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The role of complex agroforestry systems in the conservation of forest tree diversity and structure in southeastern Ghana

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Abstract The role of different agroforestry systems in the conservation of plant diversity and forest structure has not been directly compared in many agricultural dominated landscapes. In this study, we investigated tree diversity and forest structure in a complex agroforestry landscape traditionally grown for cocoa and mixed food crops and compared these to the natural forest in southeastern Ghana. The study was carried out using 36 25 m $\times$ 25 m plots. There was significant difference [95% Confidence Interval (95% CI)] in the native forest/non-crop tree species richness between the natural forest and the agroforest farmlands but species richness was similar between the cocoa and mixed food crops agroforests. The density of native forest/non-crop trees was significantly higher ($P < 0.05$) in the natural forest but similar between cocoa and mixed food crops agroforest. Similarly, the basal area of native forest/non-crop trees was significantly higher ($P < 0.05$) in the natural forest but comparable between cocoa and food crops agroforest. Of the 20 most abundant native forest/non-crop trees recorded, 12 of them showed significant responses ($P < 0.05$) to land use change with nine of the species significantly abundant in the natural forest relative to the agroforest systems. Eighteen native forest/non-crop trees species in the agroforestry systems were commonly recorded as being used; 100% of them being used as fuel wood with 83.3 and 77.8%, respectively, used as medicines and materials. The findings of this study suggests that although complex agroforestry systems are a poor substitute for the natural forest the heterogeneous mosaic landscape in which complex agroforestry forms part can be strategically managed to maximize the benefits of both sustainable agriculture production and conservation of plant diversity by acting as buffer between protected areas and intensively managed areas.

Keywords Tropical forest · Deforestation · Agroforestry · Management · Ghana

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Introduction

Human interference into primary forests that were previously free of anthropogenic disturbance is becoming common in all major blocks of remaining tropical forest (Witte 1992; Verissimo et al. 1995; Coomes et al. 2000; Kammesheidt 2002). The combined effects of selective logging and unsustainable farming practices in agricultural frontiers are expected to result in considerable loss of biodiversity. Conversion of tropical primary forest into various land use systems has serious impacts on distribution, community structure and population characteristics of flora (van Gemerden et al. 2003). Following centuries of deforestation, many tropical rainforest ecosystems are severely threatened and exist only as forest fragments. Consequently, there is a growing interest in quantifying habitat characteristics such as forest structure, floristic composition and species diversity in natural forest and human dominated landscapes (Myers et al. 2000).

Some of the important tools used for mitigating tropical deforestation are the establishment of tropical protected parks and agroforest areas. Parks are effective for preventing deforestation and thereby protecting biodiversity although they are largely unfunded and associated with substantial land use pressure (Bruner et al. 2001). Agroforestry has the advantage of being an integrated approach combining sustainable agricultural production and biodiversity conservation. Agroforestry systems can be used to protect biodiversity and assist alleviate the negative effects of deforestation by stimulating natural forest cover through cultivation of trees with agricultural crops and may serve as biological corridors between protected areas and non-protected areas (Schroth et al. 2004). Thus, agroforestry ecosystems have attracted the interest of conservation biologists working on the interface between integrated natural resource management and biodiversity conservation (Gajaseni et al. 1996; Perfecto et al. 1996; Rice and Greenberg 2000).

Complex agroforests are special type of agroforestry system characterized by a forest-like structure and significant plant diversity in which useful trees and tree crops species attain substantial greater density, compared to natural forest, through planting, selection, and management of useful species from spontaneous regeneration (Schroth et al. 2004). The principal tree crops in complex agroforest are either shade tolerant trees such as cocoa (*Theobroma cacao*) and coffee (*Coffea arabica*) or canopy trees such as rubber (*Hevea brasilensis*). In West Africa a special type of complex agroforest exist where mixed food crops are cultivated in the shade of native trees. It can be rightly argued that all agroforestry systems no matter how forest-like they may appear to be displace natural ecosystems through either clearing or replanting with crops and trees or variable levels of domestication of the original landscape and ecosystems. However, the relative impact of converting natural forest to different agroforestry systems has not been directly compared in many agricultural landscapes (Fitzherbert et al. 2008). For example, in our previous study (Asase et al. 2009), we showed that cocoa agroforestry systems has less impact on plant diversity and vegetative structure compared to unshaded intensive cocoa farming although how the cocoa agroforest compare with the other agroforestry systems is largely unknown. This information though is very important in managing agricultural landscapes for the conservation of biodiversity and sustainable agricultural production.

In this study, we investigated the role of two complex agroforestry systems in the conservation of tree diversity and forest structure in an agricultural dominated landscape traditionally grown for cocoa and mixed food crops and compared these to the natural forest in southeastern Ghana. Specifically, the objectives of this study were (1) to quantify the role of traditional cocoa and mixed food crops agroforests in the conservation of forest tree diversity compared to the natural forest; (2) to determine the structural characteristics of the natural forest and that of the two agroforest systems; (3) to analyse tree species responses to the land use changes; and (4) to document the uses of native forest/non-crop trees retained in the two agroforestry systems. It is hoped that the findings of this study will have important implications for sustainable management of agroforestry landscapes particularly for the conservation of plant diversity.

Materials and methods

Study sites

This study was conducted at two sites in the Eastern Region of Ghana between March 2007 and October 2008 (Fig. 1). Historically, the area was tropical forest, but has been extensively cleared to form a strongly agricultural landscape populated by communities of smallholder farmers. This follows a common pattern in Ghana, which now has only 7% forest cover reduced from 35% at the turn of the nineteenth century (FAO 2003). Mean annual rainfall is between 1200 and 1800 mm and the study area is characterized by a two-peak rainy season in April–June and October. A mild harmattan season occurs from November to March.

