Evaluation of Components of Vegetational Texture for Predicting Azalea Lace Bug, *Stephanitis pyrioides* (Heteroptera: Tingidae), Abundance in Managed Landscapes

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ABSTRACT The relationship between azalea lace bug, *Stephanitis pyrioides* (Scott), abundance and components of vegetational texture were examined in managed landscapes to determine which component(s) best explained patterns in lace abundance. In managed landscapes, azalea lace bug is a key pest of azaleas and its abundance varies dramatically in time and space. The components of vegetational texture examined were light exposure, plant species diversity, evenness and richness, host patch size, and structural complexity of the landscape. The best habitat predictors of lace bug abundance were structural complexity and light exposure explaining 54 and 53% of lace bug variation, respectively. Three of the remaining four components also were significantly related to lace bug abundance. Further examination of light exposure revealed that afternoon readings explained more of the variation (52%) in lace bug abundance than morning readings (9%). Of the five vegetational strata that comprise structural complexity, the overstory tree layer and ground cover/turf layer (76%) were the best predictors of lace bug abundance. The implications of this work are that landscapes can be evaluated for susceptibility to lace bugs and perhaps other pests. It also provides information for designing landscapes that support fewer pest problems, resulting in low-input sustainable landscapes.

KEY WORDS *Stephanitis pyrioides*, vegetational diversity, structural complexity, habitat management, light exposure, landscape ecology

MANY STUDIES HAVE attempted to describe and understand the relationships among various components of vegetational texture of a habitat and the abundance of phytophagous insects (Tahvanainen and Root 1972; Root 1973; Cromartie 1975a, 1975b; Raupp and Denno 1979; Bach 1980a, 1989b, 1981, 1986, 1988; Risch 1980, 1981; Rausher 1981; Kareiva 1983; Elmstrom et al. 1988; Andow 1990, 1991; Denno and Roderick 1991) and natural enemies found there (Hatley and MacMahon 1980; Andow and Risch 1985; Sheehan 1986; Russell 1989; Letourneau 1990a, 1990b; Hanks and Denno 1993; Marino and Landis 1996; Colunga-Garcia et al. 1997; Dyer and Landis 1997). Vegetational texture has been defined in terms of plant density, patch size, and vegetational diversity (Kareiva 1983, Denno and Roderick 1991). Plant density is the distance between individual plants. Patch size is the geographical extent of the host plant stand. A host plant patch can consist of all plants of the same species or plants of different species but all hosts of a common herbivore species. Vegetational diversity is the frequency and species composition of nonhost plants in association with the host plants of a herbivore (Kareiva 1983, Denno and Roderick 1991). In addition to these, several other components reflect the vegetational texture of a habitat. These include the structural complexity of the habitat; plant species diversity, evenness, and richness; plant growth form; color contrasts; and volatile plant compounds (Letourneau 1990a). Differences in vegetational texture result in variation in temperature (Andow 1991), light exposure (Risch 1981, Andow 1991), and other aspects of microhabitats (Kareiva 1983, Andow 1991). All of these factors influence the population dynamics and abundance of herbivorous insects.

Urban landscapes are often significantly more diverse than agricultural habitats because of their high plant diversity and associated arthropod fauna (Owen 1983, Rowntree 1984, Raupp et al. 1985, Dreistadt et al. 1990). However, in many geographic regions, landscapes may be dominated by a relatively small number of plant species. A survey of >30,000 plants in Maryland 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). The single most important pest of azaleas in Maryland's landscape is the azalea lace bug, *Stephanitis pyrioides* (Scott) (Raupp and Noland 1984). A thorough description of the bionomics of azaleas and azalea lace bug was presented by Trumbule et al. (1995).

