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Ecosystem services provided by agroforestry home gardens in Bengkulu, Indonesia: Smallholder utilization, biodiversity conservation, and carbon storage

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Abstract. *Wiryono, Kristiansen P, Bruyn LLD, Saprinurdin, Nurliana S. 2023. Ecosystem services provided by agroforestry home gardens in Bengkulu, Indonesia: Smallholder utilization, biodiversity conservation, and carbon storage. Biodiversitas 24: 2657-2665.* Agroforestry system provides ecosystem services such as conserving biodiversity and providing smallholder farmers with food and other daily needs. It can also generate income for the owners. This study was conducted in 105 home gardens of four villages in Bengkulu Province, Indonesia, to analyze tree species diversity and composition, uses, and potential carbon storage in the agroforestry system of home gardens. Tree data were collected on individual trees from 200 plots (10×10 m). Home garden owners were interviewed on the uses of each tree species. The species richness of trees in each village ranged from 18 to 36, with a total of 57 species (29 introduced and 28 native) for four villages. Most trees (30 species) provided food. The above-ground carbon storage of trees ranged from 29 Mg ha^{-1} to 127 Mg ha^{-1}, with an average of 87 Mg ha^{-1}. This study found that the agroforestry system in home gardens serves some ecosystem services, i.e., providing food, medicines, and other daily needs, conserving plant species and the habitat they provide, and storing carbon. These ecosystem services help villagers build resilience to changing environmental and socio-economic conditions.

Keywords: Agroforestry, conservation, introduced species, native species

INTRODUCTION

Agroforestry, or incorporating trees in agricultural land, has been carried out by communities worldwide, especially in rural areas. An example of agroforestry is a home garden, a piece of land surrounding the house or residence planted with diverse, multifunctional plant species forming a multi-layer vegetation community (Kumar and Nair 2004). Food security, nutritional security, and household consumption are common provisioning goals of home garden systems (Whitney et al. 2017; Hanun et al. 2023). However, for land owners, medicine, fuel, construction materials, and ornamental and ritual goods are also valuable outputs (Wiryono et al. 2016; Sholekha et al. 2023). In Bali, home gardens provide food and medicines (Sujarwo and Caneva 2015), while in Sumedang, West Java, people use plants from home gardens for food, medicines, ornamental, industrial material and other uses (Suwartapradja et al. 2023). In Kampung Masjid Ijok, Perak, Malaysia, home garden agroforestry consists mainly of food, medicinal and ornamental plants (Ramli et al. 2021). Home gardens in Sri Lanka provide low-cost food security throughout the year, especially for poor farmers (Mattsson et al. 2018). Likewise, in rural areas of Africa, home gardens provide food resilience to small farmers (Gifawesen et al. 2020). Despite earlier quantitative works on home gardens, ongoing studies are needed regarding the socio-economic and cultural importance of home gardens for households and local communities, particularly in the context of uncertainty due to climate change.

Home gardens can provide various functions and services due to their relatively high plant diversity; therefore, they can contribute to biodiversity conservation (Mohri et al. 2013). In a study of 402 home gardens with an area of 45.2 ha in Southern Bangladesh, 419 species from 109 families were found, six of which were listed in IUCN Red List (Kabir and Webb 2008). In other countries, home gardens also harbor many species of plants. In 40 home gardens in Malaysia, with varying sizes from less than 900 m^2 to greater than 1500 m^2, 207 species from 78 families were recorded (Ramli et al. 2021).

The diversity of benefits provided by home gardens depends on the composition of plant species in home gardens. The owners can change the species composition of home gardens in response to their needs. The increasing pressure from economic development has led home garden owners in Indonesia to plant more commercial crops in their home gardens (Prihatini et al. 2018; Abdoellah et al. 2020), which are mainly introduced species. In Sleman District, Yogyakarta, Indonesia, from 30 home gardens, 227 species were found, mainly introduced species. The dominant crops in the commercial home gardens were exotic species (Wakhidah and Sari 2019). In Bali, Sujarwo and Caneva (2015) found that 37% of home garden plants were from Malesian region (which include Indonesia) and the rest (63%) were from other floristic regions. The preference of home garden owners to plant introduced species may lead to the disappearance of native species with less economic value. A meta-analysis of 139 articles regarding alien species shows that, in general, invasive alien species cause the decline in diversity and abundance of native species (Vilà et al. 2011). However, only few studies have reported the proportion of native and introduced plant species in Indonesian home gardens (Sujarwo and Caneva 2015; Wakhidah and Sari 2019). More studies on the composition of native and exotic species in Indonesian home gardens are needed.

