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Provisioning ecosystem services of woody tree species in agroforestry systems and their socio-economic sustainability to enhance the ecological restoration potential in agro-ecological regions of degraded tropical catchment landscapes

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Abstract: Tree-rich agroforestry systems, such as home-gardens in South Asia, offer many ecosystem services (ES) as do forests in different scales in regions across the world. Hence, they have the potential to restore ESs lost due to large-scale deforested and degraded landscapes. However, the restoration potential is highly determined by the provisioning ecosystem services (PESs) derived from woody tree species in such systems, which are crucial for the well-being of the inhabitants. Moreover, due consideration in public policy in this regard in many countries is missing due to a lack of information, especially the economic values of ESs on a macro-scale. This study estimated the monetary value of PESs derived from woody-tree species along with other major agricultural products in home-gardens in agro-ecological regions of Upper Mahaweli Catchment (UMC) in Sri Lanka. A resource assessment survey was conducted across 500 home gardens in eleven agro-ecological zones within the UMC, covering two major districts, to collect primary data. A market-based approach was used to value the PESs.

The highest mean monetary value was generated from spice trees (37%), followed by timber trees (33%), food-producing (18%), fuelwood (7%), other tree-based products, including income from multipurpose tree species (3%), and medicinal products from trees (2%). The highest mean monetary value from spices was recorded from IU_2 followed by IU3c , IM_{3a} , WM_{2a} , WU_{2b}, WM_{2b} and IM_{1a} . Based on the results, it indicates that woody trees in home-gardens have a high capacity for restoring PESs lost due to the loss of tree cover in the UMC landscape. It further enhances the socio-economic well-being of the inhabitants through generating monetary income from woody tree species. However, comparatively high mean monetary values were generated from vegetables and ornamental plants, respectively, in agro-ecological regions of IU_{3d} and IU_{3e} located in higher elevations. It will be an incentive to reduce the woody tree cover of home-gardens. A special incentive package can be proposed for the home-garden owners, to enhance the tree cover of home-gardens further, for the ecological and socio-economic sustainability of the catchment landscape in the long run.

Keywords: Homegardens, Landscape restoration, Provisioning ecosystem services, Tree-rich agro-forestry systems, Socio-economic sustainability, Agro-ecological regions

Introduction

Landscape restoration is the process of regaining ecological functionality and enhancing human well-being across deforested or degraded landscapes (Beatty et al., 2018; Maginnis et al., 2005). Among the wide range of technological options adopted for the restoration and rehabilitation of degraded landscapes, agroforestry systems are being utilized in various countries for this purpose (Stanturf et al., 2017; Gupta et al., Demel, 2020). Although they provide a wide range of ecosystem services (ESs) across the landscape, their role in restoration has been ignored for a long time by land management policies (de Foresta et al., 2013) and has been overlooked in forest assessments and policies. Tree-rich agroforestry systems such as homegardesn provide these ecosystems as forests do, but on a different scale (Crossman et al., 2016). They can be considered as important landscape elements, since they provide fundamental ecosystem goods and services and largely contribute to improving the well-being of local communities (De Foresta et al., 2013; Plieninger et al., 2012). Tree-rich agroforestry systems provide similar ecosystem services generated from forests, such as provisioning, regulatory, and cultural ecosystem services, and numerous supporting ESs to generate all types of ecosystem services. They contribute to climate change mitigation through carbon sequestration (Dhanush et al., 2025; Nair et al., 2012; Plieninger et al., 2012), absorb air pollutants in urban areas (Bottalico et al., 2017), improve water resources quality, protect against soil erosion (Udawatta & Gantzer, 2022; Borrelli et al., 2021; Jose, 2009), and also dramatically improve biological diversity (Swallow and Bo, 2006).

Homegardens around the world have a long history of providing a large number of provisioning ecosystem services (PESs) such as various kinds of foods, fruits, vegetables, spices, wood products, fuelwood, livestock products, and various other products, which are common throughout the tropics and sub-tropics, as seen in Sri Lanka (Pushpakumara et al., 2012). Homegardens are considered one of the best agroforestry systems in the world, offering a wide range of ecosystem services, as mentioned in the Millennium Ecosystem Framework, based on their multi-storeyed canopy cover and high species diversity (MEA,2005). Hence, homegardens in the Tropics have a high potential of restoring ecosystem services in degraded large-scale landscapes such as upper catchments due to deforestation, depending on their tree density and diversity. A detailed study has been conducted to evaluate the potential of home gardens for restoring ecosystem services lost due to large-scale deforestation in the environmentally sensitive Upper Mahawelai Catchment (UMC) in Sri Lanka through an ecological assessment in terms of their woody tree density and diversity (Herath et al., 2024). However, the restoration potential of ESs from tree-rich agroforestry systems is highly determined by the density and diversity of woody tree species. However, the sustainability of maintaining the woody tree species is governed by the "socio-economic benefits derived from various products generated by woody tree species and other homegarden products for the well-being of the inhabitants". Hence, the estimates on tree density and diversity of homegardens are not sufficient to formulate appropriate policies to exploit their full potential capacities of restoring ecosystem services sustainably. The direct benefits received by the inhabitants from woody tree species are crucial for the sustainability of PESs derived from them.

"Globally, homegarden agroforestry systems have been documented as an important supplemental source contributing to food and nutritional security and livelihoods from homegarden products in many research studies" (Galhena, 2013). Most of these studies have focused on socio-economic benefits derived from agricultural products such as vegetables, fruits, ornamental flowers, livestock products, etc. Tree components in a homegarden play a vital role in the provision of a large number of ESs , such as provisioning, regulatory, and cultural ESs, as well as supportive services. Moreover, the monetary values of these ESs are lacking in the literature, even though this information is essential to formulate appropriate policies and strategies to enhance tree cover in degraded landscapes.