In urban landscapes, azalea lace bug abundance varies dramatically in time and space (Raupp 1984, Trumbule et al. 1995). Understanding the relationship among components of vegetational texture and azalea lace bug abundance is important for at least two reasons. First, by identifying habitat factors that correlate with lace bug abundance, existing landscapes can be evaluated and assessed for the likelihood that lace bug outbreaks will occur. This has direct implications for designing integrated pest management (IPM) programs for landscape managers (Ball 1987). Second, a more thorough understanding of the relationship between vegetational texture and pest abundance may allow landscape designers to create aesthetically appealing landscapes that are relatively refractory to pest outbreaks.

Previous studies correlated the degree of light exposure to patterns of lace bug injury and frequency of infestation of azaleas. Raupp (1984) found that the frequency with which azaleas were infested by azalea lace bug varied among azaleas in landscapes where azaleas received morning sun only, afternoon sun only, sun all day, and shade all day. Azaleas in afternoon and all day sun were more frequently infested by lace bugs than azaleas receiving morning sun only. In a related study, Trumbule et al. (1995) identified four categories of azaleas damaged by azalea lace bug and discovered that the highest light intensities were recorded over azaleas in the highest damage category and the lowest light intensities were recorded over azaleas in the lowest damage category. Neither of these previous works directly measured the relationship between azalea lace bug abundance and light exposure. In addition, both studies were limited to examining only a single component of vegetational texture, light exposure.

In this study, we examined the relationship between azalea lace bug abundance and several components of vegetational texture in managed landscape habitats. We wanted to determine which component(s) best explained patterns in lace bug abundance. The components of vegetational texture examined were light exposure, plant species diversity, evenness, and richness, host patch size, and the structural complexity of the habitat. We hope that a better understanding of the relationship between herbivore abundance and vegetational texture will assist in designing low-input, sustainable landscapes.

Materials and Methods

Study Sites. To examine the relationships among azalea lace bug abundance and components of vegetational texture in managed landscape habitats, we selected 24 established home and municipal landscapes in College Park and Takoma Park, MD. Landscapes were selected that appeared to vary in light exposure, plant species diversity, evenness, and richness, host patch size, and structural complexity. These landscapes contained azalea plants that had not been treated with pesticides for a minimum of 3 yr. Within each site, we selected one azalea plant as the study plant. We measured a 10 by 10 m area, with the study plant at the center of the square, to use as the study area.

Azalea Lace Bug Abundance. Azalea lace bug abundance was measured on each study plant within each site on 10 dates in 1994: 30 June; 5, 21, and 28 July; 9 and 15 August; 1 and 6 September; and 18 and 24 October. Lace bug abundance was measured using a standardized beating technique. Sampling was performed by beating azalea branches over a sampling device that consisted of a funnel (43 cm diameter) with a jar of alcohol attached to the bottom (modified from "knockdown" sampling method, Pedigo 1996). Plants were divided into four quadrants (front upper, front lower, back upper, and back lower) based on their orientation to the street. In each quadrant the funnel was placed under azalea branches which then received six "beats" with a small (1.25 cm diameter) wooden dowel. All insects that were knocked into the funnel slid into the jar of alcohol or were assisted into the jar with a small paint brush. Sample jars were returned to the laboratory and counts were taken of the number of lace bug nymphs and adults collected from each plant on each sampling date. To compute absolute lace bug abundance (number of lace bugs per square meter of leaf area), the leaf area sampled was measured. For each study plant, the total number of leaves beaten over the funnel was counted. Thirty of those leaves were randomly selected and their leaf area was measured (cm^2) using a leaf area meter (LI-3000, LI-COR LAMBDA Instruments, Lincoln, NE). The mean leaf area was calculated and multiplied by the total number of leaves sampled. The number of lace bugs per square meter of leaf area was determined for each plant on each sampling date and then summed over time.

