Management Strategy, Shade, and Landscape Composition Effects on Urban Landscape Plant Quality and Arthropod Abundance

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ABSTRACT Intensity and type of management, the cultural variable shade, and the combination of woody and herbaceous annual and perennial plants were evaluated for their effect on key landscape arthropod pests. Azalea lace bugs, *Stephanitis pyrioides* (Scott), and twolined spittlebugs, *Prosapia bicincta* (Say), were most effectively suppressed in landscape designed with resistant plant species of woody ornamentals and turf. Landscapes containing susceptible plant counterparts were heavily infested by these two insect species in untreated control plots. A traditional management program of prescribed herbicide, insecticide, and fungicide applications effectively suppressed azalea lace bug and produced a high-quality landscape. Targeted integrated pest management with solely horticultural oils resulted in intermediate levels of azalea lace bug. Neither program completely controlled twolined spittlebug on hollies or turf. Carabidae, Staphylinidae, Formicidae, and Araneae were not reduced by any management strategy. Lace bugs (*Stephanitis*) were more common in plots with 50% shade than those in full sun. Spittlebugs (*Prosapia*) were more common in the shade during 1996 and in the sun during 1997. Spiders and ants were more often collected in full sun plots. Carabids, staphylinids, and spiders were more commonly collected from pitfall traps in turf than in wood-chip mulched plant beds, whereas ants were equally common in both locations. The addition of herbaceous plants to the landscape beds had little effect on pest insect abundance.

KEY WORDS azalea lace bug, twolined spittlebug, integrated pest management, centipedegrass, zoysiagrass, hollies

MANAGED LANDSCAPES ARE characterized by a tremendous diversity of plant material and associated potential pests compared with traditional agricultural (monoculture) settings (Raupp et al. 1992). This degree of complexity challenges attempts to develop and implement integrated pest management (IPM) strategies. Although prospects for the implementation of IPM on a broad scale are good, several impediments to the adoption of IPM strategies in urban landscape pest management have been identified (Potter and Braman 1991, Raupp et al. 1992, Braman and Latimer 1997, Braman et al. 1998). Foremost among these impediments is clientele expectation of imperfection-free landscapes. Concerns over potential risks to human health and the environment have led to public demand for critical reassessment of current management tactics, but have in no way lessened the demand for high-quality landscapes (Braman et al. 1998). Commercial pesticide use in urban landscapes parallels Environmental Protection Agency estimates for total pesticide use in the United States, with herbicide use exceeding insecticide use, followed by fungicides (Aspelin 1994, Braman et al. 1997).

Opportunities for reducing certain pesticides in the landscape include increasing use of pest-resistant plant material (Garber and Bondari 1996). In a telephone survey of 400 homeowners in Georgia, 72% of respondents indicated a desire to learn more about pest-resistant plants, whereas 37% already sought landscape and garden plants with demonstrated resistance to pests (Varlamoff et al. 2000). Pest resistance characteristics of various landscape plant species and cultivars are becoming increasingly well documented (Smith-Fiola 1995), allowing more flexibility in landscape design to avoid pest problems. We sought to evaluate the effects of management strategies, including resistant-plant based management, on key landscape and turfgrass pests, associated beneficial insects and spiders, and landscape plant growth and quality. Arthropod occurrence and abundance also are influenced by cultural factors such as shade, irrigation, and plant nutrition (Trumble and Denno 1995, Casey and Raupp 1999) and potentially by landscape plant complexity (Leddy 1996). Herein, in addition to management effects, we further examined the influence of shade and landscape plant combinations on key pest and beneficial arthropods and on plant growth and quality.

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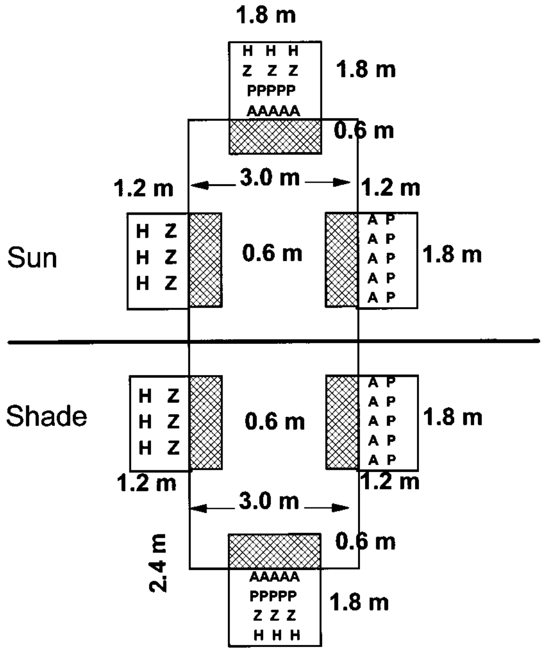

Fig. 1. Planting plan and plot dimensions for each of 20 mini-landscapes. Each landscape contained woody ornamental hollies (H) and azaleas (Z), herbaceous annual New Guinea impatiens (A), perennial verbena (P), and turfgrass (crosshatched areas). One-half of each landscape was covered with 50% shade cloth over a quonset-style PVC-pipe frame.

