Title
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Journal
Annals of the Entomological Society of America, 110(1)

ISSN
0013-8746

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Publication Date
2017

DOI
10.1093/aesa/saw063

Peer reviewed

Annals of the Entomological Society of America Advance Access published September 30, 2016

Annals of the Entomological Society of America, 2016, 1–7
doi: 10.1093/aesa/saw063
Research article

Ecology and Population Biology

Landscape and Local Habitat Correlates of Lady Beetle Abundance and Species Richness in Urban Agriculture

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Received 13 July 2016; Accepted 19 August 2016

Abstract

Landscape surroundings and local habitat management affect patterns of insect biodiversity. Knowing which landscape and local factors are more important for insect species diversity informs landscape and local scale land management, yet can be challenging to disentangle. We sought to identify 1) which landscape factors surrounding, and 2) which local habitat factors within urban community gardens influence patterns in lady beetle (Coccinellidae) abundance and species richness. We assessed lady beetle abundance and taxonomic diversity, garden habitat characteristics, and the surrounding landscape composition in 19 gardens over two consecutive years. We found that the amount of natural area surrounding gardens at 3 km was the strongest correlate of abundance and species richness. Specifically, gardens surrounded by less natural area (gardens embedded in more urban landscapes) had higher lady beetle abundance and richness. In gardens embedded in landscapes with more amounts of natural land, local habitat features such as ornamental abundance and crop diversity may become more important for maintaining lady beetle abundance and richness. Our results suggest that within more urban landscapes, lady beetles may aggregate and accumulate in relatively resource-rich habitats like gardens. Thus, urban landscape quality and local habitat management may all interact to shape lady beetle communities within gardens.

Key words: Coccinellidae, community garden, habitat management, urbanization

Local habitat features and landscape surroundings strongly influence different groups of insects in agricultural and urban environments. Local factors that influence insects include vegetative diversity and structure, abundance of crops and flowers, and grower management practices (Landis et al. 2000, Fiedler et al. 2008). In agroecosystems, certain factors are important for maintaining and conserving insect species biodiversity. For example, local factors, such as crop diversity and spatial structure (Root 1973, Andow 1991) and floral abundance and species richness (Rebek et al. 2005), have bottom-up effects on insect species diversity. Insect species respond differently to plant architecture and spatial diversity due to the spatial allocation of resources and species-specific exploitation of plant structures (Brown and Southwood 1983). From an insect predator's perspective, complex vegetative architecture may either increase (e.g., simple architecture) or decrease (e.g., complex architecture) the efficiency of finding food resources (Southwood et al. 1979, Kareiva 1987, Andow 1991). Thus, there is a relationship between vegetative community composition and structure, and insect community composition even within one trophic guild (Aquilino et al. 2005). Landscape factors that influence insects can include landscape connectivity (Hanski and Beverton 1994), landscape diversity within a sample area (Gustafson 1998), and the position along a rural to urban gradient (Mcdonnell et al. 1997). At larger spatial scales, a landscape of more diverse surrounding landscape elements such as the type of land use (e.g., urban, natural, cultivated) and the amount of land use types (Elliott et al. 2002, Gardiner et al. 2009) can affect insect predator biodiversity within agroecosystems.

The interaction between local habitat factors and surrounding landscape factors shapes insect biodiversity and community composition in agroecosystems embedded within agricultural landscapes. Landscape factors and local habitat factors are not mutually exclusive, and instead there is often an interplay between them to determine local (alpha) and regional (gamma) biodiversity (Tscharntke et al. 2012). Research shows that in simple landscapes (i.e., few land-use types), local agroecosystem factors are more important for explaining insect communities, where in complex landscapes (i.e., many diverse land-use types) local factors are usually less significant and landscape factors have a greater influence on community composition and structure (Tscharntke et al. 2005; 2012). In other systems, habitat quality may be more important for explaining species diversity than landscape factors (Fleishman et al. 2002). In sum, this body of research demonstrates that local habitat factors of systems may be more or less important, and their influence may depend on landscape diversity and composition.