Components of Vegetational Texture. Components of vegetational texture measured at each landscape site were light exposure, plant species diversity, evenness, and richness, azalea patch size, and structural complexity. The amount of light exposure that each study plant received was measured in a similar method to that used by Trumbule et al. (1995). On a single day in June with clear skies, a light meter (Decagon Sunfleck Ceptometer, Decagon Devices, Pullman, WA) was used to measure photosynthetically active radiation (PAR - waveband 400–700 nanometers). By holding the meter 8 cm above each plant, two readings were taken at 1-min intervals and the average PAR was recorded. This sampling procedure was performed in the morning and in the afternoon at each study site to determine if time of day influenced the relationship between light intensity and azalea lace bug abundance. The average of the morning and afternoon readings was also calculated.

Within the 10 by 10-m study area of each landscape site the taxa and number of each taxa of all plants were determined. Plant species diversity, evenness, and richness were estimated using a Shannon Weaver diversity index (Zar 1974). Plant species diversity was calculated as follows:

$$H' = (n \log_n n - \Sigma f_i \log_n f_i)/n,$$

where n = total number of plants; f_i = number of plants of each species; and $\log_n$ = natural log. Plant species evenness or relative diversity was calculated as follows:

$$J' = H'/H'max,$$

where $H'max = \log_n K$ and K = the total number of plant species and was the maximum possible diversity. Species richness was the total number of plant species in the habitat or K.

To measure azalea patch size, the 10 by 10 m study areas were divided into square meter sections using string (=100 squares). The area covered by each azalea patch was estimated. Azalea patch size was measured as the area of contiguous azalea foliage inclusive of the study plant and all of its neighbors within the study area. Cultivars that differed from the study plant were considered part of the host patch as long as they were contiguous with the study plant and its neighbors.

A rating system, modified from Erdelen (1984), was developed to quantify the structural complexity of each landscape site. Structural complexity is an index of the structural intricacy of a landscape based on the amount or frequency of vegetation in the three-dimensional space of the habitat. To quantify structural complexity, each landscape site was evaluated as a three-dimensional space surrounding the study plant. The length and width of the space was 10 by 10 m. The vertical vegetational strata of the space consisted of five layers, a groundcover/turf layer, an annual/perennial layer, a shrub layer, an understory tree layer, and an overstory tree layer. The presence or absence of plant material in each square meter of the three-dimensional grid was scored (10 by 10 m by five plant strata = 500 squares total). Each site's structural complexity rating was the total number of grid squares occupied by plant material. Complexity ratings of study sites ranged from 54 to 325. There was variability in the taxa and number of plants within study sites of similar complexity ratings but not in the overall abundance of vegetation. An example of the types and number of plants found in a site with a complexity rating of 118 was as follows: turfgrass covering most of the study area (groundcover/turf strata), 10 annual plants (annual/perennial strata), one boxwood (shrub strata), and three azaleas (shrub strata). The contribution of each of the five vegetational strata to azalea lace bug abundance was examined to determine which vegetational strata explained the most variation in lace bug abundance.

Statistical Analysis. In all studies, unless otherwise stated, a *P*-value less than or equal to 0.05 indicated significance. Components of vegetational texture were examined for multicollinearity (PROC REG, SAS Institute 1990). In addition, to identify which components of vegetational texture were correlated a correlation analysis was performed (PROC REG CORR, SAS Institute 1990). There was a wide range of variation in lace bug abundance among the landscape sites and azalea lace bug data were log10 $(x + 1)$ transformed and summed over the 10 sampling dates for each of the 24 landscape sites. To determine which components of vegetational texture best predicted azalea lace bug abundance, a regression analysis was performed on lace bug abundance and each of the vegetational components (light exposure, plant species diversity, evenness, and richness, azalea patch size, and structural complexity) (PROC REG, SAS Institute 1990). To more closely examine which attributes of structural complexity best predicted lace bug abundance, a forward selection multiple regression analysis of azalea lace bug abundance was performed using the complexity values of each of the five vegetational strata (groundcover/turf layer, annual/perennial layer, shrub layer, understory tree layer, and overstory tree layer) (PROC REG, SAS Institute 1990). This process determined which vegetational strata of structural complexity contributed most to lace bug abundance (PROC REG, SAS Institute 1990). To determine which sampling time of light exposure (morning only, afternoon only, or both) best explained azalea lace bug abundance, a forward selection multiple regression analysis of azalea lace bug abundance with the light exposure readings (PAR) at each sampling time was performed (PROC REG, SAS Institute 1990).