Materials and Methods

Twenty mini-landscapes were installed at the Georgia Station Research and Education Garden in Griffin, GA, during the summer and fall of 1995. Landscapes were designed to include common components of managed landscapes: turfgrass, woody ornamentals, and herbaceous annual and perennial plants. Each of the 20 mini-landscapes was designed to allow the opportunity to evaluate arthropod abundance and plant parameters when woody ornamentals and herbaceous plants were planted alone or in combination (Fig. 1). Each mini-landscape was developed as two mirror-image halves allowing us to impose 50% shade over half of each plot. Plots were a minimum of 9.1 m apart. The project was located in a newly wooded section of the Georgia Station Research and Education Garden. Oak trees *Quercus* spp., on 9.1-m spacings, had been planted in 1995 and were ≈3 m in height at planting. Each component of the mini-landscape (turf, woody plants, and herbaceous plants) was irrigated separately as necessary to prevent wilt. Landscape beds were mulched with hardwood chip mulch. Turf was mowed weekly with clippings removed.

Five management strategies were compared: (1) a susceptible plant control that received no insecticide, miticide, or fungicide; (2) a resistant-plant based strategy that received no insecticide, miticide, or fungicide; (3) a traditional management approach where plots received applications of pesticide and fertilizer in a manner typical of professionally maintained landscapes under a preventive/curative program; (4) a targeted management approach where landscapes were scouted weekly or biweekly and pest problems treated as they developed; and (5) a homeowner approach where pest problems were treated only with products readily available to homeowners.

Target Arthropod Pests. Azaleas are readily infested by the adventive azalea lace bug, which completes four generations in central Georgia (Braman et al. 1992). Previous research has identified plumleaf azalea as resistant to this pest (Braman and Pendley 1992, Wang et al. 1998). Twolined spittlebug also is widely distributed in North America and completes two generations in the Georgia Piedmont (Braman 1995). This insect has increased in significance as a landscape pest of turfgrasses and ornamentals in the southeastern United States during the last two decades in part because of increased use of a favored host plant, centipedegrass, *Eremochloa ophiuroides* (Munro.) Hack. Adults feed on herbaceous and woody plant foliage, whereas nymphal development occurs only on herbaceous plants, primarily grasses. Results of our greenhouse and field research dictated our selection of common centipedegrass for susceptible plots and 'Emerald' zoysiagrass, *Zoysia japonica* Steud. × *Zoysia matrella* (L.) Merc., for resistant plots (S.K.B., unpublished data). Holly selections were determined after observation of differential infestation of >130 holly selections by this homopteran pest (Braman and Ruter 1997).

Pests anticipated on the annual and on the perennial herbaceous plants selected included green peach aphid, *Myzus persicae* Sulzer); twospotted spider mite, *Tetranychus urticae* Koch; and western flower thrips, *Frankliniella occidentalis* (Pergande). The herbaceous impatiens, *Impatiens hawkeri* Bull., and verbena, *Verbena canadensis* (L.) Britt., were subjected to greenhouse conditioning as described by Latimer and Oetting (1999) before transplant in the field. Conditioning in this test involved 4 wk of mechanical brushing (40 strokes twice daily with a wooden pole adjusted so that the height of the bar struck only the upper one-third of the plants), a process that serves as a nonchemical means of growth regulation in greenhouse production and has been shown to substantially reduce spider mite and thrips infestations.

Plant Species and Cultivars. Pest-susceptible landscapes in this experiment were designed with selected key insect pests of southeastern United States landscapes in mind. Each landscape was planted with common centipedegrass, *Eremochloa ophiuroides* (Munro); 'Delaware Valley White' evergreen azaleas, *Rhododendron indica* variety *alba;* 'Savannah' hollies, *Ilex* × *attenuata* Ashe; 'Antares' New Guinea impatiens, and 'Homestead Purple' verbena according to the planting diagram indicated in Fig. 1. Pest-resistant landscapes were planted with Emerald zoysiagrass (*Zoysia japonica* × *Z. tenuifolia*); plumleaf deciduous azaleas, *Rhododendron prunifolium* (Small); 'Burford Nana' hollies, *Ilex cornuta* Lindl. & Paxt.; and New

Table 1. Fertilizer and pesticides applied to turfgrass (t) or ornamentals (o) in plots under traditional management

