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Unexploited potentials of trees outside forests: catchment landscape restoration through homegardens in Upper Mahaweli Catchment in Sri Lanka

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Abstract It is vital to explore the potential of homegardens as (HGs) one of the major Trees Outside Forest sources in the Upper Mahaweli Catchment (UMC) in Sri Lanka, to restore ecosystem services lost due to large-scale deforestation. Woody tree diversity of HGs was assessed using diversity indices in selected agro-ecological regions of UMC. Then biophysical, socio-economic and institutional factors affecting the tree diversity of HGs were assessed. Data was collected from woody tree species from a 500 random sample of HGs located in two major districts in UMC using a resource assessment survey coupled with a household survey. A multiple linear regression analysis was implemented with primary and secondary data, using the STATA software. A total of 64,163 trees were enumerated and 110 woody tree species from 38 families were recorded. Shannon index, Simpson index Margalef and Evenness index ranged from 1.51–3.21, 0.32–0.91, 2.06–8.76 to 0.34–0.71 respectively. The majority of Agro-ecological regions such as Upcountry Intermediate Zone–IU2, Mid country Intermediate Zone–IM3a, Upcountry Wet Zone–WU2b, Mid country Wet Zone–WM2a, WM2b and IM3c recorded high tree diversity. Comparatively high evenness recorded in agro-ecological regions of Upcountry Intermediate Zone–IU_2, Mid-country Wet Zone–WM_{2a} and Upcountry Intermediate Zone–IU_{3d}., is due to the rapid spreading of exotic species. According to the regression model (R^2–50%, $p < 0.01$), several factors affected positively and negatively on tree diversity. Tree diversity in the majority of HGs located in UMC was similar to some South-Asian tropical forests, indicating the high potential of HGs in the ecological restoration of degraded UMC landscapes. Therefore, incentive-based policy instruments should be introduced to enhance the tree diversity of HGs to restore ecosystem services and the ecological sustainability of the UMC.

Keywords Trees outside forest sources · Homegardens · Tree diversity · Ecosystem services · Landscape restoration · Upper Mahaweli Catchment

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Introduction

There is a growing awareness of trees outside forests (TOFs) in many countries all over the world with their uses in providing most of the ecosystem services provided by forests such as provisioning services, regulatory services and supporting services (De Foresta et al. 2013). Therefore, they have a high potential for restoration capacity of loss of ecosystem services in areas where there is a lack of tree cover due to large-scale deforestation (Carle et al. 2002). TOFs comprise of wide range of approaches and technologies for restoring degraded lands. Homegardens (HGs) in the tropics provide the best examples as these human-dominated landscapes play an important role in biodiversity conservation while sustaining livelihood (Mohri et al. 2023; Ciccarese et al. 2012; Albuquerqueet et al. 2005; Pushpakumara et al. 2012; Kumar and Nair 2004). Mixed planted tree species may raise biodiversity and ecosystem service status more than those of monoculture or few dominant tree species based conventional restoration strategies (Kelty 1992; Brockerhoff et al. 2017; Udayana et al. 2020). From a genetic and agronomic diversity point of view, HGs are well suited for in-situ conservation of plant genetic resources harbouring some wild relatives of plants and rare species while providing habitats for various faunal species (Watson 2002; Eyasu et al. 2020; Abebe 2005; Galluzzi et al 2010). In addition, tropical HGs contribute significantly to mitigating climate change impacts at the global level in different scales in various regions. In Sri Lanka, estimates on above-ground biomass carbon stocks were in dry zone HGs ranging from 10 to 55 Mg C ha^{-1} with a mean value of 35 Mg C ha^{-1}, whereas carbon stocks in wet zone HGs range from 48 to 145 Mg C ha^{-1} with a mean value of 87 Mg C ha^{-1}.

As it is evident that tropical HGs provide an array of ecosystem services they have a significant potential to compensate the loss of ecosystem services due to deforestation and forest degradation. Moreover, restoration by reforestation through forest plantation is often a costly, time-intensive process that typically takes many years to achieve the desired outcomes (Stanturf et al. 2012; Kerrie et al. 2012; Wainaina et al. 2020; Adams 2015). Moreover, the government of a country needs to allocate a large amount of funds to restore degraded sensitive landscapes such as upper catchments (Brancalion et al. 2019). In this context, the promotion of tree-rich TOFs is a cost-effective option for the governments to incorporate into restoration programs since TOFs like HGs are managed privately by individuals for their multifunctional benefits (Wainaina et al. 2020; Adams 2015; Hillbrand et al. 2017). The Upper Mahaweli Catchment (UMC) in Sri Lanka is known as the heart of the country due to its ecological and socio-economic significance to the country. It is located in the central highlands of Sri Lanka, which was declared as a sensitive area by the Soil Conservation Act of Sri Lanka (1996). The natural forest cover of the UMC has gradually decreased during the last two centuries and is subjected to large-scale deforestation due to plantation agriculture followed by extensive vegetable cultivation (Wickramagamage 1998; Hevawasam 2010). Thus, steep slopes are exposed to severe soil erosion and landslide hazards (Wickramagamage 1990). A number of negative consequences due to land use changes in UMC over the past decades have been recorded in previous studies (Hevawasam 2010; Gunawardhana et al. 2018). As a result, the majority of lands of highly sensitive UMC catchment landscape have been degraded and become a fragile state. Therefore, ecological restoration of the degraded catchment landscape is a priority concern in Sri Lanka.

As HGs are one of the major land uses in UMC and their capacity of restoring most of the ecosystem services that are provided by forests they can be considered one of the best candidates to include in catchment restoration programs. However, the real restoration capacity of ecosystem services of HGs is mainly determined by the extent as well as the qualitative characteristics of HGs. Fundamentally the qualitative characteristics are determined by the level of biodiversity (Fernandes and Nair 1986). Tree diversity is one of the important components of the biodiversity of a TOF system (Marchetti et al. 2018; Kharal and Nath Oli 2009; Tesfaye et al. 2014). A study conducted on a geospatial assessment to identify land use changes of the UMC over the past 25-year period from 1992 to 2017 quantitatively in terms of extent, revealed that the remaining forest cover of the UMC continued as more or less the same for the past 25 years in Upper Mahaweli Catchment while the area under HGs has increased by 60% (Herath et al. 2021). However, there is a shortage of research conducted to estimate tree diversity-related parameters on macro-level landscapes as catchments especially in Sri Lanka. In addition, the qualitative characteristics of HGs are determined by a number of biophysical factors reflected in a country's agroecological regions (Agro-ecological Zoning Guidelines 1996). Therefore, it is essential to assess the tree diversity of HGs in terms of agro-ecological regions. Moreover, the tree diversity of HGs is highly influenced by a number of socio-economic factors (Karunarathna and Gunatilake 2002; Korale-Gedara et al. 2012) in addition to biophysical factors. There are a number of institutional-related factors which also influence the tree diversity in TOF-related land uses including HGs (Motuma et al. 2008). Nevertheless, the evaluation of tree diversity considering those factors on the catchment landscape level is almost non-existent except few studies (Tesfaye et al. 2014; Araria et al. 2020) on the catchment scale in Sri Lanka.

