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REPORT

Homegardens as a Multi-functional Land-Use Strategy in Sri Lanka with Focus on Carbon Sequestration

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Abstract This paper explores the concept of homegardens and their potential functions as strategic elements in land-use planning, and adaptation and mitigation to climate change in Sri Lanka. The ancient and locally adapted agroforestry system of homegardens is presently estimated to occupy nearly 15 % of the land area in Sri Lanka and is described in the scientific literature to offer several ecosystem services to its users; such as climate regulation, protection against natural hazards, enhanced land productivity and biological diversity, increased crop diversity and food security for rural poor and hence reduced vulnerability to climate change. Our results, based on a limited sample size, indicate that the homegardens also store significant amount of carbon, with above ground biomass carbon stocks in dry zone homegardens ($n = 8$) ranging from 10 to 55 megagrams of carbon per hectare (Mg C ha^{-1}) with a mean value of 35 Mg C ha^{-1}, whereas carbon stocks in wet zone homegardens ($n = 4$) range from 48 to 145 Mg C ha^{-1} with a mean value of 87 Mg C ha^{-1}. This implies that homegardens may contain a significant fraction of the total above ground biomass carbon stock in the terrestrial system in Sri Lanka, and from our estimates its share has increased from almost one-sixth in 1992 to nearly one-fifth in 2010. In the light of current discussions on reducing emissions from deforestation and forest degradation (REDD+), the concept of homegardens in Sri Lanka provides interesting aspects to the debate and future research in terms of forest definitions, setting reference levels, and general sustainability.

INTRODUCTION

A homegarden can be defined as a complex sustainable land-use system that combines multiple farming components, such as annual and perennial crops, livestock and occasionally fish, of the homestead and provides environmental services, household needs, and employment and income generation opportunities to the households (Weerahewa et al. 2012). Second to shifting cultivation, homegardens are the oldest land-use systems worldwide that have evolved through centuries of biological and cultural transformation in response to shortage of arable lands as a consequence of induced human pressure (Nair and Kumar 2006). Homegardens are common throughout the tropics (Fig. 1), and also referred to as household or homestead farms, multi-strata tree gardens, analogue forests, compound farms, backyard gardens, village forest gardens, dooryard gardens, and house gardens.

The resemblance of homegardens to forests incur that they store carbon and include several benefits for people through offering economic stability by providing, e.g., fuelwood, timber, food, and crops (Hulscher and Durst 2000; Kumar and Nair 2004; Kumar 2006). Homegardens have the potential to result in more secure rights over and benefits from lands to land owners than natural forests as homegardens are mainly privately owned whereas forest land in many cases is owned and managed by the state (De Zoysa and Inoue 2008). Homegardens could function as a way to reduce pressure to encroach on natural forest land and are regarded in Sri Lanka as resilient to climate change partly due to the use of several adaptation strategies by the homegardeners (Weerahewa et al. 2012). Homegardens and agroforestry practices can in general also contribute to climate change mitigation through enhanced carbon sequestration (Verchot et al. 2007). Little information is,
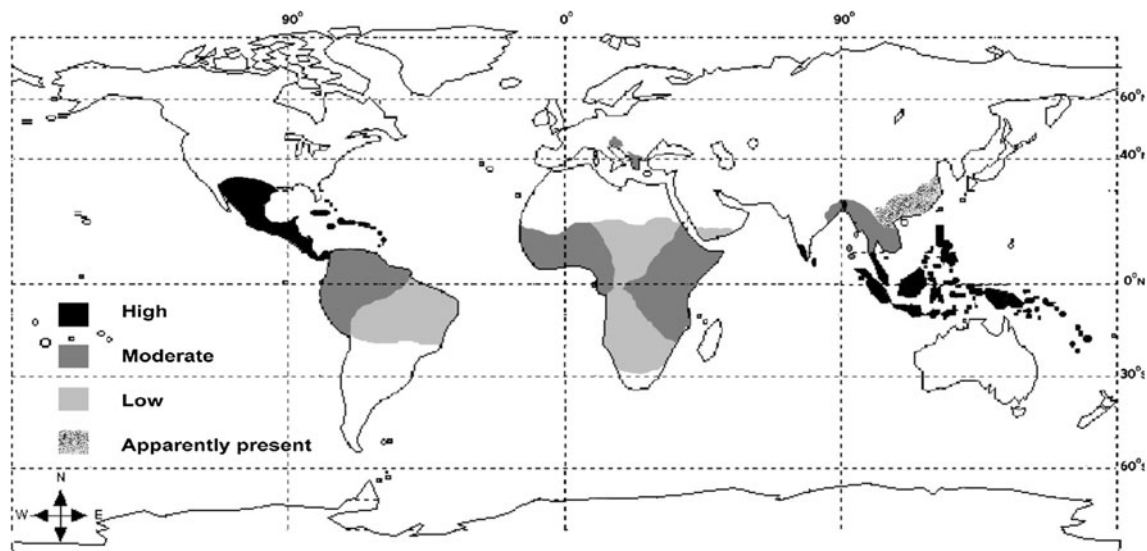
Fig. 1 The global distribution of homegarden-like structures (Nair and Kumar 2006)