Date	Fertilizer	Herbicide	Miticide/Insecticide	Fungicide
22 April 1996			Acephate 0.1125 kg AI/378 l	(o)thiophanate-methyl 227 g AI/378 l (o)
			Oxythioquinox 113.5 g AI/378 l (o)	
7 June 1996	0.25 kg N, 0.05 kg K, 0.02 kg Fe/93 m^2 (t)	MCPA 1.25 kg(AI)/ha (t)	Cyfluthrin 11.35 g AI/378 l (o)	Thipohanate-methyl 227 g AI/378 l (o)
			Oxythioquinox 113.5 g AI/378 l (o)	
			Chlorpyrifos 1.25 kg AI/ha (t)	
26 July 1996	0.025 Kg N, 0.05 kg K, 0.02 Kg Fe/93m^2 (t)		Cyfluthrin 11.35 g AI/378 l (o)	Thiophanate-methyl 227 g AI/378 l (o)
			Oxythioquinox 113.5 g AI/378 l (o)	
			Chlorpyrifos 1.25 kg AI/ha	
20 Sept. 1996	0.1 kg N, 0.25 kg K, 0.01 kg P, 0.02 kg Fe/93 m^2 (t)	Simazine 1.25 kg (AI)/ha (t)	Cyfluthrin 11.35 g AI/378 l	Thiophanate-methyl 113.5 g AI/378 l
			Oxythioquinox 113.5 g AI/378 l	
1 Nov. 1996	0.1 kg N, 0.25 kg K, 0.01 kg P, 0.02 kg Fe/93 m^2 (t)	Simazine 1.25 kg (AI)/ha (t)		
	0.7 kg N, 0.1 kg K, 0.1 kg P, 0.004 kg Fe/93 m^2 (o)			
28 Feb. 1997	0.7 kg N, 0.1 kg K, 0.1 kg P, 0.004 kg Fe/93 m^2 (o)			
6 March 1997			2% Horticultural oil (o)	
27 March 1997	0.25 kg N, 0.05 kg K, 0.02 kg Fe/93 m^2 (t)	MCPA 1.25 kg AI/ha (t)		Acephate 0.1125 g AI/378 L (o)
				Thiophanate-methyl 227 g AI/378 l (o)
		Dicamba 0.2 kg AI/ha (t)	Oxythioquinox 113.5 g AI/378 l (o)	
23 May 1997	0.25 kg N, 0.05 kg K, 0.02 kg Fe/93 m^2 (t)		Cyfluthrin 11.35 g AI/378 l (o)	
			Oxythioquinox 113 g AI/378 l (o)	
			Chlorpyrifos 1.25 kg AI/ha (t)	
17 July 1997	0.25 kg N, 0.05 kg K, 0.02 kg Fe/93 m^2 (t)		Cyfluthrin 11.35 g AI/378 l (o)	Thiophanate-methyl 227 g AI/378 l (o)
			Oxythioquinox 113.5 g AI/378 l (o)	
			Chlorpyrifos 1.25 kg AI/ha (t)	
11 Sept. 1997	0.1 kg N, 0.25 kg K, 0.01 kg P, 0.02 kg Fe/93 m^2 (t)	Simazine 1.25 kg AI/ha (t)	Cyfluthrin 11.35 g AI/378 l (o)	Thiophanate-methyl 227 g AI/378 l (o)
			Oxythioquinox 113.5 g AI/378 l (o)	
4 Nov. 1997	0.01 kg N, 0.25 kg K, 0.01 kg P, 0.02 kg Fe/93 m^2 (t)	Simazine 1.25 kg AI/ha (t)		
	0.7 kg N, 0.1 kg K, 0.1 kg P, 0.004 kg Fe/93 m^2 (t)	Tryclopyr/clopyralid 2 l/ha (t)		

Guinea impatiens and Homestead Purple verbena that had been subjected to greenhouse conditioning to impart pest resistance before transfer to the landscape (Latimer and Oetting 1999).

Management Strategies. Inputs for each of the five previously mentioned management strategies varied considerably. Fertilizer, herbicide, insecticide or miticide, and fungicide application schedules for plots receiving traditional management, which contained centipedegrass, Savannah hollies, Delaware Valley White azaleas, and bedding plants that were not previously conditioned, are outlined in Table 1. All other plots received fertilizer applications according to University of Georgia extension recommendations as follows: centipedegrass 0.25 kg/93 m^2 N in May and in August; and zoysiagrass 0.5 kg N/93 m^2 in April, June, and August applied as complete (N-P-K) turf grade fertilizer. Shrubs were fertilized at the rate of 0.5 kg N/93 m^2 in March, May, and July. Bedding plants received 0.25 kg N/93 m^2 at planting. Herbicides applied to all plots except those under traditional management included only spot sprays with glyphosate and applications of imazaquin for control of wild garlic on 8 May 1996 and 10 October 1996. No insecticides, miticides, or fungicides were applied to the susceptible plant control plots or to the resistant plant plots. Plots under the targeted management strategy were treated for azalea lace bugs on 25 March 1996 and on 25 March, 15 and 28 April, 9 June, and 7 July 1997 with 2% horticultural oil. The product applied for lace bug control in the homeowner management plots was malathion applied on 25 March 1996 and 28 March and 28 April 1997. Centipedegrass turf on targeted management plots was raked to reduce first-generation spittlebugs, and Savannah hollies were pruned each year to minimize amount of susceptible new growth available during two adult spittlebug flight periods (June through July and August through September). The five management strategies were randomly assigned among four blocks. Plots were irrigated as needed to prevent wilt symptoms.

Shade Structures. A durable, lightweight quonset-type shade structure was constructed for each mini-landscape from polyvinyl chloride pipe, construction grade-reinforcement bars, nylon rope, and commercial shade fabric (50% shade) according to the design described by Nesmith et al. (1992). Shade structure dimensions were 7.5 by 6.6 by 2.6 m. One-half of each mini-landscape was covered with a shade structure. Shade treatments were either 50% shade or no shade. These treatments were not randomly assigned because the large structures, when on alternate sides of a plot, produced undesired shade effects on the area designated as receiving full sun. Consequently, all shade structures were installed on the same side of each plot. Shade structures were installed 9 July 1996 and taken down 1 November. During 1997, shade was installed 6 May and removed 22 October.

Data Collection. Lace bug population density and age class distribution were estimated on 9 May, 19 July, and 3 October 1996; 25 March, 15 April, 15 and 29 May, 23 June, 1 and 29 August 1997; and 23 April 1998 by determining the number of each life stage present per 10 leaves selected randomly from each plant within each plot. Plant heights and widths and number of damaged terminals also were recorded at intervals. At the conclusion of the project, an estimate of bloom (number of flower buds), leaf number, and leaf area were determined.

Twolined spittlebug population estimates were made for each of two generations that occurred during 1996 and 1997. Data collected in turfgrass included the number of spittle masses per square meter on 23 July and 25 August 1996 and on 3 June and 22 August 1997. The number of adults and the damage to hollies were assessed during the first generation each year on 18 June 1996 and 25 June 1997. Holly growth and spring greenup (emergence from dormancy) on turfgrass also was assessed each year.

