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Gardening for Wildlife: Tree canopy and small-scale planting influences on arthropod and bird abundance

Marion Dresner
Portland State University, dresnem@pdx.edu

Andrew Moldenke
Oregon State University, moldenke@science.oregonstate.edu

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Do urban gardens restored with native shrubs contribute towards conservation of birds? Portland, Oregon, is a mid-sized city with many restored yard habitats and nearby regional natural areas, with yards varying in the degree of native plantings and the sizes and groupings of the yards involved. We studied several of the purported ecological benefits attributed to these widespread, but small-scale, urban gardens. We measured the relative success of yard habitats in contributing to diversity and abundance of forest-habitat birds. We studied how the abundance and diversity of shrubs, arthropods, and birds were related. We compared two neighborhoods; one having high, native tree cover, and the second having lower, non-native tree cover. Both neighborhoods had nearby greenspaces. We selected 6 replicate yards in each neighborhood, each with at least a minimum number of native shrubs. We also measured bird species richness using citizen science data.

The abundance of arthropods significantly predicted the bird species richness. Both the amount of regional and local tree cover had a stronger statistical signal than shrub cover. The presence of native species of shrubs in these yards was not a good predictor for abundance of arthropods.

Keywords

Urban yards; trophic responses to native plants; native birds; tree canopy; urban arthropods

Acknowledgements

Thanks to the yard owners who, in the interest of science, helped us collect data and allowed us to repeatedly enter their yards to conduct this study. Thanks also to Portland State University undergraduate and graduate students who help collect the data.

INTRODUCTION

Native bird diversity has measurably declined in urban areas (Marzloff 1990) due to habitat modification and increased non-native vegetation. Choices made by gardeners to plant native species in their yards may increase plant richness and diversity, but do they enhance bird diversity? By provisioning birds with arthropod food, native plants might help support bird populations in cities. During the nesting season, most terrestrial birds in North America rear their young, in part or entirely, on insects (Dickinson 1999), including many species that eat mainly plant material other times of the year. Most birds rely on arthropods for at least part of their diet throughout the year, eating spiders, beetles, ants, and insect larvae. Smaller birds may rely more on spiders than other arthropods during the winter months (Adams 2014). Studies in other countries and other regions in the U.S. indicated that native plants in suburban gardens increase the diversity of arthropods (Smith et al. 2006; Burghardt et al. 2008). Besides serving as potential urban biodiversity refuges, gardens also provide aesthetic enjoyment (see Owen 1991, 1983; Smith et al. 2006). To what degree do urban small-scale garden management choices lead to differences in abundance of birds?

Bird abundance and/or species richness have been used as indicators of urban biodiversity quality (e.g., Donnelly & Marzloff 2006; Carignan & Villard 2001) due to the prominence of birds in food webs. Bird species richness and abundance studies have been conducted in gardens in Tasmania, Pennsylvania, and Arizona. Native Tasmanian birds showed a preference for native plants, whereas exotic birds largely utilized exotic plants. Tasmanian gardens, with protective, dense shrub layers or trees, substantially affected the nature of garden bird assemblages (Daniels & Kirkpatrick 2006). In Phoenix, Arizona, native desert bird species richness increased in neighborhoods with desert landscaping designs and in neighborhoods closer to large desert tracts, whereas non-native birds frequented yard habitats that were landscaped with ornamental, exotic plants (Lerman & Warren 2011). Pennsylvania bird species of regional conservation concern were found to be 8 times more abundant and significantly more diverse in yards having native plants as compared with those without (Burghardt et al. 2008). Native landscaping, in the Pennsylvania study, was found to positively influence the avian and lepidopteran carrying capacity.

The idea of promoting native plantings in yards on private property became more widespread with promotion by the National Wildlife Federation in 1973. In Portland, Oregon, the Audubon Society has promoted gardening with native plants since 2009 as conducive to bird conservation. Some research has been conducted about the value of placing native plants in yards. Tallamy (2004) enumerated problems created due to alien plant gardens; specifically, they tended to host fewer arthropod herbivores and predators. Researchers studied native garden plants in Pennsylvania to understand how they might affect the food web, with caterpillars as a surrogate for total herbivores and breeding birds as a surrogate for total insectivore diversity (Burghardt et al. 2010). Landscaping with native plants was found to positively influence lepidopteran species diversity.

Garden arthropod abundance has been studied in Britain, where nearly ¾ of the variation in garden arthropod species richness was attributed to tree abundance (Smith et al. 2006). Other positive influences were surrounding green space and structural diversity of the vegetation.

Negative influences included increased area of hard surfaces within the garden. The size and composition of the tree canopy can have an influence on the abundance and composition of bird species. In an Australian study, the transition from native to exotic street trees correlated with a loss of insectivorous and nectarivorous bird species that depend on structurally diverse and/or native vegetation (White et al. 2004). In North America, larger birds such as crows select smaller tree patches having open foraging sites, while smaller birds such as warblers selected larger tree patches, presumably for foraging (Hostetler & Holling 2000).

A British study compared gardens in 5 cities, finding that the size of the garden, particularly aspects of the garden containing utilizable resources, had a greater ecological effect than groups of smaller gardens (Loram et al. 2008). This may have been because a larger garden might be perceived by wildlife as a large resource patch, thereby making it more suitable as habitat. The three-dimensional structure of gardens was seen to positively influence the abundance of arthropods. In another garden study, the beetle family, Carabidae, was found to be a good indicator of environmental quality in France (Croci et al. 2008); carabids were sensitive to increasing fragmentation and to presence of built surfaces which inhibited their movement within the urban landscape. A higher diversity of forest species of carabids was found in the original rural (forested) areas than in urban forest fragments in Belgium, Finland, Bulgaria and Romania (Tibor et al. 2010).

Besides tree canopy, other environmental factors exerting a large influence on urban biodiversity include impervious surface and potential habitat connectivity. Urban impervious surfaces had a negative effect upon native species richness: at local scales in Palo Alto, California for butterflies (Blair & Launer 1997), in Manchester, England for butterflies (Hardy & Dennis 1999), for birds in urban parks in Oulu, Finland (Jokimaki 1999), and for ground beetles in London, England (Davis 1978). Connectivity between urban greenspaces is important for many arthropod groups. Dispersal abilities of different arthropods influence their presence or absence in urban gardens (Vergnes et al. 2011). Three major taxa of arthropods (spiders, carabid and staphylinid beetles) were studied in gardens connected to nearby parks and were compared to unconnected gardens at four sites. Carabid beetles were rarely found in unconnected gardens, but spiders, which can disperse easily via ballooning, were common. Predatory carabid beetles, like *Pterostichus*, are important because they help regulate herbivorous arthropod populations (Forsythe 1982). The abundance of flightless predaceous beetles within a yard is likely related to how the habitat is connected to nearby patches of natural land cover, or green spaces, since they are limited in their ability to colonize new habitats.