In addition to conserving biodiversity and providing several agricultural products, the agroforestry system also sequesters carbon from the atmosphere and stores it in the plant biomass and soil (Wiryono et al. 2016; Wiryono et al. 2021). Having trees that live long and have large stems, the agroforestry system has larger above-ground carbon stock than cultivation land with seasonal crops. A global meta-analysis of carbon storage in trees shows that the agroforestry system has 46 Mg ha^{-1} more biomass in plants than cropland without trees (Ma et al. 2020). Furthermore, trees stored larger above-ground biomass than other smaller plants in the agroforestry system around Lore Lindu Park in Central Sulawesi Province of Indonesia (Wardah et al. 2011), and Karanganyar and Sragen districts, Central Java Province of Indonesia (Rawana et al. 2020). This study aims to identify some ecosystem services provided by home gardens by analyzing the uses, species diversity, species composition, and carbon storage of the trees in home gardens.

MATERIALS AND METHODS

Study area

The study was conducted in four villages, i.e., (i) Kemumu Village, (ii) Tanjung Raman Village (both villages are in North Bengkulu District), (iii) Kota Agung Village in Kepahiang District, and (iv) Surabaya Village in Bengkulu City, Bengkulu Province, Indonesia (Figure 1). The field works were conducted in August-September 2018 for the first three villages and in September 2020 for the last village.

Data collection

Samplings of trees in each village were done in 50 plots, each measuring 10 m x 10 m, bringing to a total of 200 plots for the four villages. The plots were placed purposively in the home gardens where the land was planted with mixed trees and seasonal crops. The number of plots for each home garden was between 1 and 3, depending on the size of the home garden. The number of home gardens sampled in Kemumu, Tanjung Raman, Kota Agung, and Surabaya villages was 25, 26, 24, and 50, respectively. Each woody species with a diameter at breast height (dbh, i.e., = 130 cm above ground) of >10 cm within the plot was identified, and its dbh was measured. Palms were counted as trees. The uses of trees were gathered by interviewing the home garden' owners.