however, available on area extent, carbon stock, and carbon sequestration potential of homegardens on national and district level in Sri Lanka. Consequently, limited research and analysis have been conducted so far to investigate the role of Sri Lankan homegardens in relation to policies and measures to mitigate and adapt to climatic change. Accordingly, research findings and analysis relating to these issues are in demand (Ministry of Environment 2012; Marambe et al. 2012; Pushpakumara et al. 2012; Weerahewa et al. 2012).

This paper describes the area extent and quantifies carbon stock in above ground biomass (AGB) in Sri Lankan homegardens from 1992 to 2010 compared to natural forest, and provides a future conceptual outlook by considering the different options of using homegardens to reach goals such as rehabilitation of degraded lands, carbon sequestration enhancement, and augmentation of the number and extent of environmental services in the existing homegarden systems. The paper also discusses homegardens in the context of forest definitions, baseline setting and general sustainability, with a view to incorporate them to REDD+.[1]

Homegardens in Sri Lanka

Similar to other tropical countries, homegardens in Sri Lanka are traditional life supporting systems through perennial cropping that have been practiced for centuries (de Costa et al. 2006). Trees in homegardens are classified as Trees Outside Forests (TOF) and are defined by Rawat et al. (2003) as "trees on woodland not defined as forest and other woodland". In addition to homegardens, TOF land-use systems in Sri Lanka include tea, rubber, coconut plantations, and trees along roads and railways. These land-use categories cover 1.8 million hectares (ha) or 26 % of the land area and supply 70 % of the timber and more than 80 % of the fuelwood in the country (MFE 1995; Chokkalingam and Vanniarachchy 2011). In Sri Lanka, homegardens are also categorized as a piece of land, which has a dwelling house and some form of cultivation on a total area of between 0.05 and 2.5 ha (mean 0.4 ha) (Pushpakumara et al. 2010).

Despite the small size of individual plots, the area of homegardens in Sri Lanka (20 out of 25 districts) was estimated at 977 700 ha in 2005 (FAO 2009). This adds up to around 33 % of the total forest area of Sri Lanka, and almost 15 % of the land area as shown in Fig. 2 (FAO 2009). The area increase from 1983 to 1992 amounted to almost 17 % (Table 1) (Jewell 1995). The latest available estimates at district level (25 districts) in 1995 (MFE 1995) show large variations between districts in homegarden extent as percent of total area and range from 4 to 36 %. The latest Forest Sector Master Plan (MFE 1995) also promotes the high potential of homegardens to sustain its multiple uses and estimates an increase in homegarden extent of 1 % per year until 2020 (FAO 2009).

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[1] Reducing emissions from deforestation and forest degradation in developing countries and the role of conservation, sustainable management of forests and enhancement of forest carbon stocks. In the proposed REDD+ mechanism, developed countries provide incentives and financial compensation to developing countries for climate change mitigation benefits from maintaining and enhancing forest biomass.

