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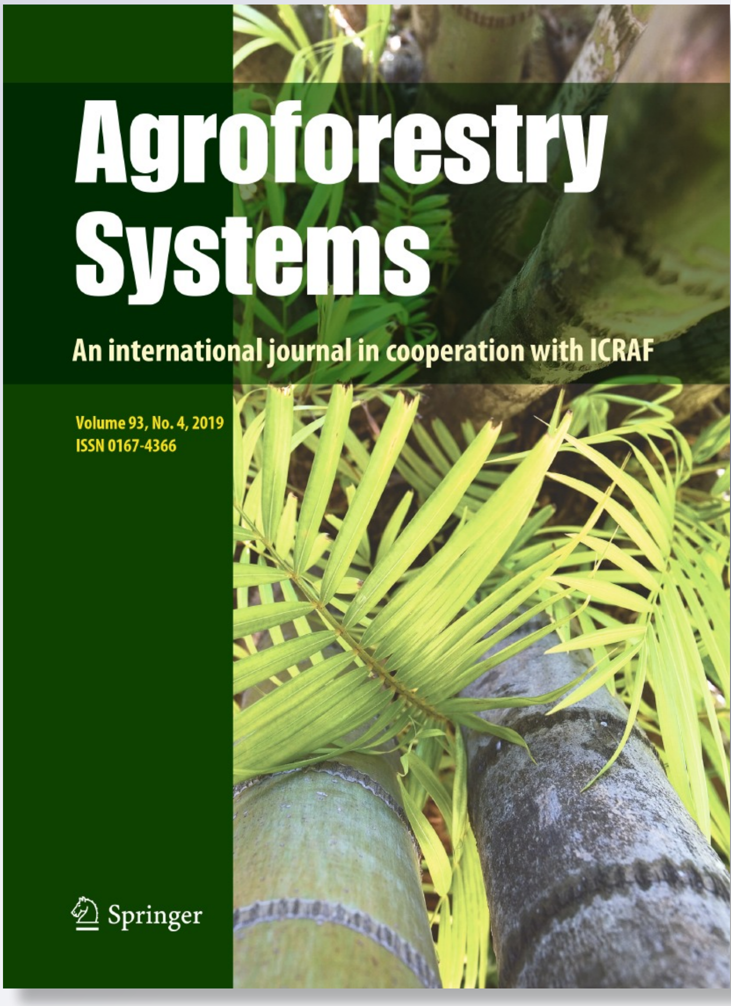

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Quantitatively characterizing the floristics and structure of a traditional homegarden in a village landscape, Sri Lanka

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Abstract Our study examined the species composition and vegetative structure of traditional homegardens within the context of the surrounding land use mosaic typical of village lands in the southwest region of Sri Lanka. We conducted interviews and spatially mapped the land uses of a single traditional village comprising over thirty households. After mapping the different land uses for each household we selected ten households and conducted a census of the vegetation of their land use areas. Land use categories included homegarden, patio, rubber, tea plantation, and secondary forest and scrub. Land holdings varied in size between 0.18 and 1.34 hectares and comprised 39% tea land, 27% homegarden, 12% patio, 17% secondary forest and scrub land, and 4% rubber plantation. We identified a total of 268 plant species on the ten properties in a total of 216 genera and 84 families across all growth habits combined (trees, shrubs, herbs and climbers). Our results show three times the plant species richness in homegardens than for any similar research on tree gardens elsewhere, but a large proportion are exotic and almost all have some kind of utilitarian purpose. The top three tree species are palms in homegardens which represent over two-thirds of the stem density and half the basal area. The conservation activities within tree gardens emphasizes the crucial—but perhaps undervalued—role local livelihoods and land management activities play in retaining tree species diversity comparable but dramatically differing in taxa as compared to the original rain forest.

Keywords Agroforestry · Rubber · Sinharaja · Tea plantation

M. Martin · K. Geiger · M. S. Ashton (✉)
School of Forestry and Environmental Studies, Yale University, New Haven, CT 06511, USA
e-mail: mark.ashton@yale.edu

B. M. P. Singhakumara
Department of Forestry and Environmental Studies, University of Sri Jayewardenapura, Nugegoda, Sri Lanka

Introduction

Homegardens across the tropics provide key goods to smallholder farmers while also contributing to conservation, pest regulation and pollination, water and nutrient cycling, erosion control, and general resilience to climate and ecosystem change (Gliessman 1990; Marsh 1998; Galluzzi et al. 2010; Galhena et al. 2013). There is no one agreed upon definition of a homegarden, but in general they are multi-story combinations of trees, shrubs, herbs and vines around homesteads that supply food, medicine, firewood, fodder, construction materials, market goods, and ornamentals.

Though centuries old, the homegarden system has continued to evolve from one generation to the next in order to suit socio-economic, cultural, and ecological needs (Caron 1995; Pushpakumara et al. 2012). In Sri Lanka, homegardens currently cover about 14.8% of the total land area and provide roughly 42% of the nation's wood and wood products (FAO 2009). Within a single property in Sri Lanka, 30–40% of the cultivated area is usually a homegarden, with a mean area of between 0.4 and 1.0 ha (Fernandes and Nair 1986; Mohri et al. 2013). This form of cultivation is therefore an integral aspect of land management in Sri Lanka, and has the potential to contribute greatly to biodiversity conservation and to a sustainable supply of goods and ecosystem services in the country.

Unfortunately tropical homegardens largely remain an ecological and economic mystery, where most research thus far gives simple species lists and descriptions (Weersum 1982; Jacob and Alles 1987; Michon and Mary 1994; Wiersum 2006). Considering how widespread this management practice is both across the tropics and within Sri Lanka, relatively little research exists quantitatively characterizing these systems, let alone examining how such systems are created and maintained, or how they function. Some authors have advocated for a more ecological approach to homegarden research, and call for computing the type of quantitative diversity indices common in studies of natural forests (Kumar and Nair 2004 and references therein). Studies have only recently begun to systematically classify the species composition of homegardens using quantitative methods such as cluster analysis in Kerala, India and Sulawesi, Indonesia (Kehlenbeck and Maass 2004; Peyre et al. 2006 and references therein). While these studies have found interesting connections between homegarden composition and socioeconomic dynamics, detailed analyses of population structure and dynamics of woody perennials remain lacking (Kumar and Nair 2004). For example, we found only one study in the southeast or south Asian regions that examined the diameter distributions of tree species (Kumar et al. 1994). In addition, there has been little evaluation of the functional diversity of Sri Lankan homegardens (Pushpakumara et al. 2012), and studies that do examine species richness lack information on the degree of heterogeneity in the study area (Kumar and Nair 2004).

This study is the first to examine homegardens from a quantitative structural perspective. In addition to following the standard methodology of producing species lists and species richness estimates, we include a detailed characterization of population structures, heterogeneity, and functional diversity. By examining the vegetation structure in this quantitative way, we are able to gain insight into the ways in which plant species are maintained over time in these systems. We also place homegarden plant diversity within the context of other small-holder land use types in order to examine the importance of the homegarden relative to both the more commercial land uses such as rubber and tea plantings and to the recovering fallows and secondary forests found on these properties. We make comparisons in floristics and structure to the original rain forest using the literature.