Bedding plant height, width, and quality measurements were made from 0 to 25 wk after planting. Plant quality ratings were taken on a 0–100 scale, where 0 indicated a dead plant and 100 was optimum quality. During 1996, New Guinea impatiens were planted on 24 April; verbena were planted 7 June. During 1997, both were planted 6 May. Visual estimates of insect- and mite-inflicted damage per plant were taken during 1996 and 1997. These damage ratings were also taken on a 0–100 scale based on percentage of foliage damaged, with 0 indicating no damage and 100 indicating a dead plant. Ratings were taken each week on newest foliage.

Beneficial arthropods evaluated for differences among management strategies, shade, or ground cover included carabid and staphylinid beetles, Formicidae (ants), and Araneae (spiders). Pitfall traps, according to the methods of Braman and Pendley (1993), were installed in the center of the turf area and the adjacent landscape bed of each of the two end beds in all 20 mini-landscapes (Fig. 1). Pitfall trap contents, containing beneficial arthropods, in turfgrass and in the wood chip mulch of adjacent beds planted with hollies, azaleas, impatiens, and verbena were collected weekly during July and August 1996 and during June through October 1997.

Data Analysis. Our experimental design was a 5 × 2 × 2 factorial with four replications. All data were subjected to analysis of variance (ANOVA) with the GLM procedure of SAS (SAS Institute 1990). Means were separated using the Fisher protected least significant difference (LSD) test.

Results

Management Strategies: Effects on Target Pests. High population levels of azalea lace bugs and twolined spittlebugs were observed on susceptible control plots during both 1996 and 1997 (Tables 2–4). Few insects or mites were ever observed on bedding plants during either year of this study.

Resistant plant-based management strategies significantly reduced pest population levels of lace bugs on azaleas (Table 2) on all dates. Although lace bugs were not completely eliminated from resistant plant-based plots, eggs, nymphs, and adults were always at least 72% lower than those in untreated, susceptible plant control plots (Table 2). The traditional management program effected significant reduction in lace bugs on 10 of the 12 dates that samples were collected (Table 2). Targeted and homeowner management plots achieved significant lace bug reductions on six and seven dates, respectively, during 1996 and 1997. Use of only horticultural oil in the targeted program was not always sufficient in maintaining lace bug suppression under those conditions where plants could be readily reinfested, as is typical of a home landscape. Similar numbers of flowers were produced by evergreen azaleas under all management strategies ($P > 0.05$). Resistant deciduous azaleas had larger leaf area ($P < 0.05$) but fewer flowers per terminal ($P < 0.05$).

Spittlebugs were not observed on either hollies or turfgrasses in resistant plant-based plots during 1996 or 1997 (Table 3). During 1996, twolined spittlebugs were suppressed and damage reduced by the traditional management program on hollies but not in turf. The targeted management program effected spittlebug reduction on hollies during June but not July and reduced spittle masses in turf during August (Table 3). During 1997 only the resistant plant-based strategy was effective in suppressing spittlebugs and their damage on hollies and turfgrasses in these plots.

Bedding plants receiving mechanical conditioning before being placed in the landscape ("resistant" management strategy) tended to remain smaller and occasionally demonstrated lower quality ratings than their counterparts in the absence of significant insect or mite pressure (data not presented). In 1996, damage ratings on plants that received mechanical conditioning were similar to or greater than those in the untreated susceptible controls; verbena and New Guinea impatiens control plants had season-long average damage ratings of 9.2 and 8.7, respectively, whereas damage ratings of conditioned plants averaged 12.2 for verbena and 14.2 for New Guinea impatiens. In 1997, conditioning had no effect on damage

Table 2. Effects of management strategy, shade, and landscape composition on azalea growth and mean number of azalea lace bug per 10 leaves

Strategy	Adults 5/9/96	Adults 7/19/96	Eggs 10/3/96	Nymphs 3/25/97	Adults 4/15/97	Adults 5/15/97	Eggs 5/29/97	Eggs 6/23/97	Eggs 8/1/97	Eggs 8/29/97
Susceptible	0.2bc	15.9a	13.9a	8.0a	0.5a	3.6a	7.8ab	9.3ab	22.6a	57.2ab
Targeted	0.5a	1.0b	8.6ab	2.4b	0.2b	2.6ab	9.4a	5.9b	30.4a	71.4a
Traditional	0.3ab	1.4b	1.9b	0.1c	0b	0.2bc	3.1bc	12.2a	14.1b	38.5c
Resistant	0c	0.6b	0b	0c	0b	0c	2.2c	0c	0.8c	3.6d
Homeowner	0.2bc	1.4b	6.7ab	0.2c	0b	0.1b	1.5b	10.7ab	24.5a	43.7bc
F	4.7***	2.25*	3.1*	21.4***	5.1***	15.1**	2.9*	6.2	14.6***	24.3***
LSD	0.2	6.4	9.2	2.1	0.2	0.7	5.3	5.4	8.4	14.3
Full Sun	0.2a	4.3a	5.4a	1.3b	0.1a	1.4a	2.5b	6.3a	12.3b	33.6b
50% shade	0.3a	1.9a	7.1a	2.9a	0.2a	1.8a	9.8a	8.9a	24.6a	52.1a
F	1.3	0.5	0.4	7.9***	1.6	1.4	18.4***	2.1	20.2***	16.6***
LSD	NS	NS	NS	1.3	NS	NS	3.3	NS	5.3	9.0
Full plot	0.2a	3.9a	6.2	2.4a	0.1a	1.4a	5.9a	5.9a	18.6a	48.2a
Woody	0.2a	4.8a	5.0	1.9a	0.2a	1.7a	6.4a	9.3a	18.4a	37.6b
F	0.02	0.1	0.1	2.8	0.5	0.6	0.03	3.7	0.01	5.3*
LSD	NS	NS	NS	NS	NS	NS	NS	NS	NS	9.0
(F)										
Mgmt*shade	1.14	0.3	0.9	3.2*	1.0	0.5	1.3	0.6	3.0	4.0**
Mgmt*subplot	7.3***	0.1	0.7	1.4	0.4	1.5	0.8	0.4	0.5	1.1
Shade*subplot	0.6	0.1	0.2	1.9	0.5	2.0	0.2	0	1.6	0.8
Mgmt*shade*Subplot	0.4	0.1	0.7	0.9	0.3	0.8	0.2	0.6	1.1	0.9