Fig. 2 Area of homegardens in Sri Lanka in relation to forests, agriculture, and other land uses. Modified from FAO (2009)
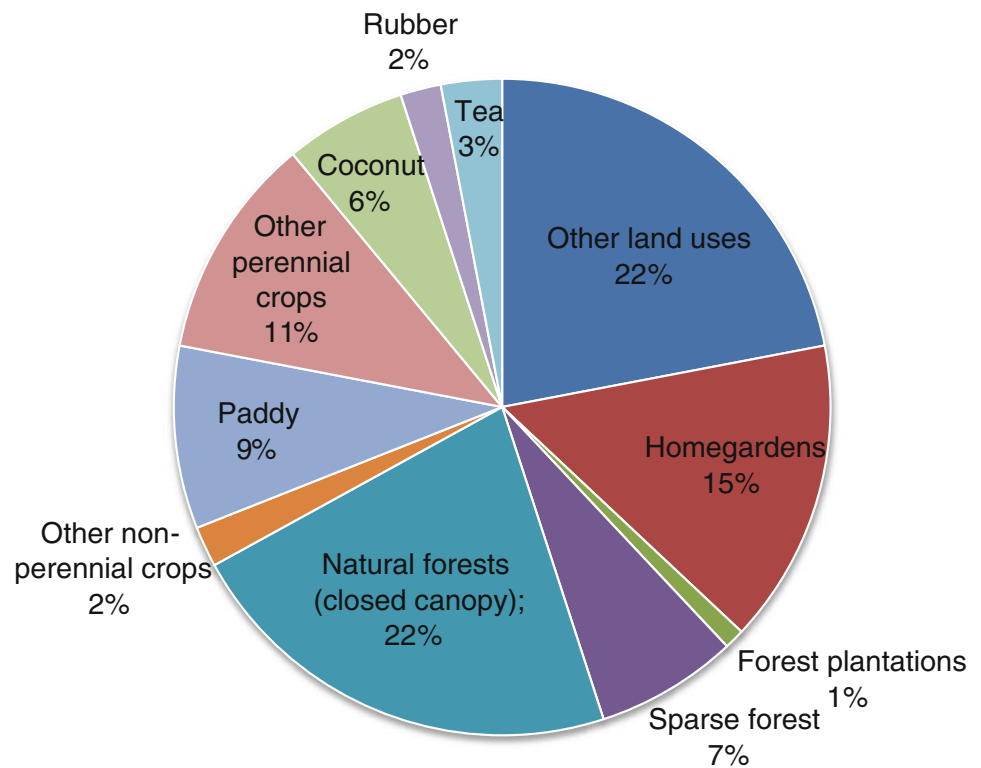

Table 1 The distribution of homegardens and natural forests in 20 out of 25 districts in 1992 (modified from Legg and Jewell 1995; Jewell 1995)

District	Land area (ha)	Area of natural forests (ha) 1992	Area of homegardens (ha) 1992	Natural forests as % of districts (1992)	Homegardens as % of districts (1992)	Change in homegardens/ natural forests 1983–1992 (%)
Ampara	450 031	166 677	16 245	37.0	3.6	−9.3/−16.4
Anuradhapura	722 178	296 776	56 143	41.0	7.8	+4.7/−6.2
Badulla	285 673	54 271	50 764	19.0	17.8	+44.1/−53.4
Batticaloa	263 983	52 818	14 359	20.0	5.4	+91.2/−18.6
Colombo	68 469	1868	8577	2.7	12.5	−42.2/+23.0
Galle and Matara	292 085	42 766	99	14.6	33.9	+15.6/+12.1
Gampaha	141 890	537	56 884	0.4	40.1	−18.4/−69.3
Hambantota	262 307	79 454	44 922	30.3	17.1	+17.0/–43.6
Kalutara	164 391	21 576	33 156	13.1	20.2	−5.9/+46.5
Kandy	192 808	33 222	61 029	17.2	31.7	+64.2/−7.7
Kegalle	168 328	15 938	46 782	9.5	27.8	+5.7/+22.8
Kurunegala	489 787	24 746	72 892	5.1	14.9	+35.9/−23.9
Matale	20 605	84 015	20 258	40.8	9.8	−1.9/+12.1
Moneragala	576 763	235 171	56 739	40.8	9.8	+19.8/−17.0
Nuwara Eliya	174 109	42 920	9172	24.7	5.3	−19.5/−0.7
Polonnaruwa	344 988	138 831	3618	40.2	10.5	+55.4/–28.0
Puttalam	315 848	99 634	64 747	31.6	20.5	+87.8/+5.9
Ratnapura	327 034	66 849	56 462	20.4	17.3	+7.6/+18.4
Trincomalee	267 991	131 441	14 083	49.0	5.3	−25.2/−1.1
Total	5 714 713	1 589 500	818 394	27.8	14.3	

In an assessment by Ariyadasa (2002) covering 87 % of the country, 400 different woody species were found in homegardens, where the majority of tree species were indigenous or endemic with multi-purpose uses. Most species were found in the wet zone districts followed by the intermediate and dry zones as a result of favorable climatic conditions with high mean annual precipitation (2000–2500 mm year^{-1}) (see Fig. 3 for visual examples of homegardens). Originally coconut (*Cocus nucifera* L.), jackfruit (*Artocarpus heterophyllus* Lam), and mango (*Mangifera indica* L.) were the prevailing species grown in homegardens but with the inclusion of commercially valuable exotic timber species such as teak (*Tectona grandis* L.), mahogany (*Swietenia macrophylla* King), Alstonia (*Alstonia macrophylla* Wall Ex G. Don), Albizia [*Albizia falcataria* (L.) Fosberg] and *Eucalyptus* spp. in the recent past, a mix of trees for various purposes are included in homegarden systems. Furthermore, homegardens are presently providing 41 % of saw log production and 26 % of the biofuel supply (MFE 1995; Ariyadasa 2002; FAO 2009). In the Sri Lankan case, the homegarden structure also has shown protection from and resilience against the tsunami in 2004 resulting from the Sumatra–Andaman earthquake (Mattsson et al. 2009).