Ecosystem valuation is necessary to enable estimates to be made available of the values of goods and services provided by an ecosystem to formulate national and international policies and incentive mechanisms (Rastogi et al., 2024; Cai & Aguilar, 2021). There is a dearth of literature on the estimation and valuation of ESs generated by agroforestry (Alam et al., 2014) with a special focus on their tree components, even though plenty of studies have been carried out to estimate the ESs provided by forests (Chiabi et al., 2022; Pechanec et al., 2027). Hence, it is vital to estimate the values of ESs generated from tree components from agroforestry systems, on a macro-scale, to understand the real restoration capacity of ESs of important tree-based agroforestry systems, such as homegardens, especially when they are distributed in degraded landscapes subjected to large-scale deforestation. Among the various ESs, provisioning services are the direct benefits obtained by people from consuming and selling products derived from homegardens for their well-being. The sustainability of the flow of ESs generated by homegardes in UMC is determined by the financial benefits acquired by homegarden owners, which are derived from tree components. Hence, it is crucial to explore the financial returns gained by homegarden owners from the tree components of their homegardens. Under such circumstances, the estimating and valuing ESs provided by woody tree species in homegardens is becoming an important way of understanding the sustainability of socio-economic benefits derived from woody trees to people (Bhandari & Upadhya, 2025; Kothke et al., 2022; Chkravarthy et al., 2019). Therefore, this study was carried out to assess the PESs provided by homegardens in Upper Mahaweli Catchment in Sri Lanka, and to estimate the monetary values of PESs generated by woody tree species in homegardens thereby deeply understanding the restoration potential of homegardes to restore the ESs lost due to large-scale deforestation that occurred over the last two centuries because of the establishment of plantation crops in large-scale in the UMC landscape.

Materials and Methods

Study area

Selected "agro-ecological zones" of the Upper Mahaweli Catchment(CMC) were considered for the study area. UMC is known as the heart of the country, considering its location in the central highlands of the country and its biophysical, including hydrological and socio-economic significance to the country since ancient times to the present generation (Tols et al., 1993). The Mahaweli carries the largest volume of water, amounting to one-seventh of Sri Lanka's total runoff, and has a catchment area that covers 15 % of the land in the country (Hewavisenthi, 1997). Thus, its capacity as the major catchment in the country should be preserved for future generations to harness multiple benefits derived from it while keeping minimal impact on the catchment. Homegardens are distributed as the "Major TOFs in the Upper Mahaweli Catchment" landscape. It has been revealed that homegardens in UMC have increased by 60% over the past 25 years, from 192-2017, while the natural forest cover remained at the same level over this period (Herath et. al, 2021). The number of negative consequences due to deforestation and land use changes in UMC has been shown by various researchers (Hevawasam, 2010; Hewavisenthi, 1997; Wcikramagamage, 1990; Gunawardhana et al., 2018). Land degradation due to soil erosion is the major environmental problem in the UMC (Wickramagamage, 1990; Hevawasam, 2010). Krishnarajah and Sumanarathne (1988) reported that the estimated soil erosion (0.05 t/ha) in well-managed homegardens in Sri Lanka is almost comparable to the annual loss of natural forests.

Data collection

The agroecological region where homegardens are located was taken as the unit of analysis since the distribution, density, and diversity of woody tree species in homegardens are mainly determined by agroecological factors. A "resource assessment survey" combined with a household survey was carried out to collect primary data during 2019-2020.

Resource Assessment Survey: "A resource assessment survey" was carried out to collect data on provisioning ecosystem services generated from woody tree species in homegardens. Initially, the primary uses of each tree species were identified by this survey. The entire homegarden was taken as the sample for this survey. Homegardens were selected randomly from ten agroecological regions of the UMC to capture a wide variation number of trees, the number of tree species, and the size of the homegarden unit within the range from 0.05- 2.5 ha, since the majority of homegardens are within this range (Pushpakumara et al., 2012; Perera et al., 1991).

By following the "standard definition provided by FAO" to define trees, the study considered only the trees in homegardens that have the DBH greater than 10cm. Tree species presence in homegardens was identified using local knowledge of the homegardens owners and the researcher's knowledge, in addition to the support of a botanical expert. The tree species taxa and nomenclature were done using literature (Aston et al., 1997; Senrathna, 2001). A list of tree species and their uses was recorded during the resource assessment survey for the entire homegarden. A total of 500 homegardes distributed in Kandy and Badulla district was the sample size. Proportional stratified random sampling technique was used as the sampling procedure to collect data from homegardens to 10 agroecological regions denoted as IM_{1a}, IM_{3a} and IM_{3c} belonging to the Mid-Country Intermediate Zone, IU_2, IU_{3c}, $IU3_d$ and IU_{3e} belonging to the Up-Country Intermediate Zone and WM_{2a}, WM_{2b}, WM_{3b} and WU_{2b} belonging to the Up-Country Wet Zone. The main reason for the selection of these agroecological regions is that homegqardens are one of the main land uses in UMC (Figure 1). In addition, from a geographical perspective, this procedure ensures spatial or demographic representativeness. It guarantees that small but significant subgroups are included in the final dataset in their correct proportions, which prevents the "dominance" of a single large group that might occur in a purely random draw.

