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The effect of land use systems on tree diversity: farmer preference and species composition of cocoa-based agroecosystems in Ghana

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Abstract Traditionally, most cocoa farms are established by removing the forest understorey and thinning the forest canopy so that cocoa seedlings can grow into productive trees by utilising the forest rent of the newly cleared area and the shade provided by the remaining trees. With the introduction of new hybrid cocoa varieties, there is a gradual shift towards the elimination of shade trees in the cocoa landscape. Farmers have found it necessary to eliminate forest tree species to effect high performance of these new varieties and as a result large areas of forested land are being lost, thereby posing a threat to biodiversity A study was carried out in Atwima, a major cocoa farming district in the Ashanti region of Ghana, to assess the impact of cocoa cultivation on tree diversity. The study also investigated farmers' preferences for tree species retained on cocoa farms as well as their traditional knowledge on tree species and their effect on cocoa cultivation. The assessment consisted of identification and enumeration of all tree species with diameter at breast height greater than or equal to 10 cm, and was carried out on one-hectare plots of: (a) Active Cocoa Farms (ACF), stratified into (i) Mature Cocoa Forest (MCF) and (ii) Young Replanted Cocoa (YRC); (b) Fallow land (FL), and (c) Natural Forest (NF). A total of four one-hectare plots replicated five times (or 20 ha) were enumerated. Tree diversity was more strongly influenced by landuse type than age of cocoa farm. Fallow lands contained a higher tree diversity followed by natural forest, with the active cocoa farms, both mature and young, containing the lowest variety of species. However, stem count was highest in the natural forest followed by FL and ACF. Generally, stem counts of important tree species, as well as those classified as either endangered or vulnerable, were extremely low in the landscape (0–2 per hectare), indicating a critical potential for conservation and rejuvenation. Farmers' preference for trees on cocoa farms was based on their usefulness. Three categories of trees emerged from their classification of trees on cocoa farms: (i) naturally occurring trees that are very useful; (ii) naturally occurring species of minor economic use; and (iii) naturally occurring tree species that are aggressive or incompatible with cocoa. Multistrata cocoa farms are a potential niche for conservation, but given the current trends in cocoa replanting, future conservation strategies will have to focus on identified targeted species which are of conservation concern, as well as those that are of value to farmers.

Keywords Agroforestry · Biodiversity conservation · Fallow · Local knowledge · Cocoa plantations

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Introduction

About 70% of the world's cocoa is produced by smallholders in West and Central Africa (FAO 2002). In Ghana cocoa cultivation is restricted to the forest region where, as a natural understorey crop, its cultivation in the past has been based on removing the forest understorey and thinning the forest canopy so that cocoa seedlings can grow into productive trees by utilising the forest rent (Ruf and Zadi 1998) of the newly cleared area and the shade provided by the remaining forest trees. Where a diverse shaded canopy is used, cocoa farms support higher levels of biodiversity than most other tropical crops. Indeed, while it has been pointed out that tropical protected areas are insufficient to preserve biological diversity and ecosystem services, even under the most optimistic scenarios (Putz et al. 2000), the importance of agricultural and forest matrix landuses outside of formerly protected areas in determining the status of biodiversity maintenance has been emphasised (Lenne and Wood 1999). Not only do matrix lands provide valuable environmental and biodiversity conservation benefits, they also provide food and cash income for millions of rural households (Lenne and Wood 1999; Fox et al. 2000).