Governmental policies have encouraged establishment and expansion of homegardens in urban and sub-urban settings through extension support, identification and creation of market conditions and tenure reforms in order to achieve national goals (Chokkalingam and Vanniarachchy 2011). These include reduced living costs and imports of food products, enhanced food security, maintenance of environmentally friendly-traditional agriculture methods and to find new avenues to test new technologies. Examples include the government program "*Api Wawamu Rata Nagamu*" (Let us grow, and uplift the nation) launched in 2007, which aimed at developing 375 000 homegardens, the national tree planting programme "*Deyata Sevana*" and the most recent program "*Divi Neguma*" (Livelihood Development) to establish 1.5 million homegardens in order to achieve self-sufficiency in vegetables and to reduce vegetable prices (Kumari et al. 2009), which was later increased up to 2.5 million homegardens (Government of Sri Lanka 2011).

Different features of homegardens in Sri Lanka have been studied, especially in terms of tree resources, biodiversity, and biophysical characteristics. In the literature emphasis has been placed on studying Kandyan homegardens located in the central mid-country region of the island, primarily in the Kandy district. Dry zone homegarden systems have a low tree density whereas Kandyan wet zone homegardens often offer a high level of plant diversity and a denser canopy structure (Jewell 1995; FAO 2009; Pushpakumara et al. 2010; Pushpakumara et al. 2012). Kandyan

homegardens also offer economic stability to farmers and provide a significant amount (30–50 %) of household income (de Costa et al. 2006; Pushpakumara et al. 2010). Senanayake (1987) reported that the bird and soil fauna within Kandyan homegardens is rich and comparable to surrounding natural forests.

The ongoing discussions on REDD+ within the United Nations Framework Convention on Climate Change (UNFCCC) have recently identified the need to take a broader approach and also to account for emissions resulting from agriculture. This is because forest and agriculture are intrinsically linked and many of the drivers of deforestation processes originate from agriculture (Geist and Lambin 2002; Hett et al. 2012). Montagnini and Nair (2004) stated three mechanisms through which agroforestry systems can reduce carbon dioxide; carbon sequestration (due to high rate of net primary production from growing trees), carbon conservation (less pressure on natural forests) and carbon substitution (long lasting carbon storage in renewable products in substitution of energy demand materials). In addition, carbon sequestration in homegardens can be considered permanent as complete biomass removal does not occur, which has been one of the key concerns in carbon sequestration projects within the Clean Development Mechanism[2] (CDM) of the Kyoto Protocol.

MATERIALS AND METHODS

In two field inventory campaigns conducted from 2006 to 2009 different tree parameters were measured for all trees with a stem diameter at breast height (DBH) of more than 3 cm. The aim of the overall assessment was to evaluate the carbon stock in AGB and structural characteristics of natural forests, although some assessments were carried out in homegardens during 2006 and 2008 (Mattsson et al. 2009, 2012). The DBH, tree height, and species information for each tree were measured from eight representative homegardens in dry zone areas (Hambantota district and Anuradhapura district) and four wet zone homegardens within the Kandy district. Sampling size was 30 × 30 m for the wet zone homegardens and 20 × 20 m for the dry zone homegardens due to their smaller sizes. Selections of representative homegardens were done to account for differences in composition and succession. For the selection of sample area within homegardens, the center point of the

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[2] The CDM is one of two flexible mechanisms under the Kyoto Protocol which allows industrialized countries with a GHG reduction commitment to invest in projects that reduce emissions in developing countries as an alternative to more expensive emission reductions in their own countries.

Fig. 3 Dry and wet homegardens where **a** is a dry zone homegarden from the district of Anuradhapura, **b** is a dry zone homegarden in Hambantota district whereas **c**, **d** are wet zone "Kandyan homegardens" in Kandy district

plot in each case was located in the center of the homegarden. Given the lack of a standard approach and available allometric equations to estimate carbon stock for homegarden systems in Sri Lanka, pan-tropical allometric equations for tropical natural forests were used. The higher species diversity and denser structure in the wet zone homegardens compared to dry zone homegardens (Jewell 1995) resulted in a division of our measurements into a dry life zone category and wet life zone category. The allometric equation (Eq. 1) developed by Brown et al. (1989) for wet zone homegardens encompassing the variables DBH, height and wood density and the allometric equation (Eq. 2) developed by Chave et al. (2005) for dry zone homegardens including the same variables were used in this categorization. These two allometric equations can be expressed as follows:

$$Y = \exp^{\left(-2.4090 + 0.9522 \cdot \ln\left(D^2 \cdot H \cdot S\right)\right)} \tag{1}$$

$$Y = \exp^{\left(-2.187 + 0.916 \cdot \ln\left(D^2 \cdot H \cdot S\right)\right)} \tag{2}$$

where Y is biomass (in kg), D is the stem diameter at breast height (cm), H is tree height (m), and S is wood density (g cm^{-3}).