Much research has demonstrated the influence of local and landscape factors on insect abundance and species richness in rural agroecosystems, yet there is still a need to understand the coupling of larger spatial factors and local habitat factors that affect insect communities in urban agroecosystems. Urban landscapes can be complex due to the interaction between heterogeneous local habitat management and greater spatial scale land-uses and processes (Burkman and Gardiner 2014). For example, Matteson and Langellotto (2011) found that increasing ornamental flower abundance to boost local habitat quality had little to no effect on bee communities in simple highly developed urban landscapes. Yet Bennett and Gratton (2012) indeed found that high parasitoid abundance was a function of high flower diversity within urban habitats embedded in simple highly developed urban landscapes. Thus, there is still much to learn about how insects respond to the interplay between local and landscape factors in an urban context, and an increased understanding of these relationships can have important consequences for ecosystem service provisioning in agriculture.

Lady beetles (Coleoptera: Coccinellidae) are charismatic components of insect communities in agroecosystems, and provide natural biological control of herbivorous pests (Cardinale et al. 2003, Obrycki et al. 2009), powdery mildew (Sutherland and Parrella 2009), and scale insects (Evans 2009) to benefit agricultural production. Increased lady beetle species diversity increases biological control services as ecological differences among species within communities can improve herbivore pest control, via niche partitioning (Snyder et al. 2006) and species complementarity (Letourneau et al. 2009). Some species introduced into agricultural systems as a biological control agents, such as the multicolored Asian lady beetle (*Harmonia axyridis*), may lead to decreased lady beetle diversity within communities and lower biological control over time (Roy et al. 2016). Thus, because lady beetle biodiversity (abundance and species richness) may act as an insightful proxy for biological control services, we sought to determine how lady beetle communities in urban agroecosystems (i.e., community gardens) are affected by surrounding landscape factors and local habitat factors. We sampled urban gardens that vary in landscape and local features across three spatially distinct regions of California to address three research questions: 1) What urban landscape factors surrounding gardens correlate with greater lady beetle abundance and species richness? 2) What local vegetation and habitat factors within urban gardens correlate with greater lady beetle abundance and richness? 3) Are landscape or local factors stronger correlates of lady beetle abundance and species richness in urban gardens? In understanding these relationships, we seek to provide information for urban agriculture management and landscape-scale urban land management approaches that may increase and conserve urban lady beetle biodiversity across the urban landscape, and potentially promote biological control services.