The first site was at Adjeikrom where traditional agroforestry systems are being practiced. The area is located between latitudes 6° and 6°30′N and longitudes 0° and 0°30′W. Two broad agroforestry land

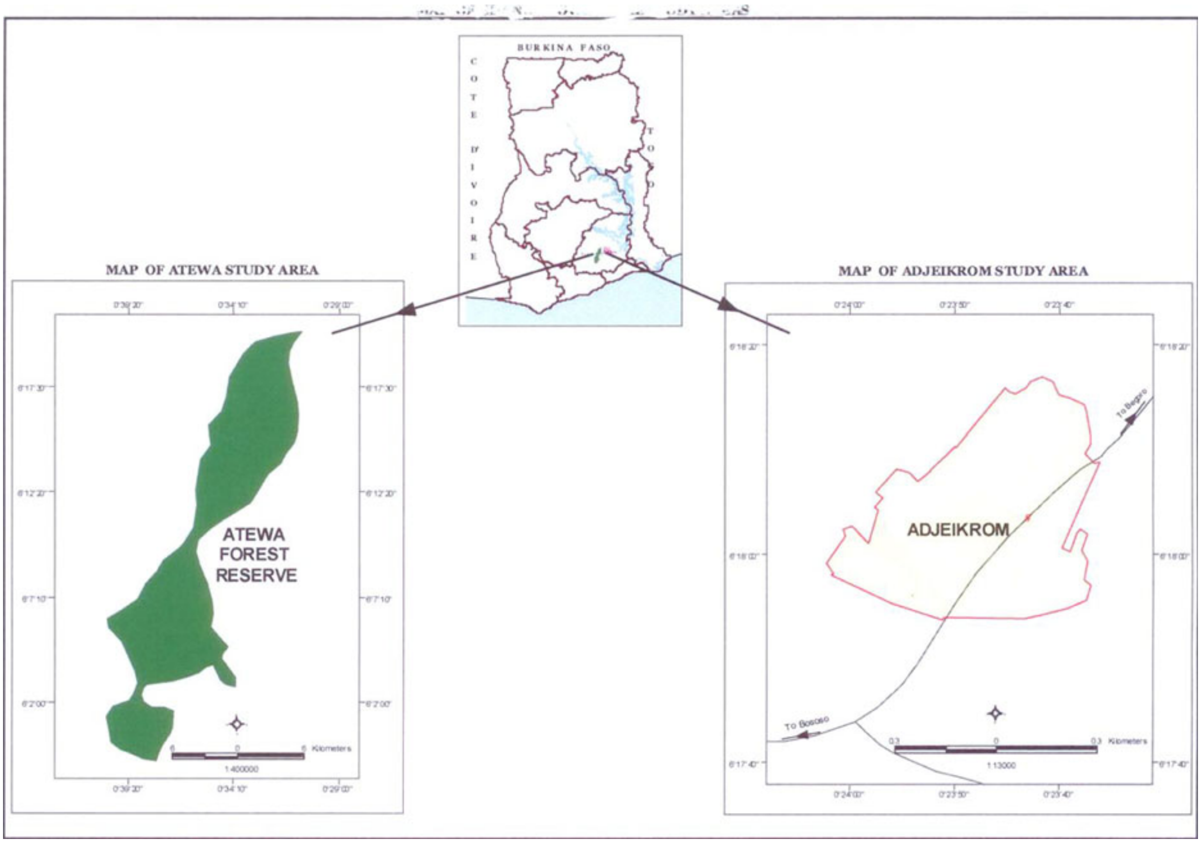

Fig. 1 Map of Ghana showing the locations of the study sites

use systems, namely, traditional cocoa (*T. cacao*) agroforest and mixed food crops agroforest were studied. The crops are traditionally cultivated in the shade of native forest trees by smallholder farmers; most of the farms are less than a hectare in size. Food crops being cultivated included plantain (*Musa paradisiaca*), banana (*Musa sapientum*), cassava (*Manihot esculenta*), maize (*Zea mays*) and cocoyam (*Colocasia esculenta*). The food crops are traditionally cultivated together on the same piece of land but without cocoa. Although cocoa agroforest farms are purposely grown for cocoa, the farms also contain other food crops such as banana, plantain and cocoyam. The cocoa agroforest farmlands were cultivated with a mixture of Amelonado (30–40 years) and Amazon cocoa varieties (10–25 years) on a gentle slope and the farms were moderately maintained in terms of weeding, harvesting of pods and pest control. Mean density of food crop trees in the mixed food crops agroforestry farmlands was 438.40 ± 61.44 (±SE) per hectare, about eight times that found in the cocoa agroforestry. The mixed food crops agroforests were between 3 and 4 years and fairly well maintained in terms of weeding and harvesting of produce. It is important to note that the mixed food crops farms are usually abandoned after 5 years of continuous cultivation as the farmers' practice essentially shifting cultivation.

The second site was at the Atewa Range Forest Reserve in the East Akim District which represented the natural forest. This reserve was used as the control in this study. There is very little primary forest left in Ghana and the Atewa Range Forest Reserve is representative of remaining natural forest in the study area (Hawthorne and Abu-Juam 1995). The reserve is located between latitudes 6° and 6°10′N and longitudes 0° and 0°36′W and covers an area of 232 km^2. The Atewa Range Forest Reserve harbours a wide variety of plant and animals species with some of the species not found elsewhere in Ghana (Hall and Swaine 1981; Hawthorne and Abu-Juam 1995). It is currently estimated that there are over 656 species of plants, 460 species of butterfly, 130 species of bird, 30 species of large mammals, 7 species of small mammals, 16 species of reptiles and 3 species of amphibian in the reserve (Forestry Commission 2003).