Materials and methods

Site description

We conducted this study in a single village, Pitekele, adjacent the 20,000 Ha Sinharaja Man and the Biosphere Reserve, a UNESCO World Heritage Site comprising a largely endemic and endangered mixed-dipterocarp rain forest in southwest Sri Lanka (Ishwaran and Erdelen 1990). The village contains thirty households that practice a mixture of land uses–rubber plantings, tea plantings, rice paddy land, homegardens, with areas of secondary forest fragments and scrub land. The village is arranged such that houses are immediately surrounded by homegardens that lie adjacent to a floodplain, where the rice paddy land is distributed. Tea and rubber plantations are usually upslope from the houses; and early successional forest and scrub land either comprise riparian area or are on the upper edges of the property adjacent the Sinharaja forest or other government lands (see Fig. 1). The land is all privately owned divided up solely among the households. An exception is the land in the floodplain that is cultivated for rice; this land is shared among families and/or households whereby different members have rights to cultivation over different years or seasons. The village is one of dozens that surround the rainforest reserve and is representative of the wider region.

Elevation varies between 300 and 700 m amsl (Ashton et al. 1997). Mean annual temperature is 26 °C with greater diurnal variation (± 2 °C) than seasonal variation. Average annual rainfall is 4000 mm, the majority of which falls during the two

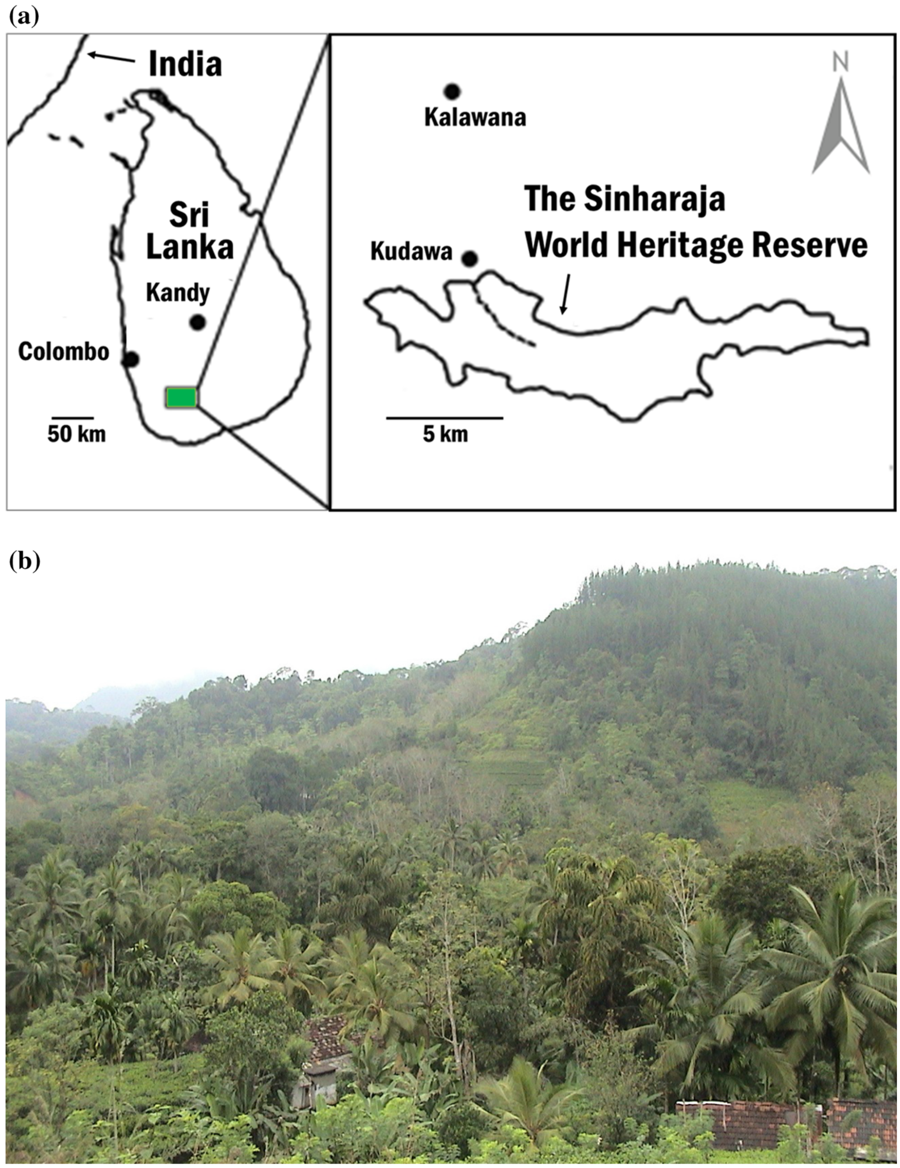


Fig. 1 **a** A map depicting the location of the village of Pitekele (adjacent the town of Kudawa) in relation to the Sinharaja World Heritage Site; and where the Sinharaja Forest lies within Sri Lanka; **b** A photograph of the village of Pitekele depicting the houses, home gardens, tea and rubber plantations; with the Sinharaja rain forest in the background

annual monsoon periods (May–July; September–December) (Ashton et al. 1997).

Sampling design

We conducted interviews and gathered field data on all thirty households within the village during June and July, 2014. We interviewed a head from each of the households regarding their land-use history, current plant uses (e.g. non-timber forest products like tea, rubber, cinnamon, and medicinal herbs), and the specific techniques of cultivating and maintaining their tree gardens. We then mapped each household's land and its uses and cover-type using GPS, and calculated the areas of each using ArcGIS. We delineated five dominant land use cover types—homegarden, patio, tea plantation, rubber planting, rice paddy, and secondary forest and scrubland—to include in our analyses. The homegarden (or core tree garden) is the area surrounding the homestead, and contains a multi-strata mix of diverse species. We separated the patio area as the small open section in front of the house where owners grow ornamentals, spices, and medicinal plants. Although the patio is not commonly included in homegarden studies, this small area immediately in front of the house warranted its own classification, as it is managed very differently than the tree garden—for example, plants are primarily cultivated in pots rather than planted in the soil itself, and the ground is often kept as bare soil or sand. Land use cover types were delineated through observation and by walking with the household member while using a GPS. While the landscape is very much an intricate mosaic, delineation of land use was usually quite clear as tea and rubber are grown in small plantation systems in the region and rarely integrated into a homegarden. If uncertainty existed in any area, we followed the designation given by the household member.

For a more detailed vegetation analysis, we then randomly selected ten of the thirty houses. Within these ten houses we identified each plant to species (when possible) and labeled the growth habit as tree, shrub, herb, or climber. These designations were based more on the structure of the plant than on a strictly botanical classification (i.e. plants such as banana are classified as shrubs even though they are not woody). For trees and shrubs, we measured height to the nearest meter using a clinometer and diameter at breast height (DBH). Our growth habit categories are tree, shrub, herb, or climber, and are.

