally complex landscapes than on azaleas in simple ones (Shrewsbury 1996). Shrewsbury (1996) also found azalea lace bug populations were dramatically lower in structurally complex landscapes compared to simple ones.

In other studies where flowers were added similar results were found. Patt et al. (1997a) planted strips of dill and coriander between rows of eggplant. This habitat manipulation increased levels of coccinellids and decreased Colorado potato beetle survival. In vineyards, a summer cover crop of buckwheat and sunflowers increased generalist predator populations, especially *Orius* sp. and spiders, within the vineyard and decreased densities of two herbivores, leafhoppers and thrips (Nicholls et al. 2000). Spiders and coccinellids ranked in the most abundant predator groups in our study plots.

We compared the number of alternative prey and natural enemies on azalea plants in plots with and without flowers. Though natural enemy and alternative prey populations were greater overall in the plots with flowers, there were no differences in abundance of either group on the azaleas themselves between plots with and without flowers, except on one date (June 1999) when alternative prey were more abundant on azaleas in plots with flowers. Moreover, even though no difference in natural enemy abundance was found on the azaleas, azalea lace bug survival was lower on azaleas in plots with flowers than plots without flowers

on three of the four dates evaluated in 1998. Arthropod sampling was done at a date close to but not coincident with dates when experimental azalea lace bug cohort survival was sampled. We could not sample the arthropod community while survival studies were underway because destructive beat sampling would have interfered with azalea lace bug survival. One explanation for differences in azalea lace bug survival but lack of difference in natural enemy abundance on azaleas in flower and no flower plots is that generalist natural enemies were mobile and closely tracked prey populations. In plots with flowers, predators may have moved from flowers onto azaleas when prey, azalea lace bug, was present. When predators reduced azalea lace bug abundance they may have moved back to flowers where alternative prey were abundant. This type of numerical or aggregative response has been found for many natural enemy species (Döbel and Denno 1994, Price 1997). Three of the five most abundant natural enemy families found in our study plots were spiders. Several studies have demonstrated that spiders move from areas with low prey abundance to areas with high prey abundance (Riechert and Gillespie 1986, Döbel and Denno 1994). In a manipulated study where azaleas had varying densities of alternative prey, Shrewsbury (1996) found spiders dispersed more from azaleas with low numbers of alternative prey than from azaleas with high numbers of prey. Another possible explanation for the lack of difference in natural enemy abundance on azaleas between plots with and without flowers is that sampling was conducted during the daytime. The predators in the present study may have foraged nocturnally and been missed during daytime sampling.

A similar pattern was found by Tooker and Hanks (2000) in established habitats where they found greater pine needle scale densities on pine trees in impoverished (or simple) landscape habitats compared to wooded habitats. They also did not detect differences in predator abundance between habitats on the scale host plant. They suggest that their sampling method was limited because they only sampled pine trees and did not evaluate abundance of predators on other nearby plants that may have supported mobile predators. Mobile predators may move between scale host plants and others in the habitat.

Differences in azalea lace bug survival between flower and no flower plots in 1998 occurred later in the season. No azalea lace bug survival differences were found on the first date (24 June). Our studies found that flower phenology, i.e. number of open flowers, increased from early to mid-season and then declined towards the end of the season. Natural enemy abundance followed a similar seasonal pattern which

may explain azalea lace bug survival patterns over the 1998 season. Azalea lace bug survival did not differ for the one date tested on 14 June 1999 even though the number of open flowers on that date was similar to that observed on 1 July 1998 when differences in azalea lace bug survival were found. These results suggest that factors other than flowers might be influencing azalea lace bug abundance. We found no direct effect of flowers on azalea lace bug survival in 1999. However, a covariate analysis indicated that pre-count azalea lace bug densities of natural infestations significantly influenced azalea lace bug survival (post-counts) even after azalea lace bug abundance had been equalized between flower treatments. This relationship was significant and positive. Plants with high pre-count densities of azalea lace bugs had high post-count densities irrespective of the presence or absence of flowers (Figure 3). Even an adjustment of azalea lace bug abundance that equalized densities between treatments did not nullify the correlation between pre- and post-counts. Clearly, unknown local factors were able to override the broader effects of flowers on these plants. Although the experimental design allowed us to collect spatial and temporal information about the community of natural enemies visiting flowers and azaleas, we did not sample all components of the natural enemy community. For example, ground dwelling arthropods were not sampled. Ground dwellers are an important group of natural enemies and perhaps differences in this component overrode effects of flower and no flowers.

Augmentative releases of green lacewing predators reduced azalea lace bug populations, whether or not flowers were present in the plots. In addition, releases of green lacewings and the presence of flowers similarly reduced azalea lace bug survival. However, the combination of green lacewing releases and flowers did not have an additive effect on reducing azalea lace bug survival. In another study evaluating augmentative release of green lacewing predators, lacewings suppressed azalea lace bug populations on azaleas in a production nursery (Shrewsbury and Smith-Fiola 2000). In both that and the present study, lacewings disappeared from study plots following pest suppression. Although green lacewings are known to feed on pollen (Patt et al. 2003), green lacewing recovery was very low from both flower and no flower plots. It is somewhat puzzling that lacewings disappeared from the study plots with flowers. Patt et al. (2003) found that *C. carnea* developed more quickly and grew larger when fed both pollen and *Drosophila* larvae compared to either food type alone. Lacewings may disperse from the plots when prey populations are low to search for additional insect prey, a potentially higher quality food source.

Cannibalism or intraguild predation may also explain why lacewings disappear from plots. Rosenheim and Wilhoit (1993) found that intraguild predation of lacewings by heteropteran predators significantly reduced lacewing abundance in cotton fields.

CONCLUSION

Augmentative release of *C. carnea* suppressed azalea lace bug populations and then lacewings disappeared from the system regardless of the presence of flowers and their associated resources. The addition of coriander and shasta daisy consistently increased alternative prey and natural enemy abundance at the plot level, however this response was variable on the azaleas themselves. Alternative prey abundance seemed to influence predator movements on a local scale and greater abundance of natural enemies suppressed azalea lace bug populations. In addition to flowers, other potential factors not identified in our study are likely influencing the system.

Results of these studies bring up future questions to address relating to: movement or dispersal of generalist predators; influence of alternative prey; role of spiders; and factors influencing disappearance of green lacewing predators (dispersal, intraguild predation, etc.).

Practical implications from this study suggest that landscape habitats can be manipulated by adding flowering plants to reduce the likelihood of insect pest outbreaks. Augmentative release of green lacewings should effectively reduce azalea lace bug populations but these releases should be considered a short-term solution. Monitoring of plants should continue in case plants are reinfested by insects. Many questions still remain regarding the implementation of this habitat manipulation practice in ornamental landscapes.

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