Data collection

Sampling was done following the method of Hall and Swaine (1981) as modified by Hawthorne and Abu-Juam (1995). This method basically involves sampling forest trees using 25 m × 25 m plots. The method was adopted because it has been successfully used in Ghana (Hawthorne and Abu-Juam 1995; Asase et al. 2009) and Cameroon (van Gemerden et al. 2003) to study forest vegetation. Thirty-six 25 m × 25 m plots were randomly distributed across the three land use types, that is, natural forest, cocoa agroforest and mixed food crops agroforest. Total number of plots was 16 for the natural forest and ten each for traditional cocoa agroforest and mixed food crops agroforest farmlands. The number of plots studied in each land use type was based on the level of heterogeneity as well as the size of the land use type following a preliminary field survey. The minimum distance between two nearest plots was 100 m in each land use type and geographical position of each plot was captured by a handheld Global Positioning System unit (Garmin GPS III plus).

Within each plot, all trees $\geq$10 cm diameter-breast-height (1.3 m above ground level) were identified to species and diameter measured. For trees with large buttresses, DBH was measured at 1.3 m from the top of the buttress because of the difficulty associated with estimating accurately DBH of trees based on measurement taken on tree trunks. Identification of the trees within the plots was done by an experienced tree spotter with the help of a field guide (Hawthorne 1990). Specimens of plants were collected and verified with voucher specimens at the Ghana Herbarium at the Department of Botany, University of Ghana.

The uses of native forest/non-crop trees species in the agroforestry farmlands were collected by interviewing local farmers. Six farmers assisted with the field inventory on uses of trees in the agroforests. The six farmers were selected by the chiefs and people of the study because they are very knowledgeable about the uses of plants. Each field ethnobotanical inventory team consisted of a botanist, two famers, 2–3 field assistants and a local field guide. The farmers consulted among themselves and then provided information on the local names and how the trees were being used. Only uses of the trees that received unanimous acclamation among the farmers are reported. The uses of the native forest trees/non-crops were classified into six groups, namely, fodder, food, fuel, materials (including timber), medicine and social uses.

Data analysis

Because sampling was not exhaustive, the rarefaction method of Gotelli and Colwell (2001) was used to estimate the expected number of species for each land use type for the construction of species accumulation curves. Species diversity was evaluated using the Shannon–Wiener index ($H' = \sum_{i=1}^{s} p_i \ \text{In}\ p_i$), where s is the total number of species and p is the relative abundance of the i species. In contrast to direct measures of species richness (number of species), this index takes into account the relative abundances of species (Legendre and Legendre 1998). Beta-diversity between the land use types was estimated using the Jaccard similarity index. The Jaccard similarity index uses species presence/absence data for two sample sets (in this case land use types) and is calculated as $J = S/(M + N–S)$, where S is the number of species shared by any two land use types (in this case M and N), N is the number of species in land use type M, and N is the number of species that in land use type N (Chao et al. 2005). The free statistical software EstimatesS version 8.0 (Colwell 2006) was used for the species accumulation curves, and estimation of species diversity and β-diversity.

Basal area of trees per hectare was calculated using the formula $\Sigma 0.0000785d^2$ where d is the DBH per tree. Statistical significant differences in density and basal area per unit areas between the land use types was analysed using analysis of variance (ANOVA), and Kruskal–Wallis test when data could not meet the assumptions for parametric tests when transformed. The assumption of normality was assessed using the Shapiro–Wilk tests (Crawley 2007). Where the tests indicated significant differences among land use types, means were contrasted with post hoc Tukey HSD tests and for non parametric data, Wilcoxon rank-sum test was used to compare means.

In order to determine tree species responses to land use changes, the relative density of the 20 most abundant native forest/non-crop species were analysed using generalized linear model (GLM). The model was fitted with logistic link function assuming Poisson distribution error followed by maximum likelihood (ML) method. Statistically significant levels are reported at $P \leq 0.05$. The free statistical software R version 2.6.0 (Crawley 2007) was used.

Results

Species composition and diversity

In total, 604 individuals of native forest/non-crop trees belonging to 146 species in 34 families were identified during the study (Appendix 1). The most species rich families included Fabaceae, Euphorbiaceae, Sterculiaceae and Apocynaceae. Of the species of trees identified nine of them, namely, *Amphimas pterocarpoides*, *Ceiba pentandra*, *Cussonia bancoensis*, *Ficus sur*, *Funtumia africana*, *Lannea welwitschii*, *Newbouldia laevis*, *Sterculia tragacantha* and *Terminalia ivorensis* were found in all the three land use types. With the exception of *Persea americana* and *Cedrela odorata*, all the tree species encountered were native forest species. The number of individuals of trees decreased from the natural forest (470 trees per hectare) through the mixed food crops agroforest (125 trees per hectare) to the cocoa agroforest (90 trees per hectare) (Table 1).

The species area curves are far from asymptotic, indicating that the areas sampled was too small to estimate the total number of species in the land use types (Fig. 2). However, with increased sampling the tree species richness is likely to be significantly higher [95% Confidence Interval (95% CI)] in the natural forest compared to the agroforestry farmlands but comparable between the traditional cocoa and mixed food crops agroforest. Thus, tree species richness was greatest for the natural forest. Mean Shannon–Wiener diversity index values differed significantly ($P < 0.001$) among the land use types with the natural forest recording the highest value and the cocoa agroforest the least value (Table 1). The difference between the cocoa and mixed food crops agroforest was not significant ($P > 0.05$).

The tree species composition similarity was highest between cocoa and mixed food crops agroforests. The β-diversity statistics showed that tree species community in the two agroforests are most similar (Jaccard index = 0.33) followed by that between the natural forest and mixed food crops agroforest (Jaccard index = 0.12). The least tree species

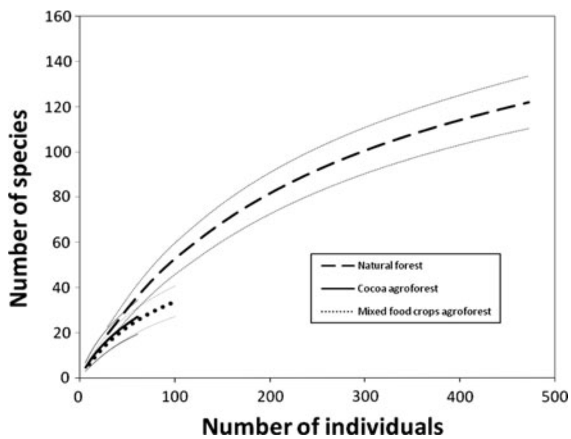

Fig. 2 Species accumulation curves (with upper and lower 95% CI for native forest/non-crop tree ≥10 cm in a complex agroforestry landscape in southern Ghana