Data analysis

We calculated total and mean areas for all land use cover types across the thirty households using ArcGIS. All other statistical calculations were computed using R (R Core Team 2016). For all diversity and richness calculations, we excluded all morpho-species that we could not identify to either genus or species (30 spp. in total), meaning that our estimates all likely underestimate the real plant diversity in this area. Using the subset of ten household vegetation data, we calculated species richness and the Shannon-Weiner diversity index both overall and by growth habit for each land cover type using the vegan package (Oksanen et al. 2016). We examine heterogeneity of vegetation composition between households (i.e. beta diversity) using the Jaccard Index, which is a measure of similarity that compares the number of species shared between two units by the total number of distinct species found across the two units (Jaccard 1901).

To examine vegetation structure across all land covers, we calculate mean density per ha and mean basal area per ha of trees and shrubs (including all unidentified morpho-species), and compare differences in land use type using one-way ANOVAs. We ran separate ANOVAs for each variable, so as to correct for potential Type I error. A Bonferonni correction was used to adjust the alpha to $p = 0.00714$ (= 0.05/7). Tukey HSD comparisons were then run within each ANOVA that was significant based on this adjusted p value to test for pairwise significant differences. To meet assumptions of homogeneity of variance (tested using the Bartlett test), a square root transformation was used on all density comparisons (for trees, shrubs, climbers, and herbs) and a log transformation was used on the shrub species richness. We also compared differences in species richness by growth habit between land use types using a Chi squared test.

Within the homegardens of the ten properties, we generate diameter distributions for the tree species by 10 cm size-classes. We examine vertical structure through a height distribution of all trees in the homegarden cover using 1 m height class intervals. For both diameter, and height distributions, the top nine species were identified based on their dominance across the ten homegardens measured. We identified the top twenty tree, shrub, and herb species, and the top fifteen climber species, using rank abundance calculations in the vegan package. For the shrubs and trees we calculate the mean basal area, mean stem density, and mean diameter (where appropriate); for all growth habits we calculate the frequency for the dominant species.

Results

Diversity and composition across land uses of the village landscape

Interviews

Interviews with the 30 household heads revealed several trends in homegarden resource management for Pitakele, Sri Lanka. Pitakele's households established their respective farms within the last 50 years, bringing with them traditional homegarden production methods. All landowners listed natural medicine, food sustenance, and cash income as important to their homegarden management. Interviews with landowners also revealed a decline in rubber production—reportedly due to excessive rain, which impedes the harvest of latex—and in cinnamon production, with a concurrent surge in tea production. Cinnamon, though present in some gardens, has all but disappeared as a means of income owing to the specialized skill required for harvest. Further, landowners reportedly favored tea as a cash crop due to heightened market access from wholesale buyers arriving daily.

Land use

We surveyed a total of 9.74 ha in the village of Pitakele of which the land use comprised 39% tea land, 27% homegarden, 12% patio, 17% secondary forest and scrub land, and 4% rubber plantation. The 30 private households that comprise the entire village have a mean of 0.56 hectares of property (not including rice paddy land which is shared). For those households that have a homegarden it comprises about 21% of their land with a mean size of 0.12 ha (range 0.07–0.33 ha) (Table 1). All households had a patio, 73% had homegardens and tea plantations, 27% had areas of secondary forest or scrub, and 10% had rubber plantings.

Diversity and composition of all land uses

We identified a total of 268 plant species on the ten properties in Pitakele in a total of 216 genera and 84 families. Tree species comprised 98 species (52% exotic), shrubs 68 species (65% exotic), herbs and grasses 76 species (96% exotic), vines 20 species

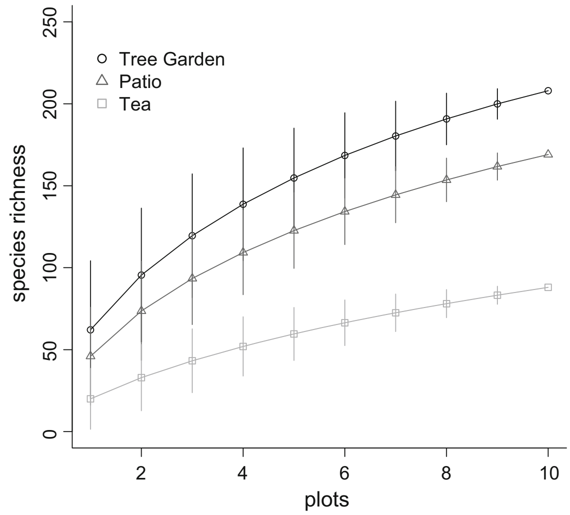


Fig. 2 Species accumulation curves for home gardens, patios and tea for the ten properties in Pitekele Village

(90% exotic), and ferns and fern allies 6 species (100% exotic). Using a jackknife estimate based on our ten households, we found an estimated total species richness in the Pitakele village of 346 species. With all land use types combined, the mean species richness by household was 94 species. Species accumulation curves demonstrate homegardens to have the greatest numbers of species, followed by the house patio (Fig. 2; Table 2). Rubber plantations have the least number of species (Table 2).

Across the ten homegardens we found 219 species in 181 genera and 73 families; in the patio areas we found 172 species in 145 genera and 61 families; in the rubber plantings we found 26 species in 23 genera and 21 families; in the tea plantations we found 88 species in 77 genera and 44 families; in secondary forest and

Table 1 Summary of land-cover across the full thirty households comprising Pitakele village, with the percent of properties with each land use cover type, the mean percent each cover comprises of a property when present, the mean area of the land use cover when present on a property (and standard deviation), and the range in areas of each land use cover type

Land use cover type	Percent of households	Percent of property	Mean area (ha)	Range (ha)
Home garden	73% (22/30)	21.0%	0.12 ± 0.09	0.07–0.33
Patio	100% (30/30)	7.0%	0.04 ± 0.02	0.01–0.12
Tea planting	73% (22/30)	30.0%	0.18 ± 0.11	0.02–0.46
Rubber	10% (3/30)	21.0%	0.12 ± 0.06	0.04–0.17
Secondary forest and scrub land	27% (12/30)	20.0%	0.12 ± 0.14	0.01–0.40
Total	NA	NA	0.56 ± 0.19	0.18–1.34

Table 2 Summary of mean diversity and vegetation structures across the different land use cover types of the ten properties. Mean species numbers here are calculated on a per property basis (not a per hectare estimate)