*, **, *** indicate significant *F* values at $P < 0.0$, $P < 0.01$, and $P < 0.001$, respectively (df = 4,217).

ratings of verbena (both treatments = 12), but damage ratings of conditioned New Guinea impatiens were significantly lower than controls on four of the 11 measurement dates (season-long average damage ratings: 18.6 for conditioned versus 21.8 for controls). The type of damage varied but the most common damage was stippling resulting from leafhopper feeding and chewed leaves probably by grasshoppers, other Orthoptera, and some lepidopteran larval feeding. When the plants flowered there was thrips damage observed as white stippling on the flowers. The insect complex on bedding plants changed during the year. During the first few weeks only aphids were present, then leafhopper damage was observed along with chewing damage to leaves. During warmer weather, thrips fed on the flowers.

Shade Effects. Lace bugs on azaleas were significantly more abundant in the shade on 25 March, 29 May, and 1 and 29 August 1997 (Table 2). Shade had little effect on azalea plant height, width, leaf area, or leaf number. Number of flowers, however, was significantly higher on plants grown in the full sun. Spittlebugs and their damage were more common in the shade during 1996. During 1997, however, more spittle masses were observed on turf in the sun during June and August and greater damage was inflicted on hol-

Table 3. Effects of management strategy, shade and landscape composition on holly growth and infestation by twolined spittlebug (TLS)

Management Strategy	No. damaged terminals 6/18/96	No. TLS adults/plant 6/18/96	No. damaged terminals 7/16/96	Holly ht (cm) 7/16/96	Holly wdt (cm) 7/16/96	No. damaged terminals 6/25/97	No. TLS adults/plant 6/25/97
Susceptible	0.8b	7.4a	6.9ab	118.3a	76.4ab	29.8b	5.2b
Targeted	1.1ab	3.1b	7.2a	113.7ab	70.9ab	29.4b	6.7a
Traditional	0.2c	2.4b	5.4c	119.4a	74.8ab	35.6a	6.4a
Resistant	0c	0b	2.0d	53.3c	51.2c	0c	0c
Homeowner	1.6a	3.0b	5.7bc	111.3ab	84.3a	32.2ab	6.4a
F	9.6***	7.8***	18.0***	167.1***	6.4***	73.4***	48.9***
LSD	0.6	3.1	1.4	6.1	13.2	4.7	1.1
Full sun	0.7a	1.7b	5.1a	101.4a	73.0a	28.6a	4.6a
50% shade	0.7a	6.3a	5.7a	104.7a	69.4a	22.2b	5.2a
F	.1	30.5***	1.9	2.5	0.9	18.2***	2.2
LSD	NS	2.2	NS	NS	NS	2.9	NS
Full plot	0.6a	3.0a	5.7a	102.5a	68.9a	26.0a	5.3a
Herbaceous	—	—	—	—	—	—	—
Woody	0.8a	3.8a	5.1a	103.6a	73.7a	24.8a	4.6b
F	2.6	0.3	2.1	0.2	1.2	0.4	4.0*
LSD	NS	NS	NS	NS	NS	NS	0.7
(*F*)							
Mgmt*shade	1.1	7.9**	0.7	0.5	1.2	3.3**	2.8*
Mgmt*subplot	1.1	0.3	0.8	0.1	0.6	0.8	4.3**
Shade*subplot	0.3	0.2	0.03	0.5	0.8	26.4***	20.0***
Mgmt*shade*subplot	0.9	0.3	1.6	0.5	0.8	2.2	3.0

*, **, *** indicate significant *F* values at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively (df = 4,217).

Table 4. Effects of management strategy, shade, and landscape composition on turfgrass growth and infestation by twolined spittlebug (TLS)

Management Strategy	% Turfgrass cover 5/1/96	No. TLS nymphal masses in turf 7/23/96	No. TLS nymphal masses/m^2 in turf 8/25/96	TLS adults/10 sweeps in turf 10/3/96	% Turfgrass cover 6/3/97	No. TLS nymphal masses/m^2 in turf 6/3/97	No. TLS nymphal masses/m^2 in turf 8/22/97
Susceptible	25.4b	0.04a	1.8a	1.4b	90.8b	17.2a	8.4a
Targeted	36.9a	0.1a	0.4b	2.1ab	83.1d	13.5a	5.7a
Traditional	19.0b	0.04a	0.7ab	2.0ab	89.4bc	17.1a	5.9a
Resistant	29.1a	0a	0b	0c	97.7a	0b	0b
Homeowner	15.7b	0.04a	0.4b	2.2a	84.6cd	15.9a	5.6a
F	12.3***	0.5	3.6	11.2	10.2***	22.1***	6.9***
LSD	7.7	NS	1.1	0.8	5.1	4.4	3.3
Full sun	39.1a	0.02a	0.1b	1.0b	93.5a	15.7a	6.3a
50% shade	15.7b	0.1a	1.4a	2.0a	84.7b	9.8b	3.9b
F	59.7***	1.8	10.7***	16.2	29.2***	17.6***	4.9*
LSD	6.3	NS	0.8	NS	5.1	2.6	2.1
Full plot	30.0a	0.02a	7.5a	1.6a	89.5a	11.6a	5.8a
Herbaceous	24.0a	0.05a	6.6a	1.6a	87.8a	12.2a	5.8a
Woody	27.3a	0.05a	8.1a	1.6a	90.0a	14.5a	3.6a
F	1.3	0.2	0.05	0.0	0.6	1.7	2.2
LSD	NS	NS	NS	NS	NS	NS	NS
(*F*)							
Mgmt*shade	0.5	1.3	3.8*	1.5	2.3	3.0*	2.2
Mgmt*subplot	0.2	0.9	0.2	0.0	0.6	0.5	0.4
Shade*subplot	0.1	0.6	0.2	0.0	0.7	0.2	0.3
Mgmt*shade*subplot	0.5	0.9	0.2	0.0	0.3	0.5	0.2