Table 1 Native forest/non-crop tree diversity and structural characteristics of non-crop trees in a complex agroforestry landscape in southeastern Ghana

Parameters	Natural forest	Cocoa agroforest	Mixed food crops agroforest
Surveyed area (ha)	1	0.63	0.63
Number of tree species identified in surveyed area	123	27	34
Shannon–Weiner index (±SE)	4.94 ± 2.0	2.46 ± 1.6	2.6 ± 2.3
Stem density (ha^{-1})	470	90	125
Basal area of trees (m^2 ha^{-1})	23.9	8.4	8.2

composition similarity was found between the natural forest and cocoa agroforest (Jaccard index = 0.085).

Structural characteristics

The structural characteristics of vegetation was studied based on stem density, basal area and diameter-size group distributions of individuals of native forest/non-crop trees. There were significant differences (Kruskal–Wallis test, $P < 0.001$) in stem density per unit area among the three land use types. Significant differences were found in the stem density of trees between natural forest and mixed crops agroforest (Wilcoxon rank-sum test, $P < 0.05$), and between the natural forest and cocoa agroforest (Wilcoxon rank-sum test, $P < 0.05$). The stem density of native forest/non-crop trees per unit area in the natural forest was about 3.8 and 5.1 times that of mixed food crops and cocoa agroforests, respectively. Stem density of forest/non-crop trees between cocoa and mixed food crops agroforest was, however, not significant (Wilcoxon rank-sum test, $P = 0.65$).

Basal area of trees per unit area also differed significantly (ANOVA, $P < 0.05$) amongst the three land use types with the natural forest recording the highest value. There were significant differences in tree basal area between the natural forest and cocoa agroforest (Tukey HSD, $P < 0.05$), and between natural forest and mixed food crops agroforest (Tukey HSD, $P < 0.05$). The basal area of trees between cocoa and mixed food crops agroforest was, however, not significant (Tukey HSD, $P = 0.99$). Basal area of native forest/non-crop trees per unit area in the natural forest was about 1.7 times that of the agroforestry farmlands.

Diameter-size group distributions of individual trees in the three land use types are presented in Fig. 3. The histogram shows that the majority of trees, 91.0, 74.4 and 57.1% for natural forest, mixed food crops and cocoa agroforests, respectively, were between 10 and 40 cm DBH-size.

Tree species responses to land use changes

Of the 20 most abundant tree species recorded, 19 were recorded in the natural forest, 8 in cocoa agroforest and 5 in mixed food crop agroforest (Table 2). Twelve of the species showed significant responses to land use change ($P \leq 0.05$). The relative

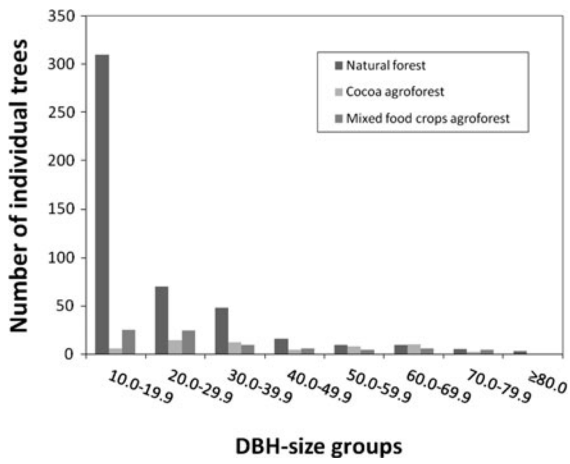

Fig. 3 Histogram of diameter-size group distribution of individuals of native forest/non-crop trees ≥10 cm in a complex agroforestry landscape in southeastern Ghana

density of nine (45%) of the most abundant native forest/non-tree crops decreased in both cocoa and mixed food crops agroforests. However, the relative density of three species, namely, *C. odorata*, *Elaeis guineensis* and *T. ivorensis* were higher in the agroforests compared to the natural forest. Relative density of *C. odorata* and *E. guineensis* were highest in cocoa agroforest and that of *T. ivorensis* was highest in the mixed food crop agroforest.

Uses of native forest/non-crop trees in agroforests

A total of 18 native forest/non-crop tree species were commonly reported being used in the cocoa and mixed food crop agroforests (Table 3). This represents 66.7 and 52.9% of the total number of tree species recorded in the cocoa and mixed food crops agroforest, respectively. All the species of trees were recorded as being used for fuel wood. Other common uses of the trees were for medicine (83.3%) and materials (77.8%). Figure 4 shows the number of species reported being used in six use categories. The useful trees in the agroforests included commercial timber species such as *T. ivorensis* and *Triplochiton scleroxylon*. Other material uses of the included the use of the stem of *A. pterocarpoides* for carving objects and that of *Nesogordonia papaverifera* as pestle for pounding ''fufu''.