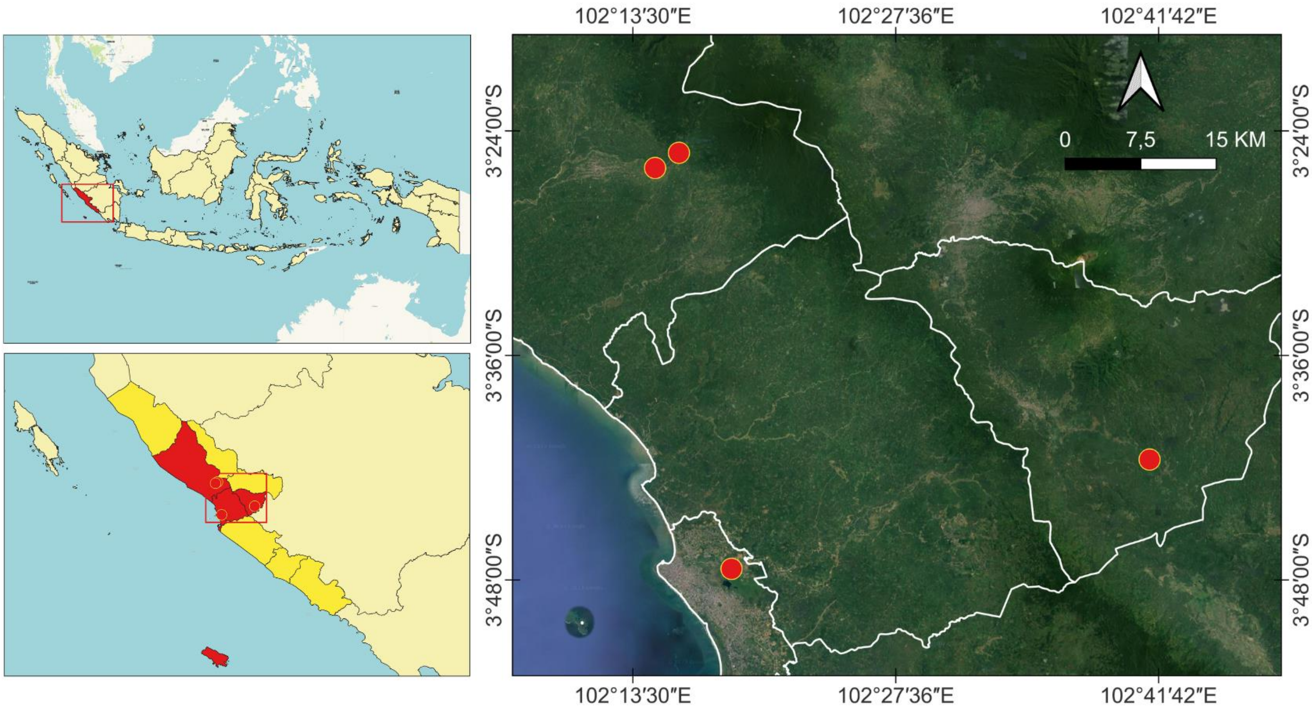

Figure 1. Study sites in Kemumu, Tanjung Raman, Kota Agung and Surabaya villages, Bengkulu Province, Indonesia

Data analysis

Tree data were analyzed for the species richness, Shannon diversity index, equitability index, Simpson dominance index, and Bray-Curtis similarity index using Palaeontological Statistics (PAST) software (Hammer et al. 2001). Species composition was analyzed by determining each tree species' importance value index (IVI) (Mueller-Dombois and Ellenberg 1974). The trees were tabulated based on the IVI. In addition, each tree species was categorized as native or introduced based on its natural distribution. Native tree species were defined as species whose natural distribution range includes Greater Sundas, consisting of Bali, Java, Borneo, Sumatra islands, and the Malay Peninsula (Lohman et al. 2011), while introduced tree species had a natural distribution that does not include Greater Sundas. The native distribution or origin of each tree species was taken from the website POWO (2021) and PROSEA (2021). For five tree species, i.e., *Archidendron pauciflorum* (Benth.) I.C.Nielsen, *Areca catechu* L., *Dimocarpus longan* Lour., *Morinda citrifolia* L., and *Spondias pinnata* (L.fil.) Kurz, the two sources give different information on their native distribution or origin of species, so other sources were consulted before determining whether they are native or introduced tree species. The estimate of above-ground biomass was done using the allometric equations in Brown (1997), Krisnawati et al. (2012), and Prayogo et al. (2018) (Table 1).

RESULTS AND DISCUSSION

Tree uses

Most tree species (32) were planted to provide food materials, including seasoning materials. Other uses were shade (8), construction (5), chemical industry (3), hedge (2), custom (2), craft (2), medicine (2), dye (1), and tobacco (1). The wood of all trees can also be used as firewood, while the leaves can also be used as forage, but these were secondary uses. Five species that grew naturally were only used for firewood. Households used most tree species (34), and only three tree species were sold, i.e., rubber tree (*Hevea brasiliensis* (Willd. ex A.Juss.) Müll.Arg.), oil palm (*E. guinensis*), and cacao (*Theobroma cacao* L.). Sixteen species were used for both self-consumption and sale (Table 2).

Tree species composition

The total species in four villages was composed of 29 introduced and 28 native species (Table 2). Mango *(Mangifera indica* L.) had the highest importance value index (IVI), i.e., 46.34, followed by coconut (*Cocos nucifera)* with an IVI of 45.33, and durian (*Durio zibethinus* Murray) at 21.37 (Table 4). Other species had IVI of less than 20. The top ten species with the highest IVI comprised seven introduced and three native species; the first to ninth species were fruit-bearing trees.

The trees were from 24 families, with five families having more species than the others, i.e., Arecaceae (5 species), Moraceae (5), Anacardiaceae (4), Fabaceae (4), and Myrtaceae (4). Other families had 1-3 species. The composition of tree species of home gardens differed among villages, with a similarity index of <0.5, except between Tanjung Raman and Kemumu Villages, i.e., 0.55 (Table 3).

Tree species diversity

The number of tree individuals in home gardens in each village ranged from 102 to 243, and the species richness from 18 to 36 (Table 4), with a total of 57 tree species belonging to 25 families (Table 4) in four villages. The species diversity index ranged from 2.43 to 3.07, the species equitability index from 0.74 to 0.88, and the Simpson dominance index from 0.06 to 0.14 (Table 2). Tanjung Raman village had the highest species richness and species diversity index (H'). Kota Agung village had a lower number of species (18) than Surabaya (27 species) but a higher H' (2.54) than Surabaya (2.43).