Household Survey: The same homegarden owners or households (500) were interviewed using a semi-structured questionnaire to obtain the data to estimate provisioning ecosystem services generated from main homegarden products. Data were obtained to estimate the benefits received from selling primary homegarden products derived from woody tree species. The type of product, the amount sold in the market and the local market price of the product etc. In addition, data to estimate benefits received from livestock, vegetables and ornamental plants was also collected to have a comparative idea of provisioning ecosystem services generated from major homegardens products. A semi-structured questioner was used to obtain data from each households/ homegardens owners related to direct benefits received from timber and non-timber products from tree species of surveyed homegardens and income benefits from other main homegarden products by incorporating open ended questions. Although there are some seasonal variations in the quantities of these goods extracted from homegardens, owners were asked to provide the quantities of such goods collected and sold annually. The "local market price values" of those products were obtained through "open discussion with the respondents and other family members" and were cross-checked from the "local marketplaces". To avoid recall bias, cross-referenced the household estimates. Further, the study used price data from multiple months or years to account for seasonal price spikes to minimize the bias due to price fluctuations.

The selection of a sample size of 500 homegardens was determined through a stratified random sampling approach to ensure statistical representativeness across the diverse topographical and climatic conditions of the Upper Mahaweli Catchment (UMC). By distributing the sample across eleven distinct agro-ecological zones within two major districts, the study captures the high degree of spatial heterogeneity inherent in tropical catchment landscapes, thereby minimizing sampling bias and enhancing the generalizability of the monetary valuation. This sample size provides sufficient statistical power to distinguish between the provisioning ecosystem services (PES) of woody species and competing agricultural land uses, such as high-elevation vegetable farming, while maintaining a manageable scope for high-resolution, primary resource assessment surveys. Ultimately, N=500 balances the need for granularity in macro-scale economic data with the logistical constraints of field-level data collection, ensuring that the resulting policy recommendations for ecological restoration are grounded in a robust and diverse dataset. A summary of the types of data collected is listed in Table 1.

Table 1: Summary of the type of data collected to estimate PESs derived from home gardens

Amount of Products from tree species	Price SL Rs.	Income/ year in SL Rs
Fruits (Number, kg)	Unit price of each fruit type	Income from fruits
Spices (kg)	Unit price of each spice category	Income from spices
Timber (cubic Feet)	Price per cubic foot	Income from timber
Fuel wood (kg)	Price per cubic foot	Income from fuelwood
Vegetables (kg)	Unit price of each vegetable (Rs/kg)	Income from vegetables
Floriculture	Unit price of each plant type (Rs.)	Income from floriculture
Livestock	Unit price of each livestock product (Rs)	Income from livestock
Total income		**(………. Rs/Yr)**

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Figure 1: Distribution of home gardens in the agro-ecological regions of UMC

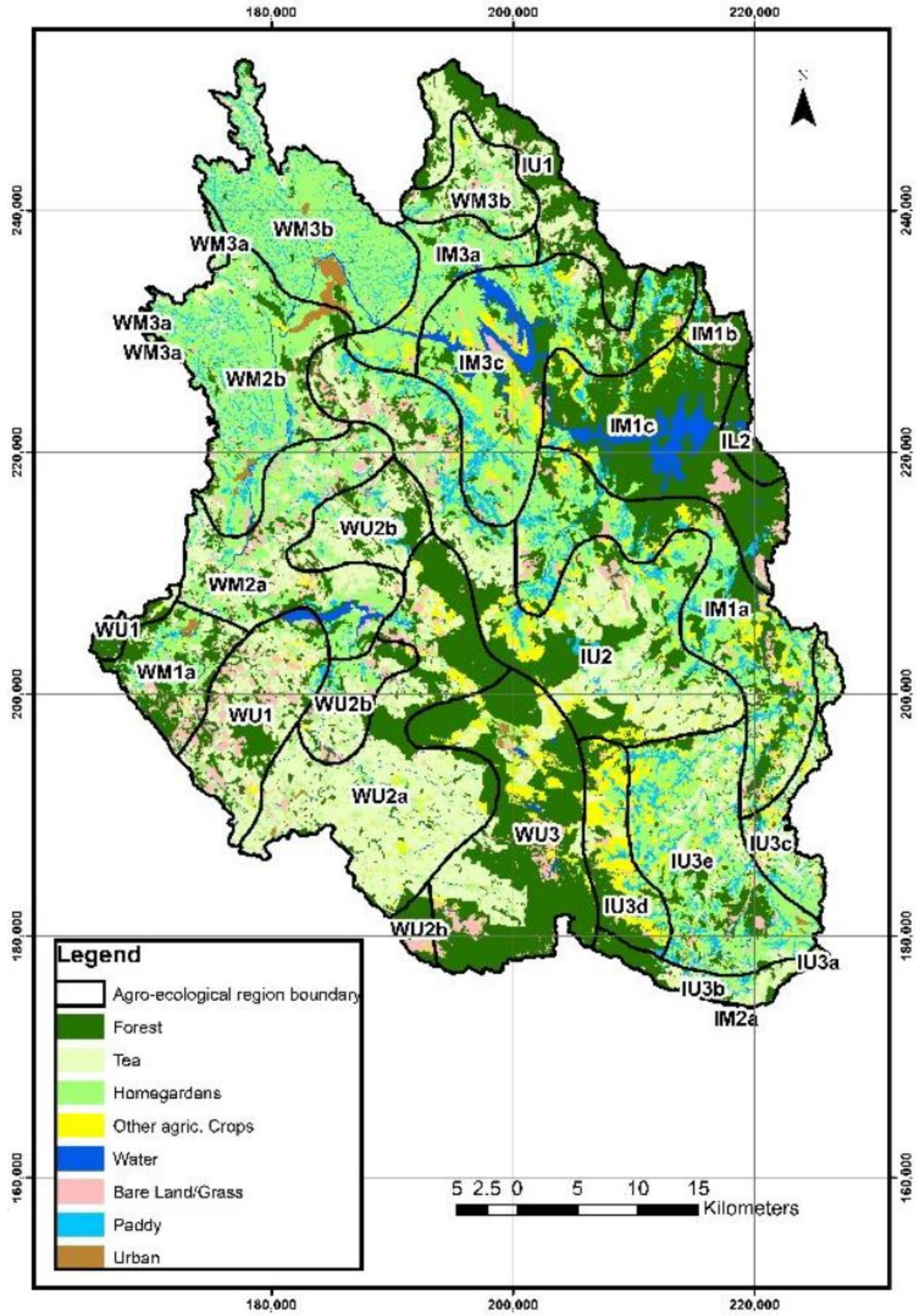

Figure 1. Distribution of homegardens in agro-ecological regions of UMC

Source: Herath, H.M.B.S. (2023)