Therefore, the main objective of this study was to assess tree diversity-related parameters of HGs and biophysical, socio-economic, and institutional-related factors affecting the biodiversity of HGs. The scientific information generated by this study will be highly useful for policymakers to formulate policy strategies to promote tree- rich HGs as a low-cost effective strategy to restore ecological services lost from deforested and degraded catchment landscapes.

Methodology

Study area

Upper Mahaweli Catchment is the study area which is the major catchment in Sri Lanka that covers 15% of the land in the Country (Fig. 1). It lies between longitude 80° 25′ to 81° 01″ East and latitude 6° 45′ to 7°30″ North and encompasses areas in Central, Uva and Sabaragamuwa provinces (De Silva 1997). Elevation ranges from 2717 m at Pidurutalagala (Gibbon 1990) which is the highest summit in the country, to 150 m at Rantembe. The catchment receives an average annual rainfall of about 2500 mm, western slopes of the catchment receive higher rainfall of up to 5500–6000 mm per year (Zubair 2003). The total surface area is 3110.81 km^2 with the sub-catchments of Kotmale, Victoria, Randenigala, Rantembe and Uma oya. It has a rugged topography, with a mean slope gradient varying from 5 to 30°. Five main soil types have been identified within the catchment with Red Yellow Podzolic soil is the dominant type, covering approximately 60% of the area (Hevawasam 2010) along with other soil types such as Immature Brown Loam, Reddish Brown Latasol, Mountain Regosols and Bog and Half-bog soils (Punyawardhene et al. 2003).

According to the 75% expectancy of annual rainfall, Sri Lanka can be divided into three major agro-climatic regions Wet Zone, Dry Zone and Intermediate Zone (Panabokke 1996). The Wet Zone covers the majority of the south-west region of Sri Lanka and the central highlands receive an annual rainfall above 2500 mm. The Dry Zone receives the annual rainfall less than 1750 mm and Intermediate Zone receives 1750–2500 mm of annual rainfall. Sri Lanka can be divided further into three major elevation zones such as Low Country where the elevation is below 300 m, Up Country where the elevation is above 900 m and Mid Country where the elevation ranges between 300 and 900 m. Based on these rainfall and elevation categories, there are 24 agro-climatic regions have been identified in Sri Lanka (Panabokke and Kannangara 1975). This classification system was further improved recently considering relief and soil characteristics and subdivided the major regions and classified into 46 agro-climatic regions (Punyawardhene et al. 2003). There are 21 agro-ecological sub-regions covered by UMC which were 6 sub-regions from Mid-country Intermediate Zone (IM), 6 sub-regions from Upcountry Intermediate Zone (IU), 5 sub-regions from Mid-country Wet Zone (WM) and 4 sub-regions from Upcountry Wet Zone (WU) (Fig. 2).

Methods

Primary and Secondary data collection

The first task of this assessment was to estimate the tree diversity of HGs. Primary data required to estimate tree diversity parameters was collected through a resource assessment survey carried out for selected HGs of UMC. Trees in HGs were enumerated. To select the trees the standard definition provided by the FAO to define a tree was considered. The study considered trees with diameter at breast height (DBH) for the resource assessment survey in accordance with FAO standard definition. During the resource assessment survey, the tree counts of all tree species in each selected HG in the study area were recorded. The knowledge of the researchers and the local knowledge of HG owners were utilized to identify tree species of