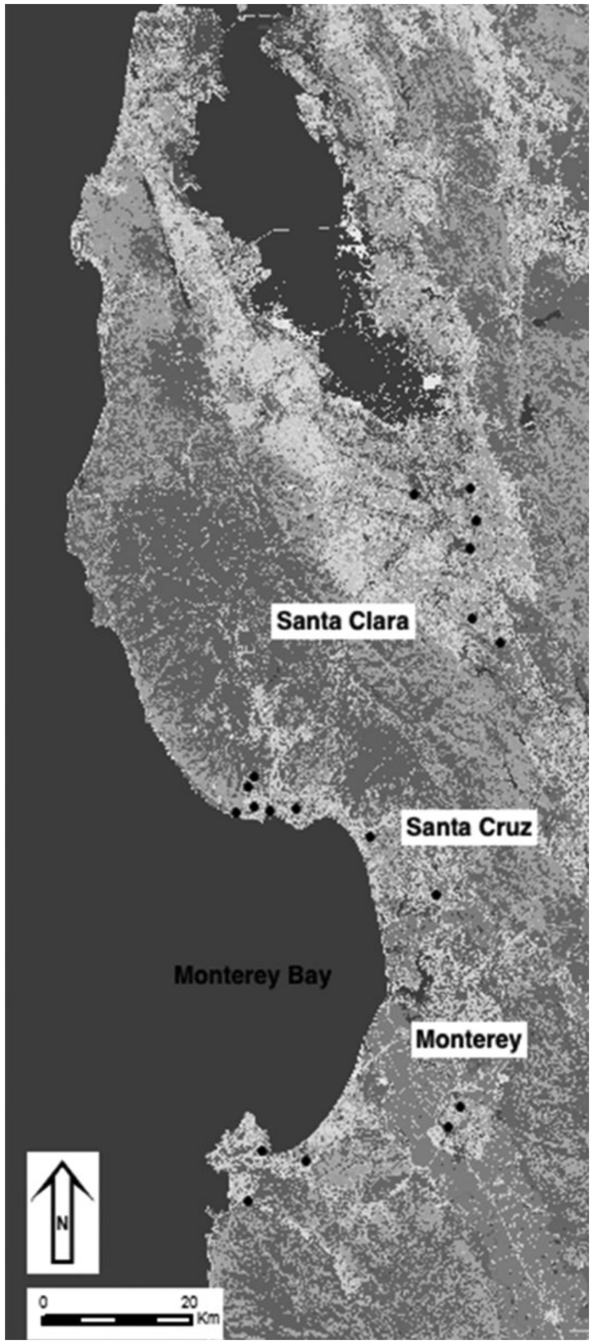

Fig. 1. The three counties (Santa Clara, Santa Cruz, and Monterey) in the California central coast in which 19 garden sites (black points) were sampled in 2014 and 2015.

Materials and Methods

Study Region

This study took place in 19 urban gardens in three counties (Santa Clara, Santa Cruz, and Monterey) in the central coast region of California, USA. The gardens differ in local habitat (structural and compositional diversity of both crop and noncrop species) and landscape context (amount of natural, agricultural, and urban habitat in the surrounding area). All gardens have been cultivated for 5–47 years, range from 444 to 15,525 m^2 in size, and are each separated by at least 2 km (Fig. 1). All of the gardens use organic management practices and prohibit the use of chemical pesticides and insecticides.

Data Collection

We sampled lady beetles in 20- by 20-m plots at the center of each garden six times during 2014 (17–20 June, 7–10 July, 27–30 July, 19–21 August, 8–10 September, 29 September–1 October) and six times during 2015 (16–19 June, 7–10 July, 31 July–1 August, 11–14 August, 1–3 September, 21–24 September). We sampled lady beetle adults with two common methods, visual surveys and sticky traps (Finlayson et al. 2008, Gardiner et al. 2009), in order to assure that a larger fraction of the lady beetle community was sampled. First, we visually surveyed and collected lady beetles in eight randomly selected 0.5- by 0.5-m plots within the 20- by 20-m plots. In each 0.5- by 0.5-m plot, we searched all herbaceous and nonherbaceous vegetation and the ground cover (e.g., leaf litter when present) for adults. Here we assumed that lady beetle food sources would be concentrated in the vegetation to attract beetles. Second, we placed four 3" by 5" yellow sticky strip traps (Item 2872, BioQuip Products Inc, Rancho Dominguez, CA) on galvanized wire stakes placed in the ground next to vegetation at four random locations and left them for 24 h. All lady beetles were identified to species—or to genus when species identification was impossible (e.g., *Scymnus* sp. on sticky traps)—using online resources (e.g., Discover Life 2014) and identification guides (Gordon 1985). Specimens are housed in a collection at the Philpott Laboratory at UC Santa Cruz. We pooled abundance and richness data from all visual and sticky traps per site for each sample date to obtain one abundance count and one species richness count per site. In our study, we define and discuss the lady beetle community of each garden as the adults sampled using both visual and sticky trap methods.

On the same dates lady beetles were surveyed we also assessed local structural characteristics and vegetation in four random 1- by 1-m plots within the 20- by 20-m plots. We determined abundance and richness of all herbaceous plants (including crops, weeds, ornamental plants), height of tallest herbaceous vegetation, and ground cover composition (percent bare soil, rocks, litter, grass, mulch; Table 1). In addition, we measured canopy cover at five points in each 20- by 20-m plot, and counted the number and species of trees and shrubs in the plot, and the number of trees and shrubs in flower. We pooled this local habitat data at each garden for each sampling period for each site.