Fruits trees such as *P. americana* and *Cola nitida* were among the trees retained/planted in the agroforests. The medicinal values of the trees were very

Table 2 Relative density of the 20 most abundant native forest/non-crop trees in a complex agroforestry landscape in southeastern Ghana

Species	Natural forest	Cocoa agroforest	Mixed food crops agroforest
Amphimas pterocarpoides Harms	0.13	0.10	0.50
Aulacocalyx jasminiflora Hook.f	1.00	–	–
Bussea occidentalis Hutch.	1.19	–	–
Carapa procera DC*	0.56	0.10	–
Cedrela odorata L.*	–	1.5	0.1
Chidlowia sanguine Hoyle*	1.65	–	–
Elaeis guineensis Jacq.*	0.13	2.30	–
Funtumia africana Stapf.*	1.36	0.40	0.10
Funtumia elastica Stapf.*	0.50	–	–
Greenwayodendron oliveri (Engl.) Verdc.	0.65	–	–
Hymenostegia afzelii Harms*	0.56	–	–
Napoleonaea vogelii Hook. & Planch	0.63	–	–
Ricinodendron heudelotii (Baill) Pierre ex Heckel.*	0.69	0.10	–
Rinorea oblongifolia Marquand*	1.3	–	–
Sterculia tragacantha Lindl.	0.13	0.40	0.40
Strombosia glaucescens Engl.	0.75	–	–
Tabernaemontana africana DC	0.63	–	–
Tabernaemontana sp.*	1.43	–	–
Terminalia ivorensis A. Chev.*	0.063	0.10	0.80
Tetrorchidium didymostemon (Baill.) Pax & K. Hoffm.*	0.56	–	–

Species with asterisks are trees that showed significant difference ($P \leq 0.05$) in their relative abundance among the three land-use types

important as the plants were being used for the treatment of many of the common ailments such as malaria and stomachaches. Species of trees such as *Alstonia bonnie* and *Khaya ivorensis* were reported being used for the treatment of various ailments. The leaves of *Ficus exasperata* was the most important fodder tree whiles trees such as *L. welwitschii* was reported used for certain rituals. Thus, the native forest/non-crop trees retained/planted in the agroforests were important sources of livelihood for the people in the study area.

Discussion

In this study the rich floristic diversity of native forest trees reminiscent of the natural forest was found to have decreased in the agroforests. This observation was, however, expected as a number of previous studies (Attua 2003; Bobo et al. 2006) have shown a reduction of forest trees species diversity with habitat modification and land use changes. The native forest/non-crop tree species diversity between cocoa and mixed food crops agroforests was similar in this study. This observation is contrary to the results of other studies (Attua 2003; Zapfack et al. 2002) which found that the diversity of vascular plants in cocoa agroforest was higher than that of mixed food crops agroforests. There is direct relationship between the type of cocoa variety cultivated and tree species richness in cocoa agroforests. For example, Amelonado cocoa agroforest which require low irradiance (that is, shade-loving cocoa) for optimum growth rate would have significantly higher species diversity than mixed food crops agroforest; whereas new cocoa varieties such as Amazon which are fast growing and more adapted to light has similar diversity as mixed food crops. In our study area, the cocoa agroforests were cultivated with a mixture of low and high irradiance cocoa varieties and this means that the agroforest were managed differently. This could explain the reason why tree species richness was similar between the cocoa and mixed-food agroforest. Differences in tree species richness in agroforestry landscapes are common due to factors such as differences in management intensity, culture and farm history (Schroth and Harvey 2007).

Table 3 Some native forest/non-crop tree species commonly reported used in cocoa and mixed food crop agroforests in southeastern Ghana

Species	Local names	Uses
Albizia zygia	Okoro	The leaves are used for the treatment of stomach aches and feeding animals. Stems are used for timber and as fuel wood. The tree is used in certain rituals
Alstonia bonnie	Nyamedua	The leaves are used for the treatment of various ailments. Stems are as fuel wood and for carving objects
Amphimas pterocarpoides	Yaya	The roots are used to treat anemia. The stem for carving objects and fuel wood. The roots of this plant are used in local rituals
Artocarpus communis	Debo	Fruits edible. The stem is used for carving objects. Both the stem and branches are used for fuel wood. Stem bark is used in certain rituals
Cedrela odorata	Cedrela	The leaves are used as vegetables and for feeding domestic animals. Stems are used as fuel wood and for carving objects. The plants have certain social uses
Celtis zenkeri	Esakoko, Papao	Stem bark for treatment of malaria. The stem and branches are used for fuel wood
Cola nitida	Bese	Seeds edible. The stem bark, seeds and roots are used in the treatment of various ailments. Stem and branches for fuel wood. Stem is also used in carving objects
Cussonia bancoensis	Kwaeborfre	The stem is used in carving objects as well as for fuel wood. The roots are used to treat ear infections
Ficus exasperata	Nyankyere, Sabratu	Leaves used in cooking and also for feeding goats and sheep. Stem and branches for fuel wood. There are certain some beliefs associated with this tree
Funtumia africana	Oke, Otuntum, Frumtum	The roots are used to treat coughs. The stem for carving and fuel wood. The roots of the plant are used in local rituals
Khaya ivorensis	Dubini	Stem bark used for the treatment of malaria and in preparation of local blood tonics. Bole used for timber. Stem and branches are used as fuel wood
Lannea welwitschii	Kumnini	Stem bark used for the treatment of abdominal pains. Stem and branches for fuel wood. The roots are also used in preparation of certain ritual concoctions
Milicia excelsa	Odum	Bole for timber. The stem bark is used to treat cough. Stem and branches for fuel wood
Nesogordonia papaverifera	Odanta	Stem used as pestle for pounding food and as fuel wood. Root bark used for treatment of headaches
Persea americana	Paya	Fruits are edible. The leaves are used for feeding goats and sheep. Stem bark are used to treat hypertension
Spathodea campanulata	Atsidituo	The stem bark used for treatment of wounds. The stem used for carving and fuel wood
Terminalia ivorensis	Emiri	Bole for timber and fuel wood. The stem bark is used to treat wounds
Triplochiton scleroxylon	Wawa	The roots are used for the treatment of oedema. The stem is for fuel wood and bole for timber

Some of the native forest/non-crop species in the agroforests were useful trees providing for the sources of fruits, medicines and timber. Similarly, in a study of traditional cocoa-based agroforestry and forest species conservation in Ondo State, Nigeria, Oke and Odebiyi (2007) found that many of the trees retained in the cocoa agroforests were fruit and timber trees. The selection and/or active planting of useful trees species may eventually lead to significant increase in the density of certain tree species in the complex agroforests compared with the rest of the landscape. For example, in southern Cameroon the density of *Dacryodes edulis* was ten times higher and that of *Milicia excelsa* was three times higher in cocoa plantations