For the carbon stock assessment in AGB, species information was used to identify wood densities following Reyes et al. (1992). It was also assumed that carbon accounted for 50 % of the biomass (Brown 1997). The AGB carbon stock was calculated for each tree and was subsequently extrapolated to plot size and hectare size. As no information is available on homegarden extent for the years 1996 and 2010, a business-as-usual (BAU) trend was assumed for these 2 years based on the area information available for homegarden on a national level in 1992 and 2005 (Jewell 1995; FAO 2009). In addition, as no information on carbon stock in AGB was available for 1996 and 2010, the carbon stock in megagrams per hectare (Mg C ha^{-1}) was assumed to be the same for all years (1992–1996–2005–2010) as measured in the two field campaigns for this study. To acquire the total AGB carbon

stock on a national level (Pg C), homegarden area extent was multiplied with the mean AGB carbon stock estimate of both dry zone homegardens and wet zone homegardens (61 Mg C ha^{-1}). From the field measurements and homegarden area information from 1992 to 2005, the total AGB carbon stock [petagrams of carbon (Pg C)] was estimated for homegardens on a national level for the periods 1992–1996–2005–2010. For more information on the natural forest inventories and methodology for AGB carbon stock estimations, see Mattsson et al. (2012).

RESULTS

The carbon stock in AGB in the sampled dry zone homegardens ranged from 10 to 55 Mg C ha^{-1} with a mean value of 35 Mg C ha^{-1} ($\pm$ 24) whereas in the sampled wet zone homegardens it ranged from 48 to 145 Mg C ha^{-1} with a mean value of 87 Mg C ha^{-1} ($\pm$ 42). The tree density per hectare ranged from 338 in the dry zone homegardens to 2108 in wet zone homegardens, which is reflected in the higher carbon stock estimates within the wet zone homegardens (Table 2).

The total carbon stock in homegardens was estimated as 50 Pg C (1992), 53 Pg C (1996), 60 Pg C (2005), and 63 Pg C (2010) as shown in Fig. 4.

Mattsson et al. (2009) estimated the carbon stock for dry zone homegardens as much higher (107.9 Mg C ha^{-1}) compared to the values in this assessment due to the use of a general formula for Indian forests, taking into account the basal area and not considering other parameters. The estimates from Mattsson et al. (2009) are comparable with the figures from Dissanayake et al. (2009) who estimated a similar AGB carbon stock in homegardens in Kandy (90 Mg C ha^{-1}) and Matale (104 Mg C ha^{-1}) districts. They extrapolated the carbon stock in AGB using homegarden area information on district level resulting in a total carbon stock estimate of 5.5 Pg C in the Kandy district and 2.1 Pg C for Matale district. Premakantha et al. (submitted) also showed that homegardens in Nuwara Eliya district contain 2.1 Pg C (77 Mg C ha^{-1}). Perera and Rajapakse (1991) found that the tree density in Kandyan homegardens varied from 92 to 3736 trees ha^{-1} with over 70 % of the homegardens being considered as dense, holding 500–1500 trees ha^{-1}, which is mostly within the range of this study.

Mattsson et al. (submitted) estimated that the AGB carbon stock in natural forests range from 22 to 181 Mg C ha^{-1} in six natural forest types and with a tree density ranging from 337 to 1136 trees ha^{-1}, for the same forest types.

As shown in Table 2, homegardens in the dry zone are generally low in tree density and also hold lower carbon stocks than the wet zone homegardens. The wet zone homegardens have denser structure and richer tree species diversity (FAO 2009). When using the extrapolated data on area extent and carbon of forest and homegarden in a joint assessment (Fig. 4) it is evident that the homegardens harbor an important share of carbon in the natural forest ecosystem, increasing from almost one-sixth in 1992 to nearly one-fifth in 2010. In addition, due to the decreasing trend of natural forest cover loss from 2005 to 2010 and increasing trend of homegarden extent from 1992 to 2010, the combined total area of homegardens and natural forests has increased from 2005 to 2010. However, this extrapolation approach must be viewed with some caution due to the limited sample size of homegardens. Including estimates of carbon in below ground biomass into the analysis above could increase the carbon values significantly. Below ground biomass dynamics in homegardens are little studied and needs further attention, but due to a high diversity and abundance of woody perennials in homegardens it is possible that carbon assimilation in soil organic carbon (SOC) is higher in homegardens compared to many other land-use systems (Kumar and Nair 2004). For example, Roshetko et al. (2002) estimated that the SOC of Indonesian homegardens ranged between 10.4 and 103.7 Mg C ha^{-1}.