We examined the surrounding landscape composition with data from the 2011 National Land Cover Database (NLCD; Jin et al. 2013). We created four main land use categories including: 1) natural land (combined deciduous forest [NLCD number 41], evergreen forest [42], mixed forest [43], shrub/scrub [52], and grassland/herbaceous [71]); 2) urban land (combined developed low intensity [22], developed medium intensity [23], and developed high intensity [24]); 3) open land (developed open space [21]); and 4) agriculture land (combined pasture/hay [81], and cultivated crops [82]). These categories allowed us to determine the percent of urban, natural, and agricultural land surrounding garden sites and to determine the dominant landscape association or context. We assessed landscape composition within buffers surrounding gardens at 200 m and 3 km. We chose 200 m as a fine-scale landscape variable because it has been defined as the edge of the surrounding landscape matrix in rural agricultural systems to assess lady beetle spillover dynamics (Rand and Louda 2006). We chose 3 km as a large-scale landscape variable because it is the dispersal range cited for many common lady beetle species in California (Gordon 1985) and is similar to other lady beetle studies (e.g., Gardiner et al. 2009). Within each 200 m and 3 km buffer, we used spatial statistics tools in ArcGIS (v. 10.1) to calculate the

Table 1. Explanatory and dependent variables used in the analysis

Explanatory variables	Scale	Min. value	Max value	Mean
Garden size	acres	0.11	3.84	1.09
Garden age	years	6.00	48.00	19.11
% Bare soil cover	1 × 1 m	2.00	99.75	41.38
% Grass cover	1 × 1 m	0	33.00	3.49
% Herbaceous plant cover	1 × 1 m	1.25	95.75	50.39
% Mulch/Straw cover	1 × 1 m	0	96.50	25.22
% Rock cover	1 × 1 m	0	50.00	4.90
% Leaf litter cover	1 × 1 m	0	81.75	10.92
Height of tallest vegetation (cm)	1 × 1 m	4.50	261.25	82.75
No. of flowers	1 × 1 m	0	3000.00	139.80
No. of crop spp.	1 × 1 m	0	15.00	5.28
No. of ornamental flower spp.	1 × 1 m	0	7.00	1.57
No. of weed spp.	1 × 1 m	0	14.00	5.15
No. of grass spp.	1 × 1 m	0	3.00	0.86
% Canopy cover	20 × 20 m	0	55.54	0.62
No. of trees/shrubs	20 × 20 m	0	91.00	16.95
No. of trees/shrubs in flower	20 × 20 m	0	28.00	4.80
% Urban land	200-m radius	6.52	100.00	71.82
% Open land	200-m radius	0	72.46	16.91
% Natural land	200-m radius	0	52.17	10.04
% Agricultural land	200-m radius	0	7.19	0.39
% Urban land	3-km radius	14.61	93.95	53.40
% Open land	3-km radius	5.85	25.05	13.82
% Natural land	3-km radius	0.05	58.47	20.67
% Agricultural land	3-km radius	0	23.82	4.20
Dependent Variables				
Lady beetle abundance	20 × 20 m	0	71	8.94
Lady beetle species richness	20 × 20 m	0	9	2.01
Aphidophagous abundance	20 × 20 m	0	21	1.55
Aphidophagous species richness	20 × 20 m	0	6	0.91

Minimum, maximum, and mean indicate cumulative values over the whole sampling period.

percentage of each land cover type by dividing the area of each type within a buffer by the total area in each buffer (Environmental Systems Research Institute [ESRI] 2011). Last, we added the percentage of each type for each respective category to determine the total amount of each land cover for each category, within each buffer.

Data Analysis

We used tree structured regression models using the *party* package in R (v. 0.99.489) (R Core Team 2016, Hothorn et al. 2015) to determine what local factor variables and landscape factor variables best explain greater lady beetle abundance and species richness. The tree regression models are a nonparametric class of regression trees that can analyze nominal, ordinal, and numeric response variables like abundance. The tree regression models utilize recursive partitioning by conditional inference, and are appropriate for analyzing data sets with multiple covariates such as our own. Further, these models allow one to visualize the relationship among explanatory variables and the respective hierarchy of importance. We analyzed the data ($n = 204$ observations over 2014 and 2015) using these trees for lady beetle abundance and species richness as our response variables, and landscape factors (i.e., percent of land cover categories) at 200 m and 3 km spatial scales ($n = 8$) and local habitat factors ($n = 17$) as the explanatory variables (Table 1). Next, we isolated aphidophagous species (i.e., predators of aphid herbivore pests; refer to Table 2). Here our intent was to use the presence and richness of these species as a potential indicator for pest control services, as aphids are common pests in gardens. We also examined patterns for lady beetle data without including *Psyllobora viginitimaculata* (a mycophagous species) because it is ubiquitous in the data, and might have skewed other community patterns. We set the models with a minimum criterion of 0.95 (i.e., *P*-value smaller than 0.05), and a minimum value of 20 sum of weights (i.e., number of instances or cases) to implement a split in the tree. We ran the analyses for total lady beetle abundance, total species richness, aphidophagous lady beetle abundance, and aphidophagous species richness as our dependent variables in the model (Table 1). In the analysis, each sampling period per year represented an individual replicate. We chose to analyze each as an individual replicate because in our field observations the vegetative composition (i.e., plants and crops grown) and vegetative structure (i.e., the orientation of plants, the structure of garden beds) changes within the sites month to month in response to temporal variation and changes in management. This analysis aimed to best account for how beetles may respond to this monthly variation.