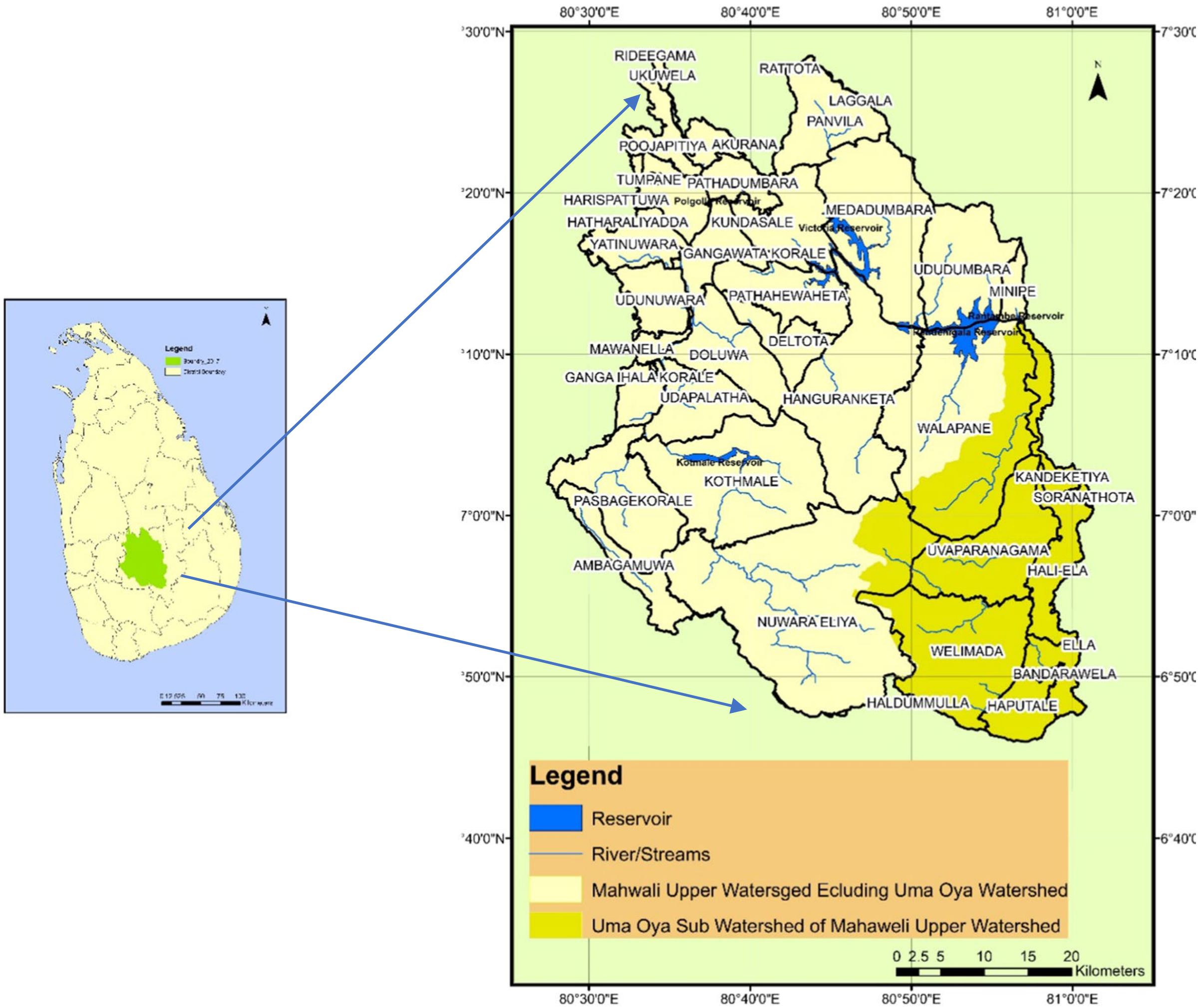


Fig. 1 Study area map—the Upper Mahaweli Catchment area. Herath HMBS (2021) *Source*

HGs. They were confirmed by consulting a Botanist. Tree species nomenclature was done using the literature (Senaratna 2001; Wijesinghe 1994).

Sampling technique: The entire HG was considered as a sample. There are three districts covered by the UMC area. However, the main land use type in Kandy and Badulla district is HGs. Nuwara-Eliya district is mainly covered with tea land use. Therefore, only the Kandy and Nuwara-Eliya districts were considered to obtain the necessary data for the analysis. Divisional Secretariate Divisions (DSDs) are the administrative level next to the districts. The Gramaseva Niladhari Divisions (GNDs) are the lowest administrative units after the DSDs. To select the HGs which were taken as samples, a stratified and randomized sampling technique was used to obtain a total of 500 samples. The Kandy and Badulla districts were taken as strata. Data from HGs from selected 28 GNDs from four DSDs in the Kandy district and twenty GNDs from four DSDs in the Badulla district were collected. The reason for selecting the random sampling technique was to capture a wide variation of HGs in terms of size, age, location and socio-economic status of HG owners.

Data analysis

Estimation of tree diversity

It is appropriate to use several indices to assess the diversity of HGs instead of using one or two (Morris et al. 2014). Tree species richness and Biodiversity of HGs in term of tree diversity was calculated using the following indices.

Shannon–Weiner diversity index (H) (Shannon and Wiener 1949; Krebs1985) is commonly used to estimate the biodiversity of a community. The equation for the Shannon Weiner index is as follows:

$$H = -\sum_{i=1}^{s} p_i ln p_i$$

where H = Index of species diversity, pi = Proportion of the ith species, s = Total number of species.

Simpson index (*D*), a measure of species dominance or evenness was obtained using the following equation (Simpson 1949).

$$D = \frac{\mathrm{N(N-1)}}{\mathrm{n(n-1)}}$$

D = Simpson reciprocal diversity index (note: D is the real 1/D for Simpson's Diversity) N = total number of organisms of all species found n = number of individuals of a particular species.

Evenness is the proportion of species or functional groups present on a site (Magurran 1988). Equitability of evenness refers to the degree of the relative dominance of each species in that area and it was calculated as:

$$\mathrm{E = H'/log\ S}$$

where, H′ is the Shannon index, S is the number of species.

Margalef index measures species richness and it is highly sensitive to sample size although it tries to compensate for sampling effects diversity index was calculated by using the formula (Margalef 1968).

$$\mathrm{D = S - 1/log\ N}$$

where, S = total number of species, N = total number of individuals.

The agro-ecological region which surveyed HGs located was taken into the analysis.

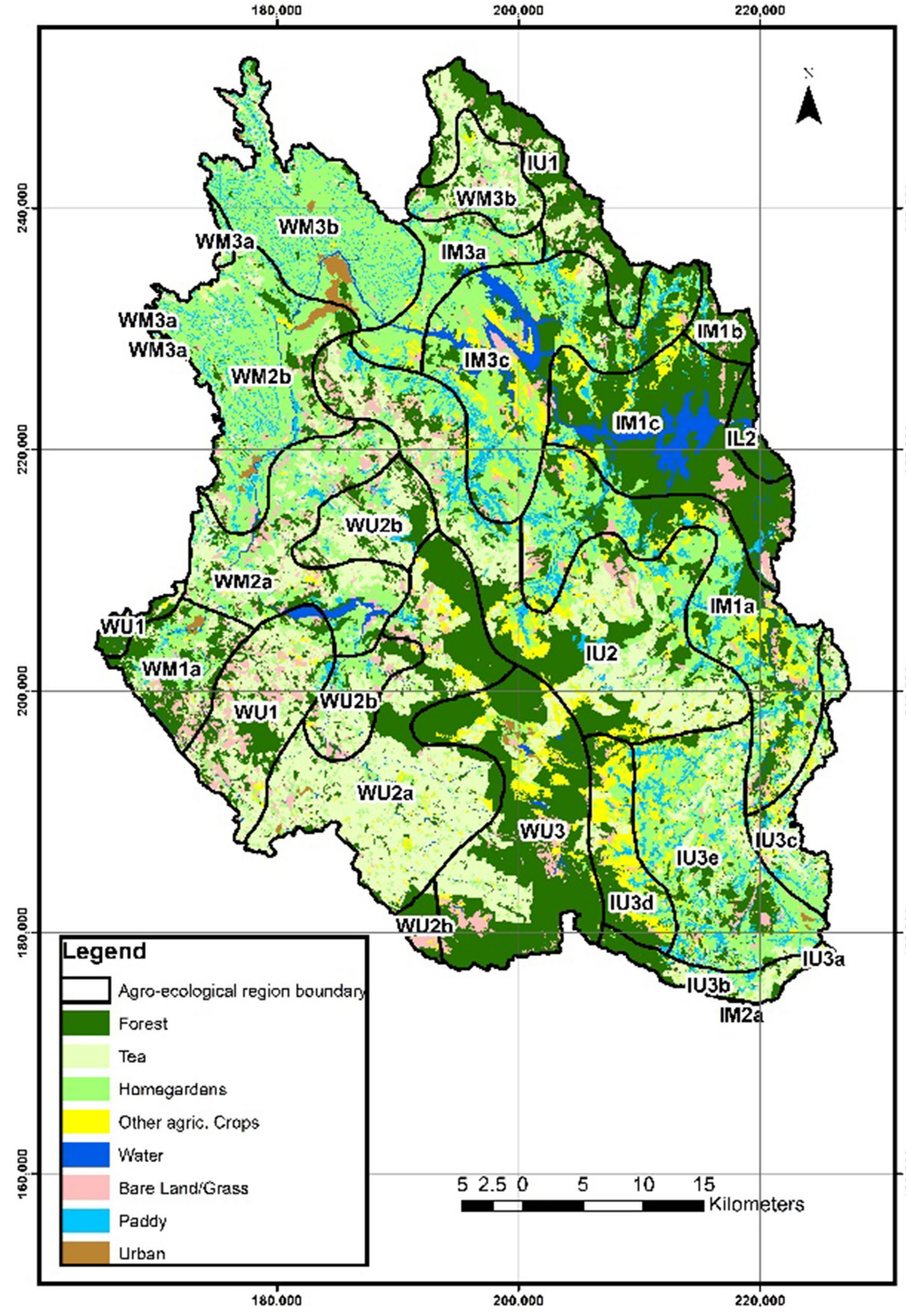
The next stage of the assessment was to analyse the biophysical, socio-economic and institutional-related factors that influence tree diversity.