Over time, however, the practice of thinning the forest and planting cocoa under the residual shade has given way to a practice where the forest is now clear-felled, burnt and the cocoa planted. This method of cocoa establishment has been identified as a major cause of deforestation in the country. Despite the fact that some trees are left for shade, as the cocoa growing expands into virgin forest, these areas are eventually depleted of trees (Ministry of Environment and Science 2002). The traditional agroforestry, perennial and long-fallow shifting cultivation systems are being replaced by "modernized" monocultures (Collier et al. 1994; Perfecto et al. 1996; Thrupp 1998). Furthermore, the introduction of new hybrid cocoa varieties has led to a gradual shift towards the elimination of shade trees in the cocoa landscape (Ruf et al. 2006). Farmers have found it necessary to eliminate forest tree species to effect high performance of these new varieties and as a result large areas of forested land are being lost, thereby posing a threat to biodiversity conservation. The future of such cocoa-led deforestation is an urgent question for both environmentalists and for the cocoa industry, as forest resources become increasingly scarce and valuable. Attempts to control this problem and at the same time maintain or increase production include the rehabilitation of ageing cocoa farms and the recycling of land in response to the extensive deforestation and loss of traditional cocoa growing land. Gockowski and Sonwa (2008) showed that over 60% of new cocoa planting is now on old fallow lands compared to 30% in forest, and while Anim-Kwapong and Osei-Bonsu (2009) demonstrate the technical feasibility of this, there are clearly strategic decisions to be made in the retention of advanced tree species regeneration, or new planting on such lands.

There are historic precedents that indicate, irrespective of whether the adoption of "modernised" cocoa production systems have been developed in response to specific technological, socio-economic or historical factors, that traditions of growing cocoa in agroforests helped to slow down processes of deforestation (Ruf and Schroth 2004). However, Ruf and Schroth (2004) describe the very different origins of cocoa production systems in the Côte d'Ivoire, Brazil and Cameroon and how these are influenced by changes in context, such as through immigration in the Côte d'Ivoire, to bring about instability in traditional practices. Any new strategies will have to take careful heed of these historical lessons.

Even though agro-ecosystems dominate tropical landscapes, their potential value for conserving biodiversity has been largely ignored (Klein et al. 2002). Maintenance of biological diversity is likely to be determined by agricultural and forestland uses outside formally protected areas (Siebert 2002). In Ghana and Cote d'Ivoire for instance, 50% of total cocoa farm area in both countries is under mild shade while an average of 10 and 35% is managed under no shade in Ghana and Côte d'Ivoire respectively (Freud et al. 1996: cf. Padi and Owusu 1998). Today, the majority of cocoa production is concentrated in established biodiversity hotspots (Myers 1986). However, cocoa cultivation that maintains higher proportions of shade trees in a diverse structure (cocoa agroforestry) is progressively being viewed as a sustainable land-use practice that complements the conservation of biodiversity (Alger 1998; Rice and Greenberg 2000; Leakey 2001; Schroth et al. 2004). One reason is because cocoa agroforestry has been noted to meet ecological, biological and economic objectives. Farmers derive multiple benefits from shaded polyculture systems. For example, their livelihood needs may be better met by the multitude of products and services provided by the more diverse agroecosystem of traditional (rustic) and shade multistrata cocoa systems. Inventories of plant species in shaded cocoa systems revealed a wealth of plants of commercial or domestic value to the farmer, above and beyond the value of the shade the canopy species provided (e.g. Oduro et al. 2003; Osei-Bonsu et al. 2003; Asare 2005; Sonwa et al. 2007; Asase and Tetteh 2010).

A number of studies in Ghana have revealed that farmers possess very good knowledge of trees and their importance, or otherwise, in the cocoa landscape (Amanor 1996; Asare 1999, 2006; Osei-Bonsu et al. 2003; Anglaaere 2005). In spite of the purported potentials and abilities of cocoa agroforestry and the various recommendations from research and development agencies, very few attempts have been made to use cocoa agroforestry as a large-scale conservation instrument in tropical countries (Parrish et al. 1998). Furthermore, Greenberg et al. (2000) claim that, to date, biological diversity in cocoa production has been poorly studied, and argue that there is only a limited amount of work which upholds the notion that cocoa farms with diverse shade canopies support greater biodiversity, as compared to other cash crop systems in lowland tropics (Rice and Greenberg 2000). In addition no work has statistically compared biodiversity across the whole spectrum from pristine forests, to different levels of shade to no-shade cocoa systems. Hence, it is quantitatively difficult to assess the importance of cocoa production for biodiversity and to identify the specific elements of shade production that are important (Donald 2004). Asase and Tetteh (2010) have shown in south-eastern Ghana that complex agroforestry cocoa systems can function as a buffer between forested lands and intensively managed areas, but there has been otherwise limited research investigating the impact of cocoa cultivation on biodiversity conservation in Ghana. It is against this background that a study was carried out to provide baseline information for developing the potential of native forest tree species for use in planted multistrata cocoa agroforestry systems for income diversification, livelihood improvement and biodiversity conservation. The main objectives of this study were to investigate the effect of the current trend in cocoa cultivation on tree diversity in the study area, to elicit and document farmers' ecological knowledge on the interactions between trees and cocoa in multistrata cocoa systems, and to identify tree species valued by the farming community for incorporation into agroforestry systems.