Results

We found 1,809 individuals of 16 unique species across 2014 ($n = 877$) and 2015 ($n = 932$). The most common lady beetles in our samples included the mildew-eating *Psyllobora vigintimaculata* (71.3% of all individuals), mite-eating *Stethorus* spp. (6.1%), and the aphidophagous *Hippodamia convergens* (5.1%) and *Harmonia axyridis* (5.0%; Table 2). We captured a greater number of individuals via visual sampling methods than by using the sticky trap method. Of those captured, 62.7% of samples came from visual surveys and 37.3% from sticky traps. However, sticky trapping captured a greater number of species ($n = 16$) than visual ($n = 13$) over the course of the 2-yr sampling period. Overall, few species were only observed in a single site (Table 2).

The percent amount of natural land within 3 km had the greatest influence on lady beetle abundance and richness in each model. Total lady beetle abundance was greater in gardens situated in landscapes with less than four percent natural land within 3 km (Fig. 2a; $P < 0.001$). In gardens surrounded by more than four percent natural land within 3 km, lady beetle abundance was greater in sites with greater ornamental flower species richness (Fig. 2a; $P = 0.03$). In gardens with fewer ornamental flower species, abundance was slightly greater in gardens surrounded by more open land within 3 km (Fig. 2a; $P = 0.03$). Lady beetle species richness was most influenced by the amount of natural land within 3 km, with richness greatest in gardens surrounded by less natural land within 3 km ($P = 0.001$), in smaller gardens ($P = 0.02$), and in gardens with fewer trees and shrubs ($P = 0.007$; Fig. 2b). In gardens surrounded by more natural land, richness was greatest in gardens with less mulch and straw ($P = 0.004$) and fewer crop species ($P = 0.03$).

For aphidophagous lady beetle species, natural area within the landscape was also the most influential predictor of increased abundance (Fig. 2c; $P = 0.005$). In gardens surrounded by less natural land, abundance was greater in gardens with more trees and shrubs ($P = 0.03$). Species richness of aphidophagous lady beetles was

Table 2. Lady beetle species collected in urban gardens in the California Central Coast between June–October 2014 and 2015

Tribe or Genus	Species	No. of sites found	Feeds on	Ecological function in agriculture
Adalia	*Adalia bipunctata*	1	Aphids and mites	Predator/pest control
Coccinella	*Coccinella californica*	8	Mostly aphids	Predator/pest control
Coccinella	*Coccinella septempunctata*	7	Mostly aphids	Predator/pest control
Cycloneda	*Cycloneda polita*	4	Mostly aphids	Predator/pest control
Cycloneda	*Cycloneda sanguinea*	8	Mostly aphids	Predator/pest control
Harmonia	*Harmonia axyridis*	12	Mostly aphids	Predator/pest control
Hippodamia	*Hippodamia convergens*	16	Mostly aphids	Predator/pest control
Hyperaspis	*Hyperaspis quadrioculata*	5	Aphids and scale insects	Predator/pest control
Nephus	*Nephus binaevatus*	1	Aphids and scale insects	Predator/pest control
Olla	*Olla v-nigrum*	1	Mostly aphids	Predator/pest control
Psyllobora	*Psyllobora vigintimaculata*	17	Fungus	Fungus and mildew control
Scymnus	*Scymnus coniferarum*	2	Mites and scale insects	Predator/pest and mite control
Scymnus	*Scymnus cervicalis*	1	Mites and scale insects	Predator/pest and mite control
Scymnus	*Scymnus marginicollis*	8	Mites and scale insects	Predator/pest and mite control
Scymnus	*Scymnus nebulosus*	1	Mites and scale insects	Predator/pest and mite control
Scymnus	*Stethorus punctum*	12	Mites and scale insects	Predator/pest and mite control