Assessment of factors affecting tree diversity of HGs in UMC

Tree diversity is influenced by a number of socioeconomic factors in human-dominated landscapes like agroforestry systems (Scales and Marsden 2008; Kinyili et al. 2020; Gosling et al. 2021). In addition, agroforestry practices are determined by several socioeconomic aspects faced by HG owners. Some of them are directly or indirectly related to institutions' policies and programs implemented by the government and non-governmental organizations. Therefore, the effect of such factors on the tree diversity of HGs was assessed using multiple linear regression analysis. As a measure of tree diversity, the Shannon–Weiner diversity index was used as the predictor variable. Socio-economic, agronomic, demographic, spatial and supporting facilities received by HG owners under various institutional policies were used as independent variables such as area of the HGs (ha), age of the HGs (years), Percentage area change of the HG (%) with respect to the area of HG in 1992 and 2020, agro-ecological region that GND (Gramaseva Niladhari Division) which is the lowest administrative boundary level in Sri Lanka) located (dummy), Sub catchment where the HG is located (dummy), distance to the nearest town (km), population density of GN Division (per square km), area of HG under pepper cultivation (ha), area of HG under tea cultivation (ha), area of HG vegetable cultivation (ha), Institutional Support of the Department of Agriculture, Forest Department, Mahaweli Authority of Sri Lanka and Non-Governmental Organizations (NGO) to develop HGs. Dummy variables were used to find the relationship between institutional support and Shannon's diversity index. Those factors were regressed against the Shannon–Weiner diversity index of the home garden. The model applied for the regression analysis is mentioned below (Korale-Gedara et al. 2012).

$$Y = \alpha + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_{3++....}\varepsilon$$

where; y-is the Shannon Diversity Index, X_i: Independent variables as listed in Table 1. *βi: Coefficients*, Ɛ–stochastic error term.


180,000
200,000
220,000
240,000
160,000
N
IU1
WM3b
WM3a
IM3a
IM1b
IM3c
WM2b
IM1c
IL2
WU2b
WM2a
IM1a
WU1
IU2
WM1a
WU2a
WU3
IU3c
IU3e
IU3d
WU2h
IU3a
IU3b
IM2a
Legend
Agro-ecological region boundary
Forest
Tea
Homegardens
Other agric. Crops
Water
Bare Land/Grass
Paddy
Urban
5 2.5 0 5 10 15
Kilometers

◂**Fig. 2** Distribution of HGs in agro-ecological regions of UMC with respect to other land uses in 2017. Herath HMBS (2021) *Source*

In addition to the resource assessment, a household survey using a structured questionnaire was also carried out using the same HG owners or the households to collect primary data on socio-economic characteristics of HGs such as area of the HG, age, change area from 19,992 to 2020, the cultivated area of various types of crops etc. The secondary from secondary sources and the spatial data were derived from the Geographic Information System using the satellite images acquired in 2020 from the USGS data source. Primary and secondary data for each independent variable are listed in Table 1.

Statistical data analysis

Data were analysed using STATA statistical software to obtain estimates of the above-mentioned diversity indices. Kruskal–Wallis test (Conover 1999) was used to confirm the differences in tree diversity among agro-ecological regions and multiple linear regression analysis was done using the STATA software to identify the factors that influenced tree diversity of HGs.

Results and discussion

Tree diversity parameters

Altogether 64,163 trees were enumerated from 500 HGs surveyed in the study area of the UMC. The total area of the HGs surveyed was 132 ha. The tree density within HGs ranged from 95 to 2170 trees ha^{-1}. The high density of trees in HGs revealed in this study agrees with the earlier findings in Sri Lanka (Perera and Rajapaksha 1991). The average tree density of HG is around 502 trees/ha. The average tree density of HGs is the same as some tropical forests in Uganda: 479 trees ha^{-1} (Gerald and David 2004) and the Eastern Ghats in India: 435–767 trees ha^{-1} (Naidu and Kumar 2016). Some authors have shown that there is a similarity between Kandyan HGs to a natural forest (Perera and Rajapaksha 1991). A total of 110 woody tree species categorized under 38 families were recorded in surveyed HGs in UMC. Similar occurrence of tree species has been recorded in tropical lowland evergreen forests in South Asia (Kumar and Nair 2004; Naidu and Kumar 2016; Sirinivas and Parthasarthy 2000; Shastri et al. 2002). It indicates that woody tree species occurrence in HGs in the UMC is almost close to that of South-Asian tropical evergreen forests.

Table 2 illustrates the list of species that occurred in surveyed HGs with their scientific name, family name, number of HGs that each species occurred, the percentage of occurred and the origin of each species. According to Table 2 the highest occurred tree species in surveyed HGs (92.8%) is *Gliricidia sepium* which is well-known as a multipurpose tree species, commonly found in HGs in UMC. Altogether around 85% of tree species belonged to native and endemic tree species. Approximately 11.8% of tree species were endemic. The majority of tree species are (74.50%) native to Sri Lanka, South Asia and the South-Eastern region. The most important finding in terms of in-situ conservation of floral diversity through HGS was the presence of endemic tree species even in small numbers in HGs. However, around 15% of tree species recorded were exotic species. Different mixtures of these species occurred in surveyed HGs. The presence of a mixture of tree species enhances the restoration capacity of the UMC in the long run.