Estimation of Provisioning Ecosystem Services (PESs)

Market price-based valuation of ecosystem services is considered a valid method of estimating the contribution of PESs to human wellbeing (Daw et al., 2016; TEEB, 2010). In general, quantification and valuing of PESs are much easier as they capture direct benefits received by homegardens owners from homegardens products, which the majority are traded in the market. In this study, the provisioning ecosystem services generated from the main homegarden products mentioned above, which are being sold in the local market, were estimated. The market price method was used for direct use values for provisioning products (Grădinaru, 2013; Singh et al., 2002; Pant et al., 2012). To estimate the "values of ecosystem services", quantities of products were obtained from tree species such as timber, food, export agriculture crops (spices), and fuel wood. In addition, benefits received from livestock, vegetables, and ornamental plants were also estimated to have a comparative idea of PESs generated from woody tree species and other major homegardens products. Monetary values of homegarden products were estimated for each homegarden simply by multiplying the annual quantity sold in the surveyed year (2020) by the local market price. Area of the homegaren was obtained from the household survey. Then the monetary value of each product was calculated on a per-hectare basis for surveyed homeardens in the agroecological regions mentioned above. Finally, the mean monetary value was estimated for each agroecological region using STATA software. Kruskal-Wallis test (Conver, 1999) was used to compare the mean monetary values of homegarden products in agroecological regions.

To minimize recall bias in valuation, instead of relying solely on owner-reported values, the study used a Market Approach. Home gardens vary in size. Comparing raw monetary output between a 0.25-acre garden and a 2-acre garden creates a "size bias." All monetary values were reported per unit area (Rs. /Ha) to allow for fair comparison across regions. Market values of products can fluctuate. Using a single-point-in-time price creates a "snapshot bias. Therefore, a weighted average annual price was used to calculate the mean monetary value.

Results and Discussion

Tree species and their provisioning ecosystem services

This study identified 110 woody tree species belonging to 38 genera in a total of 500 homegarden samples distributed among 10 agro-ecological regions of UMC. The details of tree species, such as the family name, scientific name, the species occurrence in terms of the percentage of homegardens, and the uses of each woody tree species, are listed in Table 2. Enumerated tree species provided direct benefits such as timber, food, medicinal materials, fuelwood, spices, green manure, and fodder. In addition, some tree species recorded in this study provided several other uses. For example, gum and resins and leaves of some trees were used as raw materials for industries, and some tree leaves were used for decoration purposes, fencing, shading etc. Therefore, PESs generated from each tree species based on their use categories of surveyed homegardens in UMC were recorded by this study (Table 2).

According to Table 2, the highest percentage of tree species provided timber (36.23%). This is comparable with previous findings in Sri Lanka (Ariyadasa, 2002; Karunarathna and Gunathilaka, 2002). Homegardens in Sri Lanka contribute to about 40% of the timber requirement of the country (FSMP, 1995). About 23% of tree species were used for food. The majority of them produced edible fruits (Pushpakumara et al., 2016). In addition, leaves, flowers, and tender shoots were taken to prepare food. Approximately 15% of tree species were multipurpose trees. Multipurpose tree species were very common in homegardens of both districts. Around 8% of species recorded from the surveyed homegardens provided medicinal products. Various parts of trees such as leaves, bark, roots, flowers, and fruits were needed for medicinal purposes. However, "the majority of the tree species" have the potential to be used for medicinal purposes, as they are which are being used for medicinal purposes in other countries at present, but are not being exploited in our country. According to literature, various parts of almost all tree species have a medicinal value for human beings or for animals (The World Forest Organization, 2022).

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Table 2: Woody tree species in homegardens and their provisioning ecosystem services

	Scientific Name	Percentage of HGs occurred	Use Code*
Myrtaceae	*Psidium guajava*	90.8	b,c1
Fabaceae	*Gliricidia spp.*	92.2	c,f,g,h
Moraceae	*Artocarpus heterophyllus*	87	a,bc2,f,g,h
Anacardiaceae	*Mangifera indica*	84	b,c2,f,g
Arecaceae	*Cocos nucifera*	83.4	a,b,c1,f,h
Apocynaceae	*Alstonia macrophylla*	68	a,c2,f
Arecaceae	*Areca catechu*	70.6	a,b,e,f,h
Lauraceae	*Persea americana*	79.6	b,f,
Rutaceae	*Citrus reticulata*	66.8	b,c1,h
Myrtaceae	*Syzygium malaccense*	66	b,h
Murtaceae	*Eucalyptus torelliana*	42	a,c2,f,h
Arecaceae	*Cocos nucifera*	63.8	a,b,c1,f,h
Meliaceae	*Swietenia macrophylla*	65.6	a,c2, g
Sapindaceae	*Nephelium lappaceum*	60.4	b,
Myrtaceae	*Psidium cattleianum*	60.2	b,c2
Rutaceae	*Citrus sinensis*	58	b,c1,h
Annonaceae	*Annona reticulata L.*	54	b,c1,h
Magnoliaceae	*Magnolia champaca*	53	a,c1,e,f,h
Proteaceae	*Grevillea robusta*	50	a,c2,f,h
Meliaceae	*Toona sinensis*	50	a,c2,f,h
Arecaceae	*Caryota urens*	48.2	a,b,c1,g,h
Myrtaceae	*Eucalyptus grandis*	46.8	a,c2,f.h
Moraceae	*Artocarpus altilis*	42.6	a,b,c2,f
Myrtaceae	*Syzygium aromaticum*	24	b,c1,e,i
Sapindaceae	*Filicium decipiens*	22	a,c2,f,h
Sapotaceae	*Pouteria campechiana*	35	b,1c,h
Phyllanthaceae	*Phyllanthus emblica*	35	b,c1
Clusiaceae	*Garcinia mangostana*	34.2	b,c2
Lauraceae	*Neolitsea cassia*	30	a,c2,d,f,g
Euphorbiaceae	*Macaranga peltata*	34	d,c1, g,h
Anacardiaceae	*Spondias cytherea*	31.8	b,c1,g
Fabaceae	*Tamarindus indica*	29.2	a,b,c1,f