Methods

Study area

The study was conducted in Bontomuruso and Gogoikrom, in the Atwima district of Ghana, which is located between latitudes 6° 22′ and 6° 46′ N and longitudes 1° 52′ and 2° 20′ W in the south-western part of the Ashanti Region of Ghana. The district is a major cocoa producing area and lies within the wet semi-equatorial climatic zone, marked by double maxima rainfall. Mean annual rainfall ranges between 1700 and 1850 mm. The main rainfall season occurs from March to July with a minor rainy season lasting from September to November. The main dry season lasts from December to mid-March, during which period the devastating North-Easterly (harmattan) winds blow over the area. Temperatures are uniformly high throughout the year, with mean monthly minimum and maximum temperatures of 27 and 31°C occurring in August and March respectively. Relative humidity is generally high throughout the year.

The district is located within the moist semi-deciduous ecological zone, which is characterised by predominantly *Celtis-Triplochiton* association as described by Taylor (1960). This zone is the most extensive of all the forest types in Ghana, and trees here become taller than in any other (Hall and Swaine 1981). The moderate rainfall within this forest zone leads to more depletion of soil nutrients than in types of lower rainfall. Base saturation is generally high, however, (60–80%) providing a pH of about 5–6. Total exchangeable bases are generally below 10 mequiv/100 g soil, but this appears adequate for the considerable tree growth characteristic of the type. Elevation is moderate and lies between 150 and 600 m (Hall and Swaine 1981).

Assessment of tree species diversity and species richness

Assessment of tree species diversity in the natural forest was carried out in the Jimira forest reserve, near Bontomuruso, in November, 2001. The reserve was created in 1932 and has been seriously affected by logging and fire damage; the last logging in this reserve was in 1986 (Hawthorne and Abu-Juam 1995), as at the time of this assessment. At the time of assessment only 91 ha of the reserve was considered not to have been affected by fire (Hawthorne and Abu-Juam 1995), and it is in this area that the assessment was carried out. The study of tree diversity in FL was carried out in 12–16 year old fallows, while that in MCF and YRC was carried out in 15–18 year old and 3–5 year old cocoa farms, respectively, in and around Bontomuruso in the Atwima district of Ghana. The mature cocoa farms (MCF) were established after clearing the forest and leaving some residual shade and also selectively managing coppice shoots for the provision of overhead shade, while the young replanted (hybrid) cocoa was and is established on completely clearfelled plots. The only trees that are left in the YRC farms during site preparation are mainly fruit trees and small sized tree species that serve as early shade but do not grow into canopy trees. Since fallows and farms of the above age categories mostly did not occur contiguously plot location was dependent on the distribution of each of these land types in the area. Also, plot demarcation on cocoa farms tended to cut across a number of farms (at least 2), and not restricted to one farm ownership per plot due to the small nature of some individual farm holdings. All the assessments were carried out between October and December 2002, at the end of the second (minor) rainy season.

In the natural forest (NF), the area was stratified between three topographic positions (upland, mid-slope and lowland or lower slope). Two plots of 1 ha each were demarcated in different sections of each of the lowland and mid-slope strata, while one plot was demarcated in the upland stratum, using a 150 m tape and a compass. This resulted in five 100 m × 100 m (50000 m^2) or 5 ha assessed. Tree species assessment in the other landuse systems also involved the use of five 1-ha plots in each landuse system. For ease of data collection, each of the 1 ha plots was divided into four quadrats of 50 m × 50 m, and each quadrat further divided into ten strips of 5 m × 50 m. All tree species with diameter at breast height greater than or equal to 10 cm (DBH $\geq$10 cm) were identified and recorded by walking along, and measuring the diameters of trees, in each strip. The number of individuals recorded for each species in each 1 ha plot was used to estimate tree density for the different tree species in each land type.