Table 3 illustrates the tree species occurrence of different taxonomic families of the surveyed HGs. According to Table 3 the most dominant species recorded was from the family Fabaceae with 11 species. Interestingly, a similar finding has been recorded in HGs in Northeast India (Das and Das 2015), where out of the total of 47 families recorded, Fabacea was the dominant family with 18 species. The highest number of trees recorded in a species was also from the family Fabaceae (Table 3). The most abundant species in HGs in the current study area was Gliricidia *sepium* which belongs to the same family. The species was widely distributed in almost all agro-ecological regions in the study area due to fast growth with high adaptation capacity for various agroclimatic conditions, required fairly less space to accommodate in HGs and easiness of maintenance (Alamu et al. 2023). It is the most popular multipurpose tree species of HGs in Sri Lanka which is being used for various purposes such as live fencing of the boundaries of HGs, supporting trees for paper, fuelwood, fodder, nitrogen-rich green manure and as a shade tree in tea. The other families that recorded the highest number

Table 1 List of independent variables

Independent variable	Units/Coding for dummy variables	Data sources
Socio-economic variables		
Area of the HG	Hectares	Household survey
Area square of the HG	Hectares	Squire root of the area of the HG
Age of the HG	Years	
Percentage area changed of the HGs	Percentage	The change of the area of HG from 1992 to 2020 as a percentage
Pepper area	Hectares	Household survey
Tea area	Hectares	Household survey
Annual crop-based area of the HG	Hectares	Household survey
Demographic variables		
Population density of the DSD	(Person/sq km2)	Department of senses and statistics Sri Lanka
Spatial variables		
Distance to the nearest town	Meters	Proximity analysis using Arc GIS
Sub catchment where HG is located	Dummy variable coded 1 for if HG located in Victoria sub-catchment otherwise 0	Proximity analysis using Arc GIS
Institutional support		
Support of the Department of the Agriculture (DOA)	Dummy variable coded 1 for receiving the support from DOA 0 for otherwise	Household survey
Support of the Department of Export Agriculture (DEA)	Dummy variable coded 1 for receiving the support from DEA 0 for otherwise	Household survey
Support of the Forest Department (FD)	Dummy variable coded 1 for receiving the support from FD 0 for otherwise	Household survey
Support of the Mahaweli Authority of Sri Lanka (MA)	Dummy variable coded 1 for receiving the support from MA 0 for otherwise	Household survey
Support of the Non-Government Organizations (NGO)	Dummy variable coded 1 for receiving the support from NGO 0 for otherwise	Household survey

of species were Anacardiaceae and Myrtaceae (6–8 species), followed by Arecaceae and Rutaceae (4–6 species). The families that occurred with a fewer number of species are also listed in Table 3.

Out of the 38 species recorded in surveyed HGs of UMC, the most abundant top 10 are species illustrated in Table 4. *Gliricidia sepium, Areca catechu, Cocos nucifera, Artocarpus heterophyllus* and *Mangifera zeylanica* were the most abundant native species in HGs. Several commercially valuable exotic timber tree species—*Swietenia macrophylla, Eucalyptus grandis, Grevillea robusta, Eucalyptus torelliana* and *Astonia macrophylla* were also represented among the top 10 species (Table 4). According to Table 4, the most prominent feature was the high tree density of individual exotic species compared to native species. The government tree planting programs implemented by the Forest Department promoted these species due to their high timber value, fast growth, and high yield. However, concerning the total number of tree species found in HGs 85% of tree species are native to Sri Lanka and the region, including endemic tree species and, only 15% are exotic species (Table 2). Similar results have been recorded from a Tree Resource Outside Forests assessment in Sri Lanka carried out for a number of districts (Ariyadasa 2002).

Tree diversity of Homegardens in agro-ecological regions of the UMC

Trees in HGs in almost all agro-ecological regions such as IM1a, IM3a, IM3c, IU2, IU3d, IU3e, WM2a, WM2b, WM3b and WU2b form complex structures with a multi-layered configuration except in IU3d. A considerable space of HGs in IU3d is allocated for vegetable cultivation. HGs in IM3a, IU2, WM2a, and

Table 2 List of species occurred in surveyed HGs and their details

Scientific Name	Family Name	No. of HGs occurred	Percentage of HGs occurred	*Origin
Psidium guajva	Myrtaceae	454	90.8	N
Gliricidia sepium	Fabaceae	461	92.2	E
Artocarpus heterophyllus	Moraceae	435	87.0	N
Mangifera indica	Anacardiaceae	420	84.0	N
Cocos nucifera	Arecaceae	417	83.4	N
Alstonia macrophylla	Apocynaceae	340	68.0	E
Areca catechu	Arecaceae	353	70.6	N
Persea americana	Lauraceae	398	79.6	N
Citrus reticulata	Rutaceae	334	66.8	N
Syzygium malaccense	Myrtaceae	330	66.0	N
Eucalyptus torelliana	Murtaceae	210	42.0	E
Cocos nucifera	Arecaceae	319	63.8	I
Swietenia macrophylla	Meliaceae	328	65.6	E
Nephelium lappaceum	Sapindaceae	302	60.4	N
Psidium cattleianum	Myrtaceae	301	60.2	N
Citrus sinensis	Rutaceae	290	58.0	N
Annona reticulata L	Annonaceae	270	54.0	N
Magnolia champaca	Magnoliaceae	265	53.0	N
Grevillea robusta	Proteaceae	250	50.0	E
Toona sinensis	Meliaceae	250	50.0	E
Caryota urens	Arecaceae	241	48.2	I
Eucalyptus grandis	Myrtaceae	234	46.8	E
Artocarpus altilis	Moraceae	213	42.6	N
Syzygium aromaticum	Myrtaceae	120	24.0	N
Filicium decipiens	Sapindaceae	110	22.0	E
Pouteria campechiana	Sapotaceae	175	35.0	N
Phyllanthus emblica	Phyllanthaceae	175	35.0	N
Garcinia mangostana	Clusiaceae	171	34.2	N
Neolitsea cassia	Lauraceae	150	30.0	I
Macaranga peltata	Euphorbiaceae	170	34.0	N
Spondias cytherea	Anacardiaceae	159	31.8	N
Tamarindus indica	Fabaceae	146	29.2	N
Thespesia populnea	Malvaceae	122	24.4	N
Anacardium occidentale	Anacardiaceae	111	22.2	N
Ceiba pentandra	Malvaceae	105	21.0	E
Santalum album	Santalaceae	93	18.6	N
Albizia lebbeck	Fabaceae	120	24.0	E
Tectona grandis	Lamiaceae	86	17.2	E
Myristica fragrans	Myristicaceae	75	15.0	N
Sesbania grandiflora	Fabaceae	85	17.0	N
Aegle marmelos	Rutaceae	100	20.0	N
Azadirachta indica	Meliaceae	70	14.0	N
Pinus	Pinaceae	50	10.0	E
Ligustrum robustum	Oleaceae	25	5.0	I
Erythrina variegata	Fabaceae	81	16.2	N
Flacourtia indica	Salicaceae	66	13.2	N