Malvaceae	*Thespesia populnea*	24.4	c1,d,f,g,h
Anacardiaceae	*Anacardium occidentale*	22.2	b,c1
Malvaceae	*Ceiba pentandra*	21	a,f,h
Santalaceae	*Santalum album*	18.6	c1,i
Fabaceae	*Albizia lebbeck*	24	a,c2,f,h
Lamiaceae	*Tectona grandis*	17.2	a,c2,f
Myristicaceae	*Myristica fragrans*	15	b,c1,e,h
Fabaceae	*Sesbania grandiflora*	17	b,c1,d,g,h
Rutaceae	*Aegle marmelos*	20	b,c1,h
Meliaceae	*Azadirachta indica*	14	a,c1,h
Pinaceae	*Pinus caribaea*	10	a,c2,h
Oleaceae	*Ligustrum robustum*	5	a,f, h
Fabaceae	*Erythrina variegata*	16.2	c1,d,f,g.h
Salicaceae	*Flacourtia indica*	13.2	b,c1
Moraceae	*Artocarpus nobilis*	11	a,b,c1,f
Lecythidaceae	*Careya arborea*	10	b.c1.f,h
Combretaceae	*Terminalia bellirica*	9	a,b,c1
Malvaceae	*Theobroma cacao*	8	b,c2,f,h
Rutaceae	*Chloroxylon swietenia*	11.2	a,c2
Burseraceae	*Canarium zeylanicum*	5	a,c1,d,h,f
Fabaceae	*Senna spectabilis*	4.8	a,c1,f
Sapotaceae	*Manilkara zapota*	9.8	b,c1
Rosaceae	*Eriobotrya japonica*	9.4	a,b,c1,f
Elaeaocarpaceae	*Elaeocarpus serratus*	17	a,b,c2
Apocynaceae	*Alstonia scholaris*	8.4	a,c1,f,h
Sapotaceae	*Madhuca longifolia*	8.2	b,c1, f,h
Anacardiaceae	*Mangifera zeylanica*	7.8	b,c1, f
Meliaceae	*Melia dubia*	8.8	a,c2, f
Arecaceae	*Loxococcus rupicola*	5	b,c1,h
Apocynaceae	*Petchia ceylanica*	5.6	a,c1, f
Rutaceae	*Limonia acidissima*	6.2	b,c1
Oxalidaceae	*Averrhoa bilimbi*	5.8	b,c1
Verbenaceae	*Vitex negundo*	4	a,c1,h
Anacardiaceae	*Semecarpus coriacea*	5	a,c1, f
Myrtaceae	*Syzygium zeylanicum*	3	a,c2, f
Meliaceae	*Chukrasia tabularis*	3	a,c2, f
Anacardiaceae	*Semecarpus subpeltata*	4	a,c1, f
Combretaceae	*Ficus hispida*	3	a,c1, f
Fabaceae	*Pterocarpus marsupium*	3.2	a,c1, f
Lamiaceae	*Bauhinia racemosa*	2	a,c1, f
Rubiaceae	*Canthium coromandelicum*	2	a,c2, f
Bombacaceae	*Durio zibethinus*	5	a,c1, f
Lauraceae	*Cryptocarya membranacea*	2	a,b,c1,h

Combretaceae	*Terminalia arjuna*	3.8	a, c1
Rhizophoraceae	*Carallia brachiata*	4	a,f, c1
Myrsinaceae	*Ardisia elliptica*	2	a,b,c1
Fabaceae	*Sesbania grandiflora*	4	b,c1,d,g,h
Clusiaceae	*Calophyllum inophyllum*	2.8	a,f
Moraceae	*Ficus collosa*	2	a,d
Sapindaceae	*Schleichera oleosa*	2.4	a, c1
Clusiaceae	*Garcinia quaesita*	3	b,c1,d,e
Phyllanthaceae	*Bridelia retusa*	2.4	a,b,f..c1
Fabaceae	*Holoptelea integrifolia*	1.6	a,c1,h
Fabaceae	*Syzygium revolutum*	1.6	a,c1,h
Lamiaceae	*Vitex pinnata*	3	a,c1,h
Rubiaceae	*Haldinia cardifolia*	1	a,c2,h
Malvaceae	*Sterculia foetida*	1.8	a,c1,h
Fabaceae	*Pterocarpus santalinus*	2	c1,h
Moraceae	*Ficus benghalensis*	2	a,c1
Malvaceae	*Grewia tiliifolia*	1.4	a,f
Poaceae	*Bambusa vulgaris*	2	a,f, h
Dilleniaceae	*Dillenia retusa*	1.6	a,c1
Combretaceae	*Strychnos potatarum*	1.2	a,c1
Apocynaceae	*Cerbera manghas*	1.2	a,c1
Murtaceae	*Diospyros ebenum*	1	a,c2
Thymelaeaceae	*Gnidia glauca*	0.8	a,c2
Malvaceae	*Pterospermum suberifolium*	0.8	a,c1
Fabaceae	*Pericopsis mooniana*	2	a,c2
Clusiaceae	*Garcinia morella*	0.8	a, b,c1
Apocynaceae	*Carissa carandas*	1	a, b,c1
Sapotaceae	*Manilkara hexandra*	1	a, b,f,c1
Phyllanthaceae	*Antidesma Bunius*	1.2	a, b,f,c2
Rutaceae	*Acronychia pedunculata*	0.6	a, b,f,c1
Myrtaceae	*Syzygium rubicundum*	0.8	a, b,f,c1
Malvaceae	*Berrya cordifolia*	3	a, b,f,c2
Rubiaceae	*Adina cordifolia*	0.6	a, b,f,c2
Putranjivaceae	*Drypetes sepiaria*	0.6	a, b,f,c1
Fabaceae	*Cynometra cauliflora*	0.8	a, b,c1