Table 1. Allometric equations to estimate above-ground biomass of trees

Tree species	Allometric equation	References
Acacia mangium	ABG = 0.070 $D^{2.58}$	Krisnawati et al. (2012)
Elaesis guinensis	ABG = 0.002 $D^{3.49}$	Krisnawati et al. (2012)
Swietenia macrophylla	Log ABG = -1.32 + 2.65 log D	Krisnawati et al. (2012)
Pometia sp.	Log ABG = 0.841 + 2.572 logD	Krisnawati et al. (2012)
Ficus sp.	Ln ABG = -2.59 + 2.6 LnD	Krisnawati et al. (2012)
Areca catechu	ABG = 0.0689 $D^{2.59}$	Prayogo et al. (2018)
Other branching trees	ABG = 42.69-12.800(D)+1.242(D^2)	Brown (1997)

Note: ABG: Above-ground biomass (kg), D: Diameter (cm). The allometric equation for *A. catechu* was also used for *Cocos nucifera* L., while that for *Elaeis guinensis* Jacq. was also used for *Arenga pinnata* (Wurmb) Merr. Carbon was estimated at 0.47 biomass

Table 3. Similarity index (Bray-Curtis) in home gardens among four villages in Bengkulu Province, Indonesia

	Kemumu	Tanjung Raman	Surabaya	Kota Agung
Kemumu	1	0.55	0.35	0.44
Tanjung Raman	0.55	1	0.47	0.45
Surabaya	0.35	0.47	1	0.43
Kota Agung	0.44	0.45	0.43	1

Table 2. List of tree species in the home gardens (n = 200 plots) from all four villages in Bengkulu Province, Indonesia, with family, category, importance value index (IVI), average carbon of trees (Mg ha^{-1}), uses and economic use

Species	Family	Origin	IVI (%)	Biomass (Mg ha-1)	Carbon (Mg ha-1)	Uses	Economic use
Mangifera indica L.	Anacardiaceae	Introduced	46.34	41.8	19.66	Food	OU
Cocos nucifera L.	Arecaceae	Introduced	45.33	23.9	11.22	Food, med, craft, custom, cons	OU, sale
Durio zibethinus L.	Malvaceae	Native	21.37	17.4	8.17	Food, cons	OU, sale
Areca catechu L.	Arecaceae	Native	19.31	3.42	1.61	Craft, custom, dye, food, industry	OU, sale
Theobroma cacao L.	Malvaceae	Introduced	15.85	2.07	0.97	Food	Sale
Syzygium aqueum (Burm.f.) Alston	Myrtaceae	Native	13.66	4.56	2.14	Food	OU, sale
Nephelium lappaceum L.	Sapindaceae	Native	13.33	8.46	3.98	Food	OU, sale
Archidendron pauciflorum (Benth.) I.C.Nielsen	Fabaceae	Native	12.03	4.76	2.24	Food, med	OU, sale
Artocarpus heterophyllus Lam.	Moraceae	Introduced	11.28	8.47	3.98	Food	OU, sale
Hevea brasiliensis (Willd. ex A.Juss.) Müll.Arg	Euphorbiaceae	Introduced	10.76	3.69	1.74	Industry	Sale
Gliricidia sepium (Jacq.) Walp.	Fabaceae	Introduced	9.22	3.82	1.80	Hedge	OU
Persea americana Mill.	Lauraceae	Introduced	5.48	4.14	1.95	Food	OU
Swietenia macrophylla King	Meliaceae	Introduced	4.73	0.82	0.39	Cons, shade	OU
Artocarpus altilis (Parkinson) Fosberg	Moraceae	Introduced	4.58	1.28	0.60	Food	Sale
Ficus benjamina L.	Moraceae	Native	4.09	6.59	3.10	Shade	OU
Lansium parasiticum (Osbeck) K.C.Sahni & Bennet	Meliaceae	Native	4.03	3.68	1.73	Food	OU
Maesopsis eminii Engl.	Rhamnaceae	Introduced	3.75	1.99	0.93	Cons	OU
Dysoxylum mollissimum Blume	Meliaceae	Native	3.59	4.30	2.02	Cons	OU, sale
Parkia speciosa Hassk.	Fabaceae	Native	3.57	2.73	1.28	Food	OU, sale
Elaeis guineensis Jacq	Arecaceae	Introduced	3.30	10.4	4.86	Industry	Sale
Syzygium malaccense (L.) Merr. &L.M.Perry	Myrtaceae	Native	3.27	1.64	0.77	Food	OU, sale
Phyllanthus acidus (L.) Skeels	Phyllanthaceae	Introduced	3.04	0.26	0.12	Unused	
Dimocarpus longan Lour.	Sapindaceae	Introduced	3.01	2.79	1.31	Food	OU
Psidium guajava L.	Myrtaceae	Introduced	2.80	0.74	0.35	Food	OU
Tectona grandis L.f.	Lamiaceae	Introduced	2.75	4.14	1.95	Cons	OU
Muntingia calabura L.	Muntingiaceae	Introduced	2.44	0.60	0.28	Shade, food	OU
Arenga pinnata (Wurmb) Merr.	Arecaceae	Native	2.27	3.87	1.82	Food	OU, sale
Syzygium polyanthum (Wight) Walp.	Myrtaceae	Native	2.18	0.46	0.21	Food	OU
Pometia pinnata J.R.Forst. & G.Forst.	Sapindaceae	Native	1.85	0.00	0.00	Food	OU
Ceiba pentandra (L.) Gaertn	Malvaceae	Introduced	1.76	1.16	0.55	Craft, frwd	OU
Magnolia champaca (L.) Baill. ex Pierre	Magnoliaceae	Native	1.63	1.41	0.66	Cons	OU
Mangifera kemanga Blume	Anacardiaceae	Native	1.50	0.19	0.09	Food	OU
Annona muricata L.	Annonaceae	Introduced	1.48	0.55	0.26	Food	OU
Averrhoa bilimbi L.	Oxalidaceae	Introduced	1.45	0.85	0.40	Food	OU
Artocarpus odoratissimus Blanco	Moraceae	Native	1.17	1.19	0.56	Unused	OU
Spondias pinnata (L.f.) Kurz.	Anacardiaceae	Native	1.11	0.51	0.24	Hedge, forage	OU
Spondias dulcis Parkinson	Anacardiaceae	Introduced	0.97	0.86	0.41	Food	OU, sale
Myristica fragrans Houtt.	Myristicaceae	Introduced	0.90	0.10	0.05	Food	OU