Table 2 (continued)

Scientific Name	Family Name	No. of HGs occurred	Percentage of HGs occurred	*Origin
Artocarpus nobilis	Moraceae	55	11.0	I
Careya arborea	Lecythidaceae	50	10.0	N
Terminalia bellirica	Combretaceae	45	9.0	N
Theobroma cacao	Malvaceae	40	8.0	N
Chloroxylon swietenia	Rutaceae	56	11.2	N
Canarium zeylanicum	Burseraceae	25	5.0	I
Senna spectabilis	Fabaceae	24	4.8	N
Manilkara zapota	Sapotaceae	49	9.8	N
Eriobotrya japonica	Rosaceae	47	9.4	E
Elaeocarpus serratus	Elaeaocarpaceae	85	17.0	N
Alstonia scholaris	Apocynaceae	42	8.4	E
Madhuca longifolia	Sapotaceae	41	8.2	N
Mangifera zeylanica	Anacardiaceae	39	7.8	I
Melia azedarach	Meliaceae	44	8.8	N
Loxococcus rupicola	Arecaceae	25	5.0	I
Petchia ceylanica	Apocynaceae	28	5.6	I
Limonia acidissima	Rutaceae	31	6.2	N
Averrhoa bilimbi	Oxalidaceae	29	5.8	N
Vitex negundo	Verbenaceae	20	4.0	N
Semecarpus coriacea	Anacardiaceae	25	5.0	I
Syzygium zeylanicum	Myrtaceae	15	3.0	N
Chukrasia tabularis	Meliaceae	15	3.0	N
Semecarpus subpeltata	Anacardiaceae	20	4.0	I
Ficus hispida	Combretaceae	15	3.0	N
Pterocarpus marsupium	Fabaceae	16	3.2	N
Bauhinia racemosa	Lamiaceae	10	2.0	I
Canthium coromandelicum	Rubiaceae	10	2.0	N
Durio zibethinus	Bombacaceae	25	5.0	E
Cryptocarya membranacea	Lauraceae	10	2.0	N
Terminalia arjuna	Combretaceae	19	3.8	N
Carallia brachiata	Rhizophoraceae	20	4.0	N
Ardisia elliptica	Myrsinaceae	10	2.0	N
Sesbania grandiflora	Fabaceae	20	4.0	E
Calophyllum inophyllum	Clusiaceae	14	2.8	N
Ficus collosa	Moraceae	10	2.0	N
Schleichera oleosa	Sapindaceae	12	2.4	N
Garcinia quaesita	Clusiaceae	15	3.0	I
Bridelia retusa	Phyllanthaceae	12	2.4	N
Holoptelea integrifolia	Fabaceae	8	1.6	N
Syzygium revolutum	Fabaceae	8	1.6	I
Vitex pinnata	Lamiaceae	15	3.0	N
Haldinia cardifolia	Rubiaceae	5	1.0	N
Sterculia foetida	Malvaceae	9	1.8	N
Pterocarpus santalinus	Fabaceae	10	2.0	N
Ficus benghalensis	Moraceae	10	2.0	N
Grewia tiliifolia	Malvaceae	7	1.4	N

Table 2 (continued)

Scientific Name	Family Name	No. of HGs occurred	Percentage of HGs occurred	*Origin
Bambusa vulgaris	Poaceae	10	2.0	N
Dillenia retusa	Dilleniaceae	8	1.6	I
Strychnos potatarum	Combretaceae	6	1.2	N
Cerbera manghas	Apocynaceae	6	1.2	N
Diospyros ebenum	Murtaceae	5	1.0	N
Gnidia glauca	Thymelaeaceae	4	0.8	N
Pterospermum suberifolium	Malvaceae	4	0.8	N
Pericopsis mooniana	Fabaceae	10	2.0	N
Garcinia morella	Clusiaceae	4	0.8	N
Humboldtia laurifolia	Apocynaceae	5	1.0	N
Manilkara hexandra	Sapotaceae	5	1.0	N
Antidesma Bunius	Phyllanthaceae	6	1.2	N
Acronychia pedunculata	Rutaceae	3	0.6	N
Syzygium rubicundum	Myrtaceae	4	0.8	N
Berrya cordifolia	Malvaceae	15	3.0	N
Adina cordifolia	Rubiaceae	3	0.6	N
Drypetes sepiaria	Putranjivaceae	3	0.6	N
Cynometra cauliflora	Fabaceae	4	0.8	N

*Origin: *N* Native to Sri Lanka, South Asia, South East Asian region; *I* Indigenous; *E* Exotic species

Table 3 Tree species occurrence in different taxonomic families

Number species belonged to each families	Family	Number of species
> 10 species	Fabaceae	11
6–8	Anacardiaceae, Myrtaceae	6
4–6	Arecaceae, Rutaceae	5
2–4	Sapindaceae, Apocynaceae, Sapotaceae, Meliaceae, Lauraceae, Lamiaceae,Clusiaceae, Phyllanthaceae, Combretaceae, Annonaceae, Moraceae, Rubiaceae	4
0–1	Magnoliaceae, Proteaceae, Santalaceae, Rhamnaceae, Lecythidaceae, Lecythidaceae, Lecythidaceae, Rhizophoraceae, Salicaceae, Myristicaceae, Bignoniaceae, Caricaceae,Poaceae, Euphorbiaceae, Murtaceae, Ebenaceae, Putranjivaceae, Dilleniaceae, Oxalidaceae, Myrsinaceae, Burseraceae, Bombacaceae, Verbenaceae, Elaeaocarpaceae	1

WU2b where typical HGs showed four to five vertical canopy layers. Table 5 illustrates tree diversity-related parameters estimated using Shannon Index, Simpson Index, Margalef Index and Evenness Index. The Shannon Index varied from 1.51 to 3.20 with an average of 2.30. Simpson Index varied from 0.91 to 0.32 with an average of 0.68, Margalef Index varied from 8.76 to 2.06 with an average of 6.27 and the evenness varied from 0.71 to 0.34 with an average of 0.51 in HGs in the study area. The results of the tree