	Growth habit	Tree gardens (n = 10)	Patio (n = 10)	Rubber (n = 2)	Tea (n = 10)	Secondary forest and scrub (n = 5)
Density (plants/ha)	Trees	1095 ± 363^{a}	838 ± 398^{ab}	356 ± 107^{bc}	232 ± 103^{c}	608 ± 447^{abc}
	Shrubs	1025 ± 352^{a}	760 ± 300^{a}	164 ± 38^{b}	91 ± 61^{b}	213 ± 336^{b}
	Herbs	592 ± 400^{ab}	988 ± 665^{a}	66 ± 21^{bc}	66 ± 73^{c}	87 ± 109^{c}
	Climbers	107 ± 93^{a}	233 ± 244^{a}	17 ± 24^{b}	10 ± 14^{b}	5 ± 10^{b}
	Total	3737 ± 1007	3346 ± 1272	750 ± 162	481 ± 233	1121 ± 1141
Basal area (m^2/ha)	Trees	17.49 ± 9.37^{a}	7.04 ± 4.05^{b}	14.82 ± 6.2^{ab}	4.78 ± 4.44^{b}	11.92 ± 7.73^{ab}
	Shrubs	1.03 ± 1.08	0.81 ± 0.66	0.00	0.14 ± 0.26	0.14 ± 0.30
	Total	18.53 ± 8.98^{a}	7.86 ± 4.27^{b}	14.82 ± 6.2^{ab}	5.11 ± 4.38^{b}	12.07 ± 7.78^{ab}
Total species	Trees	85	58	12	43	35
	Shrubs	53	36	6	19	17
	Herbs	65	60	7	21	13
	Climbers	16	19	1	5	3
	Total	219	172	26	88	68
Percent richness	Trees	39.8%	33.7%	46.2%	48.9%	51.5%
	Shrubs	24.2%	20.9%	23.1%	21.6%	25%
	Herbs	29.7%	34.9%	26.9%	23.9%	19.1%
	Climbers	7.3%	11.0%	3.8%	5.7%	4.4%
Species richness	Trees	27 ± 8^{a}	17 ± 7^{ab}	8 ± 4^{b}	11 ± 7^{b}	12 ± 12^{b}
	Shrubs	16 ± 8^{a}	10 ± 5^{a}	4 ± 2^{ab}	4 ± 2^{b}	5 ± 7^{b}
	Herbs	18 ± 7^{a}	15 ± 5^{ab}	5 ± 2^{bc}	4 ± 4^{c}	4 ± 5^{c}
	Climbers	4 ± 2^{a}	4 ± 1^{a}	1 ± 1^{b}	1 ± 1^{b}	1 ± 2^{b}
	Total	64 ± 23^{a}	46 ± 16^{ab}	17 ± 8^{bc}	20 ± 10^{c}	21 ± 25^{bc}
Shannon diversity	Trees	2.15 ± 0.4^{a}	2.45 ± 0.4^{a}	1.35 ± 0.4^{b}	1.60 ± 0.7^{b}	1.59 ± 0.7^{b}
	Shrubs	1.85 ± 0.7	1.84 ± 0.5	0.57 ± 0.4	0.94 ± 0.5	0.71 ± 1.0
	Herbs	2.29 ± 0.4^{a}	2.13 ± 0.4^{a}	1.26 ± 0.2^{ab}	0.92 ± 0.7^{b}	0.80 ± 0.9^{b}
	Climbers	1.05 ± 0.6^{a}	1.24 ± 0.4^{a}	0	0.12 ± 0.3^{b}	0.26 ± 0.5^{b}
		3.09 ± 0.5^{ab}	3.27 ± 0.5^{a}	2.05 ± 0.4^{b}	2.17 ± 0.6^{b}	2.24 ± 0.6^{b}

Total species is the species richness found across the entire ten properties. Unknown species were excluded from all diversity calculations, but were included as stems or individuals in density and basal area estimates. Tukey's test of multiple comparisons of means denote differences among land use cover type for each growth habit (tree, shrub, herb, climber) for the different measures ($p < 0.05$). Letters shared by the same land use are not significantly different (a > b>c)

scrub land we found 68 species in 49 genera and 33 families.

The distribution in species richness between plant growth habits (i.e. the relative dominance in richness of trees, shrubs, herbs and climbers) was significantly different between land uses (Chi Square test, $X^2 = 20.82$, df = 12, $p = 0.05$). Species richness in both the homegarden and patios was highest in trees and herbs, followed by shrubs and then climbers, while in rubber, tea, and secondary forest the numbers of species of shrubs and herbs are both much lower relative to tree diversity (Tables 2, 3).

Homegardens and patios had the highest densities of plants comprising all growth habits as compared to the lowest, tea, which was seven-fold lower. Homegardens and patios had significantly more of

Table 3 Summary of ANOVA results examining differences between the land use cover types of tree garden, patio, rubber plantation, tea plantation, and secondary forest and scrub

ANOVA response variable	F-statistic (4, 31)	*p* value
Tree density[a]	11.47	7.88e−06***
Shrub density[a]	24.75	2.87e−09***
Herb density[a]	17.17	1.6e−07***
Climber density[a]	24.75	2.87e−09***
Basal area (total)	6.319	0.000771***
Basal area (trees only)	6.6	0.0015**
Species richness (total)	10.2	0.00002***
Tree species richness	6.636	0.000559***
Shrub species richness[b]	8.317	0.000112***
Herb species richness	12.71	3.1e−06***
Climber species richness	11.06	1.09e−05***
Shannon diversity	7.74	0.0002***

To correct for potential Type I error due to the number of tests we ran, we used a Bonferonni correction to adjust the alpha to $p = 0.0042$ as the minimum value for statistical significance

[a]Square root transformed

[b]Log transformed

all growth habits as compared to the other land uses (Table 3). In particular, we found significantly higher densities of trees per ha in homegardens and patios compared to all other land uses (ANOVA, $F_{5,31} = 29.64$, $p < 0.00001$; Tukey HSD, $p < 0.05$). Basal areas were predictably the lowest for tea, which were three-fold lower than the basal area of the homegarden, which was the highest (Tables 2, 3; ANOVA, $F_{5,31} = 5.44$, $p = 0.001$). Patios had basal areas that approached that of tea suggesting that though equally dense, the trees and shrubs are all relatively smaller than those of the homegarden.

Diversity, composition and structure of the homegardens

Diversity and composition

Looking at only the homegarden land use, we found a mean Jaccard Index of Similarity in Pitakele of 0.77 (range of 0.61–0.91) for all species, and of 0.65 (range of 0.37–0.80) for tree species only, signifying a 77% similarity in composition of all species between households and a 65% similarity of tree species between households. All of these richness counts and estimates exclude the morpho-species that we were unable to identify (a total 8 in homegardens), so actual richness is likely higher across all land cover types.

The top three dominant species are palms which represent over two-thirds of the stem density and half the basal area (Table 4). Interestingly only three of the top twenty trees in homegardens are native–including one of the three palms–with the other two palms (betel palm; coconut) being ancient introductions. Over fifty percent of the top twenty trees (12 out of 20) are fruit trees. All the introduced tree species are from Latin America and the far east Asia/Pacific. None are from Africa. Only three trees are regarded chiefly for their timber one of which is a naturalized weedy species that is not purposefully cultivated (*Alstonia macrophylla*).

Nine of the top twenty shrubs are native, a much higher proportion in both density and abundance as compared to trees (Table 5). Most of the shrubs are cultivated for a variety of uses—medicine, religious values (temple flowers), ornamental, spice, and vegetables. Herbs species (including grasses and ferns) represent a similar set of diverse uses though only 6 out of 20 are native (Table 6); while only one climber is native out of sixteen recorded (Table 7).

When tabulating the 75 most abundant tree, shrub, herb and climber species within a homegarden their uses are numerous: 17 have edible fruits; 15 produce sugars and spices; 17 are eaten as vegetables and 12 are ornamentals; 6 have medicinal properties; 5 are weeds; 3 are used for their timbers; 3 are used as religious offerings; and 2 is used for fodder/shade. Interestingly, only a few of these plants can be considered multi-purpose–meaning more than one use listed above.