Vernonia arborea Buch.-Ham.	Asteraceae	Native	0.89	0.30	0.14	Cons	OU
Cinnamomum porrectum (Roxb.) Kosterm	Lauraceae	Native	0.83	1.03	0.48	Frwd	OU
Citrus aurantiifolia (Christm.) Swingle	Rutaceae	Introduced	0.66	0.09	0.04	Food	OU
Gnetum gnemon L.	Gnetaceae	Native	0.63	0.33	0.16	Food	OU
Syzygium aromaticum (L.) Merr. & L.M.Perry	Myrtaceae	Introduced	0.60	0.23	0.11	Food	OU
Morinda citrifolia L.	Rubiaceae	Introduced	0.54	0.06	0.03	Med	OU, sale
Citrus sinensis (L.) Osbeck	Rutaceae	Introduced	0.54	0.02	0.01	Food	OU
Metroxylon sagu Rottb.	Arecaceae	Introduced	0.53	0.91	0.43	Unused	
Terminalia catappa L.	Combretaceae	Native	0.44	1.91	0.90	Shade	OU
Fagraea fragrans Roxb.	Gentianaceae	Native	0.42	0.49	0.23	Shade	OU
Manilkara zapota (L.) P.Royen	Sapotaceae	Introduced	0.41	0.05	0.02	Food	OU, sale
Acacia mangium Willd.	Fabaceae	Introduced	0.41	0.04	0.02	Frwd, shade	OU
Ficus septica Burm.f	Moraceae	Native	0.28	0.04	0.02	Unused	
Aleurites moluccanus (L.) Willd	Euphorbiaceae	Native	0.27	0.04	0.02	Food	OU
Cinnamomum burmanni (Nees & T.Nees) Blume	Lauraceae	Native	0.27	0.04	0.02	Food	OU
Jatropha curcas L.	Euphorbiaceae	Introduced	0.27	0.03	0.01	Unused	
Artocarpus integer (Thunb.) Merr	Moraceae	Native	0.27	0.03	0.02	Food	OU
Baccaurea racemosa (Reinw. ex Blume) Müll.Arg.	Phyllanthaceae	Native	0.27	0.02	0.01	Unused	OU
Peronema canescens Jack	Lamiaceae	Native	0.27	0.02	0.01	Cons	OU
Total			300.0	185.3	87.1		