*Provisioning ecosystem services: Timber -a, Food/Edible Fruit - b,
Current Medicinal use – c1, potential medicinal use -c2 Green manure _d, Spices -e
Fuelwood - f, Fodder -g, Other -h (industry, fencing, shading, decoration etc.)

Approximately 10% of tree species directly use fuelwood with high calorific value. This figure is compatible with other findings in Sri Lanka (Ariyadasa, 2002; Heenkenda, 2014). However, dead materials and pruned branches of any tree species can be used as fuelwood. Approximately 3% of tree species produced valuable spices that generated cash income to the homegarden owners and foreign earnings to the country. Around 2 % of tree species were used for green manure for paddy and vegetable crops. Nearly 3% of tree species were used for fodder, mainly to feed cattle. Approximately 3% of tree species belonging to other categories were utilized for various purposes, including raw materials for industries, fencing, shading, and decoration purposes.

“Monetary Values of Provisioning Ecosystem Services” Provided by Homegardens in agroecological regions of UMC

Figure 2 illustrates the mean values of PESs provided by homegardens in different “agro-ecological regions of UMC”. According to the “Kruskal-Walli’s test”, there is a significant difference ($p< 0.05$) in mean monetary values of provisioning ecosystem service or direct benefit obtained from homegarden products among agroecological regions of UMC. The highest mean value of PESs was generated by spices in homegardens in most of the agro-ecological regions. The highest mean value of monetary income from spice tree species which were recorded from majority of agroclimatic regions in the UMC such as IU_2 (around Rs.114020.00 ± 45600.00 $ha^{-1}Yr^{-1}$) followed by IU3c (Rs.110560.00 ± 51680.00 $ha^{-1}Yr^{-1}$), IM_{3a} (Rs. 105650.00 ± 82564.50 $ha^{-1}Yr^{-1}$), WM_{2a} Rs.102560.00 ± 83520.00 $ha^{-1}Yr^{-1}$), WU_{2b} (Rs. 82500.00 ± 45800.00 $ha^{-1}Yr^{-1}$), WM_{2b} (Rs. 70500.00 ± 28900.00 $ha^{-1}Yr^{-1}$), and IM_{1a} (Rs. 45456.00 ± 25635.50 $ha^{-1}Yr^{-1}$).

Homegarden owners earn income in these regions from spice trees, such as clove (*Syzygium aromaticum*), nutmeg (*Myristica fragrans*), and aricanut (*Areca catechu*). A smaller number of *Syzygium aromaticum* and *Myristica fragrans* trees in homegardens have been recorded due to the size, management aspects, and other socio-economic reasons such as the price fluctuations and access to the market. Even though the homegardens have a smaller number of these trees in homegardens they have a high potential to earn higher cash income, depending on the provisioning ecosystem service they provide. Income from paper (Piper *nigrum*) was also added to calculate the total benefits from spices. In general, pepper is grown with the support of a tree such as *Gliricidia sepium, Gravillea robusta,* and Erythrina *variegate*. Growing pepper increases the tree cover of homegardens. Homegarden owners obtain direct benefits from peeper cultivation in the majority of agroecological regions, such as IM_{3a}, IM_{3c}, IU_2, IU_{3c}, IU_{3e}, WM_{2a}, $WM_{2b,}$ and WU_{2b}. Spices in Sri Lanka are famous for their unique flavours. They have a higher export earning capacity to earn foreign exchange under the current economic crisis, prevailing throughout the country due to the deficit of trade balance. In addition to providing spice products, these trees provide many other ecosystem services which are not traded through the market but should incur a much higher total value, because these trees generate other ecosystem services such as carbon sequestration, storm water protection, and soil erosion control etc. These services are essential for the ecological as well as “socio-economic sustainability” of the catchment.