*, **, *** indicate significant *F* values at $P < 0.05$, $P < 0.01$, and $P < 0.001$, respectively (df = 4, 87).

lies in the sun (Tables 3 and 4). Turfgrass emergence from dormancy was significantly delayed under shade conditions both years (Table 4). Sun and shade effects were pronounced on bedding plant growth and quality (Fig. 2). The sun-intolerant New Guinea impatiens produced larger, better quality plants in the shade both years, whereas the reverse was true for the sun loving verbena. In contrast, more arthropod damage was observed in New Guinea impatiens in the shade (Fig. 3), whereas greater damage was evident on verbena grown in the sun.

Landscape Composition Effects. Lace bugs on azaleas were rarely influenced by presence or absence of bedding plants within the same subplot (Table 2). On one occasion, 29 August 1997, more lace bug eggs were observed in azaleas planted adjacent to bedding plants compared with subplots with only azaleas and hollies (Table 2). Spittlebugs on hollies were more numerous in full plots (plots containing both woody and herbaceous plants) on 25 June 1997 but not on any other date on hollies; or on any date in turfgrass samples (Tables 3 and 4). Impatiens plants were larger and of superior quality in full plots during 1996 and to a lesser degree during 1997 (data not shown), possibly because the woody plants provided relieving shade for these sun-intolerant plants.

Effects on Nontarget Arthropods. Management strategy had no effect on abundance of carabid or staphylinid beetles in turf and landscape beds during 1996 or 1997 (Fig. 4). Spiders and ants were more common in plots receiving targeted management during 1996 but not during 1997 (Fig. 4). Carabid beetles were more common in the shade during 1997 but not during 1996, whereas staphylinids were largely unaffected in this regard (Fig. 5). Spiders were more commonly collected in the sun as were ants during 1996 (Fig. 5). Carabid and staphylinid beetles and spiders were much more common in pitfalls in turf, whereas

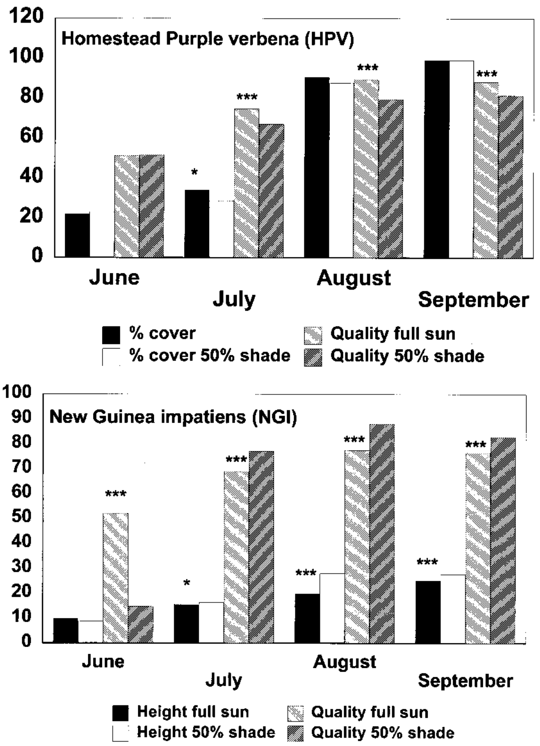

Fig. 2. Effect of shade on plant growth and quality of Homestead Purple verbena and New Guinea impatiens.

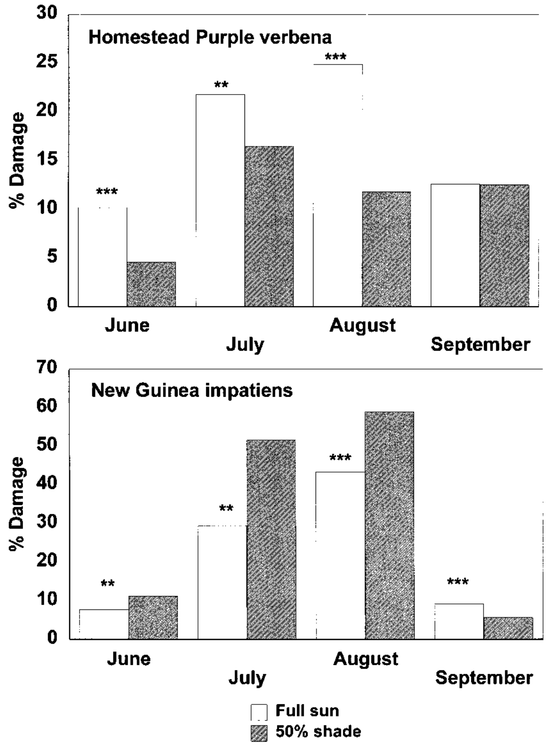

Fig. 3. Effect of shade on degree of insect and mite damage to Homestead Purple verbena and New Guinea impatiens.