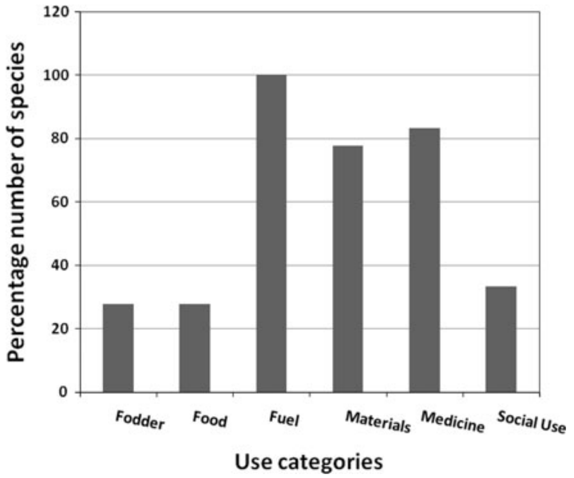

Fig. 4 Representation of number of species in use categories for native forest/non-crop trees ≥10 cm in a complex agroforestry landscape in southeastern Ghana

than elsewhere in the landscape (Van DijK 1999). Similarly, in this study the relative density of three species, namely, *C. odorata*, *E. guineensis* and *T. ivorensis* were higher in the agroforests compared to the natural forest. Our results also confirm that of previous studies in that the trees retained in agroforests are usually useful trees which also provide shade to reduce the rate of trans-evaporation, erosion and wind breaks (Duguma et al. 2001). It is important to indicate that there were many more trees in the two agroforests reportedly being used in the study area and that only the commonly mentioned used trees are reported here.

Generally, the conversion of natural forests to agricultural farmlands involves the removal of a substantial number of forest trees (Makana and Thomas 2006) with subsequent replacement with non-forest trees (Asase et al. 2009) In this study, forest species were being replaced with non-forest species such as *C. odorata* especially in the cocoa agroforest. The replacement of native forest trees with non-forest species in cocoa agroforest is also evident from floristic inventories in Costa Rica (Guiracocha et al. 2001). It was also found that the population density of majority of the most abundant tree species declined in the agroforest. This is a worrying scenario as non-forest species cannot support other biodiversity in terms of functionality.

The result of the study also showed that the natural forest had a greater number of small-sized native forest/non-crop trees than the agroforests systems suggesting that there is limited recruitment of forest trees species in agroforests especially in cocoa agroforests. This means that vegetation structure of the two agroforestry systems are simplified compared to that of the natural forest. Nevertheless, the complex agroforestry systems have at least some structural characteristics of the natural forest and may help reduce edge effects between the natural forest and open agricultural fields such as unshaded cocoa farmlands whereby decreasing mortality of forest trees that are not well adapted to drier microclimate. This could prevent the final collapse of isolated forest fragments and forest reserves in agricultural landscapes (Gascon et al. 2000). Besides offering habitats for a number of plants and animal species including many forest dependent species, the complex agroforest systems can make an important contribution to the conservation of regional biodiversity by enhancing landscape connectivity, reducing edge effect and improving local climate (Saatchi et al. 2001; Schroth et al. 2004). Farmers must therefore be encouraged to retain trees in farmlands or replant native trees in agroforests to replace old trees when they die.

It is evident from the above discussion that management of forest trees for shade as well as other human uses has clear implications for the conservation of plant diversity in agricultural landscapes. For example, management practices could affect the longer term potential role of the two complex agroforestry systems in the conservation of forest trees and structure. This is because the mixed food crops agroforest system is based on slash-and-burn and shifting cultivation practices, which, due to population pressure and reduced fallow cycle, is no longer sustainable. It means that the cocoa agroforestry systems are superior to the mixed food crops agroforestry systems in the longer term. This result is similar to that of Duguma et al. (2001).

The fact that plant diversity show species loss and turnover as baseline forest is being converted to agricultural farmlands means that protection of natural forest should be part of any biodiversity conservation strategy in the study area. Forest protection alone is, however, unlikely to succeed because of the increasing pressure for more land for farming and other socio-economic factors. From the data presented it is clear that the complex agroforests are a poor substitute for the natural forest both in terms of native forest tree species richness and vegetation structure. Despite the loss in forest trees and simplification of forest structure, complex agroforestry systems have been found to support relatively higher species richness compared to other land use types such as unshaded farming systems (Bisseleua et al. 2007; Herve and Vidal 2008). As indicated earlier, our previous study in the study area (Asase et al. 2009) showed that cocoa agroforest supported higher species richness compared to unshaded cocoa farms. There is also the possibility of additional trees being recruited from the soil seed bank. The extent to which the complex agroforests are therefore needed as partial substitute for natural forest in landscape conservation strategies will obviously depend on the availability of natural forests (Schroth et al. 2004). Since there is increasing demand for land and food production leading to agricultural intensification the heterogeneous mosaic landscape in which the complex agroforestry systems forms part could, however, be strategically managed to maximize the benefits of both sustainable agriculture production and conservation of plant diversity.

In conclusion, although complex agroforestry systems are a poor substitute for natural forest they have the potential role to conserve forest trees and structure especially in agricultural dominated landscapes by acting as buffer between protected areas and other intensively managed areas. If complex agroforests are to play a significant role in the medium to long term future tropical landscapes conservation of plant diversity, they must also be profitable and make significant contributions to the livelihood of their owners. This will be a major motivation for owners to practice complex agroforestry farming.