Elicitation of farmers' knowledge

Ecological knowledge elicitation was carried out using Participatory Rural Appraisal (PRA) techniques, augmented with a formal approach to the acquisition of local knowledge using the methods outlined by Dixon et al. (2001). The participatory rural appraisal (PRA) methodologies used include key informant, group and individual interviews and discussions, and transect walks and farm visits to gather primary and secondary information from the study communities. To collect detailed ecological knowledge from farmers, the study focused on a limited number of carefully selected individuals referred to as key informants, in each village. Key informants have been defined as a selected group of individuals who are likely to provide information, ideas and insights on a particular topic (Kumar 1987). A number of researchers have used stratified samples of key informants on the basis of socio-economic factors thought to influence knowledge. For instance, Thapa (1994), working in the eastern hills system of Nepal, selected informants on the basis of gender, ethnicity and altitude while Den Biggelaar and Gold (1995), in a study of farmers agroforestry practices in Rwanda, selected the most knowledgeable farmers on trees and tree cultivation. In this study a mix of the two approaches was used, with certain modifications. Fifteen key informants were selected from each village on the basis of ethnicity (i.e. natives and settlers), and on the basis of the most knowledgeable farmers in cocoa cultivation and management. Informal interviews were used throughout the knowledge elicitation process. According to Southern (1994) informal interviews are meant to put farmers at ease and gain information through the creation of a friendly atmosphere. They allow natural conversation and discussions to take place unlike questionnaire which, according to Rusten and Gold (1991), are biased culturally and based on the world view of the researcher. A checklist of informal interviews was prepared, to ensure that important issues were not left out during discussions. The interviews typically lasted about 1 h and were mostly conducted on

Tuesdays, as farmers in the study villages do not go to farm on this day. Transect walks and farm visits were then done to validate issues discussed during the various key informant and group discussions.

Data analysis

The observed tree biodiversity characteristics of the natural forest, fallow land, mature cocoa farm and young replanted cocoa were analyzed using PCORDWIN (McCune and Mefford 1997) and EstimateS (Colwell 2005). Analysis involved the use of Multivariate Analysis such as Detrended Correspondence Analysis (DECORANA or DCA), as well as diversity and shared species analysis, using PCORDWIN (McCune and Mefford 1997) and EstimateS (Colwell 2005). Decorana displays the main variation in the composition of vegetation samples in a two-dimensional diagram so that samples with similar composition are positioned close together while samples differing greatly are positioned far apart. Species richness and diversity for the four landuse systems were also analysed using the PCORDWIN software. Size (DBH) distribution of the species in the different landuse systems was analysed in MS-EXCEL.

Statistical significant differences in density 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.

Results

Effect of landuse system on tree species richness and diversity

Species-area curves indicated 5 ha to be sufficient area to record all species present in the different land use systems (Fig. 1). Floral diversity did not differ significantly between the natural forest (126 species) and the fallow lands (133). However, these two land use systems had significantly higher floral diversity

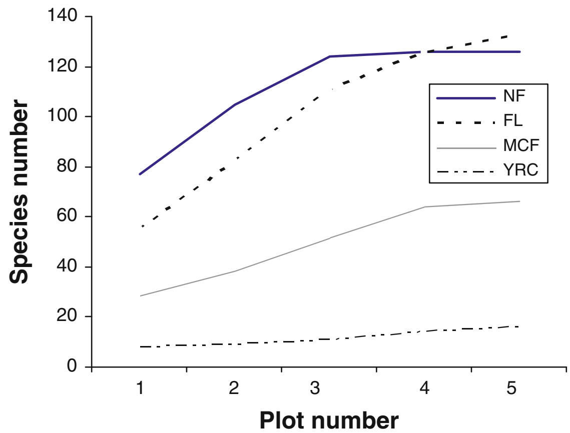

Fig. 1 Plot-based species accumulation curves of trees ≥10 cm dbh in four different landuse systems in the Atwima district, Ghana. *NF* Natural forest, *FL* fallow land, *MCF* mature cocoa farm, *YRC* young replanted cocoa. Plot size = 1 ha