Vegetation structure

Within homegardens, diameter distributions showed an inverse-J shape when all species were combined (Fig. 3). When viewed separately, size classes of some individual tree species also showed inverse-J distributions (e.g. *Mangifera, Nephelium, Citrus*), but others showed more irregular size-class distributions with many small juveniles but relatively few saplings and poles and then more larger individuals (e.g. *Areca, Artocarpus, Caryota, Cocos*) (Fig. 4). *Carica*, *Citrus* and *Gliricidia* were all only represented in the smaller size classes up to 15 cm DBH.

Table 4 Dominant tree species found on ten Pitakele home gardens based on rank abundance, with common names, use, mean diameter, frequency (number of households present), proportion (the number of individuals per species relative to total trees across all home gardens), tree density per hectare, and basal area per hectare

Species—trees	Common name	Use	Rank	Proportion	Frequency	Mean density/ha	Mean BA (m^2/ha)	Mean DBH (cm)
Areca catechu (E*)	Betel palm	Masticant	1	49.4	10	540 ± 284	4.67 ± 2.82	9.9 ± 4.7
Cocos nucifera (E*)	Coconut	Spice	2	6.7	10	80 ± 26	1.84 ± 0.75	15.4 ± 10.4
Caryota urens (N)	Fishtail palm	Syrup	3	3.9	10	43 ± 27	1.63 ± 1.46	20.9 ± 11.9
Artocarpus heterophyllus(E*)	Jak fruit	Fruit/timber	4	3.5	9	38 ± 39	3.93 ± 7.18	24.4 ± 21.9
Nephelium lappaceum (E)	Rambuttan	Fruit	5	3.4	10	37 ± 36	0.81 ± 0.83	12.6 ± 13.3
Mangifera indica (E*)	Mango	Fruit	6	3.1	10	33 ± 17	0.73 ± 0.88	13.6 ± 13.9
Gliricidia sepium (E)	Gliricidia	Fodder/ shade	7	2.4	9	26 ± 28	0.17 ± 0.16	8.8 ± 3.8
Alstonia macrophylla (E)	Alstonia	Timber/ weed	8	2.3	8	25 ± 26	0.16 ± 0.20	6.8 ± 8.8
Persea americana (E)	Avocado	Fruit	9	2.3	9	25 ± 38	0.53 ± 1.40	7.0 ± 7.3
Artocarpus altilis (E)	Breadfruit	Fruit	10	2.1	6	23 ± 39	0.52 ± 0.68	18.4 ± 14.3
Carica papaya (E)	Papaya	Fruit	11	2	8	21 ± 36	0.06 ± 0.08	4.5 ± 3.8
Citrus aurantiifolia (E)	Lime	Fruit	12	1.6	6	17 ± 23	0.03 ± 0.05	4.5 ± 4.1
Psidium guajava (E)	Guava	Fruit	13	1.2	5	14 ± 26	0.01 ± 0.01	2.3 ± 2.8
Durio zibethinus (E)	Durian	Fruit	14	1.2	3	13 ± 24	0.07 ± 0.11	8.8 ± 4.5
Syzgium malaccensis (E)	Jambu aya	Fruit	15	0.9	7	10 ± 11	0.03 ± 0.08	4.8 ± 5.2
Sesbania grandiflora (E)	Hummingbird tree	Vegetable	16	0.8	2	8 ± 25	0.01 ± 0.01	1.0 ± 1.4
Annona muricata (E)	Soursop	Fruit	17	0.8	6	8 ± 8	0.05 ± 0.06	6.0 ± 5.0
Pericopsis mooniana (N)	Nedun	Timber	18	0.7	2	8 ± 21	0.01 ± 0.01	4.2 ± 2.1
Tetrameles nudiflora(N)	Di Labu	Timber	19	0.5	3	6 ± 14	0.02 ± 0.01	5.3 ± 1.1
Citrus reticulate(E)	Mandarin	Fruit	20	0.5	5	6 ± 8	0.07 ± 0.18	10.8 ± 8.4

All means are shown with standard deviations

E exotic, *E** pre-colonial exotic, *N* native

Vertical canopy structure in the homegardens showed few distinct canopy layers, although there was some distinct clumping of smaller canopied species such as *Gliridicia sepium* around 2 m, and of *Citrus* species between 2 and 8 m (Fig. 5). Many of the taller canopy dominants such as *Areca catechu, Artocarpus heterophyllus,* and *Caryota urens* can be found throughout the vertical distribution reaching maximum canopy heights of 21, 20 and 20 m respectively. Similarly, mid-canopy species such as *Nephelium lappaceum* and *Mangifera indica* are found throughout the vertical distribution from sapling size through their maximum respective heights of 19 and 16 m respectively.

Discussion

This is the first study to examine quantitative structure of homegardens in a wet zone in Sri Lanka from a

Table 5 Dominant shrub species found on ten Pitakele home gardens based on rank abundance, with proportion (the number of individuals per species relative to total trees across all home gardens), frequency (number of households that comprise the species), and mean density per ha

Species—shrubs	Common name	Use	Rank	Proportion	Frequency	Density/ha
Musa spp (N)	Banana/plantain	Fruit	1	15.7	10	20 ± 45
Pavetta indica (E*)	Pavetta	Medicinal	2	15.1	8	11 ± 24
Clidemia hirta (E)	Koster's curse	Naturalized weed	3	13.3	9	91 ± 268
Coffea arabica(E)	Coffee	Beverage	4	11.3	8	135 ± 134
Cinnamomum verum (N)	Cinnamon	Spice	5	9	8	37 ± 40
Garcinia morella (N)	Goraka	Spice	6	5.4	10	114 ± 129
Manihot esculenta (E)	Manioc	Food/vegetable	7	4.9	9	55 ± 61
Codiaeum variegatum (E)	Variegated croton	Ornamental	8	3.6	9	12 ± 37
Solanum torvum (E)	Turkey berry	Naturalized weed	9	2.2	8	49 ± 59
Vigna unguiculata (E*)	Cowpea	Vegetable	10	2.1	3	8 ± 10
Abelmoschus esculentus (N)	Okra	Vegetable	11	2	3	159 ± 111
Tibouchina lepidota (E)	Glorybush	Ornamental	12	1.5	4	12 ± 20
Pandanus amaryllifolius (N)	Pandan or Rampé	Spice	13	1.2	8	153 ± 387
Jacaranda mimosifolia (E)	Jacaranda	Ornamental	14	1.2	2	9 ± 21
Cajanus cajan (N)	Pigeon pea	Vegetable	15	1.1	5	10 ± 24
Rosa spp (E)	Rose	Ornamental	16	1	4	9 ± 28
Psidium guineense (E)	Strawberry guava	Fruit	17	0.9	4	23 ± 22
Saraca asoca (N)	Ashoka tree	Sacred/temple	18	0.9	1	7 ± 11
Murraya koenigii (N)	Curry plant	Spice/medicinal	19	0.8	7	16 ± 39
Tabernaemontanta divaricata (N)	Jasmine	Medicinal/temple	20	0.7	5	21 ± 65

stand dynamics perspective in terms of diameter distribution, individual species population structure, and vertical canopy, and one of first to examine these aspects in homegarden systems across all of South and Southeast Asia. Ali and Mattson (2017a, b) examine the relationship between species diversity, tree size variation, and aboveground biomass in a dry region of the country, and find that structural diversity impacts aboveground biomass more than species diversity does. Thus they argue that the same patterns between stand structural diversity and biomass that are seen in forest ecosystems around the world can also be applied to this planted and intensively managed form of land use (Ali and Mattson 2017a). However, while these studies are key steps toward understanding the relationship between homegarden structure and function as carbon sinks, they do not go further to examine population structures from the perspective of stand dynamics or stand management. Our study is also unique in that we examine homegarden structure and diversity in the context of the adjacent rain forest and of other land-uses within the small-holder system—both in terms of quantifying heterogeneity between properties, but also comparing land uses within properties.