Table 1. Summary of mean ± SE number and range in azalea lace bug abundance and measurements for components of vegetational texture from established urban landscapes in College Park and Takoma Park, MD, 1994

	n	Mean ± SEM	Range
Azalea lace bug[a]	24	319.78 ± 149.83	1–3,122
Azalea patch size (m^2)	24	7.94 ± 1.49	0.37–32.52
Structural complexity	24	170.67 ± 19.29	54–325
Light exposure (PAR)	24	1,113.72 ± 213.10	17–3,225
Plant species evenness	24	0.76 ± 0.03	0.46–0.94
Plant species diversity	24	1.56 ± 0.11	0.57–2.51
Plant species richness	24	9.17 ± 1.01	3–20

[a] Azalea lace bug abundance is the number of lace bugs per square meter of leaf area.

Results

Azalea Lace Bug and Components of Vegetational Texture. Azalea lace bug densities had a wide range in abundance among the 24 landscape sites (Table 1). Similarly, there was a wide range in the measurements for components of vegetational texture in the 24 landscape habitats (Table 1).

The components of vegetational texture exhibited multicollinearity. Therefore, a multiple regression analysis was not performed. A strong negative linear association existed between structural complexity and light exposure ($r^2 = -0.73$) (Table 2). Not surprisingly, there were strong positive linear associations between structural complexity and plant species richness ($r^2 = 0.65$) and between plant species richness and plant species diversity ($r^2 = 0.77$) (Table 2).

The best habitat predictors of azalea lace bug abundance were structural complexity ($r^2 = 0.54$) and light exposure ($r^2 = 0.53$). In addition, three of the remaining four components were significantly related to lace bug abundance (Table 3). Plant species richness also

Table 2. Correlation matrix demonstrating the relationship between components of vegetational texture measured in established urban landscapes in College Park and Takoma Park, MD, 1994

	Patch	Complexity	Light	Evenness	Diversity	Richness
Azalea patch size	1.00	0.44*	−0.33	−0.39	0.04	0.23
Structural complexity	0.44*	1.00	−0.73**	−0.30	0.36	0.65**
Light exposure	−0.33	−0.73**	1.00	−0.01	−0.41*	−0.55**
Plant species evenness	−0.39	−0.30	−0.01	1.00	0.57**	0.01
Plant species diversity	0.04	0.36	−0.41*	0.57**	1.00	0.77**
Plant species richness	0.23	0.65**	−0.55**	0.01	0.77**	1.00

Correlation matrix of r values (PROC REG, SAS Institute 1990). *, **, Correlation coefficients were significant at $P < 0.05$, and $P < 0.01$, respectively; df = 22.

explained a relatively large amount (41%) of the variation in lace bug abundance (Table 3).

Further examination of light exposure revealed that morning readings of light exposure explained less variation in lace bug abundance than afternoon readings (partial $r^2 = 0.09$, partial $r^2 = 0.52$, respectively) (Table 4). The use of both morning and afternoon readings explained only slightly more of the variation in lace bug abundance ($r^2 = 0.61$) than afternoon readings alone (Table 4). These relationships were positive and indicated that as light exposure increased, azalea lace bug abundance increased. Of the five vegetational strata comprising structural complexity (groundcover/turf, annual/perennial, shrub, understory tree, and overstory tree) the combination of the overstory tree layer and the groundcover/turf layer explained 76% of the variation in lace bug abundance (Table 5). These two factors were the best descriptors of azalea lace bug abundance. The overstory tree layer correlated negatively with lace bug abundance, indicating that the more overstory trees in a landscape, the fewer lace bugs. Alternatively, the ground cover/turf layer was positively correlated with lace bug abundance, indicating that as more ground cover/turf is found in a landscape, lace bug abundance is greater. This is not surprising because turf was more commonly found than any other ground cover, and study areas with more turf had fewer trees. It was also interesting that the vegetational stratum containing azaleas contributed very little to the variance in lace bug abundance (partial $r^2 < 0.05$).