DISCUSSION

The well-adapted agroforestry system of homegardens could have a potential for achieving multiple goals of climate change adaptation and mitigation as well as poverty reduction and sustainable development that could be of relevance for the Sri Lankan government. In this future outlook we suggest an elaboration that homegardens are extended and tested beyond only being located and developed around homesteads. This option entails discussing different pathways grouped into rehabilitation of degraded lands,

Table 2 Mean and range AGB carbon stock in homegardens for dry zone and wet zone, respectively

Homegarden system	Mean AGB carbon (Mg C ha^{-1})	AGB carbon range (Mg C ha^{-1})	Mean number of trees per hectare	Std. deviation	95 % CI	n
Dry zone	35	10–55	338	24	16	8
Wet zone	87	48–145	2108	42	41	4

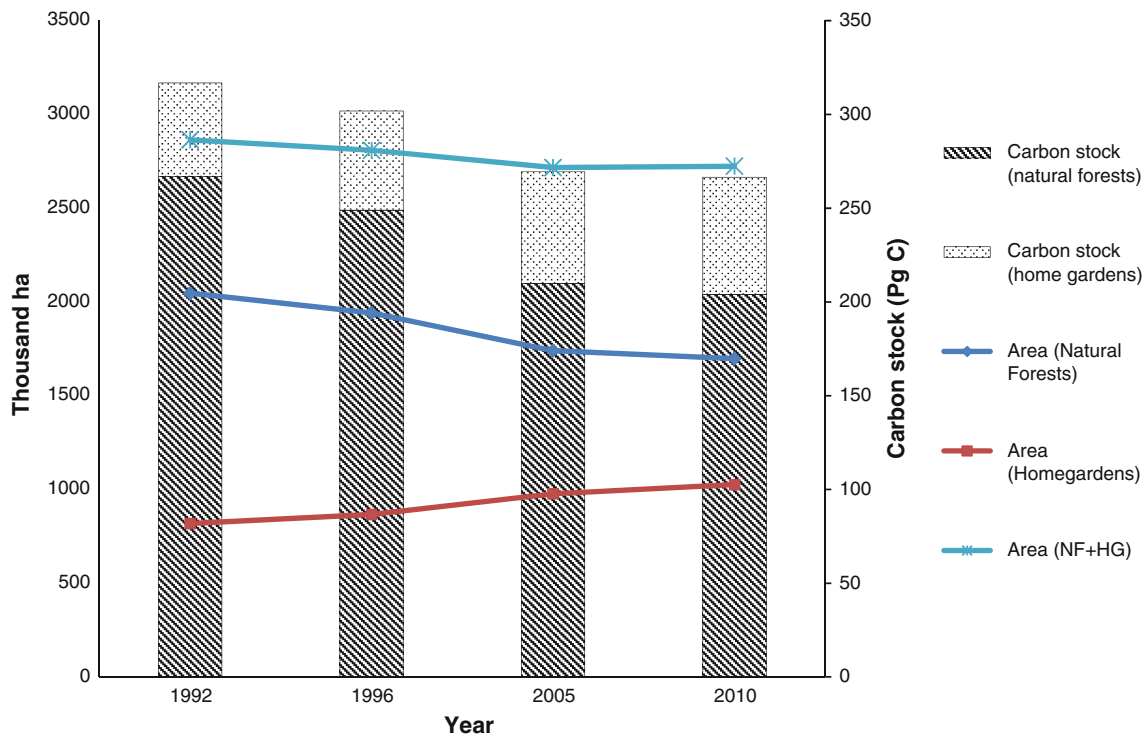*Std* standard, *CI* confidence interval, *n* number of sampled plots

Fig. 4 Area change for homegardens, natural forests, and total above ground biomass carbon content for homegardens and natural forests 1992–2010

expansion and intensification of the system, as well as enhancement of benefits. Finally we will highlight a few implications for the REDD+ process.

Pathway 1: Rehabilitation of Degraded Lands

According to Hewage et al. (2002) about 50 % of all land in Sri Lanka is in some stage of degradation mainly due to soil erosion and soil fertility degradation. Homegardens are one option among many that could be used to rehabilitate degraded lands.

For Socio-economic and Environmental Purposes

After the tsunami in 2004, it was shown in the Hambantota district that households with homegardens or in the vicinity of neighbors' homegardens were less damaged from the hazard than those without (Mattsson et al. 2009). The role of homegardens as protection was also well described by people living along the coast who also suggested them as measure for future protection. However, geographical matchmaking between the location of degraded lands and human settlements will be necessary. There may be limited opportunities to expand homegardens in densely populated urban districts while less populated rural districts hold larger potential for expansion.