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Appendix 1

Appendix 1 Native forest/non-crops tree species, their families and density (individuals ha^{-1}) in a complex agroforestry landscape in southeastern Ghana

Species	Family	Natural forest	Cocoa agroforest	Mixed food crop agroforest
Albizia adianthifolia W.Wight.	Fabaceae	2	0	1.6
Albizia ferruginea Benth.	Fabaceae	0	0	1.6
Albizia zygia J.F Macbr.	Fabaceae	3	0	1.6
Alstonia bonnie De Wild	Apocynaceae	0	1.6	0
Amphimas pterocarpoides Harms	Fabaceae	7	1.6	24
Aningeria robusta (A.Chev.) Aubrév & Pellegr.	Sapotaceae	2	0	0
Anthonotha fragrans (Baker f). Exell & Hillc.	Fabaceae	3	0	0
Anthonotha macrophylla P. Beauv.	Fabaceae	3	0	0
Antiaris toxicaria Lesch.	Moraceae	4	0	1.6
Antidesma laciniatum Müll. Arg.	Euphorbiaceae	2	0	0
Elaeis guineesis Jacq.	Arecaceae	10	6.4	1.6
Antrocaryon micraster A.Chev. & Guillaumin.	Anacardiaceae	3	0	0
Artocarpus communis Forst.	Moraceae	0	1.6	0
Aulacocalyx jasminiflora Hook. f.	Rubiaceae	16	0	0
Baphia nitida Lodd.	Fabaceae	0	0	1.6
Baphia pubescens Hook. f.	Fabaceae	0	0	1.6
Blighia sapida Kon.	Sapindaceae	4	3.2	0
Blighia welwitschii (Hiern) Radlk.	Sapindaceae	1	1.6	0
Bombax brevicuspe Sprague	Bombacaceae	1	0	0
Bridelia atroviridis Müll. Arg.	Euphorbiaceae	1	0	0
Bridelia grandis Pierre ex Hutch.	Euphorbiaceae	2	0	0
Bridelia micrantha Baill.	Euphorbiaceae	1	0	0

Appendix 1 continued

Species	Family	Natural forest	Cocoa agroforest	Mixed food crop agroforest
Bussea occidentalis Hutch.	Fabaceae	19	0	0
Caloncoba echinata Gilg.	Flacourtiaceae	2	0	0
Canarium schweinfurthii Engl.	Buseraceae	1	0	0
Carapa procera DC.	Meliaceae	9	0	1.6
Cedrela odorata L.	Meliaceae	0	1.6	1.6
Ceiba pentandra L. Gaertn.	Bombacaceae	1	1.6	1.6
Celtis malbraedii Engl.	Ulmaceae	2	3.2	0
Celtis zenkeri Engl.	Ulmaceae	1	0	1.6
Chidlowia sanguinea Hoyle.	Fabaceae	33	0	0
Chrysophyllum sp.	Sapotaceae	1	0	0
Chrysophyllum subnudum Baker.	Sapotaceae	7	0	0
Cleidion gabonicum Baill.	Euphorbiaceae	1	0	0
Cleistopholis patens Engl. & Diels.	Annonaceae	4	0	0
Cleistopholis sp.	Annonaceae	0	0	1.6
Coffea sp.	Rubiaceae	3	0	0
Cola gigantea A.Chev.	Sterculiaceae	3	0	0
Cola millenii K.Schum	Sterculiaceae	0	1.6	0
Cola nitida A.Chev.	Sterculiaceae	6	1.6	0
Cordia millenii Baker.	Boraginaceae	1	0	0
Craterispermum cerinanthum Hiern.	Rubiaceae	0	0	0
Crudia gabonensis Pierre ex Harm.	Fabaceae	2	0	0
Cussonia bancoensis Aubrév & Pellegr.	Araliaceae	4	1.6	1.6
Cuviera nigrescens Wernham.	Rubiaceae	1	0	0
Cylicodiscus gabunensis Harms.	Fabaceae	1	0	0
Dacryodes klaineana (Pierre) H.J.Lam.	Buseraceae	2	0	0
Daniellia sp.	Fabaceae	0	0	1.6
Dialium aubrevillei Pellegr.	Fabaceae	4	0	0
Diospyros gabunensis Gürke.	Ebenaceae	2	0	0
Diospyros kamerunensis Gürke.	Ebenaceae	5	0	0
Diospyros sp.	Ebenaceae	0	0	1.6
Discoclaoxylon hexandrum Pax & K.Hoffm.	Euphorbiaceae	2	0	0
Discoglypremna caloneura Prain.	Euphorbiaceae	3	0	0
Discoglypremna kamerunensis	Euphorbiaceae	2	0	0
Distemonanthus benthamianus Baill.	Fabaceae	1	0	0
Drypetes principum Hutch.	Euphorbiaceae	5	0	0
Enantia polycarpa Engl. & Diels.	Annonaceae	4	0	0
Entandrophagma angolense C.DC.	Meliaceae	6	0	0
Entandrophagma cylindricum Sprague.	Meliaceae	1	0	0
Entandrophragma sp.	Meliaceae	0	0	3.2
Erythrophleum ivorense A.Chev	Fabaceae	1	0	0
Erythroxylon manni Oliv.	Erythroxylaceae	2	0	0
Ficus exasperata Vahl.	Moraceae	0	0	3.2
Ficus mucuso Welw. ex Ficalho.	Moraceae	2	0	0
Ficus sur Forssk.	Moraceae	2	1.6	6.4