Discussion

This study identified two components of vegetational texture, landscape structure and light exposure, as the best predictors of azalea lace bug abundance, relative to host patch size and plant species diversity, evenness, and richness in managed landscapes. Our results are consistent with several studies that have demonstrated greater herbivore abundance and injury in sunny, exposed habitats (Louda et al. 1987, Collinge and Louda 1988, Moore et al. 1988, Cappuccino and Root 1992). Louda et al. (1987) measured herbivory on 13 species of native herbaceous forbs that crossed a natural sun/shade ecotone. They found three species were more damaged in the shade, five species were more damaged in the sun, and five species exhibited no difference in herbivory between sun and shade. They suggested that levels of herbivory were species-specific rather than habitat related. Moore et al. (1988) found that western tent caterpillar, *Malacosoma californicum pluviale* Dyar, egg masses and tents were more abundant on south facing branches than on shaded, north facing branches of host trees. They suggested that thermal warming of south facing foliage influenced ovipositional behavior in comparison to foliage quality. Ovipositional choices in turn determined patterns of egg deposition and subsequent patterns of herbivory. Cappuccino and Root (1992) found that the chrysanthemum lace bug, *Corythucha marmorata* (Uhler), laid more eggs on exposed edge plants of a host patch than on shady interior plants. Eggs on these exposed edge plants developed faster than eggs on the shady interior plants. Cappuccino and Root (1992) suggested that microclimate was a prime determinant of chrysanthemum lace bug distribution and abundance. Collinge and Louda (1988) found higher *Scaptomyza nigrita* Wheeler densities in sunny habitats. Slightly higher soluble carbohydrate concentrations in sun leaves, rather than variation in defensive glucosinolate levels,

Table 3. Summary of regression analyses of azalea lace bug abundance and components of vegetational texture from established urban landscapes in College Park and Takoma Park, MD

Vegetational Component	*n*	*F*	*P*	r^2	b^a	SE (b)	*a*	SE (a)
Structural complexity	24	20.83	0.0002	0.54	−0.0070	0.0016	2.87	0.3084
Light exposure	24	20.45	0.0003	0.53	0.0007	0.0002	0.79	0.2462
Plant species richness	24	12.64	0.0023	0.41	−0.1208	0.0339	2.69	0.3424
Plant species diversity	24	5.87	0.0260	0.25	−1.0092	0.4159	3.09	0.6258
Azalea patch size	24	5.41	0.0320	0.23	−0.0650	0.0279	2.11	0.2800
Plant species evenness	24	0.66	0.4274	0.04	1.3213	1.6270	0.70	1.2011

Lace bug abundance was summed over 10 sampling periods in 1994. Azalea lace bug abundance was the $\log_{10}(x + 1)$ transformation of the number of lace bugs per square meter of leaf area.

[a] Model is y = a + bx where y = lace bug abundance and x = vegetational component.

Table 4. Summary of a forward selection multiple regression analysis of azalea lace bug abundance and light exposure readings taken in the morning and afternoon

Sampling time	*n*	*F*	*P*	Partial r^2	Model r^2	b^a	SE (b)	*a*	SE (a)
Afternoon	24	20.48	0.0002	0.52	0.52	0.0014	0.0003	0.69	0.2506
Morning	24	4.37	0.0510	0.09	0.61	0.0004	0.0002	0.58	0.2388

Light readings (PAR) were taken over azaleas in 24 established urban landscapes in College Park and Takoma Park, MD. Azalea lace bug abundance was the $\log_{10}(x + 1)$ transformation of the number of lace bugs per square meter of leaf area.