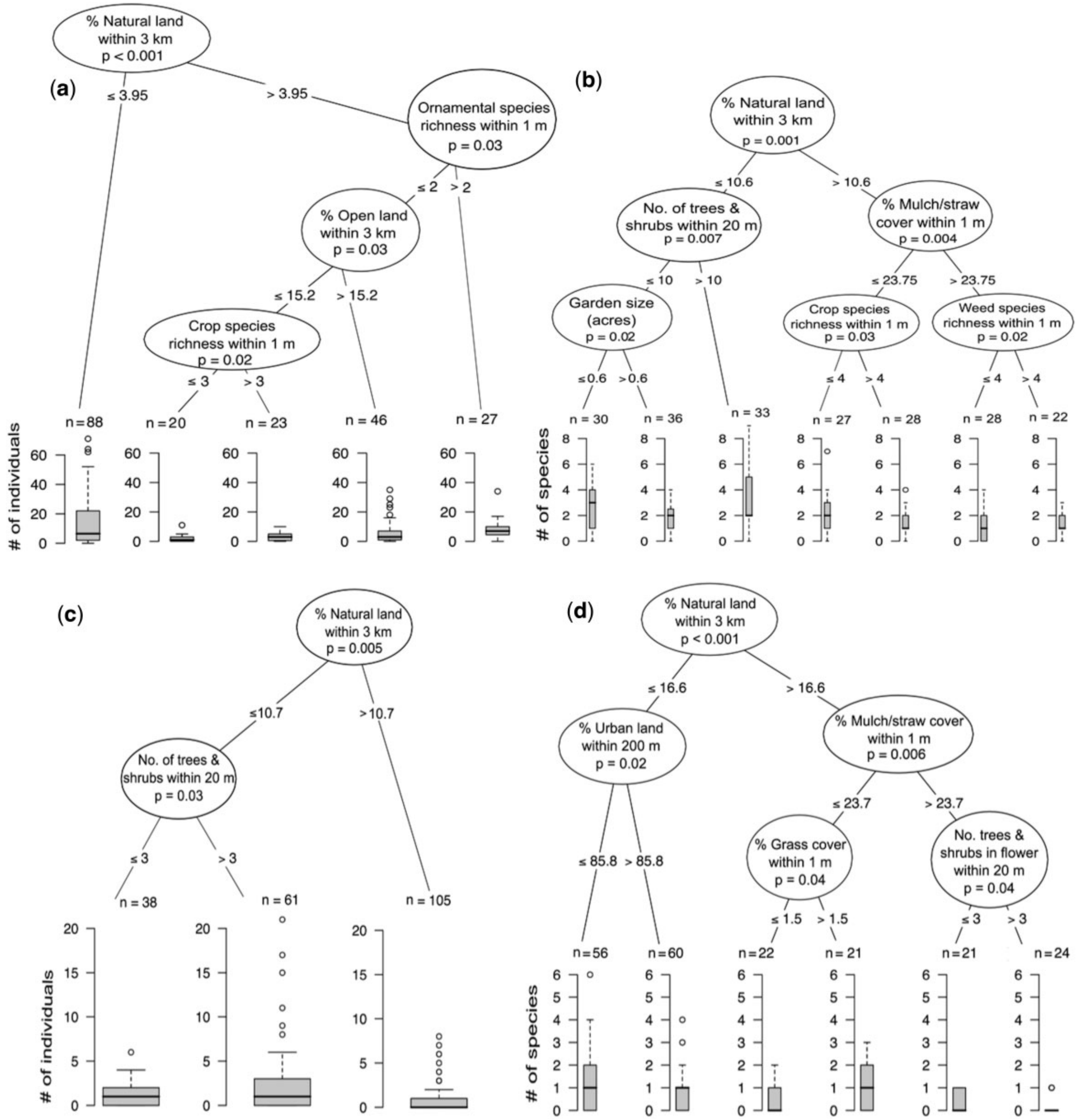

Fig. 2. Tree structured regression models displaying the landscape and local correlates of (**a**) abundance of lady beetle individuals, (**b**) species richness of lady beetles, (**c**) abundance of aphidophagous individuals, and (**d**) species richness of aphidophagous individuals in urban gardens.

greatest in gardens surrounded by less natural land within 3 km (Fig. 2d; $P < 0.001$). In gardens surrounded by more natural land, richness was greatest in gardens with less mulch and straw ($P = 0.006$) and more grass ($P = 0.04$).