Appendix 1 continued

Species	Family	Natural forest	Cocoa agroforest	Mixed food crop agroforest
Funtumia africana Stapf.	Apocynaceae	21	3.2	6.4
Funtumia elastica Stapf.	Apocynaceae	8	0	0
Garcinia gnetoides Hutch & Dalziel	Clusiaceae	1	0	0
Greenwayodendron olivieri (Engl.) Verdc.	Annonaceae	5	0	0
Guarea cedrata Pellegr. ex A.Chev.	Meliaceae	1	0	0
Hannoa klaineana Pierre & Engl.	Simaroubaceae	4	0	0
Harungana madagascariensis Poir.	Clusiaceae	1	0	0
Heritiera utilis Sprague.	Sterculiaceae	1	0	0
Holarrhena floribunda T. Durand & Schinz.	Apocynaceae	0	3.2	0
Hymenostegia afzelii Harms.	Fabaceae	9	0	0
Khaya ivorensis A.Chev.	Meliaceae	0	0	4.8
Lannea welwitschii (Hiern) Engl.	Anacardiaceae	1	1.6	1.6
Lovoa trichiloides Harms.	Meliaceae	1	0	0
Macaranga barterii Müll.Arg.	Euphorbiaceae	1	0	0
Macaranga huerifolia Beille.	Euphorbiaceae	7	0	0
Maesobotrya barteri Hutch.	Euphorbiaceae	5	0	0
Mareya micrantha Müll.Arg.	Euphorbiaceae	1	0	0
Milicia excelsa C.C. Berg.	Moraceae	0	1.6	9.6
Millettia zechiana Harms.	Fabaceae	0	1.6	4.8
Monodora myristica Blanco.	Annonaceae	4	0	4.8
Monodora tenuifolia Benth.	Annonaceae	1	0	0
Morinda lucida Benth.	Rubiaceae	1	0	0
Musanga cecropioides R.Br.apud Tedlie.	Cecropiaceae	2	0	0
Myrianthus arboreus Beauv.	Cecropiaceae	0	0	3.2
Myrianthus libericus Rendle.	Cecropiaceae	7	0	0
Napoleonaea vogelii Hook & Planch.	Lecythidaceae	10	0	0
Nesogordonia papaverifera (A.Chev.) Capuron ex N. Hallé.	Sterculiaceae	4	0	4.8
Newbouldia laevis Seem.	Bignoniaceae	3	1.6	6.4
Omphalocarpum sp.	Sapotaceae	3	0	0
Pachypodanthium staudtii Engl. & Diels.	Annonaceae	3	0	0
Pachystela brevipes Baill.	Sapotaceae	1	0	0
Parkia bicolor A.Chev.	Fabaceae	5	0	0
Pentaclethra macrophylla Benth.	Fabaceae	1	0	0
Pericopsis elata (Harms) Meeuwen.	Fabaceae	1	0	0
Persea americana Mill.	Lauraceae	0	11.2	0
Peterisanthus macrocarpus (P.Beauv.) Liben.	Lecythidaceae	1	0	0
Piptadeniastrum africanum (Hook.f) Brenan.	Leguminoseae	4	0	0
Placodiscus boya Aubrév & Pellegr.	Sapindaceae	1	0	0
Pycnanthus angolensis (Welw.) Exell.	Myristicaceae	5	0	0
Rauvolfia vomitoria Afzel.	Apocynaceae	2	0	3.2
Rhodognaphalon brevicuspe (Sprague.) Roberty	Bombacaceae	1	0	0
Ricinodendron heudelotii (Baill.) Pierre ex Heckel.	Euphorbiaceae	1	0	1.6
Ricinodendron heudelotii (Baill.) Pierre ex Heckel.	Euphorbiaceae	5	0	0
Rinorea oblongifolia C.Marquand.	Violaceae	10	0	0

Appendix 1 continued

Species	Family	Natural forest	Cocoa agroforest	Mixed food crop agroforest
Rinorea prasina Chipp.	Violaceae	1	0	0
Rinorea sp.	Violaceae	1	0	0
Rothmannia hispida K.Shum. Fagerl.	Rubiaceae	1	0	0
Rothmannia longiflora Salisb.	Rubiaceae	1	0	0
Rothmannia whitfieldii (Lindl.) Dandy.	Rubiaceae	1	0	0
Sapium aubrevillei Leandri.	Euphorbiaceae	2	0	0
Scottelia klaineana Pierre.	Flacourtiaceae	4	0	0
Spathodea campanulata Buch.- Ham ex DC	Bignoniaceae	0	4.8	0
Sterculia oblonga Mast.	Sterculiaceae	2	0	0
Sterculia rhinopetala K.Schum.	Sterculiaceae	1	0	0
Sterculia tragacantha Lindl.	Sterculiaceae	2	6.4	6.4
Strombosia glaucescens Engl.	Olacaceae	12	0	0
Syzygium guineense DC.	Myrtaceae	1	0	0
Tabernaemontana africana A.DC.	Apocynaceae	10	3.2	0
Tabernaemontana sp.	Apocynaceae	23	4.8	0
Terminalia ivorensis A.Chev.	Combretaceae	1	12.8	1.6
Terminalia superba Engl. & Diels.	Combretaceae	0	1.6	0
Tetrorchidium didymostemon (Baill). Pax & K.Hoffm.	Euphorbiaceae	9	0	0
Tieghamela heckeli Pierre ex. A. Chev.	Sapotaceae	3	0	0
Treculia africana Decne ex Trécul.	Moraceae	1	0	0
Trema guineense (Schumach & Thonn.) Ficalho.	Ulmaceae	1	0	0
Trema orientalis Blume.	Ulmaceae	2	0	0
Tricalysia discolor Brenan.	Rubiaceae	5	0	0
Tricalysia sp.	Rubiaceae	1	0	0
Trichilia monadelpha (Thonn.) J.de Wilde.	Meliaceae	8	0	0
Trichilia prieureana A.Juss.	Meliaceae	5	0	0
Trichilia tessmannii Harms.	Meliaceae	2	0	0
Trilepesium madagascariensis DC	Moraceae	2	0	0
Triplochiton scleroxylon K.Schum.	Sterculiaceae	0	3.2	3.2
Turraenthus africanus (Wew). Ex DC. Pellegrin	Meliaceae	2	0	0
Vernonia titanophylla Brenan	Asteraceae	1	0	0
Voacanga africana Stapf ex Scott-Elliot.	Apocynaceae	0	0	1.6
Xylia evansii Hutch.	Fabaceae	4	0	0
Xylopia aethiopica A.Rich.	Annonaceae	1	0	0
Xylopia villosa Chipp.	Annonaceae	1	0	0
Zanthoxylum gilletii P.G. Waterman.	Rutaceae	4	0	0
Totals		470	89.6	124.8

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