In this study, we focus on arthropods and birds because they are critical components of the urban food web. Predaceous arthropods eat plant-eating arthropods, and birds eat predaceous and herbivorous arthropods. Many native-plant gardeners expect native plants to be more beneficial than non-native plants because of promotional material suggesting the vegetation of ornamental plant leaves is often not palatable to insects. Native arthropods, however, are adapted to the chemical defensives produced by local native plants (Tallamy 2004). However, many non-herbivorous arthropods use ornamental plants for concealment or to capture arthropod prey. Burkhardt et al. (2010) found that non-native plants supported significantly fewer caterpillars of both specialist and generalist species, but the effect size was smaller when the non-natives were close relatives (congeneric) of native host plants. It should be noted that predaceous arthropods, however, use plants, including ornamental non-native plants, for concealment to capture arthropod prey. In this study, we did not differentiate between the 2 very different uses of shrub; we were interested primarily in factors that could explain differences in bird diversity between neighborhoods. Most Portland-area bird species, both insectivores and omnivores, consume arthropods during the breeding season, including Coleoptera, Diptera, Hymenoptera, Hemiptera, Lepididoptera and Hymenoptera larvae, and Araneae (Hagar 2004).

Our study was conceived of as a means to generate data pertinent to urban ecology and to interest community members in urban ecology. Arthropods and birds were chosen as dependent variable focal groups. Even though birds are actively consuming arthropods during the spring, flying arthropods, which we collected in Malaise traps, are likely hatching and entering into system regularly. Birds are important species for many reasons, but were chosen as a focus because many yard owners and those who participated in this study were interested in bird conservation. Yard owners are an important audience because they make ecologically-relevant landscaping choices. The link was made between yard plants, arthropod herbivores on yard plants and their predators, and spring-nesting birds as secondary predators. Through this lens, we sought to examine whether plant choices in yards are meaningful ecologically, or only symbolically. Many participants had 'certified' yards, and were proud to have signage indicating to their neighbors that they were concerned about urban conservation. We chose neighborhoods having different tree cover and tree species, i.e. native or non-native, because we presumed this might help explain differences in insect and bird variation between neighborhoods in the study in this report.

Questions:

Does the percent cover of native plants in the yards under study influence arthropod abundance?
Does the tree cover (0.5 ha around each yard under study) influence arthropod abundance?
Does arthropod abundance influence bird abundance during the spring nesting season?

MATERIALS AND METHODS

Study Area

Two neighborhoods were chosen for the study: (1) Hillsdale (45.4758° N, 122.6908° W), having a considerable amount of tree cover and forest patches dispersed between residential yards; and (2) Laurelhurst (45.5262° N, 122.6239° W), having only one large greenspace and considerably less tree cover. Tree cover ranged between 97-76% in Hillsdale and 52-46% in Laurelhurst (City of Portland, 2017). Both neighborhoods had similar property values (Hillsdale range = 0.5-1.2 $million, Laurelhurst range =0.35-1$million), and variety in yard sizes (Hillsdale average = 7000 ft^2, Laurelhurst average = $6800ft^2$). Each yard studied was at least 500 ft. from another sampled yard, and was thereby considered to be independent.

Study Design

Over 3 successive spring seasons, branch beating (described below) was conducted in 25 yards on a variety of native and several ornamental shrubs species to test which shrub species host most arthropods. After average arthropod abundance results were complied, a total of 7 native species and one ornamental species were sought in yards in the two neighborhoods as a basis for inclusion in this study. Individual yard sites were selected based on minimum (at least 3) native shrub species composition as well as the yard owner's willingness to participate. We included the very common non-native species, *Rhododendron*, to serve as a comparison constant throughout the neighborhoods, as the variety of ornamental plants in yards varied widely. In Portland, Oregon, yards that are planted with native species typically use native forest-related species. The two neighborhoods were chosen *a priori* due to their differences in tree cover and tree species composition.

We chose birds as the particular taxa to target because of the overall conservation goal of backyard habitats. Bird species were classified by habitat preference, belonging in either a 'forest' or 'open canopy' designation (Donnelly and Marzluff 2004) to make better sense of their association with degree of tree canopy vs. open/urban landcover differences. The "forest" category contains only native bird species, whereas the open habitat category includes several introduced and common or 'urban-adapted' species, such as song sparrows, and 'urban-exploiter' species such as crows (McKinney 2002).

Six yards in each neighborhood were chosen in each neighborhood. The range in numbers and species of native plants in each yard varied considerably. All yards were sampled between mid-April through early June, a period when most species of birds in this region were nesting. We reasoned that since this was the period of time when most birds were feeding themselves and their nestlings arthropods, the comparison between arthropod abundance and bird species richness would be most meaningful.

Data collection

Prior to the study reported in this article, branch beating (widely used to collect shrub arthropods) was used to sample arthropods on a variety of commonly planted shrubs, using 5 beats per individual shrub. We sampled the same species of shrubs whenever possible across yards to reduce the variability, focusing on the following commonly planted shrubs: Snowberry, (*Symphoricarpos albus)*, non-native *Rhododendron sp*., Thimbleberry (*Rubus parviflorus*), Red-flowering currant (*Ribes sanguineum*), Hazelnut (*Corylus cornuta*), Oceanspray (*Holodiscus discolor*), Indian plum *(Oemleria cerasiformis*), and Vine Maple (*Acer circinatum*).