[a] Model is $y = a + bx$ where y = lace bug abundance and x = sampling time.

were the most likely determinants of higher levels of leaf mining on host plants in sunny habitats.

In contrast to these studies, Hajek and Dahlsten (1986) found light exposure of birch trees to be the most important variable discriminating between shaded trees with large populations of aphids and unshaded trees with low aphid densities. They suggested shaded trees provided a more favorable microclimate for aphids and that natural enemies were not as effective in shady habitats. Maiorana (1981) observed several plant species and found plants in the shade incurred more herbivore damage than conspecific plants in the sun. She suggested herbivores were favored in shady habitats because of the greater availability of refuges there. Larsson et al. (1986) found foliar concentrations of phenolic compounds in willows grown under low light conditions to be only about one-third those of plants grown under high light conditions. They suggested that the relative availability of carbohydrates for construction of carbon-based defensive compounds, such as phenolics, explained the difference in susceptibility of willow leaves to *Galerucella lineola* (F.). These leaf beetles preferred to feed on shaded plants where phenolics were less concentrated. Nuckols and Conners (1995) compared amounts of leaf area damaged by several guilds of insects attacking seven tree species found in urban landscapes and more natural forest settings. Although total damage did not differ between trees in urban plantings and forests, damage by chewing insects was consistently greater on trees in natural settings.

Differences in structural diversity or complexity of a habitat has been shown to affect both herbivore and natural enemy abundances (Hatley and MacMahon 1980, Bach 1981, Letourneau 1990a, Riechert and Bishop 1990, Hanks and Denno 1993, Döbel and Denno 1994, Marino and Landis 1996, Colunga-Garcia et al. 1997, Dyer and Landis 1997). Although Hanks and Denno (1993) did not directly measure habitat complexity of their study sites, they found high populations of white peach scale on isolated mulberry trees in landscapes, whereas in more structurally complex woodlot settings, mulberry did not support high densities of white peach scale. They implicated differences in predation by natural enemies between habitats as a primary determinant of this pattern (Hanks and Denno 1993). In a similar study, Pinto (1980) found densities of obscure scale lower in wood lot settings. He argued that these differences were maintained in part because the primary parasitoid of obscure scale was three times more abundant on pin oaks in natural woodlot settings than in ornamental settings. Furthermore, Risch et al. (1983) reviewed 150 published accounts that examined the effect of varying vegetational diversity on herbivore abundance. They found that of the 198 species examined, 53% decreased in diversified habitats, 18% increased, 9% exhibited no change, and 20% were variable. Overall, these studies indicate a general pattern of herbivore abundance to be lower in both more diversified and shadier habitats. Our studies are in agreement with this pattern.

Regression coefficients indicated that as structural complexity of a landscape increased, lace bug abundance decreased and as light exposure increased, lace bug abundance increased. In addition, there was a strong negative correlation between structural complexity and light exposure. This is not surprising because of the five vegetational strata that comprise structural complexity, the overstory tree layer contributed more (71%) to explaining the variation in lace bug abundance than the groundcover/turf layer, annual/perennial layer, shrub layer, or understory layer. It is the overstory tree layer that would most greatly influence the level of light received by azaleas. The implication of this relationship is that the overstory tree layer of structural complexity is an indirect measure of light exposure. Furthermore, the overstory tree

Table 5. Summary of a forward selection multiple regression analysis of azalea lace bug abundance and complexity of each of the vegetational strata that make up total structural complexity

Vegetational strata[a]	*n*	*F*	*P*	Partial r^2	Model r^2	b^b	SE (b)	*a*	SE (a)
Overstory tree	24	52.90	0.0001	0.71	0.71	−0.0180	0.0024	2.35	0.1639
Groundcover/turf	24	4.35	0.0493	0.05	0.76	0.0083	0.0040	1.90	0.2623

Lace bug abundance was summed over 10 sampling periods and structural complexity was estimated in 24 established urban landscapes in College Park and Takoma Park, MD, 1994. Azalea lace bug abundance was the $\log_{10}(x + 1)$ transformation of the number of lace bugs per square meter of leaf area.