Discussion

Our study shows that lady beetle abundance and species richness correlate with both local and landscape factors, but that one landscape feature tends to be at the top of the hierarchy. In our study system, the amount of natural land within 3 km (an ecologically relevant scale for lady beetles) had the greatest influence on local abundance and species richness within urban gardens. In particular, we found that there is a split such that different local factors were important predictors of lady beetle abundance and richness depending on the amount of natural land in the landscape.

Our first question was what landscape factors surrounding gardens correlate with greater lady beetle abundance and species richness. We found that landscape factors significantly influence lady beetle communities within urban gardens, and specifically, the amount of natural and urban land present in the surrounding landscape at greater spatial scales. Among our sites, we found that abundance and species richness was greater in gardens embedded in more urban landscapes with very little natural land-use surroundings.

This was surprising, as theory may predict that habitats surrounded by less natural land would have fewer species due to a low availability of resources within the surrounding urban landscape matrix (Vandermeer and Carvajal 2001). This suggests that lady beetles may be accumulating or concentrating in gardens in more urban landscapes (i.e., those surrounded by predominantly urban land use) due to a low availability of resources and habitat elsewhere in the surrounding landscape. In these landscapes, the garden may provide the only available habitat refuge. Some lady beetle species may indeed be attracted to urban landscapes; for example, the invasive *H. axyridis* has been found to show a preference for urban habitats like gardens and parks (Roy et al. 2016) to suggest that lady beetle species likely experience the urban landscape matrix differently.

Our second question was what local vegetation and habitat factors within urban gardens correlate with greater lady beetle abundance and richness. Here, we found that certain garden habitat factors correlate with lady beetle abundance and richness, indicating that garden management can provision for lady beetle habitat. In particular, we found that gardens that incorporate different structural elements can positively and negatively influence lady beetle communities. For example, lady beetle species richness increased in the presence of more trees and shrubs in gardens, indicating that increased habitat complexity and structure of annual, long-established vegetation may provide critical habitat for resident species. Further, we found that lady beetle abundance increased as the number of flowers in gardens increased, providing an example of how local management can easily provision for beetles by planting a suite of ornamental flowers or crops that have a high number of flowers. Interestingly, lady beetle abundance decreased in more diverse cropping systems, and richness decreased in the presence of greater mulch and straw ground cover. This may be explained instead by resource concentration in structurally simple habitats, where herbivores are more likely to concentrate in monoculture stands of their host plant and in turn attract predators to these locations (Root 1973, Andow 1991). Thus although this study did not attempt to infer herbivore prey populations and densities within gardens, this finding suggests that certain local factors that were important for lady beetle communities may also influence herbivore (e.g., aphid) populations and therefore be influencing lady beetles.

Our third question was whether landscape or local factors were stronger correlates of lady beetle abundance and species richness in urban gardens. In our study system, our results suggest that landscape factors play a stronger role in shaping lady beetle communities within urban gardens than local factors. We found that local management was less important for gardens that are embedded within more urban landscapes, which suggests that there may be a threshold of the net effect of local management to provision for lady beetle biodiversity in urban landscapes with little land-use diversity (i.e., simple landscapes). This has been found in rural agricultural systems, where local habitat management strategies (e.g., native plantings like hedgerows or flowers) in farms surrounded by monoculture fields with little land-use diversity have little effect on increasing insect species diversity (Tscharntke et al. 2012). A similar trend may be at work in our urban system, where gardens that are surrounded by predominantly urban land-uses are relatively resource-rich habitat in an otherwise resource-desolate urban landscape, and individuals and species may accumulate over time due to high colonization and low emigration. Here, habitat availability may be more important than habitat quality in these simple landscapes, where specific habitat factors such as greater floral abundance and crop diversity are less significant if a garden is located in an intensively developed landscape with little natural vegetation or land-use diversity.