In the study primarily reported here, we collected aerial arthropods by setting malaise flight-intercept traps for 1 week in backyards of each neighborhood during the peak of the bird breeding season. Pitfall traps were set for 1 week in transects of 3 per yard, collected, and identified to species; all of the arthropods larger than 2mm, a minimum size consumed by local birds (Hagar 2004), were quantified. Percentage cover of shrubs was measured via a transect set along the long axis of each yard. Species were identified and distinguished as native or ornamental. Tree cover assessment was conducted using aerial photographs of 0.5 hectare surrounding each yard using a recent tree inventory (City of Portland 2017). Bird data was collected with point counts, using trained volunteers over an 8-week period from mid-April to the beginning of June. Point counts were established in each yard with 50-meter circular transects. Data was collected two times per week for a 10-minute period between 6-9 AM using both visual and auditory cues. The species data was corroborated by an ornithology graduate student, who collected bird species data in parallel. We collected data on all bird species, but analyzed data on only the bird species that feed primarily on arthropods during nesting season.

Statistical Analysis

Arthropod richness and total arthropod abundance was calculated for each yard. A ratio of native to introduced arthropod species was calculated whenever known. Bird point count data was summarized, and species richness and abundance was calculated for each yard. Shrub transects were summarized and percent cover from each yard was calculated. Total native shrub cover and total ornamental shrub cover was calculated. Tree cover was calculated for each yard for a 0.5 ha area surrounding each yard.

The data was analyzed using 'R' (vegan package), and included several general linear models to test for significance of relationships between important variables, non-metric multidimensional scaling, (NMDS) to collapse information from multiple dimensions so that they can be visualized and interpreted. MANOVA was also used to test for significant differences between the two neighborhoods and our major groupings of data.

RESULTS

Focusing on the role of shrubs in each yard, we compared the overall abundance of arthropods collected by branch beating over several seasons in the most prevalent species of shrubs in Portland neighborhoods. Snowberry had overall the highest arthropod abundance and variation between the 3 years of sampling. Total arthropod density on each shrub species varied widely from year to year (as shown by whiskers of box plots in Figure 1). This initial study directed us to focus on yards containing the shrub species that had higher numbers of arthropods collected on them for our focus in this study of two neighborhoods.

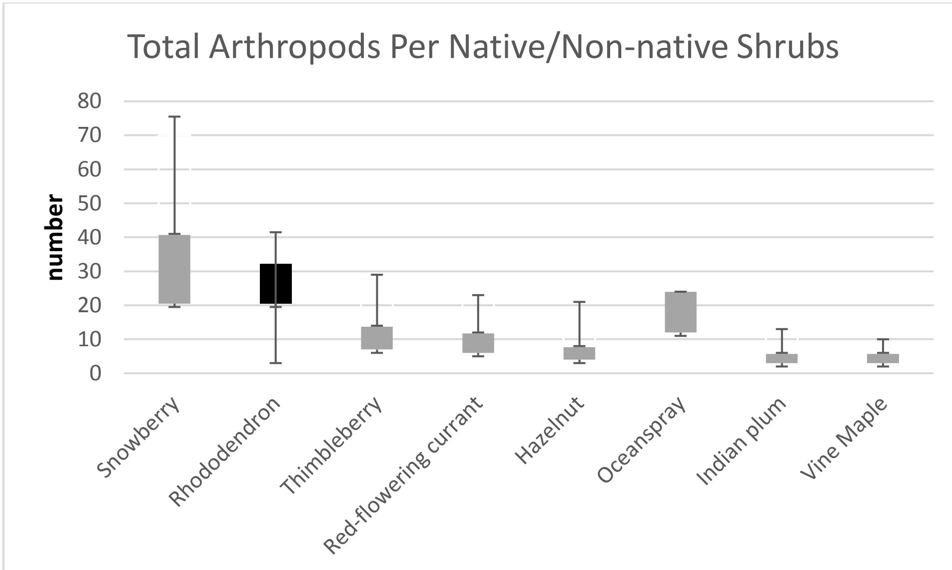


Figure 1: Box and Whisker plots showing variation in arthropod abundance on 8 shrub species over three years of sampling. Median values indicated by horizontal line through box, box indicates interquartile range between first and third quartiles, whiskers indicate minimum and maximum values 1.5 IQR of the quartiles. (Snowberry (*Symphoricarpos albus)*, Non-native *Rhododendron sp*., Thimbleberry (*Rubus parviflorus*), Red-flowering currant (*Ribes sanguineum*), Hazelnut (*Corylus cornuta*), Oceanspray (*Holodiscus discolor*), Indian plum *(Oemleria cerasiformis*), and Vine Maple (*Acer circinatum*).

Tree canopy was important in the selection of the two comparison neighborhoods. Laurelhurst had a lower overall relative tree cover (52%), while Hillsdale was higher (77%) (City of Portland 2012). At a patch level, tree cover at 0.5 ha surrounding each yard was calculated. As shown in Figure 2, patch tree cover in Hillsdale was significantly higher, ranging between 62-95% and lower in Laurelhurst ranging between 44-66%. Hillsdale has abundant tree cover, (primarily the native *Acer macrophyllum* (Bigleaf maple), 11% and *Pseudotsuga menziesii* (Douglas-fir), 10%, *Pinus contorta & P. ponderosa* (8%) containing more native tree species than most other Portland neighborhoods; many of these trees occur in small, remnant patches of 'unbuildable' land. Laurelhurst has primarily introduced broadleaf trees, especially *Acer sp*. (Maple varieties) 30%, and *Prunus sp*. (Flowering cherry) 12%).

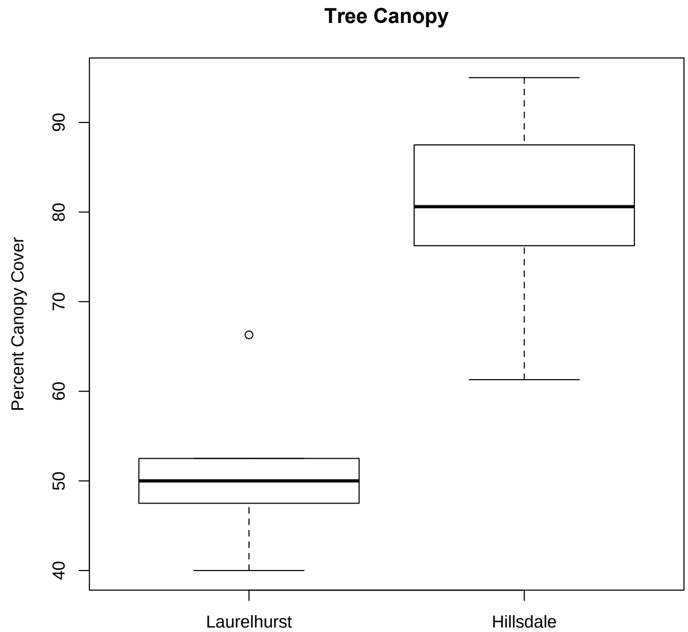


Figure 2. Box and Whisker plots showing differences in tree canopy between the two neighborhoods. Median values indicated by horizontal line through box, box indicates interquartile range between first and third quartiles, whiskers indicate minimum and maximum values 1.5 IQR of the quartiles.