[a] The annual/perennial strata, shrub strata, and understory tree strata did not significantly contribute to the model ($P > 0.50$) and therefore were not included.

[b] Model is $y = a + bx$ where y = lace bug abundance and x = vegetational strata.

layer is a better predictor of lace bug abundance (71%) than light exposure readings taken in the afternoon (52%), morning (9%), or a combination thereof (61%).

Interestingly, Trumbule and Denno (1995) found that it was not the effect of light exposure per se on the plants that explained patterns of lace bug abundance. Their studies in the greenhouse and outdoor nursery beds revealed that azalea lace bugs survived better, were more fecund, and preferred to feed and oviposit on shade grown azaleas rather than azaleas grown in full sun (Trumbule and Denno 1995). Lace bug fitness was positively associated with plant vigor (leaf-water relations, plant chemistry, or morphology) (Trumbule and Denno 1995). These findings contrast with this study that clearly indicate greater lace bug abundance with increasing light exposure and others that demonstrate greater damage to azaleas receiving higher levels of light (Raupp 1984, Trumbule et al. 1995). Trumbule and Denno (1995) examined this conundrum further and found that survivorship of uncaged lace bugs was lower on plants placed in shaded woodlots versus open-lawn habitats. Their results suggested higher levels of arthropod predation in shaded habitats as the mechanism for reduced lace bug survival in those habitats. Our results concur with the work of Trumbule and Denno (1995) and indicate that factors other than light exposure alone influences patterns of azalea lace bug abundance.

In conclusion, our findings demonstrate that two readily measured factors, structural complexity and light exposure, are strongly related to and predictive of lace bug abundance in landscapes. We provide a method to quantify structural complexity of landscapes based on the occurrence of vegetation in the three dimensional space of the habitat. Moreover, measuring the overstory tree layer only of structural complexity provides the most practical and highly accurate estimate of lace bug abundance, more so than total structural complexity or light readings recorded in the afternoon or morning. Additionally, our data indicate that a landscape with a total structural complexity rating >175 would be a low risk landscape relative to lace bug outbreaks. Moreover, a landscape with an overstory tree strata that has a structural complexity rating of >55 would also be a low risk landscape. Alternately, a landscape with a total complexity rating of <125 or an overstory tree strata complexity rating of <25 would be high risk landscape. Any complexity ratings between the high and low risk ratings described above would be considered moderate risk landscapes. Other components of vegetational texture, such as plant species diversity, evenness, and richness, and host patch size, that others have found important in explaining herbivore abundance patterns, were less important than structural complexity or light exposure in this system. The mechanisms underlying greater abundance of azalea lace bug in simple, exposed landscape habitats relative to complex shady ones were not elucidated in this study but are discussed elsewhere (Shrewsbury 1996).

Our findings have significant implications for pest management. Landscape sites can be evaluated for susceptibility to lace bugs and perhaps other pests. Complexity and light exposure measurements can be used to predict relative levels of azalea lace bug abundance. More complex landscapes have fewer pest outbreaks than simple ones. Therefore, complex landscapes require less input in terms of monitoring time and application of control measures.

With respect to landscape design, the most important single factor limiting azalea lace bug abundance is the presence of an overstory tree layer. Although it is difficult to add large overstory trees to existing landscapes, it is possible to add trees that will grow and provide overstory canopy as the landscape matures. Furthermore, azalea lace bug populations may be greatly reduced by planting azaleas beneath overstory trees. If azaleas must be planted in sunny exposed locations, then landscape managers and homeowners should be prepared to spend greater amounts of time and resources monitoring lace bug populations and intervening when lace bug populations reach unacceptable levels.

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