than the mature cocoa farms (66 tree species) which in turn differed significantly from the young replanted cocoa farms, which were the most species-poor habitats, with only 16 tree species recorded in the 5 ha (Table 1). In absolute terms, stem count was highest in the natural forest where 721 stems were recorded, with the Fallow land recording 532 trees and the mature cocoa farm and young replanted cocoa landscapes recording 217 and 74 trees respectively in the 5 ha plot sampled for each landuse system. However, the difference in stem count between the natural forest and the fallow lands was not statistically significant, but these two systems again differed significantly from the mature cocoa farm which in turn differed significantly from the young replanted cocoa lands. Thus the fallow lands and the natural forest were species richest and had the highest diversity overall, among all the habitat types, followed by the mature cocoa farms, with the young cocoa farms being the least diverse and the poorest in terms of species richness.

A comparison of the species found in the different landuse systems, however, revealed that the natural forest and the fallow lands were quite similar in terms of species composition, with 102 species encountered in both land types, while the least similarity in species composition was observed between the natural forest and the young cocoa farms, where only nine of the 126 species in the former were found in the young cocoa farm (Table 2). Of the 66 species

Table 1 Total stem count, number of species and species diversity in different landuse systems in Atwima district, Ghana

Landuse system	Total stem count	Richness (No. of tree species)	Diversity	Shannon index	Simpson index
Natural forest (NF)	721a	126a	4.610a	3.92	58.63
Fallow land (FL)	532b	133a	4. 553a	4.50	74.45
Mature cocoa (MCF)	217c	66b	3.933b	4.69	86.11
Young replanted cocoa (YRC)	74d	16c	2.363c	4.76	90.41

Plot size for each landuse system = 5 ha

Figures in a column carrying the same letter are not significantly different at $P < 0.01$ (Tukey's multiple range test)

Table 2 Shared species and similarity statistics, using EstimateSWin750 software

First sample	Second sample	Sobs first sample	Sobs second sample	Shared species observed	Sorensen classic	Jaccard classic
NF	FL	126	133	102	0.787	0.649
NF	MCF	126	66	48	0.500	0.333
NF	YRC	126	16	9	0.126	0.067
FL	MCF	133	66	52	0.522	0.353
FL	YRC	133	16	15	0.201	0.111
MCF	YRC	66	16	10	0.243	0.138

Plot size for each sample = 5 ha. *NF* Natural forest, *FL* fallow land, *MCF* mature cocoa farm, *YRC* young replanted cocoa

recorded on the mature cocoa farms, as many as 52 were shared with the fallow lands and 48 with the natural forest, while only 10 species were found in the young cocoa farms. The Detrended Correspondence Analysis (DCA) of the species recorded in the four landuse systems further revealed that the natural forest and fallow lands were similar in composition (depicted by the closeness of points and aggregation of species between the two points), while the mature cocoa farms and the young cocoa farms were markedly dissimilar to the other landuse systems in terms of species composition (Fig. 2).

Analysis of the study also revealed that certain species in this area could only be found in particular landuse systems and not in others. Among the 163 species recorded in the study area, 16 (10%) of them were unique to the natural forest, and were not found in any of the other three landuse systems. Similarly, 11 (7%) and 7 (4%) of the species were unique to the fallow lands and mature cocoa farms respectively, while no particular tree species was exclusive to the young cocoa farms (Table 3).

Stem distribution in the fallow lands displayed an inverted J shape, similar to that of the natural forest (Fig. 3), with smaller diameter trees (10–30 cm DBH) dominating both systems. In contrast to this, larger diameter trees (31–60 and 61–90 cm DBH) dominated the tree population in the cocoa farms. The larger size class distribution of the species in the cocoa farms can be attributed to the cocoa management system, which begins with the selective thinning of the original forest stand to leave a few large desirable tree species as shade for the developing cocoa. Subsequent regeneration of tree species is considered as weed growth and they are therefore removed during weeding, or under natural circumstances they may not persist due to the heavy shading from the cocoa canopy.