The Hillsdale neighborhood, having abundant native tree diversity, had higher overall bird species richness (25 species), whereas the Laurelhurst neighborhood, with mostly introduced tree species cover, had lower bird diversity (17 species). Bird species known not to consume insect prey during the nesting season were removed from the analysis, since we sought to compare arthropod abundance and diversity with bird abundance and diversity, species removed included the Rock dove, Goldfinch, and House finch. Forest bird species richness (mostly native species) was higher in the Hillsdale neighborhood (Table 1), while open canopy bird species richness (including non-native bird species) was higher in Laurelhurst (Table 1). The native forest bird assemblage, including species that are generally recorded as declining (e.g., Donnely & Marzluff 2006) illustrates the importance of habitat quantity and structure, whereas the open canopy assemblage includes species becoming more common as they can tolerate more developed, urban environments.

Table 1. Differences in bird species richness and abundance between neighborhoods

Forest Bird Species	**Hillsdale**	**Laurelhurst**	**Open Canopy Species**	**Hillsdale**	**Laurelhurst**
Stellar Jay	13	0	Robin	11	1
Spotted Towhee	12	1	Song Sparrow	11	4
Chestnut Backed Chickadee	4	1	Bushtit	9	2
Red breasted Nuthatch	4	4	Crow	8	5
Swainson’s Thrush	2	0	Anna's Hummingbird	8	4
Blue Throated Grey Warbler	2	0	Black Capped Chickadee	7	4
Orange Crowned Warbler	2	0	Black Headed Grosbeak	2	0
Downy Woodpecker	2	1	Western Scrub Jay	2	2

Red Bellied Sapsucker	1	0	Bewick’s Wren	5	4
Wilson’s Warbler	1	0	Northern Flicker	5	2
Pacific Wren	1	0	Dark Eyed Junco	2	4
Hairy Woodpecker	1	0	Black Headed Grosbeak	2	0
Varied Thrush	1	0	Ruby Crowned Kinglet	0	1
			House sparrow*	0	2
			Starling*	0	1
Total richness	**13**	**4**	**Total richness**	**12**	**13**

*=Introduced species

We compared the shrub cover in the yards, collapsing the data into two groups; native and ornamental shrubs. Figure 3 shows the overall differences between the two neighborhoods in the percentage of average native vegetation compared with average percentage of ornamental plants. This large variation between neighborhoods in yard vegetation was initially believed to help determine other ecological differences. We are confident than additional sampling will substantiate the higher (p=0.025) percent cover of introduced shrubs and trees in the Laurelhurst neighborhood (Figure 3, median = 63, minimum = 5.9, maximum = 82) relative to the cover of introduced shrubs in the Hillsdale neighborhood (median= 0.55, minimum= 0, maximum = 25). In contrast, Hillsdale might have a higher percent cover of native shrubs, but the sample size is too small to distinguish them (Figure 3, median = 64.3, minimum= 21, maximum = 110, with canopy layering) compared to the same in Laurelhurst (median= 46, minimum = 17, maximum = 129).

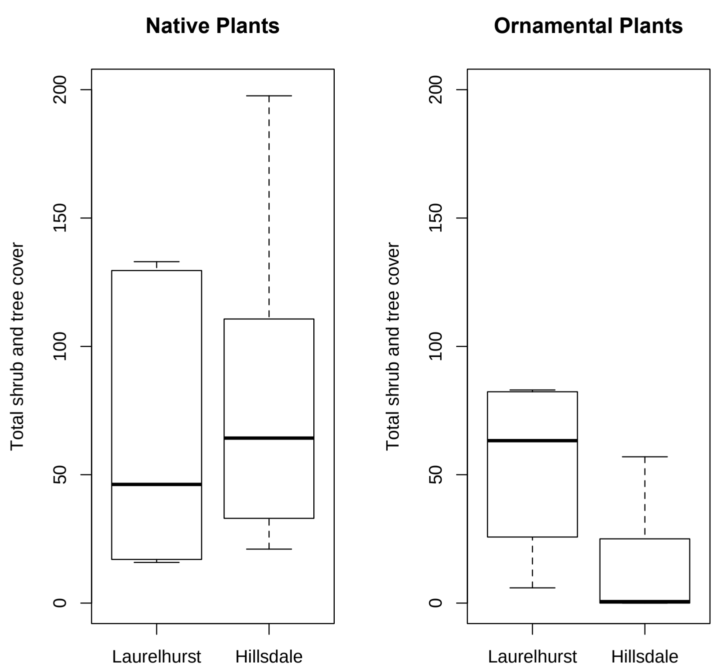


Figure 3. Box and whisker graph illustrating overall abundance of native and ornamental shrubs and small trees within and differences between yards within and between neighborhoods under study.

We sampled for ground-dwelling beetles, using pitfall traps, specifically sorting the samples for carabid beetles. Hillsdale, with its numerous small patches of forested habitat, consequently apparently had the higher, but not significantly so, abundance of these beetles (Figure 4). No native species of *Pterostichus* were encountered.

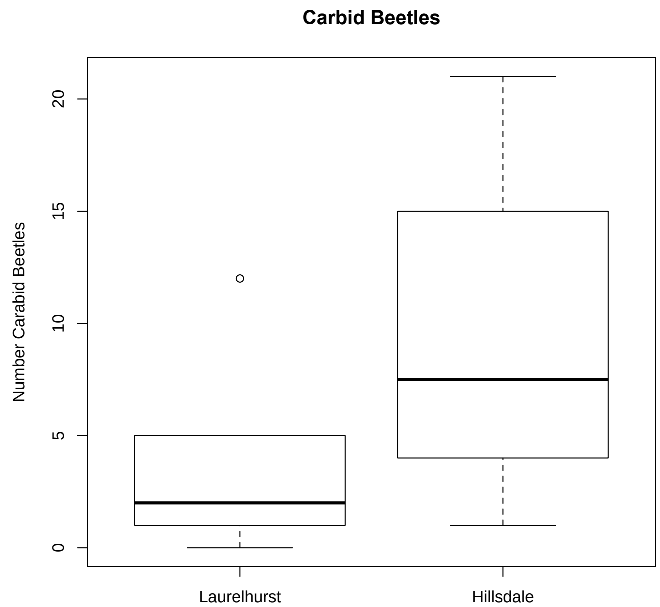


Figure 4. Average *Pterostichus melanarius* abundance between the two neighborhoods, using box-and-whisker plots. Laurelhurst neighborhood had one outlier yard with a higher number of beetles.