Homegarden diversity

With a total of at least 219 species, our study found much higher homegarden diversity in Pitakele village compared to other studies done on homegardens in Sri Lanka. Previous research shows extremely variable homegarden species richness, with total species found per region or village ranging from 27 woody species (Jacob and Alles 1987) to 43 annual and perennial plants (Sangakkara and Frossard 2016) to 55 edible species (Caron 1995) to 116 tree species (Weerahewa et al. 2012) to 125 total plant species (Perera and Rajapakse 1991) to 289 total plant species (in a suburban area) (Kumari et al. 2009). Similarly, our mean richness per homegarden of 64 species is much higher compared to other estimates of 4–18 species/

Table 6 Dominant herb species found on ten Pitakele home gardens based on rank abundance, proportion (the number of individuals per species relative to total trees across all home gardens), and frequency (number of households where the species was found)

Species—herbs	Common names	Use	Rank	Proportion	Frequency
Ananas comosus (E)	Pineapple	Fruit	1	13.8	9
Colocasia esculenta (E*)	Taro	Vegetable root	2	7.3	9
Blechnum spp (N)	Blechnum fern	Weed	3	6.1	10
Anthurium andraeanum (E)	Anthurium	Ornamental	4	5.4	8
Zingiber officinale (E*)	Ginger	Spice	5	5.2	9
Syngonium angustatum (E)	Syngonium	Ornamental	6	5	8
Sphagneticola trilobata (E)	Trailing daisy	Ornamental/invasive	7	4.8	5
Capsicum spp (E)	Peppers	Spice	8	4.7	10
Cynara scolymus (E)	Globe artichoke	Vegetable	9	4.5	6
Curcuma longa (E*)	Turmeric	Spice	10	4.2	10
Plectranthus zatarhendi (N)	Tulsi	Medicinal	11	3.5	2
Bergonia erythrophylla (E)	Bergonia	Ornamental	12	3.2	2
Crinum latifolium (N)	Trumpet lily	Ornamental	13	2.4	6
Commelina diffusa (E)	Dayflower	Weed	14	2.1	2
Centella asiatica (N)	Centella	Vegetable	15	1.8	2
Tagetes erecta (E)	Marigold	Ornamental	16	1.6	7
Cymbopogon citratus (E*)	Lemon grass	Spice/medicinal	17	1.6	5
Ipomoea batatas (E)	Sweet potato	Vegetable	18	1.6	7
Hibiscus micranthus (N)	Hibiscus	Vegetable	19	1.5	3
Alocasia indica (N)	Alocasia	Vegetable	20	1.3	5

Table 7 All climber species found in ten Pitakele homegardens based on rank abundance, proportion (the number of individuals per species relative to total trees across all home gardens), and frequency (number of households where the species was found)

Species—climbers	Common name	Use	Rank	Proportion	Frequency
Philodendron maxima (E)	Philodendron	Ornamental	1	33.3	4
Mikania cordata (E)	Bitter vine	Weed	2	19.8	9
Piper betel (E*)	Betel leaf	Spice	3	16.2	7
Psophocarpus tetragonolous (E)	Winged bean	Vegetable	4	8.4	4
Piper nigrum (E)	Black pepper	Spice	5	5.8	5
Merremia umbellata (E)	Hog vine	Medicinal	6	4.6	3
Jasminum malabaricum (E)	Jasminum	Ornamental	7	2.7	4
Clitoria ternatea (E)	Asian pigeon wings	Vegetable	8	2	3
Dioscorea trifida (N)	Indian yam	Vegetable	9	1.7	3
Piper longum (E)	Long pepper	Spice	10	1.3	2
Momordica charantia (E)	Bitter melon	Vegetable	11	1.2	3
Benincasa hispida (E)	White gourd	Vegetable	12	0.8	2
Passiflora edulis (E)	Passion flower	Fruit	13	0.8	3
Desmodium spp (E)	Tick trefoil	Ground cover	14	0.7	2
Cucurbita maxima (E*)	Squash	Vegetable	15	0.3	2
Passiflora quadrangularis (E)	Giant granadilla	Fruit	16	0.3	2

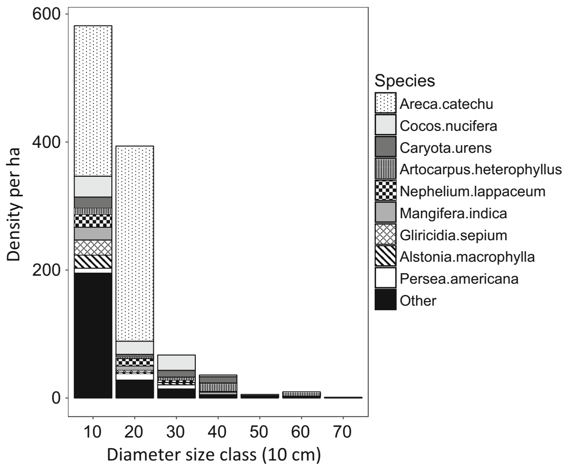


Fig. 3 Diameter distribution by 10 cm size-classes of all trees in home gardens are based on mean densities per hectare across the ten properties. The nine most dominant species are highlighted in separate color patterns, and all other trees are grouped together as "Other". For legibility, we exclude the mean density of 0.3 trees/ha of *Artocarpus* in the 120 cm size-class from the figure