Table 4 Top 10 Species based on species abundance in Homegardens surveyed in Agro-ecological regions of UMC

Species rank	Species name	Number of individuals/ha	Most abundant agro-ecological regions of surveyed HGs in UMC
1	*Gliricidia sepium*	293.34	IM1a, IM3a, IM3c, IU2, IU3d, IU3e, WM2a, WM2b, WM3b, WU2b
2	*Areca catechu*	39.12	IM1a, IM3a, IM3c, IU2, IU3e, WM2a, WM3b, WU2b
3	*Cocos nucifera*	20.45	IM1a, IM3a, IM3c, IU2, IU3e, WM2a, WM2b, WM3b, WU2b
4	*Artocarpus heterophyllus*	16.71	IM1a, IM3a, IM3c, IU2, IU3e, WM2a, WM2b, WM3b, WU2b
5	*Swietenia macrophylla*	11.53	IU2, IU3e, WM2a, WM2b, WU2b
6	*Eucalyptus grandis*	10.25	IU3d, IU3e, WM2a, WM2b
7	*Mangifera zeylanica*	7.86	IM1a, IM3a, IM3c, IU2, IU3d, IU3e, WM2a, WM2b, WM3b, WU2b
8	*Grevillea robusta*	7.46	IU2, IU3c, IU3e, WM2a, WM2b, WU2b
9	*Eucalyptus torelliana*	7.34	IU2, IU3c, IU3e, WM2a, WM2b, WU2b
10	*Astonia macrophylla*	6.97	IU3c, IU3d, IU3e, WM2a, WM2b

Table 5 Tree diversity parameters of homegardens in agro-ecological regions of UMC

Ago-ecological region	Shannon index	Simpson index	evenness index	Mrgalef index
IM1a	1.97	0.56	0.38	6.37
IM3a	2.85	0.81	0.41	8.03
IM3c	2.40	0.76	0.44	5.68
IU2	3.20	0.89	0.51	8.76
IU3c	2.31	0.71	0.39	6.05
IU3d	1.51	0.32	0.83	2.06
IU3e	1.89	0.62	0.71	4.78
WM2a	2.60	0.74	0.63	6.19
WM2b	2.50	0.71	0.41	7.07
WM3b	2.52	0.71	0.38	6.87
WU2b	2.65	0.74	0.34	7.12
Average	2.40	0.69	0.49	6.27

species diversity based on the diversity indices are comparable to the values reported by several workers in the region (Vargese and Balasubramanyan 1998; Tarakeswara et al. 2018; Saikia and Marsden 2016; Singh and Sahoo 2022).

The highest tree diversity was recorded in the IU2 agro-ecological region where world-famous tree-rich Kandyan HGs known as the Kandyan forest gardens are present. In IU2 the Shannon Index was 3.20, the Simpson Index was 0.89, Margalef Index was 8.76 and the Evenness Index was 0.51. According to the studies conducted in the regions, Bardhan et al. (2012) have shown that the Shannon–Weiner index for Natural Forest Cover in Bangladesh was 2.99. It can be seen that the tree diversity of HGs in some agro-ecological regions of UMC of Sri Lanka is somewhat similar to the natural forest in South Asian countries based on the Shannon index value. A higher Simpson value and less evenness of the surveyed HGs in the majority of agro-ecological regions in UMC implies that the tree diversity of HGs in both the Kandy and Badulla districts of UMC is high.

HGs in the majority of agro-ecological regions such as IM1a, IM3a, IM3c, IU2, WU2b and WM3b were dominated by native tree species except for a few agro-ecological regions such as IU3d, IU3e and WM2a indicate spreading of exotic species. As most of the exotic species have high timber value with a fast growth rate, they have been included in government afforestation, reforestation programs and tree planting programs in HGs too (Forestry Sector Master Plan 1995). In addition, the climate, and edaphic factors in most ecological are highly favourable for the spread of these species.

Factors affecting tree diversity using the Shannon diversity index of HGs

The results obtained from the multiple linear regression model to test the influence of various factors influencing tree diversity are described in Table 6. The model was statistically significant ($p<0.01$, $R^2=58\%$). According to the results, out of all factors listed in Table 6, factors such as area of the HG, age of the HG, area under pepper cultivation, area under tea cultivation, distance to the nearest town and support from the Department of Agriculture and Department of Export Agriculture Crops significantly influenced the tree diversity of HGs while other factors had non-significant influence.

The results show that the Shannon's Diversity Index is positively correlated ($p<0.01$) with the area of the HG while it is negatively significant ($p<0.05$) with the area squared. Therefore, it can be concluded

Table 6 Results of the multiple linear regression model

Variable	Linear model					
Dependent variable	Tree diversity of HG based on Shannon–Weiner diversity index					
Independent variables	Mean	Standard deviation	Coefficient	Standard error	*t* value	Level of significance
Scio economic factors						
Area of the homegarden	0.277	0.29	1.4888***	0.2197	6.74	0.0001
Area square of the homegarden			−0.091**	0.1438	−2.14	0.033
Age of the homegarden	76.51	27.47	−0.0012*	0.0008	−1.49	0.09
Percentage area changed of the homegarden			0.0004	0.0003	1.51	0.131
Education level of the household head			0.25463	0.15783	1.64	0.242
Pepper area	65.31	83.43	−0.0054***	0.0004	−12.36	0.0001
Tea area	35.23	41.58	−0.06896***	0.1811	−3.81	0.0001
Annual crop-based area of the homegarden	0.0186	0.0592	−2.1428***	0.3834	−5.59	0.0001
Demographic factors						
Population density of the DSD	1175	1166	0.0052*	0.0058	6.02	0.065
Biophysical factors						
Distance to the nearest town	7.885	7.301	0.011***	0.0035	3.18	0.007
Sub catchment where homegarden is located			0.0282	0.164	0.17	0.864
Institutional support						
Support of the Department of the Agriculture			−0.1029*	0.0567	−1.81	0.091
Support of the Department of Export Agriculture			0.061*	0.0691	4.35	0.068
Support of the Forest Department			−0.097*	0.0786	−0.98	0.328
Support of the Mahaweli Authority of Sri Lanka			−0.1156	0.0421	−2.793	0.207
Support of the NGO			0.3102	0.30628	4.94	0.282
Agro-ecological region effect						
Agro-ecological region–fixed effect			Yes			
Coefficient			2.0405	0.1434	14.17	0.000
No. of observations			500			
Test			F = 25.31			
Probability value			0			
R-squared			0.5818			
Adjusted R-squared			0.5588			

Level of significance–***$p<0.01$, **$p<0.05$, *$p<0.1$

that there is an inverted parabolic relationship between the Shannon index and the area of the HG. It implies that though the diversity increases with the area of HGs up to a certain extent, after that they tend to decrease, with further increase in size. These results are consistent with the findings of Korala-Gedara et al. (2012) on HGs in Sri Lanka. Interestingly, a similar observation was found during the field survey that high tree diversity in small HGs and less tree diversity in large-scale HGs. The main reason for the declining tree diversity of most of the large-size HGs is the conversion of them into crops such as pepper, tea, and annual crops especially in rural areas. Karunarathne and Gunathilake (2002) revealed that tree cultivation reduced with the increase in land holding size in rural areas in Sri Lanka.