We inquired if, by choosing two neighborhoods having apparent differences, we were really comparing two dissimilar groupings of yards. Results of a MANOVA showed the two neighborhoods were significantly different when comparing values of the arthropod, bird, and tree cover data ($F = -3.081$, $r^2 = 0.76$, $p < 0.05$).

We inquired if yards having higher canopy cover of native shrubs also had higher arthropod abundances. This relationship approached significance, but the variance was high, and the result was not significant. No trendline could be drawn (Intercept =10.909, $t = 2.124$, $p < 0.431$, not significant).

Origin of arthropod species, whether native or introduced, were compared by neighborhood. As shown in Figure 5, the ratio of native forest arthropod species to introduced arthropod species was found to be higher for Hillsdale (average 2.29) than Laurelhurst (average 0.99).

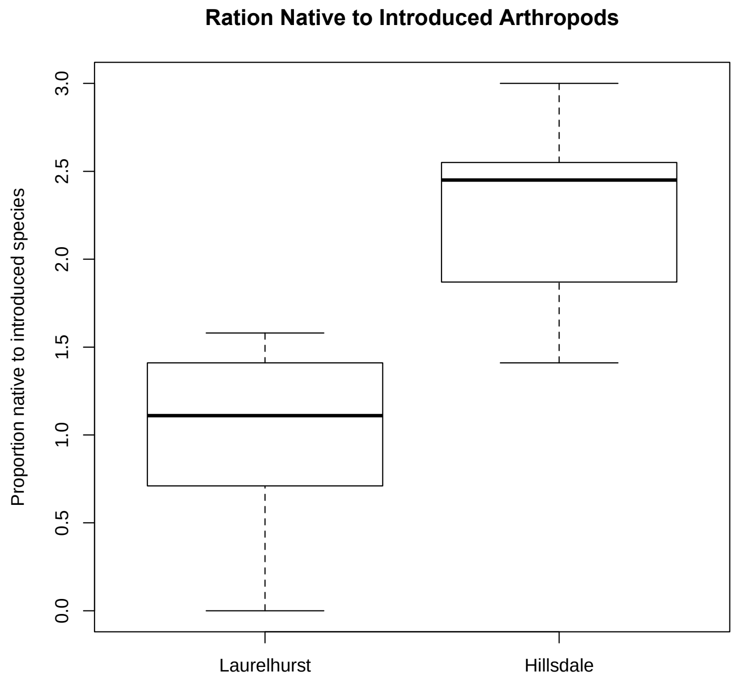


Figure 5. Box and Whisker plot comparing ratio of native to introduced invertebrate species between the two neighborhoods, Hillsdale and Laurelhurst

A general linear model was run comparing arthropod abundance and bird abundance in yards in the two neighborhoods (Figure 6a). Bird abundance was found to be significantly related to arthropod abundance (Intercept= 7.78, T= 3.26, p<.0012, r^2= 0.57). Additionally, the overall level of tree cover was correlated with the abundance of bird species that are moderately tolerant of urbanization (forest species), and birds generally very tolerant of urbanization (open canopy species).

A General Linear Model comparing arthropod abundance and bird species richness was conducted for all yards and was also found to be significantly related to arthropod abundance (Figure 6b) (Intercept = 1.5996, T = 4.073, p <.0024, r^2 = 0.62).

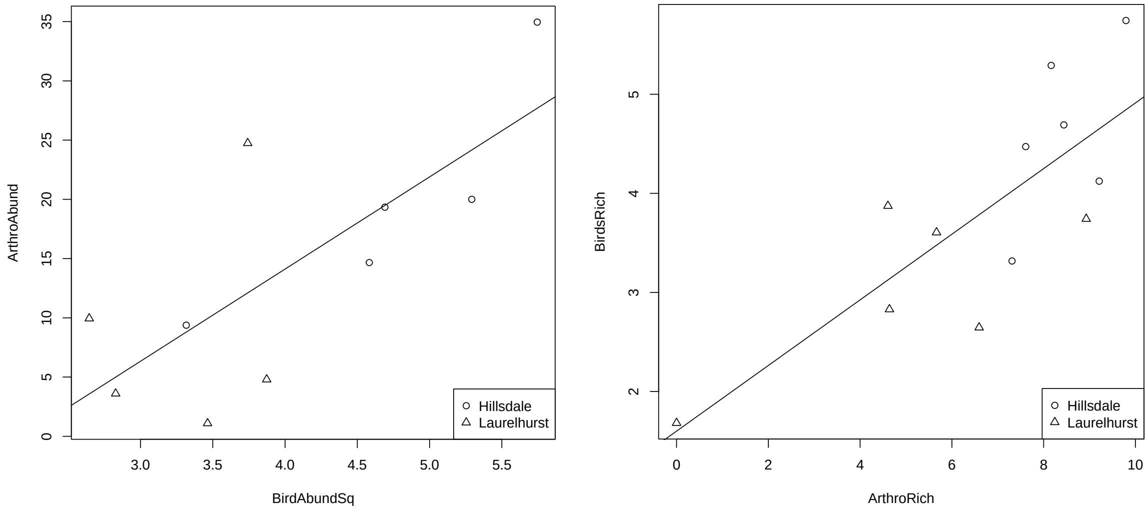


Figure 6. General linear models comparing arthropod abundance and bird abundance among yards (A) and arthropod abundance and bird species richness among yards (B).