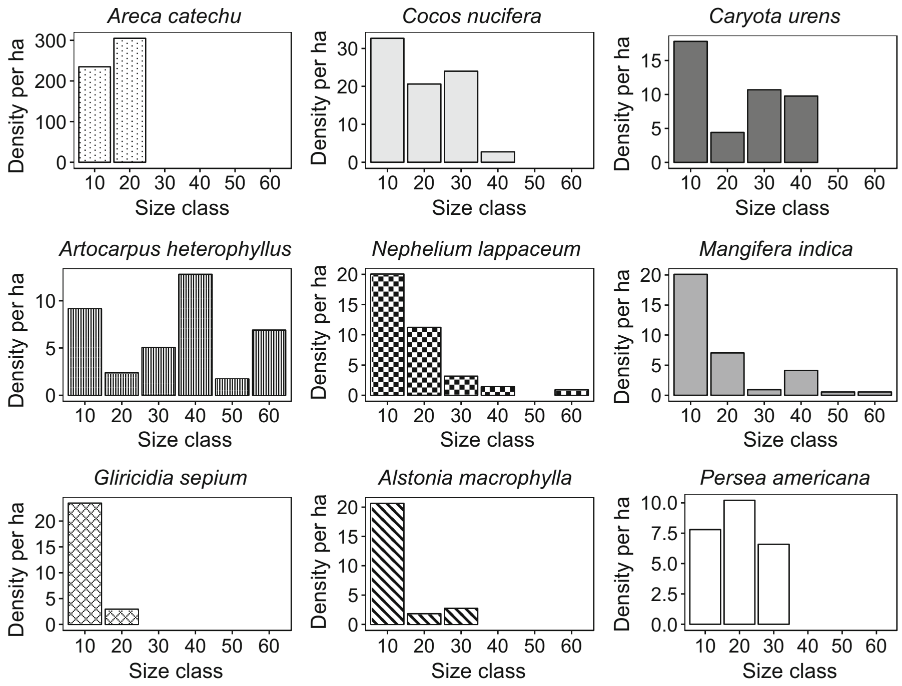
homegarden (Jacob and Alles 1987) or 42–46 species/garden (Perera and Rajapakse 1991; Lindara et al. 2006; Kumari et al. 2009). Some of these differences may be due to differences in methodology (i.e. woody perennials vs. edible plants vs. trees vs. total plants), and some may be due to underlying differences between wet, dry and intermediate climate types in Sri Lanka (e.g. Sangakkara and Frossard 2016). Pitakele is a rural village located at low elevation in a wet climate, all factors which may contribute to high species diversity levels (Ashton et al. 1997).

Few studies explicitly measure the beta diversity (or heterogeneity) of species compositions between homegardens, making it difficult to compare our findings to other regions either within Sri Lanka or the broader region of South and Southeast Asia. Using the Jaccard Index for beta diversity we found a mean similarity between homegardens of 77% for all species, and of 65% when only considering tree species. One other study—an assessment of homegardens across multiple regions in Bangladesh—used the Jaccard Index as a quantitative metric of floristic similarity for trees and shrubs, and found a mean similarity of 68% across regions (Kabir and Webb 2008). Although our level of heterogeneity is slightly lower than that found in Bangladesh, it is actually quite impressive given that our comparisons are between households within a single village rather than between different villages across an entire country. However, tropical rain forest of the same lowland wet type as the Sinharaja show plot similarities as low as 3–30% (Wilkie et al., 2004); meaning the original forest has much greater across site or stand heterogeneity than homegardens.

A study of the Sinharaja forest recorded 211 tree species > 10 cm DBH from 119 genera and 43 families, with tree richness by stand ranging between 115 and 144 species (Gunatilleke and Gunatilleke 1985). In this study five groups of twenty-five 100×50 m plots comprising a total of 25 ha were arranged across 20,000 ha of the forest, each group in a different region (Gunatilleke and Gunatilleke 1985). In another study of a contiguous very large 25 ha plot 205 tree and shrub species > 1 cm DBH were recorded (Gunatilleke et al. 2006). While this is certainly higher tree diversity than we identified in Pitakele, the total of 136 tree and shrub species found in 1.68 ha of the ten homegardens sampled, and the 166 tree and shrub species sampled in the 4.74 ha across the ten households and land uses, is close to the range of woody plant richness recorded in the adjacent 25 ha contiguous plot in the adjacent rain forest if the Pitakele plot is extrapolated to the same area sampled as the rain forest. Some authors claim that homegardens have similar levels of "diversity" to native forest based on the Shannon-Weiner Index (Senanayake et al. 2009; Bardhan et al. 2012). In Pitakele, both homegardens and patio land uses have Shannon-Weiner Index values over 3.0 (and over 2.0 for just tree species). These values are much higher than previously reported mean values for Sri Lankan homegardens of 1.55–1.77 (Senanayake et al. 2009).

Our values compare favorably with more seasonal forests such as dry dipterocarp forest in Thailand. Such forests exhibit Shannon-Weiner indices that range from 1.9 to 4.0 for tree diversity (Sahunalu et al. 1979; Aye et al. 2014). But they are low for what would be native wet evergreen mixed dipterocarp forest for the Sinharaja. Though we have no directly comparable Shannon Weiner measures of tree diversity for studies in the Sinharaja, similar forest types for wet evergreen mixed dipterocarp forests in the Andamans, India; Western Ghats, India; and Central Kalimantan, Indonesia range from 3.4 to 3.5 (Rasingam and Parathasarathy 2009), 3.14 (Varghese and

Fig. 4 Diameter distributions for the nine most dominant tree species viewed individually (patterns are consistent across all figures). Densities per hectare are means across the ten properties, and here are shown on a linear scale. Note that the x-axes represent 10 cm size-classes, and that the y-axes are scaled differently across the different species



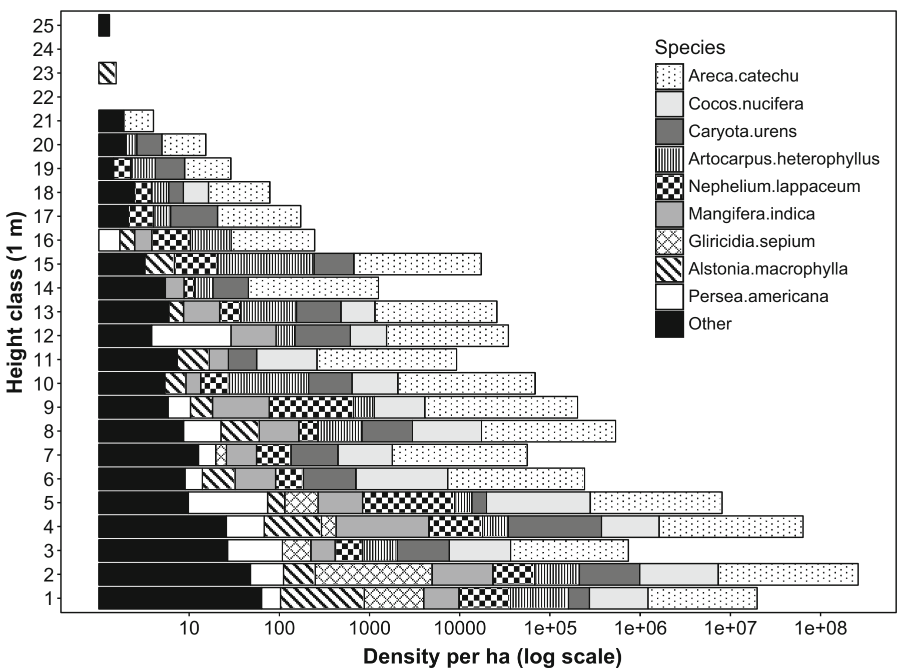


Fig. 5 Height distribution of all trees in the home gardens are based on mean densities per hectare on a log scale across the ten properties. The nine most dominant species are highlighted in separate patterns, and all other trees are grouped together as "Other"

Balasubramanyan 1999) to 4.17 (Brearley et al. 2004) respectively.