The mean monetary values from vegetables were comparatively higher in homegardens belonging to agroecological regions of IU_{3d} (Rs.. 102760.00 ± 75230.50 $ha^{-1}Yr^{-1}$) and IU_{3e} (Rs. 100160.00 ± 82350.50 $ha^{-1}Yr^{-1}$). Direct benefits from ornamental plants are also high in these two regions of IU_{3d} (Rs. 95230.00 ± 40350.00 $ha^{-1}Yr^{-1}$) and IU_{3e} (Rs. 100160.00 ± 55350.00 $ha^{-1}Yr^{-1}$). Agroclimatic factors of these regions are highly favourable for vegetable growing and floriculture, which have been lucrative businesses in these regions for a number of decades. Therefore, there is a tendency to convert the majority of the space of homegardens into vegetable and floriculture, and it is not favourable for the catchment ecological sustainability since these agroclimatic regions are located at higher elevations above 1500m in the upper catchment headwater area of the UMC (Herath et al., 2021). The dense natural montane forest cover of these regions had been severely deforested due to the conversion of them into large-scale tea cultivation for centuries, which was introduced by the British during the colonial period. Subsequently, most of the land in these regions has been converted to vegetable cultivation. The soil erosion in these regions is at a higher level due to tea cultivation and intensive vegetable cultivation (Hweawasam, 2010; Wickramagamage, 1990). Tree cover in these regions is crucial as it covers a majority of the headwater area of the UMC, located in higher elevation, and it is a highly sensitive and fragile area of the country as well. Considering these issues, the forest ordinance was amended in 1938 to ban the clearing of forests above 1500m elevation for plantations and to be gradually converted to indigenous species (FSMP, 1995). Hence, homegardens in such areas play a vital role in enhancing the tree cover of the UMC.

Homegardens in most of the agro-ecological regions generate high income from timber trees which is next to the income from spice trees, and were recorded from IU_2 (Rs. 85700.00 ± 28450.00 $ha^{-1}Yr^{-1}$), IU_{3c} (Rs. 78250.00 ± 20630.00 $ha^{-1}Yr^{-1}$), WM_{2b} (Rs. 88500.00 ± 25600.00 $ha^{-1}Yr^{-1}$), IM3a (62000.00 ± 23450.00 $ha^{-1}Yr^{-1}$), WU_{2b} (Rs. 58650.00 ± 20620.00$ha^{-1}Yr^{-1}$), IM1a (52463.50 ± 21345.50 $ha^{-1}Yr^{-1)}$ and WM_{2a} (Rs. 48550.00 ± 25400.00 $ha^{-1}Yr^{-1}$).

All agroecological regions of the UMC are favourable for tree growing, even though their distribution is determined by, many biophysical and socio-economic factors (Herath et.al., 2023). High earning capacity from timber trading is an incentive for home garden owners to grow trees in their homegardens. Homegardens in these regions received additional income from fuelwood during timber selling. However, it was revealed through the household survey that homegarden owners face a lot of challenges in earning income from timber, such as the long gestation period, lack of planting materials, stringent regulations for timber felling and transportation, etc. Moreover, a higher value of provisioning services from timber is an incentive for the homegarden owner to grow trees, thus it is highly favourable to enhance the ecological and socio-economic restoration capacity of the catchment landscape in the long run.

Figure 2: Mean monetary values of provisioning ecosystem services provided by surveyed homegardens in agro-ecological regions of UMC

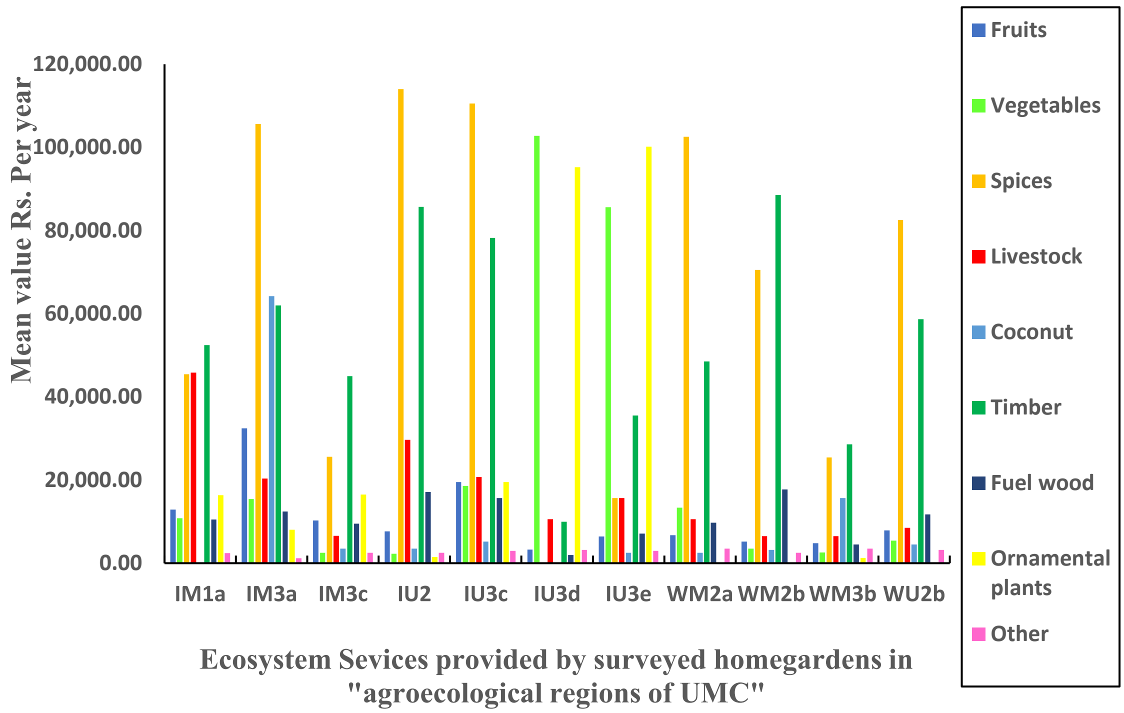
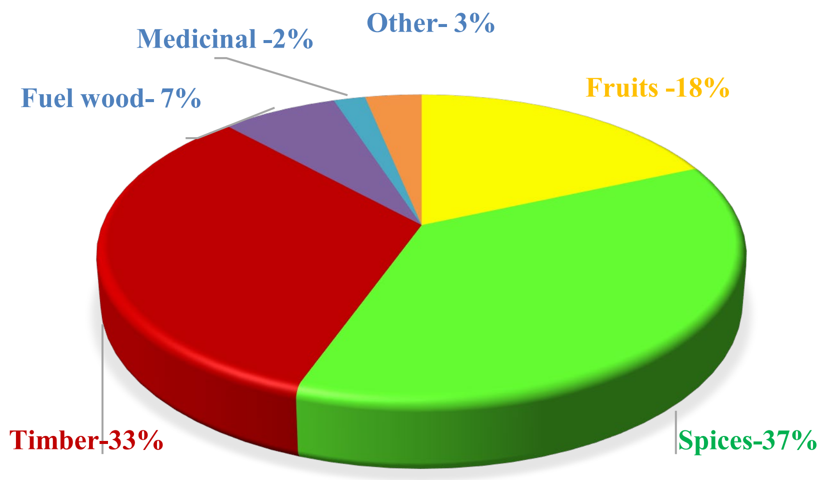