A General Linear Model comparing bird species richness and patch level tree cover (Figure 7) determined that species richness of birds was significantly related to tree cover (Intercept = 1.792, t = 2.933, p <0.0135, $r^2 = 0.47$). When comparing tree level at a patch-scale, (0.5 ha around each yard), tree cover is shown to have an overall influence on the abundance of both arthropods and birds. As indicated above, tree species composition varied between the two neighborhoods, with Native Douglas fir and Bigleaf maple in Hillsdale, and predominantly non-native Red and Norway Maple, and *Prunus* species in Laurelhurst.

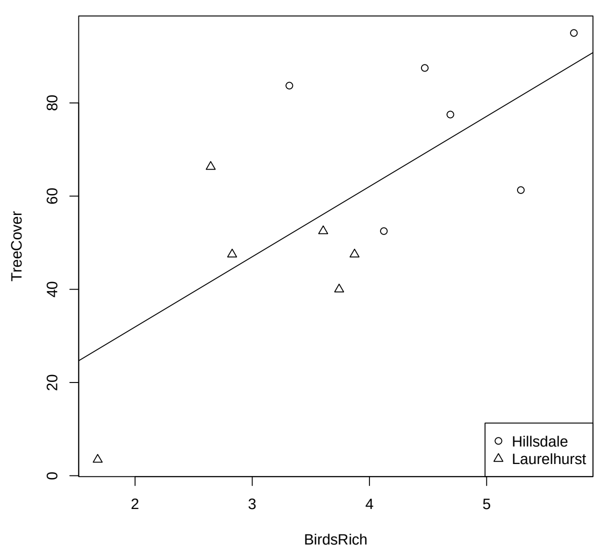


Figure 7. General linear model comparing tree cover and bird species richness among yards.

Patch-level tree cover, arthropod abundance and richness and bird abundance and richness data were combined in an NMDS (Figure 8), with two groupings emerging. The data thus sorted into two distinctive communities, based upon neighborhood in which the yard occurred (with one exception for each neighborhood), illustrating significant ecological differences between the two neighborhoods.

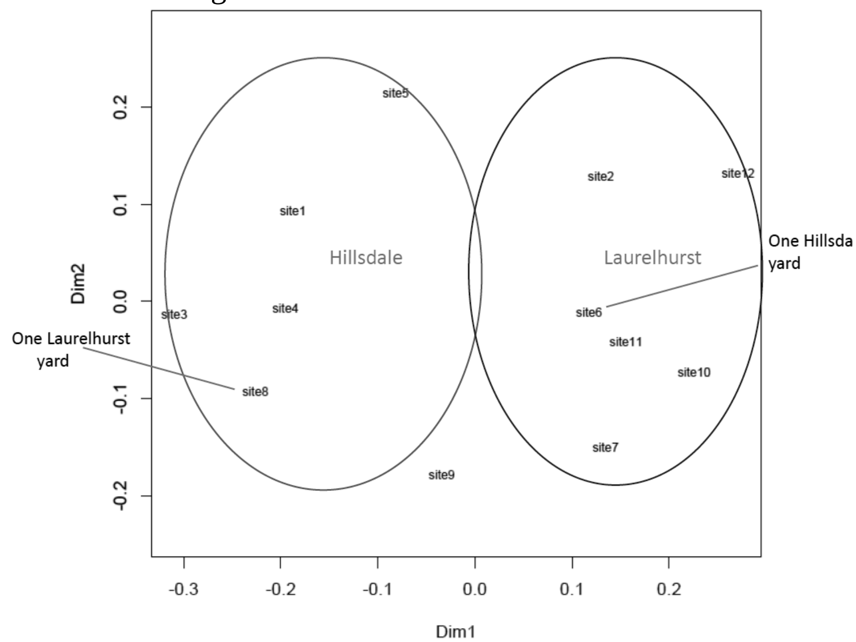
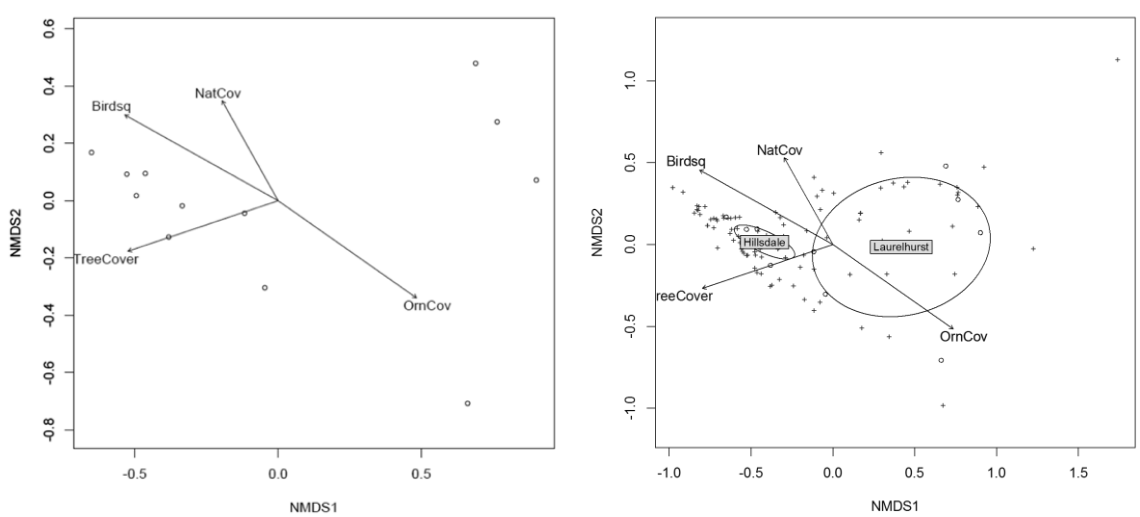


Figure 8. Results of NMDS ordination indicating all data separates into two distinct communities, closely following the distinction between the two neighborhoods. (Ordination initial value 13.63, Iter =10, value 9.75, final value 9.67, converged)

Vector analysis showed arthropod abundance, tree cover in a 0.5 ha area around each yard, and native shrub cover to be correlated with bird species richness in the Hillsdale community, and ornamental cover as a correlate in the Laurelhurst neighborhood (Figure 9A, B). Arthropod abundance, ornamental shrub cover and the Laurelhurst neighborhood correlated with bird species richness (Figure 9A, B).