In contrast, gardens that are surrounded by more natural land uses or a diversity of land uses may experience lower abundance and species richness of lady beetles at certain time points due to high mobility and low residency time. Lady beetles aggregate in natural forested or grassland areas to overwinter and reproduce (Hagen 1962) or to escape competition pressures (Gardiner et al. 2009), and gardens near large natural areas may function as resource sites, not residential habitat. This would explain why specific local habitat variables, such as greater ornamental flower richness, were important for explaining greater lady beetle abundance and species richness in gardens surrounded by more natural area. Here, we may find longer residency times in higher resource quality gardens, in which local vegetation complexity and resource availability, like the availability of pollen food resources, can attract individuals to and maintain populations within gardens (Rebek et al. 2005, Lundgren 2009) and relax dispersal processes (Hanski and Beverton 1994, Fleishman et al. 2002).

Last, while our study did not aim to explicitly test species–area relationships in gardens, it is interesting to note the indication of a "small island effect" within highly developed landscapes. Small island effects can occur when environmental disturbance and stochasticity fail to uphold species–area relationships in island biogeography theory (Lomolino 2001, Lomolino and Weiser 2001). The theory has been used to explain increased insect population numbers in highly disturbed urban habitats such as roundabouts (Helden and Leather 2004) and increases in bird species richness postdisturbance in rural agriculture (Ferraz et al. 2003). We found a negative correlation between garden size and species richness, and that gardens situated in intensively developed urban areas harbor high species richness regardless of being large (e.g., >1 acre) or small (e.g., <0.5 acres). The two community gardens where we found the highest species abundance and greatest richness are small, but are some of the only green spaces in the urban centers of Salinas and Santa Cruz, respectively. Thus, these gardens may function as critical habitats in perhaps an otherwise low resource quality urban landscape. In sum, our findings in this landscape show that there is an interplay between landscape and local factors that influence lady beetle communities in gardens, which can have significant management implications at both a local and a landscape scale.

In conclusion, lady beetle species are important for biological control services, controlling crop pests, mildew, and disease. Provisioning for a diverse lady beetle community requires an understanding of how multiple factors at multiple scales affect patterns of lady beetle community composition. Future research should examine the effects of the urban landscape on lady beetle population movement, and explore how gardens within a landscape may be connected via lady beetle dispersal, and how this may be important for urban conservation and urban landscape planning. To conclude, this study demonstrates that for urban growers, a perspective beyond the garden gate to the surrounding landscape may be the first step when strategizing local habitat management for lady beetle communities that provide a suite of ecosystem services for food cultivation in urban agriculture.

Acknowledgments

We thank the field and lab work provided by Y. Bravo, J. Burks, H. Cohen, V. De la Fuente, K. Ennis, A. García, P. Gillette, M. Hash, R. Hruska, B. Ferguson, M. MacDonald, L. Marin, H. Morales, M.E. Narvaez Cuellar, M. Otoshi, M. Plascencia, R. Quistberg, G. Santiz Ruiz, R. Schreiber-Brown, and S-S. Thomas. We also thank the urban community gardens and gardeners for supporting and facilitating our research: Aptos Community Garden, Beach

Flats Community Garden, Berryessa Community Garden, the Center for Agroecology and Sustainable Food Systems, Chinatown Community Garden, Coyote Creek Community Garden, El Jardín at Emma Prusch Park, The Forge at Santa Clara University, Giving Garden at Faith Lutheran Church, Homeless Garden Project, La Colina Community Garden, Laguna Seca Community Garden, Live Oak Green Grange Community Garden, MEarth at Carmel Valley Middle School, Mi Jardín Verde Community Garden at All Saints' Episcopal Church, Our Green Thumb Garden at Middlebury Institute of International Studies, Salinas Community Garden at St. George's Episcopal Church, and Trescony Community Garden. This research was financially supported by the Center for Agroecology and Sustainable Food Systems, the Environmental Studies Department at the University of California, Santa Cruz, and an Annie's Homegrown Sustainable Agriculture Scholarship.

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