The relatively high rates of diversity across all levels of a homegarden, never-the-less, are especially promising for biodiversity conservation of species with utilitarian value. However, it is important to recognize the diversity of the homegarden is one that is a cornucopia of species that now have wide pan-tropical ranges caused by human introductions. There are relatively few native species that are purposefully cultivated in homegardens. Within the village landscape the one land use that comprises primarily native plants are the secondary forest fragments and scrub. In this land use tree and shrub species are relatively species poor per unit area and almost all classified as pioneers with only about 20% that are actually found in the original mature rain forest of the Sinharaja (Gunatilleke and Gunatilleke 1990; Gunatilleke et al. 2006). Additionally, comparisons in the composition of homegardens with the adjacent Sinharaja rain forest are very different. The Sinharaja is dominated by large tree families (Clusiaceae, Dipterocarpaceae) with over 70% endemicity and 40% of the tree species recognized as globally threatened (Gunatilleke and Gunatilleke 1990). In both the homegardens and the wider land uses endemicity and threatened species comprise a minimal component of the tree and shrub flora, and are largely dominated by one “tree” family (Palms—Arecaceae) with an over-representation of fruit trees in a wide-ranging number of families (e.g. Anacardiaceae, Moraceae, Sapinaceae). But homegardens have a far greater diversity than any other form of land-use in the region and potentially can play an important buffering role in their “novel” biodiversity conservation surrounding protected areas where native forests only represent a small fraction of the total land area.

Homegarden structure and function

In the Sinharaja rain forest, the mean density of 696 trees/ha is below the mean density in homegardens of 1159 trees/ha, while the mean basal area in the native forest of 38.7 m^2/ha is higher than the homegarden basal area of 17.49 m^2/ha (Gunatilleke and Gunatilleke 1985)—in other words, homegardens in Pitakele have more trees per unit area compared to the adjacent native forest, but these trees are smaller. The differences in density can partly be related to differences in sampling design–the rain forest plots measured only trees greater than 10 cm dbh whereas in our study all trees greater than dbh were measured. Basal area is more reflective of differences between the homegardens and rain forest as the measure is more dependent on the size dimensions and numbers of larger trees as compared to smaller ones. The homegardens only had two trees with diameters greater than just 60 cm (a 116 cm *Artocarpus heterophyllus* and a 64 cm *Vitex altissima*), while in the rain forest there were a mean of 50 trees/ha greater than 59 cm in diameter (150 girth breast height) (Gunatilleke and Gunatilleke 1985). These differences in structure are due to the type and age classes of species found in each—homegardens are dominated by palms, fruit trees, and species for firewood and basic timber needs, none of which grow to a large diameter to serve their intended purpose and most grow relatively fast and are relatively short-lived. In addition most of these gardens are relatively young, created when the village was established in the 1950’s. The large trees in the rain forest on-the-other-hand are estimated to be at least 100 years old.

The distribution of tree heights demonstrates how densely layered homegardens are in vertical space, especially considering the high diversity of shrubs, herbs, and climbers that are also integrated into these systems. The homegardens comprise an upper canopy or emergent layer (17–21 m) of palms (*Areca*, *Caryota, Cocos*); a more shade tolerant canopy of *Artocarpus heterophyllus* (< 15 m); a mid-canopy of *Mangifera* (< 13 m);, and *Nephelium* between about 4–9 m. Such canopy structure is dwarfed by the canopy heights of the adjacent rain forest that, depending upon site, reaches heights of between 30 and 40 m (Ediriweera et al. 2008).

Other studies on Sri Lankan homegardens report similar results. Perera and Rajapakse (1991) found that for Kandyan homegardens, except for the highly heterogeneous herbaceous ground layer (< 1 m), all demonstrate a vertical strata that had distinct species with the canopy layer (> 10 m) dominated by *Artocarpus heterophyllus* and *Cocos nucifera*; mid-canopy layer (2.5–10 m) dominated by *Areca catechu* and *Gliricidia sepium*; and a sub-canopy layer (1–2.5 m) dominated by *Coffea spp.*

Overall, the size-class structure of trees in Pitakele homegardens fits an inverse-J shaped curve. This distribution pattern differs from the findings of Kumar et al. (1994) in Kerala, India, where the diameter structure exhibited a slightly skewed (+) distribution with highest frequencies in the 20–30 cm size-class. We believe our diameter distribution is largely due to the diversity of tree and palm species that can occupy different canopy levels and have different maximum sizes. In natural mixed-species stands, such a diameter distribution is common even if in an even-aged successional system, especially where shade-intolerant, shallow-crowned trees dominate the upper canopy allowing more shade tolerant species to exist beneath (Oliver and Larson 1996).

Shifting economic landscape and homegarden composition

In 1989 the Sinharaja Man and Biosphere Reserve was established, and villagers were banned from harvesting forest products that had previously been easily available. This shift may have increased the importance of the homegarden as a source of food, medicine, resin, and building materials to replace wild-harvested forest products, although most homegardens were initially planted prior to this when the village was first established in the 1950's. More recently, villagers report shifting their homegarden species compositions to respond to changes in market conditions. In particular, villagers began to replace rubber and cinnamon as the dominant cash crops with tea, due to a combination of the rising price of tea and the access to wholesale tea buyers who now bring daily trucks along the road (see Navalkha 2018 for a discussion of the role of the road on the village). Landowners also reported that environmental shifts impacted this decision, as excessive rain in the past years impeded the harvest of latex, as did shifts in expertise, as cinnamon requires very specialized skills to harvest. While not the main focus of this study, qualitatively we did not observe any strong patterns regarding the impacts of gender or socio-economic position on homegarden composition. And although there are government programs in the region that promote homegarden agroforestry, these programs mostly distribute seeds or seedlings of particular species—recently with a grant of 100 cinnamon seedlings per landowner (Navalkha, pers comm)—and are unlikely to be responsible for the incredibly high diversity of species found on these properties, especially as these homegardens were initially planted well before any government programs existed.

Conclusions

Many past studies tend to focus on static assessment of a homegarden at one point in time. While it is complicated and costly to follow changes in homegardens over time, examining population structure of the tree and shrub species can be a way of examining the processes of maintaining a homegarden and its future canopy development. Our study is a beginning in characterizing quantitative structure and composition, and provides some key insights into the dynamics of homegardens and the continuous process of regenerating the canopy while maintaining a diverse portfolio of trees, palms, shrubs, and herbaceous plants.

We demonstrate that homegardens in Sri Lanka can be extremely diverse and productive systems that can contribute to biodiversity (and germplasm) conservation of economically important plant species. However, there is one important caveat: their structure and species composition are noticeably different from the original rain forest. We potentially provide knowledge for these systems to inform modern-day agriculture in regards to climate resilience and risk aversion to pests and diseases. We furthermore advocate for more studies to apply this approach across other villages in various climate zones close to forest reserves, as understanding plant species diversity and heterogeneity at a broader landscape level and across multiple land-uses is becoming increasingly important for conservation efforts.

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