A: Vectors only B: Vectors with neighborhood overlay

Figure 9A, B. Vector analysis showing all sites (Hillsdale sites clustered on left, Laurelhurst sites lower center and on right). 99999 permutations. Figure 9 shows 12 sites. None of the vectors had significant values, although bird species richness was closest to being significant (bird richness (r^2=0.37, p>0.12, tree cover r^2= 0.30, p>0.19, native shrub cover r^2=0.16, p> 0.473, ornamental cover r^2=0.35, p> 0.1484).

Figure 9B shows the clustering of arthropod species plus the overlay of neighborhood effect within a .95 confidence interval. Although none of the vectors were significant, bird species richness showed strong directionality for one neighborhood (p = 0.12), Hillsdale, and ornamental shrub cover showed strong directionality for the other neighborhood (p=0.148), Laurelhurst.

DISCUSSION

In our study of two Portland neighborhoods, arthropod abundance, bird abundance, bird richness, region tree canopy and patch tree canopy were correlated. Regional tree canopy and patch tree canopy together appear to be the drivers of arthropod abundance, which, in turn, would drive spring insectivore and omnivore bird abundance and richness. Existing street tree canopy is primarily driven by City of Portland street tree policies; the existence of remnant native tree patches in Hillsdale is due to having “unbuildable” areas of steep terrain.

Birds are important arthropod predators in spring. In our study, the abundance and richness of birds was linked to arthropod abundance and richness. Bird predation on arthropods is an important link in canopy food webs of temperate-zone forests (Gunnarsson & Hake 1999). How birds traveling in an urban area might be attracted to a particular area is interesting; birds may use cues like the abundance of con-specifics in choosing particular habitats. Individual insectivorous birds which have extensive knowledge about a site may attract other individuals and other species of arboreal insectivores (Rodewald 2012).

Overall regional tree density appears important for bird diversity. Since the home range requirements of most of the bird species, as well as the flying arthropods, extends across wider areas than a single backyard, they appear to be responding to both a regional and a patch level. Regional tree cover helps drives temperature and humidity, and the effect of low and non-native tree cover was seen in the associative responses of both the introduced arthropod and bird habitat guilds to open-canopy ‘sunny’ conditions characteristic of the Laurelhurst neighborhood. High native tree cover, conversely, shows response by ‘forest’ bird and native arthropod guilds, strongly shade-associated, and characteristic of the Hillsdale community. The abundance of insects collected from Malaise traps, and native arthropod species richness were 3x higher in the native forested Hillsdale community.

The composition of the tree canopy, differing between the two neighborhoods in this study, had corresponding affect for arthropods and birds. Studies by Burkhardt and colleagues (2008) and Tallamy (2004) determined that there was a strong relationship between native shrubs and trees and caterpillar abundance in eastern US yards. In western Oregon, native hardwood species (e.g., Bigleaf maple) were found to support 57% of lepidopteran species richness and

69% of their abundance (Hammond and Miller 1998, cited in Hagar 2007). Many neotropical bird species, consuming arthropods during the breeding season, are associated with deciduous trees and shrubs (Hagar 2007). Additionally, there are differences in herbivorous arthropod productivity and concealment opportunities for predaceous arthropods among different shrub species and degrees of maturity of shrubs that may influence the overall habitat quality of neighborhoods for birds.

However, within each yard, overall arthropod abundance and richness is indistinguishable within their shrubby habitat elements. The high variance between the actual abundances and species compositions (both plant and arthropod) between individual backyards and shrub species mitigates against clear-cut outcomes in the current research design. Many introduced arthropod species were collected, creating a novel arthropod species assemblage, obscuring the presumption in the literature that native plants are beneficial because chemical defenses produced by local native plant species are overcome by native arthropods. Urban gardens themselves are novel vegetation assemblages, combining ornamental, native, and, frequently, invasive plants.

This study points to tree cover as an important factor in predicting arthropod abundance in non-arboreal portions of in urban yards. Our study also determined that the pattern of tree cover and of arthropod abundance parallels the pattern of bird species richness. Neighborhoods with high tree cover have previously been shown to have an enhanced ecological benefit in maintaining elements of a spring food web. Smith and colleagues (2006) concluded that tree canopy was an important determinant of arthropod species richness, and large patches of trees supported more individuals compared to small urban remnants and edge sites. The age of the tree canopy may also matter; species of *Eucalyptus* having a long history of residence in a region supported a greater variety of arthropods in Australia (Bhullar & Majer 2000). Expanding the extent of woodlands may be a good choice for promoting biodiversity conservation in cities like Portland, which has many remnant forested sites.

On the ground surface, we found higher numbers of carabid beetles in the pitfall samples from Hillsdale as compared with Laurelhurst. Carabid beetle abundance is indicative of better habitat connectivity. Many large carabids were found to have low dispersal capacity (Varet, Burel, & Petillon 2014) and need continuous suitable habitat elements. Croci and colleagues (2008) found movement of carabids within the urban landscape of cities in France to be difficult without habitat connectivity; their presence within a yard is probably related to how the habitat is connected to nearby patches of natural land cover. Future studies of urban habitat connectivity in Portland, Oregon might involve these taxa.

As urban areas continue to grow, urban-adaptable species also expand. Native species, especially the 'edge species' that can utilize gardens and smaller greenspaces, may be conserved through the enhancement of habitat beyond parks and greenspaces, improving the quality of developed lands through concentration on urban gardens (McKinney 2006). The ecological benefit of planting natives in an individual garden, however, although not supported by this study, may help in the long-term. Research on the effect of developing habitats in adjacent gardens to increase the available habitat patch size is recommended.

Development of a ranking system

Besides tree cover composition, relative density of tree cover, percent cover of the shrub layer, and arthropod abundance, four other explanatory variables have some support in the literature, but have not yet been assessed in yards in Portland. These include vegetation layering, relative age of vegetation, conditions of ground (vegetated, gravel, wood chips, etc.) and size of the yard. More complex vegetation layering from the ground level to the canopy, may provide habitat for greater forest species diversity (Gil-Tena, Saura & Brotons 2007). Vegetation maturity and structure might impact the ability to harbor both arthropods and birds; more mature vegetation in a neighborhood has been attributed to higher bird species richness (Lernam and Warren 2011). The composition of the ground cover would likely affect the occurrence of both terrestrial arthropods and ground-feeding birds. The total size of the vegetated part of the yard, which affects the patch size, is an additional variable. Taken together, these variables influence bird abundance and richness.