Note: cons: construction material, frwd: firewood, med: medicine, OU: own use

Above-ground carbon storage

The above-ground biomass of trees in home gardens ranged from 62.8 Mg ha^{-1} to 271 Mg ha^{-1}, with an average of 185.3 Mg ha^{-1}, and the carbon storage ranged from 29.5 Mg ha^{-1} to 127 Mg ha^{-1} with an average of 87.1 Mg ha^{-1} (Table 5). Mango (*M. indica*) had the highest above-ground carbon storage, i.e., 19.7 Mg ha^{-1}, followed by coconut (*C. nucifera*) 11.2 Mg ha^{-1} and durian (*D. zibethinus*) 8.17 Mg ha^{-1} (Table 2).

Discussion

Tree uses

The ability to utilize home garden produce in various ways provides landowners with greater home consumption and income diversification opportunities (Leakey and Tchoundjeu 2001). All the top ten species except the rubber tree are fruit-bearing trees. Mango, durian, and bell fruit are usually consumed fresh as fruit but can be processed into juice or other food products. Jackfruit can be consumed as a vegetable, as fresh fruit, and made into other beverages and food products. Cocoa is made into beverage and food products. Areca nut is consumed for medicinal purposes, and *jengkol* fruit is for vegetables. The coconut tree is a multipurpose species. Its young fruit's flesh and water can be used as a beverage, and coconut milk as a vegetable and food ingredient. Its young leaves are made handicrafts and are usually used for traditional ceremonies, while its old leaves are used for firewood, and its stems are used in construction.

Four of the top ten tree species in the study were also found as the most frequently found trees in home gardens of Kampung Masjid Ijok, Perak, Malaysia, namely coconut (rank first), rambutan (second), mango (third), and areca palm (sixth) (Ramli et al. 2021). In 40 urban home gardens in Sao Luis city of Brazil, 63% of 186 species were fruit-bearing trees: mango had the highest frequency, i.e., 95%, followed by coconut, 90% (Akinnifesi et al. 2010). Another study of home gardens in Monte Alegre, Para, Brazil, showed that coconut ranked first in frequency and mango ranked fourth (Santos and Vieira 2021). In sub-humid lowland Ethiopia, mango was the essential tree in home gardens (Tadesse et al. 2019). In Andongrejo Village, Jember District, East Java, Indonesia, coconut ranked first and mango third (Hartoyo et al. 2020). In Harapan Makmur Village of Central Bengkulu, among the trees, the rubber tree had the highest importance value index and the coconut the third (Wiryono et al. 2016). The dominance of fruit-bearing trees in home gardens indicates that home gardens are essential for food production, which can help to maintain food security for smallholder farmers (Duffy et al. 2021).

Tree species composition

The conservation value of home gardens will be high if they contain a significant portion of native species, scarce species because there is a tendency for modern agriculture to replace local species with exotic species with more desirable (i.e., commercial) genetic traits (Li et al. 2014). The tree species richness in 2 ha home gardens in this study is much lower than that in the natural forest in Sumatra, which may reach 300-500 in a three ha-plot (Rennolls and Laumonier 2000). However, it is certainly much higher than that in monoculture plantations and annual rotational cropping systems (Bardhan et al. 2012; Ahrends et al. 2015). In Indonesia, the most planted genera in plantation forests are only two, i.e., *Acacia* (71%) and *Eucalyptus* (21%) (BPS Indonesia 2020).

Table 4. Tree species richness, number of individuals, dominance index (D), Simpson species diversity index (1-D), Shannon diversity index (H′), and equitability index in home gardens of four villages in Bengkulu Province, Indonesia

Parameter	Kemumu	Tanjung Raman	Kota Agung	Surabaya	Average
Richness	34	36	18	27	28.75
Individual trees	243	233	102	199	194.25
Dominance D	0.09	0.06	0.10	0.14	0.10
Simpson 1-D	0.91	0.94	0.90	0.86	0.90
Shannon H′	2.78	3.07	2.54	2.43	2.71
Equitability J	0.79	0.86	0.88	0.74	0.82