For Carbon Offset Purposes

Within the Kyoto Protocol, the CDM mechanism for sink-related forestry activities (A/R CDM) includes several methodologies that focus on rehabilitation of degraded lands (e.g., Methodology AR-AM0003 'Afforestation and reforestation of degraded land through tree planting, assisted natural regeneration and control of animal grazing'; used in an A/R project in Sichuan, China); and eight projects with clear rehabilitation purposes are registered and running. One limitation to the A/R CDM projects in general is that the carbon credits they produce (tCERs) are temporary due to the uncertainties with permanence within terrestrial sink projects compared to for example energy efficiency projects. For the same reason tCERs from A/R CDM projects are excluded from the European Trading System (EU-ETS), which is why there are only 39 projects in the CDM A/R project cycle at present (UNFCCC 2012).

The use of terrestrial carbon sinks is, however, more popular within the voluntary carbon market outside the UNFCCC and Kyoto Protocol; with 46 % of the voluntary carbon credit sales in 2012 coming from forest-based projects (Diaz et al. 2011). The value of the forest carbon market was 8.5 million USD in 2005 and had increased to 177.6 million USD in 2010 (ibid.). Voluntary certification schemes available for forest and land-use projects are for

example the Verified Carbon Standard (VCS), the Climate Action Registry, Plan Vivo, or the Carbon Fix Standard (Henders and Ostwald 2012).

Pathway 2: Expansion of Homegardens as a Land-Use Strategy

The idea on expanding homegardens into new areas is related to the pathway of rehabilitation of degraded lands. As expansion in this sense should not promote competition between productive agricultural land and deforestation, degraded land is a promising land-use type where expansion could take place.

Expansion by Use of Open Dry Forest

The estimated area of open dry forests is presently 500 000 ha or about 7.5 % of Sri Lanka's total land area where about 85 % of these are considered to be degraded (Hewage et al. 2002). According to Mattsson et al. (2012), the open forests presently hold 14 Pg C in above and below ground biomass carbon. Hypothetical calculations on establishing homegardens on these degraded forest lands (assuming enrichment planting within existing degraded forest) would yield an additional carbon stock (excluding below ground biomass) of almost 5 Pg C using the low range conservative estimate of 10 Mg C ha^{-1} as found in dry zone homegardens. This would be equivalent to the total carbon stock (5.5 Pg C) found in Kandy district by Dissanayake et al. (2009). However, there are several limitations for expanding homegardens into this land-use system since many open forest areas are protected in national parks and conservation areas. Also as mentioned earlier, the traditional use of homegardens has been around homesteads inherently meaning close to where people live. The idea of expanding into degraded open dry forest would in that sense require new management strategies.

Expansion by Use of Degraded Lands

Even if the estimates of degraded lands of 50 % of the total land in Sri Lanka (Hewage et al. 2002), these values should be used with caution, as the rehabilitation potentials are likely. This could include benefits of reduced erosion, changed and preferably improved hydrology and local climate, but also additional costs for implementing the management system. One potential incentive for expanding homegardens into degraded lands in addition to improved economic and social benefits from market and subsistence products could be the use of offset mechanisms that can attract investors to cover start-up costs. On the other hand, it is possible that these soils are of poor quality, which could prolong growth and hence it could take a long time for investors to get their money back within a reasonable timeframe.

Pathway 3: Intensification of Homegardens for Increased Benefits

With increased demand of land-based products and services, homegardens exemplify a system that offers many benefits for its local users without external criteria defining or price tagging them. However, many certification schemes and offset systems suggest the development of externally defined standards for products and services to be supplied and meet the increased demand to be produced from the same piece of land.

Increase the Number and Level of Environmental Services

One reason for the survival of the ancient homegardens as a land-use system is probably the direct supply of required goods and services to its user. The same historical sustainability can be found in other ancient agroforestry systems such as the parkland system (Bayala et al. 2008) and old peanut areas (Tschakert et al. 2004) in Western Africa. With the increased pressure on land to produce more products and services due to population increase and increased consumption patterns, the future strategies for land-use management need to include multiple aims for the same piece of land rather than single use, e.g., agriculture land, cattle ranging or production forest.