It was observed a negative correlation between the tree species diversity and the age of the HG ($p<0.1$). A similar finding was recorded in HGs in North-East India (Soibam and Kumar 2021). During the field survey, it was observed that the land extent of old HGs is much higher than that of young HGs. Hence, the majority of the area of the old HGs has been converted into crops such as tea, pepper, banana and vegetables. There was a significant negative ($p<0.01$) relationship between the pepper cultivated area of the HG and Shannon's Diversity Index. It was observed during the field survey that the majority of the area of the medium (0.2–0.8 ha) to large (>0.8 ha) HGs have been converted into Pepper with *Gliricidia sepium*. Therefore, the number of *Gliricidia* trees on these HG was comparatively higher than the other woody tree species. Therefore, Shannon's diversity index in HG with pepper cultivation was low. Growing more pepper in the HG brings financial returns to HG owners. The Shannon's Diversity Index in HGs with tea cultivation was also relatively low and a similar relationship was found with pepper. HG owners gain financial returns by converting a certain extent of their land into tea, pepper or tea and pepper intercropping systems in some agro-ecological regions such as WM2a and IU3c of surveyed HGS in UMC.

There was a significant ($p<0.01$) negative relationship between the annual crop-based area which is the vegetable-cultivated area of the HG and Shannon's diversity index (Table 4). It also implies that the tree diversity of HG is decreased due to the conversion of a distinct area of HG into annual cash crops to gain short-term financial returns by removing trees. This tendency was observed in agroecological regions of IU3d and IU3e at higher elevations of UMC (Herath et al. 2021; Wickramagamage 1990). Shannon's Diversity Index is low in HGs in DSDs such as Bandarawela and Walimada in the Badulla district, which are extensively vegetable-growing areas of the UMC. A similar relationship has been revealed in the Nuwara-Eliya district of UMC in Sri Lanka where vegetables are grown extensively (Herath et al. 2021).

There is a positive correlation between the population density of the DSD with Shannon's diversity index a ($p<0.1$). It was observed during field investigations that HG owner's choices for selecting tree varieties in HGs are very wide in highly populated areas where diverse communities live. They try to incorporate a number of different varieties instead of a few, depending on their different requirements such as food, shade, fencing firewood, medicine and for decoration purposes. This type of composition increases Shannon's diversity index in densely populated areas.

The Shannon's diversity index has a positive relationship ($p<0.01$) with distance to the nearest town from home gardens. These findings are in conformity with those reported by Kaya et al. (2002) and Abebe (2005) for tropical HGs. HGs in rural areas which were located away from towns grow a greater number of tree species with a higher number of individuals due to the availability of sufficient space. In addition to that, the conversion of HGs into monoculture crops such as tea and pepper with *gliricidia* or any other vegetable-based annual crops is comparatively low in HGs located near the town area. Similar findings were recorded in a study conducted to assess land use conversions of HGs in UMC in Sri Lanka (Herath et al. 2021) and in rural Ghana (Appiah et al. 2019).

HG owners receive numerous support directly or indirectly from various government and non-governmental organizations for the maintenance of their HGs through various programs. Hence tree diversity of HGs is also influenced by institutional support received by HG owners. It shows that the Support of the Department of the Agriculture and Support of the Department of Export Agriculture negatively and significantly ($p<0.1$) correlated with the Shannon's diversity index. The field investigation revealed that the Department of Agriculture promotes crops, the majority are non-tree species. The Department of Export Agriculture promotes spice crops including pepper cultivation. Under such situations, Shannon's diversity index would reduce. The Forest Department is implementing a number of tree planting programs to promote tree cover in HGs as they are the major supply source of timber to the country (Forestry Sector Master Plan 1995; Ariyadasa 2002; Karunarathna and Gunathilaka 2002). However, the majority of plants they promote are exotic species as they possess high timber value, fast growth rate and are well adapted to most of the agroecological regions of UMC which finally affect tree diversity (Ministry of Mahaweli Development and Environment 2016). During the field survey, it was revealed that tree-planting programs implemented by NGOs promote native species. However, this influence was statistically not significant due to a limited number of NGO involvement.

Conclusion and recommendations

Tropical homegardens as Trees Outside Forest sources are capable of generating most of the ecosystem services provided by a forest. Catchment restoration is one of the best unexploited and under-recognized ecosystem services derived by tree rich homegardens to overcome a number of limitations encountered with afforestation and reforestation through plantation forests implemented by government and non-governmental organizations for the restoration of degraded landscapes in various countries including Sri Lanka. The capacity of restoring ecosystem services of homegardens is determined by their extent and their qualitative characteristics. Those parameters are influenced by a number of biophysical factors which are represented by the physical characteristics in agro-ecological regions which they occupy. In addition, socio-economic, demographic and institutional related factors also highly influence the tree diversity of HGs. Upper Mahaweli Catchment has a vital ecological and socio-economic significance to the Sri Lanka. However, it has been subjected to severe degradation due to large-scale deforestation over the past two centuries and practically it is impossible to enhance the natural forest cover. Homegardens are one of the major land uses in UMC which are having a great potential to compensate for the loss of ecosystem services due to deforestation and forest degradation. Homegardens in UMC have the potential to restore ecosystem services through human induce regeneration as well as natural regeneration in the long run. In this study, it was revealed that HGs in most of the agro-ecological regions of UMC possess high tree diversity based on the diversity indices. Therefore, the study suggests to promote a special incentive package to HG owners who are maintaining high tree diversity at the expense of their opportunity cost of converting them into other cash earning cultivations. This can be achieved by inclusion of HGs into climate change mitigation strategies through REDD + programs as a best potential candidate. However, relevant authorities should pay much attention to the spreading of exotic species in large numbers in certain agro-ecological regions which would result in the threat of diminishing native species. This study can be taken as a model to develop catchment restoration strategies through TOFs in other regions of the continent and the world.

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Declarations

Competing interests The authors declare no competing interests.

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