Table 2. Above-ground tree biomass and carbon storage in the study sites

Village	Biomass (Mg ha^{-1})	Carbon (Mg ha^{-1})
Kemumu	271.	127
Tanjung Raman	269	126
Kota Agung	62.8	29.5
Surabaya	139	65.2
Average	185	87.1

In the study sites, the number of introduced tree species (29 species) was almost the same as that of the native ones (28 species). In a study of home gardens in Sleman, Yogyakarta, Indonesia, most of the 227 plant species recorded were introduced (Wakhidah and Sari 2019), but no specific number was given. No other studies were found on the proportion of introduced species in Indonesian home gardens. On the Island of Santa Catarina, Brazil, 101 plant species were recorded in 109 home gardens, most of which were introduced species (Peroni et al. 2016). On the other hand, In São Luís City, Brazil, from 40 home gardens, 186 plant species were recorded, 60% of which were native to the area (Akinnifesi et al. 2010). In the Kachabira district in Southern Ethiopia, in 83 home gardens, each was sampled using a 10 × 10 m plot, 24 species of trees were found, 8 of which were introduced (Legesse and Negash 2021). In another study in sub-humid lowland Ethiopia, 25 out of 56 tree species (dbh >5 cm) recorded in 54 home gardens were introduced (Tadesse et al. 2019). Meanwhile, in southern Bangladesh, more native species, including all life forms, were recorded in home gardens than the introduced ones (Kabir and Webb 2008). In four home gardens with a total area of four hectares in the urban region of Kerala, India, 66 species of trees (dbh >10 cm) were recorded, of which a third were introduced (Padmakumar et al. 2021).

Introduced tree species may have detrimental impacts on native species. A well-known example was the introduction of the Japanese chestnut tree (*Castanea crenata* Siebold & Zucc.) to the United States in 1876, which accidentally brought exotic fungus, *Cryphonectria parasitica* (Murrill) M.E.Barr, which drove the native American chestnut (*Castanea dentata* (Marshall) Borkh.) to the brink of extinction (Collins et al. 2017). In addition, some introduced plants have become invasive, leading to the decline in abundance and diversity of the native ones (Vilà et al. 2011). Therefore, conservation agencies often remove invasive introduced plant species to protect the native ones. However, with globalization, the introduction of plant species is unavoidable. Fortunately, not every introduced plant species becomes invasive and threatens the native biodiversity; in fact, introduced plant species may increase the overall diversity of an ecosystem (Sagoff 2005). Therefore, some ecologists recommend that conservation biologists should not focus on removing the introduced species, but they should evaluate whether an exotic species is harmful or beneficial to overall biodiversity —the species' function matters, not the origin (Davis et al. 2011). In addition, determining a species as native or introduced is not always straightforward because there are varying definitions of native species (Crees and Turvey 2015).

Perhaps more importantly, in terms of smallholder livelihoods, the high proportion of introduced species in home gardens indicated that home garden' owners are not concerned with the conservation of native species but would instead grow trees that have economic value (Feintrenie et al. 2010). The most dominant tree species with the highest importance value index (IVI) in the four villages was mango (*M. indica*, IVI = 46.34), an introduced species, followed by coconut (*C. nucifera*, 45.33), *durian* (*D. zibethinus* 21.37), areca palm (*A. catechu*, 19.31), cacao (*T. cacao*, 15.85), bell fruit (*S. aqueum* 13.66), *rambutan* (*N. lappaceum*, 13.33), *jengkol* (*A. pauciflorum*, 12.03), jackfruit (*A. heterophyllus*, 11.28), and rubber tree (*H. brasiliensis*, 10.76). Only three of the top ten species are native: *durian*, *rambutan*, and bell fruit trees. According to PROSEA (2021), the coconut's origin needed to be clarified. The species was not included in the Greater Sunda Island in the POWO (2021), so coconut was categorized as an introduced species in this study. According to Ahuja et al. (2014), however, the origin of coconut was Malesia, which includes Greater Sunda Island.