Figure 3 illustrates the percentages of the total mean value of provisioning ecosystem services generated from tree species from all surveyed homegardens in UMC. It clearly indicates that the highest income is generated from spice trees (37%), followed by timber trees (33%), fruit trees (18%), fuelwood (7%), and other tree-based products, including income from various products from tree species (3%), such as gum, resin, ornamental products, etc. Only 2% of tree species provide income from medicinal products. It was observed during the survey that exploitation of medicinal products and cash earnings from tree species are very low, even though almost all tree species have a medicinal value. The reason is the unawareness among owners and communities living at present, even though their ancestors have utilized them to treat various illnesses of humans and farm animals. As a traditional practice, most of the medicinal parts taken from tree species in homegardes are shared among homegardens owners freely in low quantities, depending on the demand. The mean monetary values generated from fodder and green manure were negligible since there was no market for such items during the survey period. Materials used for green manure and fodder for cattle raising are also shared among neighbours freely in low quantities.

Figure 3: Percentages of the total "mean monetary value of provisioning ecosystem services" generated from tree species in surveyed homegardens of UMC



Conclusion and recommendations

Woody trees in "homegarden agroforestry systems" play a vital role in the restoration of ecosystem services in degraded landscapes. The study reported an overall a total of 110 woody tree species belonging to 38 genera in surveyed homegardens in UMC. The study revealed that homegardens in UMC possess high potential of providing provisioning ecosystem services from woody tree species, and they are the most prominent ecosystem services obtained from tree species. Households generate significant income from trees depending on the extent and the use category of tree species, such as timber, food, spices, and fuelwood. The mean monetary values from provisioning ecosystem services provided by tree species are significantly high in surveyed homegardens in almost all agroecological regions of UMC.

Homegardens located in the majority of agroecological regions generate higher direct benefits from woody tree species. Therefore, the owners earn high economic benefits in terms of monetary returns. Those benefits are incentives for growing woody tree species in their homegardens. Growing more and more woody tree species generates many other ecosystem services simultaneously. Finally, it enhances the restoration potential of agroforestry systems that can be qualified as one of the best alternative strategies to compensate for the loss of tree cover due to "large-scale deforestation" happened in the catchment landscape over the last two centuries.

However, homegarden owners received extraordinary profits from vegetable cultivation and ornamental plants with flowers in their homegardens, which led to maintaining a few trees. Even though it is financially beneficial for homegarden owners to grow vegetables and ornamental plants in certain agro-ecological regions, it is a disincentive to enhance tree cover in those regions. Tree cover in these regions is crucial as it covers a majority of the headwater area of the UMC, located in higher elevation, and it has been declared the higher elevation regions as highly sensitive and fragile areas of the country. Therefore, authorities should take policy strategies to enhance tree cover in these regions. In addition, the regulation of the banning of the clearing of forests above 1500 m elevation should be further strengthened.

Even though each tree has a potential medicinal value from any part of the tree, the exploitation of benefits from medicinal products from tree species is relatively low in the majority of homegardens. Government as well as non-governmental organizations should intervene in this matter to raise awareness and provide technical expertise to obtain medicinal products from tree species in home gardens, thereby generating cash earnings.

Since these trees provide many other ecosystem services, such as carbon sequestration, storm water protection, and soil erosion control, etc., government authorities should introduce an appropriate incentive package to promote these trees in homegardens to raise foreign earnings to the country as well as to maintain the "ecological as well as socio-economic sustainability of the catchment" in the long run. This study can serve as a model to illustrate one of the low-cost and viable alternative strategies for ecological and socio-economic restoration of degraded landscapes in similar regions worldwide.

To ensure the scientific rigor of this study and the reliability of its findings, several measures were implemented to mitigate internal data biases and enhance the validity of the derived conclusions. By employing a stratified random sampling technique across eleven distinct agro-ecological zones, the study minimized selection bias, ensuring that the diverse micro-climates and socio-economic conditions of the Upper Mahaweli Catchment were proportionately represented. To address potential response bias and inaccuracies in self-reported income, the resource assessment survey cross-referenced farmer interviews with physical field inventories of woody tree species. Furthermore, using a market-based valuation approach provided a standardized, objective metric, reducing the subjectivity inherent in non-market valuation methods. To mitigate data skewness caused by outliers, mean monetary values were analyzed alongside species diversity indices. This multi-dimensional analysis allowed the study to distinguish between short-term financial incentives and long-term ecological benefits. By triangulating primary survey data with established ecological frameworks, the conclusions reflect a balanced synthesis of economic realities and environmental needs, providing a robust foundation for the proposed policy interventions and incentive packages.

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