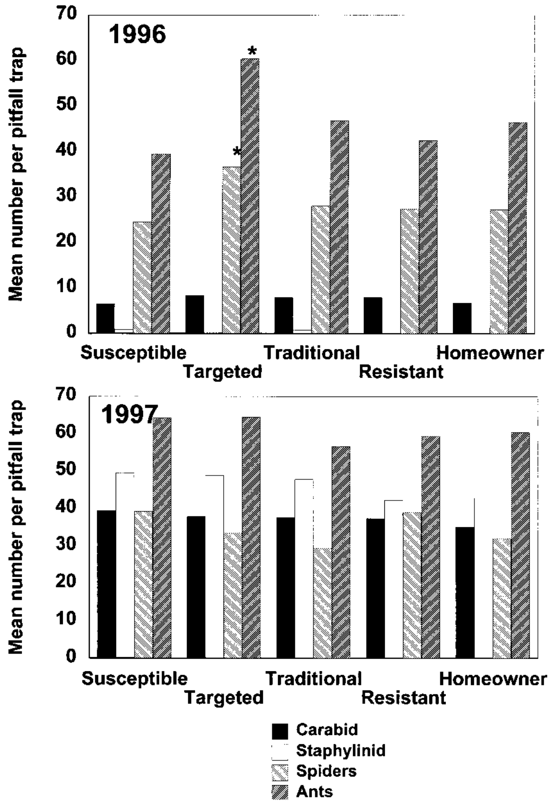

Fig. 4. Effect of management strategy: susceptible untreated controls, targeted treatment, traditional prescribed cover sprays, resistant plant based, and use of only products readily available to homeowners on abundance of beneficial arthropods in the landscape. *, Significant difference from the untreated control $P < 0.05$.

ants were equally abundant in turf and in mulched landscape beds (Fig. 5).

Discussion

Use of pest resistant plants in landscape design was, by far, the most effective pest suppression management strategy for the key pests, azalea lace bug and twolined spittlebug, on woody ornamentals and turf. Annual and perennial herbaceous plants used in this study were more often effected by the cultural variable shade than by any pest management strategy imposed. Previous research had demonstrated pest suppression in the greenhouse with mechanical growth regulation (Latimer and Oetting 1999). We were unable to determine any carryover effects in the landscape under our conditions of low populations of mites, aphids, whiteflies, and thrips. However, we did observe a population of pests being transported from the greenhouse to the field in 1996. A few isolated populations of whiteflies (*Bemisia argentifolli* Bellows & Perring) were transported to the field and established. These populations did not increase to damaging levels but they did persist throughout the summer. There was no movement of whiteflies from one research landscape to another. The insects observed most often were typical for the habitat found in the surrounding area and not major greenhouse pests. The exceptions were aphids early in the season and thrips that moved into the area later when the temperature was higher. However, these pests never increased to even moderate population levels. Ants, spiders, and lady beetles were the most common natural enemies observed. These arthropods are also more typical for the outdoor environment where the landscapes were established and not commonly used for introduction into greenhouses.

Although New Guinea impatiens derived benefit from addition of woody plants to the subplot, this benefit is probably an artifact of improved cultural conditions, i.e., shade on a sun-intolerant plant. Pest populations and plant growth of woody plants were rarely influenced by the addition of herbaceous bedding plants to the subplot. Although the complexity of landscape habitats has been shown to influence azalea lace bug abundance (Leddy 1996), our simple addition of bedding plants did not increase or decrease lace bugs in these plots.

Our observations of increased azalea lace bug abundance in shaded plots support those of Trumble and Denno (1995) who reported that lace bugs preferred to feed and oviposit on shade- rather than sun-grown plants. In their study, adult fecundity, longevity, sur-

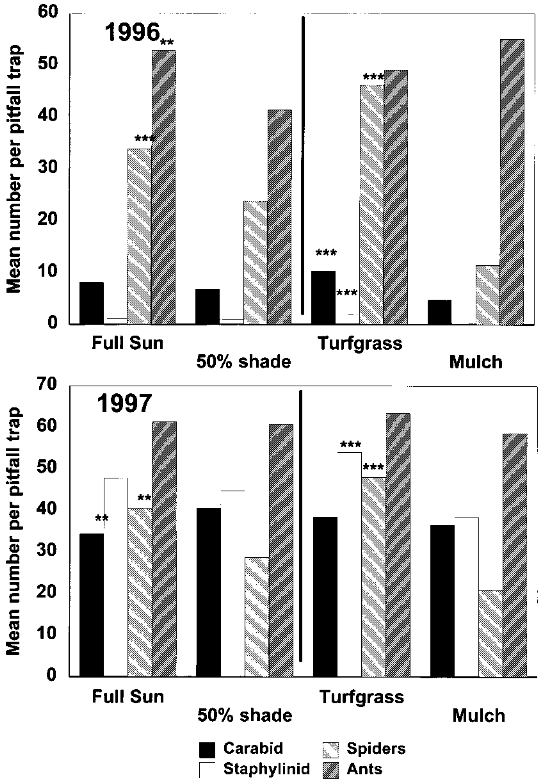

Fig. 5. Effect of shade and ground cover on abundance of beneficial arthropods in the landscape. ** and ***, Significant differences between sun and shade or between turfgrass and mulch at $P < 0.01$ or $P < 0.001$, respectively.

vivorship, and plant damage inflicted were all higher on shade-grown plants in direct contrast to observations by horticulturists and entomologists that azaleas in sunny habitats sustain more damage than those in shaded habitats. Differential predation rates in naturally shaded habitats account for lower lace bug incidence in more complex (shaded) landscapes (Trumble and Denno 1995, Leddy 1996).