Using our data, rankings were developed on a scale of 1-5 for tree cover, arthropod abundance, and shrub layer composition (Figure 10). Visual observations were made for the 4 additional criteria above. These variables were aggregated and used to create a system of relative rankings of yards in different neighborhoods. Using this ranking, Hillsdale yards had an average composite score of 24 points, and Laurelhurst having a composite score of only 12.

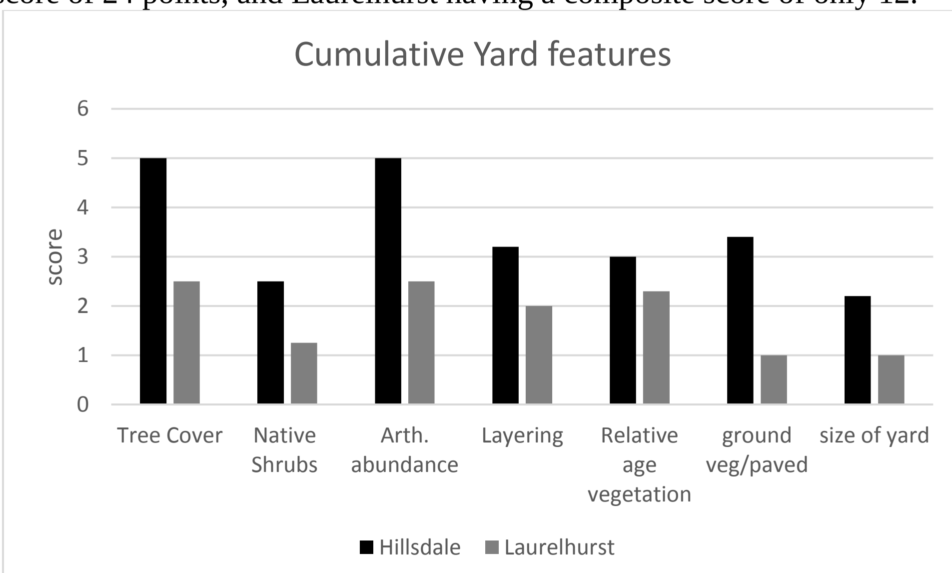


Figure 10. Relative rankings of the 8 factors used in assessment of yards. Tree cover, native shrub cover, and arthropod abundance are taken from the data in this study. The other variables (*i.e.*, layering, relative age of vegetation, ground paved/vegetated, and size of yard), had scales developed based on the literature described above with 1 being none and 5 being a maximum possible.

Next Steps

Since only a small number of yards in each neighborhood were investigated, a next step is to include more yards in the study. By collecting data from more yards in other neighborhoods, including those without necessarily native shrubs but with similar tree canopy, we might learn more about how individual plantings might have an additive effect. We did not control for use of garden amendments in yards; for instance, fertilization has been found to decrease resistance of woody plants to herbivores (Hermes 2002). We did not control for supplemental watering; garden plants and other organisms may or may not tolerate summer drought. Intermittent drought stress may have underappreciated effects on host quality for herbivores, especially phloem sap suckers (Huberty & Denno 2004). Although participants indicated they did not rely on pesticides, we did not control for total use of pesticides over time; applications of pesticides increase populations of mites and scales, can disrupt natural enemy communities and relaxation of top-down forces (Dreistadt & Dahlsten 1986). The role of supplemental feeding with bird feeders was not examined, but may be consequential for omnivorous species (e.g., Fuller et al 2008).

Although we had a small sample size, other studies of ecological effects of the plants in yard habitats used small sample sizes to discover valuable trends. For example, Burkhardt et al., (2008), using 6 pairs of yards, were able to determine that those having native plants supported significantly more caterpillars, bird abundance, avian diversity than yards without native plants. Gunnarson and Hake (1999) studied six sites in Sweden to understand the significance of bird predation in tree canopy arthropods in Sweden. Nevertheless, the team continues to study yards in additional neighborhoods having variation in tree canopy composition.

The role of habitat connectivity in urban conservation should be investigated. The distance of yards from greenspaces (parks and forest fragments) that contain residual diversity should be examined relative to the mobility characteristics of the arthropod taxa, especially the hyperdiverse soil-inhabiting taxa, many of which have very limited dispersal abilities. Arthropods and bird abundance in yards might prove to be connected with populations in nearby wooded parks. Most organisms can utilize habitat stepping-stones and these may support populations or desirable wildlife while deterring pest movement (Ignatieva & Meurk 2011). In a second small study in Hillsdale, one of the two neighborhoods, Gulick (2017) suggest that proximity of greenspaces and yards with trees makes a difference for species richness of forest-habitat bird species. Yards with trees might thus help connect greenspaces, enhancing the movement of forest species. In the future, studies that measure the insects which urban birds are actually eating would be insightful. Additionally, conducting comparative nest productivity studies in yards would help us understand how yard habitats contribute to avian reproduction.

Can a single urban yard maintain or increase biodiversity? The question of scale is important; it could be quantified with better resolution. Many species inhabiting the shrubs are not herbivorous, would most likely respond primarily to the 3-dimensional habitat structure, and making it unlikely they respond to native vs ornamental shrubs in a yard. If, as is generally believed, caterpillars are the main component of the diet for nestling birds, their abundance would most likely be determined by a mix of regional and local tree canopy patterns. We might be able to account for the smaller impact provided by shrubs and small trees in a yard by covering some shrubs to prevent bird predation, then comparing arthropod abundance on the covered plants to those plants not covered. We might compare yards with no native plants and no native tree cover, with native tree cover and no native plants. In a time-series study of the same gardens, we might learn if yards supported increasingly more arthropods and birds as the vegetation matures. Studies of specific arthropod families and specific bird species relationships might inform us about specific evolutionary predator-prey relationships (e.g. Blue Tit and caterpillar abundance, Marciniak et al. 2007).

There are several implications from this study to agencies promoting habitat yard programs. The tree canopy has great value for urban conservation. Programs promoting planting native plant habitats in urban yards could work to ensure that tree canopy in neighborhoods is maintained and enhanced. Although we did not study habitat connectivity, working to make tree canopy more continuous with tree cover in local parks is another possible step. Lastly, there is an equity issue; in Portland and other cities, neighborhoods with adequate tree canopy are often higher income areas, with low-income areas having reduced canopy. Often, these programs are not managed by the same agencies, which may put them at cross purposes.

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