Tree species diversity

The Shannon diversity index (H') of trees (2.43-3.07) in the home gardens in each village was considered medium. It was higher than H' of trees in home gardens in Harapan Makmur Hamlet, i.e., 0.99 (Wiryono et al. 2016), in Monte Alegre, Pará, Brazil, which ranged from 0.60 to 2.33 (Santos and Vieira 2021), in northern Ethiopia, i.e., 0.93 (Manaye et al. 2021), but comparable to that of home gardens in Thodupuzha, Kerala India, i.e., 2.73 (Padmakumar et al. 2021), Kampung Masjid Ijok, Perak Malaysia, i.e., 1.66-3.61 (Ramli et al. 2021). The equitability index in each village (0.74-0.88) was considered high, indicating that no species strongly dominated the home gardens in the number of individuals, as shown in the low Simpson dominance index (0.06-0.14). However, some species dominated the home gardens through their large size, as shown in the high importance value index and carbon storage (Table 2).

The simpler indicator of species diversity is the number of species or richness, which varied considerably among the four villages, although the total areas of plots were the same. The highest species number (36) in Tanjung Raman Village was twice as higher as that in Kota Agung Village (18). Tanjung Raman had higher species richness because it had a higher number of individuals (233) than Kota Agung (102). Kemumu village, which had a high individual number (243), also had high species richness (34). The home garden owners in Kota Agung village planted fewer trees than in other villages because they prefer planting coffee in their home gardens.

Tree species richness (18-36 species) in the home gardens sampled in each village was considered low. In Harapan Makmur Hamlet, Central Bengkulu, 38 species of trees (dbh >10 cm) were recorded in 23 home gardens with the same sampling regime (Wiryono et al. 2016), slightly higher than in this study. The total number of tree species (57) recorded in home gardens from the four villages over 1.86 ha was slightly lower than that of trees (dbh >10 cm) in 4 urban home gardens with a total area of 4 ha in Kerala, India, which was 66 (Padmakumar et al. 2021). However, the total species in this study was higher than 56 species of trees (dbh >5 cm) found in 54 home gardens, in sub-humid lowland Ethiopia, with a total sample area of 4.86 ha (Tadesse et al. 2019). In Kampung Masjid Ijok of Perak Malaysia, 61 species of trees were found in 40 home gardens with the size ranging from <900 m^2 to >1500 m^2, but no data on the total area sampled and minimum dbh of trees were given (Ramli et al. 2021).

Carbon storage

Home gardens contribute to climate mitigation due to the presence of trees that sequester and store carbon for a long time. In this study, the average above-ground biomass of trees in home gardens from four villages varied considerably, from 62.8 Mg ha^{-1} to 271 Mg ha^{-1}, with an average of 185 Mg ha^{-1}, equivalent to 87.1 Mg ha^{-1} carbon. The tree biomass in this study was slightly higher than that in the agroforestry systems near Lore Lindu National Park in Central Sulawesi, Indonesia, which ranged from 67.4 Mg ha^{-1} to 237 Mg ha^{-1} with an average of 139 Mg ha^{-1} (Wardah et al. 2011). The average carbon storage in trees in this study was also higher than that in Harapan Makmur hamlet in Central Bengkulu, Indonesia, i.e., 69.5 Mg ha^{-1} (Wiryono et al. 2016), in Sragen and Karanganyar, Central Java Indonesia, 31.4 Mg ha^{-1} (Rawana et al. 2020), and in Kerala India, 31.9 Mg ha^{-1} (Padmakumar et al. 2021). In northern Ethiopia, the above-ground carbon in home gardens was even much smaller, i.e., 5.36 Mg ha^{-1} because the average diameter of woody plants was only 12.5 cm, while in woodlot agroforestry system was 21.4 Mg ha^{-1} because the density of woody plants was more than ten times of that in home gardens (Manaye et al. 2021).

The estimates of biomass and carbon storage among studies, however, vary due to their real values and the differences in the methods used in those studies. However, a global meta-analysis concludes that agroforestry systems generally store above-ground biomass and carbon more than the cropland without trees, with an average of 46.1 Mg ha^{-1} (Ma et al. 2020). That analysis also shows that high plant diversity in agroforestry has high above-ground biomass. However, an analysis of agroforestry in Sulawesi found that biodiversity had no or weak correlation with carbon storage (Kessler et al. 2012). In addition, a study in parkland agroforestry in northern Ethiopia found no correlation between above-ground carbon and species diversity (Gebrewahid and Meressa 2020).

This study found that the agroforestry systems in home gardens provide essential ecosystem services, i.e., providing food, medicine, and other daily needs, conserving flora and wildlife habitat, and storing carbon. The conservation value of home gardens can be increased by enriching the home gardens with rare native species. However, those species should have economic value so home garden owners can benefit from those plants.

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