The increase in number of spittlebugs in full sun during 1997 also contradicts existing dogma that two-lined spittlebugs are more problematic in the shade. We speculate that the general abundance of spittlebugs in shaded turf reflects the moisture conditions available to the nymphs rather than a preference for shade itself. The plots in our study were supplied with adequate irrigation to prevent moisture stress and spittlebugs may have been favored in grass grown in the sun under conditions better suited agronomically.

Management strategy had minimal influence on occurrence of ground beetles, rove beetles, spiders, or ants. This finding indicates a relatively benign effect on nontarget arthropods of standard lawn care practices as has been demonstrated previously (Arnold and Potter 1987, Braman and Pendley 1993, Heng-Moss et al. 1998). Use of a pest-resistant turf also did not reduce the abundance of generalist predators in these landscape plots. Carabids, staphylinids, and spiders were all more common in grass than in landscape beds, suggesting that addition of turfgrass may afford the benefit of increased natural enemies in the landscape.

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References Cited

Arnold, T. B., and D. A. Potter. 1987. Impact of high maintenance lawn-care program on non-target invertebrates in Kentucky bluegrass turf. Environ. Entomol. 16: 100–105.

Aspelin, A. L. 1994. Pesticide industry sales and usage: 1992 and 1993 market estimates. Office of Pesticide Programs, US-EPA, Washington, DC.

Braman, S. K. 1995. Two-lined spittlebug, pp. 88–90 *In* R. Brandenburg and M. Villani [eds.], Turfgrass insect pests. Pest Handbook Series. Entomological Society of America, Lanham, MD.

Braman, S. K., and J. G. Latimer. 1997. Integrated pest management for urban landscapes *In* K. Bondari [ed.], New developments in entomology. Res. Signpost India. 225–234.

Braman, S. K., and A. F. Pendley. 1992. Evidence for resistance of deciduous azaleas to azalea lace bug. J. Environ. Hortic. 10: 41–43.

Braman, S. K., and A. F. Pendley. 1993. Relative and seasonal abundance of beneficial arthropods in centipedegrass as influenced by management practices. J. Econ. Entomol. 86: 494–504.

Braman, S. K., and J. M. Ruter. 1997. Preference of twolined spittlebug for *Ilex* species, hybrids, and cultivars. J. Environ. Hortic. 15: 211–214.

Braman, S. K., J. G. Latimer, and C. D. Robacker. 1998. Factors influencing pesticide use and integrated pest management implementation in urban landscapes: a case study in Atlanta. HortTechnology 8: 145–149.

Braman, S. K., R. D. Oetting, and W. Florkowski. 1997. Assessment of pesticide use by commercial landscape maintenance and lawn care firms in Georgia. J. Entomol. Sci. 32: 403–411.

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

Casey, C. A., and M. J. Raupp. 1999. Effect of supplemental nitrogen fertilization on the movement and injury of azalea lace bug (*Stephanitis pyrioides* (Scott) to container grown azaleas. J. Environ. Hortic. 17: 75–98.

Garber, M. P., and K. Bondari. 1996. Landscape maintenance firms: II. Pest management practices. J. Environ. Hortic. 14: 58–61.

Heng-Moss, T., F. Baxendale, and T. Riordan. 1998. Beneficial arthropods associated with buffalo grass. J. Econ. Entomol. 91: 167–172.

Latimer, J. G., and R. D. Oetting. 1999. Conditioning treatments affect insect and mite populations on bedding plants in the greenhouse. HortScience 34: 235–238.

Leddy, P. M. 1996. Factors influencing the distrubution and abundance of azalea lace bug, *Stephanitis pyrioides*, in simple and complex landscape habitats. Ph.D. dissertation, University of Maryland, College Park, MD.

Nesmith, D. S., P. L. Raymer, M.S.S. Rao, and D. C. Bridges. 1992. A durable, lightweight structure for conducting field shading experiments. HortScience 27: 1274–1275.

Potter, D. A., and S. K. Braman. 1991. Ecology and management of turfgrass insects. Annu. Rev. Entomol. 36: 383–406.

Raupp, M. J., C. S. Koehler, and J. A. Davidson. 1992. Advances in implementing integrated pest management for woody landscapes. Annu. Rev. Entomol. 37: 561–585.

SAS Institute. 1990. User's manual, version 6. SAS Institute, Cary, NC.

Smith-Fiola, D. C. 1995. Pest resistant ornamental plants. Rutgers Cooperative Extension, New Brunswick, NJ.

Trumble, R. B., and R. F. Denno. 1995. Light intensity, host-plant irrigation, and habitat related mortality as determinants of the abundance of azalea lace bug (Heteroptera: Tingidae). Environ. Entomol. 24: 898–908.

Wang, Y., C. D. Robacker, and S. K. Braman. 1998. Identification of resistance to azalea lace bug among deciduous azalea taxa. J. Am. Soc. Hortic. Sci. 123: 592–597.

Varlamoff, S., J. G. Latimer, W. J Florkowski, J. L. Jordan, and S. K. Braman. 2000. Homeowner interest in environmental gardening practices. Pollut. Prevent. Rev. (in press).

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