Increase of Carbon Stock

Even though our estimates on the carbon stock in homegardens (10–145 Mg C ha^{-1}) are lower than those found in natural forests (22–181 Mg C ha^{-1}), it is worth elaborating what implication this homegarden system has on the general terrestrial carbon in Sri Lanka, and what the implications would be if the system was included in a general forest definition; i.e., if homegardens would be considered as forests. If the planned homegarden area increase of 1 % per year until 2020 is met, as suggested by the Government of Sri Lanka (MFE 1995), homegardens would sequester an additional 9.5 Pg C in 2020 compared to 2005 (using a mean value of 61 Mg C ha^{-1} between dry zone and wet zone homegardens), or 1.5 Pg C (using the low range conservative estimate of 10 Mg C ha^{-1} as found in dry zone homegardens). Alternatively, if the BAU area increase from 1992 to 2005 is sustained until 2020 and if it is excluded from the 1 % target, homegardens would hold an additional 7.5 Pg C in 2020 compared to 2005. If both these trends and goals (BAU and 1 % target) are met this would mean an additional 9 Pg C using conservative figures or 17 Pg C if using the mean value of 61 Mg C ha^{-1}.

This can be compared with the latest available annual reported emission from Sri Lanka's land use and forestry sector that is 27.9 Pg CO_2 in 1994 (UNFCCC 2005).

Implications for the REDD+ Process

Over the last years the scope and debate on REDD+ has widened from only deforestation and forest degradation to include processes of enhancement of forest carbon stocks, sustainable management of forests and also agriculture (REDD++) in order to give incentives for a wider suite of countries to participate. Sri Lanka has been one of the countries supporting the expanded focus of REDD+, highlighting the need for compensation to be provided for conservation and sustainable management of forest resources (UNFCCC 2008). A National Joint Program was initiated in 2011 to assist in the development of an effective REDD+ strategy and to contribute to reduction of emissions from deforestation and forest degradation from 2011 to 2014 (Ministry of Environment 2012). In March 2012, the UN-REDD programme endorsed US$4 million in funding for Sri Lanka to prepare and implement REDD+ strategies (UN-REDD 2012).

If REDD+ is broadened to include agroforestry land-use systems, homegardens could be folded into REDD++. As seen in Fig. 1, homegardens are often located in pantropical carbon hotspots where high-density tropical forests are present. Defining agricultural systems within REDD+ will primarily be a political decision, but if the intention is to provide incentives for carbon sequestration through, e.g., enhancement of forest carbon stocks and sustainable management of forests, there are reasons to include homegardens since they have a substantial share in terrestrial carbon stock, offer many other benefits and can reduce pressure to encroach on adjacent natural forest land. Reference to homegardens and trees outside forests are repeatedly highlighted in Sri Lanka's REDD+ readiness preparation proposal to the UN-REDD programme and the World Bank's Forest Carbon Partnership Facility (Ministry of Environment 2012). For example, recommendations were made that homegardens should be included into a forest definition and that homegardens should be included within the National REDD+ Programme as they offer high potential for carbon sequestration and ancillary co-benefits. In addition, the role of homegardens under REDD+ should be harmonized with existing tree planting programmes such as the *Deyata Sevana* and *Divi Neguma* (ibid).

In terms of reference level setting, the carbon stocks would be higher in a system where homegardens are included, which could be an unwanted description of the past for a REDD+ aspiration country such as Sri Lanka. It could also give higher incentives to increase the carbon density of homegardens if a REDD+ system rewards those

activities. In terms of reference levels, it has to be considered that only new homegarden areas that exceed the 1 % increase as planned by the government until 2020 would be additional for carbon sequestration under REDD+. Furthermore, using homegardens for direct conservation purposes under REDD+ is problematic as there are hardly any additionality due to the fact that they are long-term, permanent, and ancient systems—and thus little threat of potential emissions. In terms of general sustainability, homegardens are user-driven, which inherently means that rather than pure conservation of natural forests, homegardens produce multiple benefits of direct relevance for local livelihoods. These issues have recently been highlighted in the discussions on REDD+ safeguards at the 18th Conference of the Parties to the UNFCCC in Doha 2012 (UNFCCC 2011). The issue of well documented acceptance should be considered a key factor in terms of sustainability of any land-use management plan or strategy.

CONCLUSIONS

The AGB carbon stock in homegardens of Sri Lanka was shown to range between 10 and 145 Mg C ha^{-1} where dry zone homegardens range from 10 to 55 Mg C ha^{-1} with a mean value of 35 Mg C ha^{-1} (SD = 24) whereas carbon stock in the sampled wet zone homegardens range from 48 to 145 Mg C ha^{-1} with a mean value of 87 Mg C ha^{-1} (SD = 42). In addition, homegardens have an important share of AGB carbon stock in the national forest ecosystem, increasing from nearly one-sixth in 1992 to almost one-fifth in 2010. This assessment shows the potential of using homegardens for future land-use planning and multiple benefits including carbon sequestration potential, particularly in terms of land scarcity and climate mitigation options.

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