Farmer perception and preferences for tree species on cocoa farms

Farmers identified a number of trees found on farms as well as their respective characteristics, uses and their ecological interactions with cocoa. Trees were classified by farmers as either good or bad on the basis of their compatibility with cocoa as neighbour trees. Thus a good tree was described as one that is suitable as shade for cocoa, and vice versa. Farmers' knowledge on tree diversity on cocoa farms was based on their usefulness. Thus during discussions, three categories emerged from their classification of

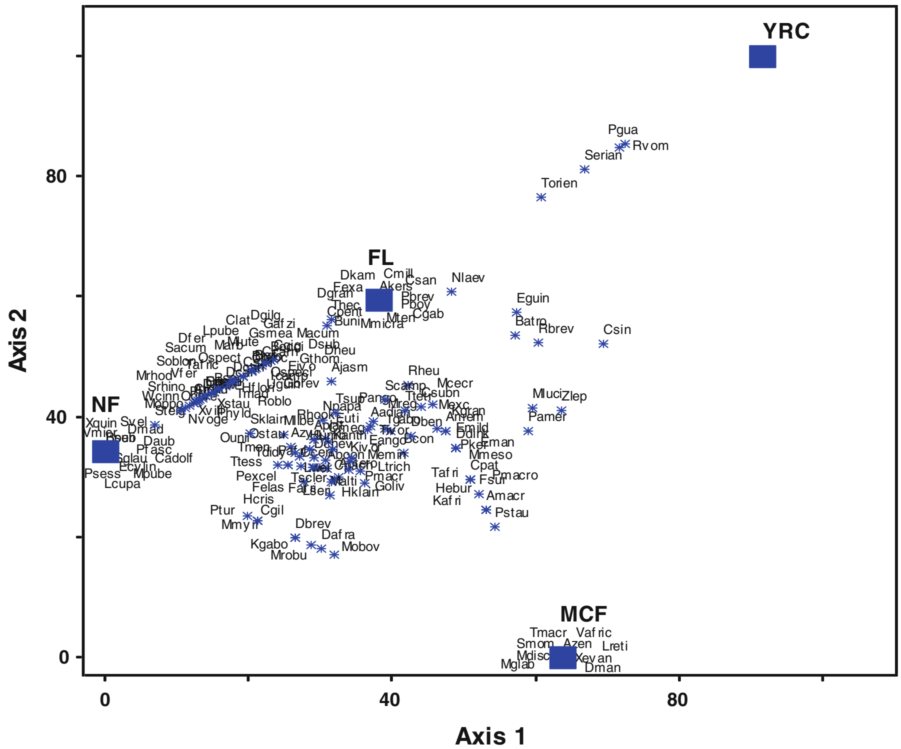

Fig. 2 Detrended correspondence analysis (DCA) of 163 tree species in four landuse systems in the Atwima District, Ghana (Power transformed data). *NF* Natural forest, *FL* fallow land, *MCF* mature cocoa farm, *YRC* young replanted cocoa

Table 3 Tree species unique to each landuse system

Natural forest	Fallow land	Mature cocoa farm	Young replanted cocoa
Baphia nitida	*Aubrevillea kerstingii*	*Irvingia gabonensis*	–
Breviea sericea	*Blighia unigujata*	*Margaritaria discoidea*	–
Bussea occidentalis	*Chidlowia sanguinea*	*Spondias monbin*	–
Celtis adolfi-friderici	*Cola millenii*	*Tieghemella heckelii*	–
Cynometra megalophylla	*Corynanthe pachyseras*	*Tricalysia macrophylla*	–
Dialium aubrevillei	*Cylicodiscus gabunensis*	*Voacanga africana*	–
Dichapetalum madagacarensis	*Diospyros kamerunensis*	*Xylia evansii*	–
Entandrophragma cylindricum	*Ficus exasperate*		–
Hexalobus crispiflorus	*Monodora tenuifolia*		–
Lecaniodiscus cunioides	*Pachystela brevipes*		–
Pancovia sessiliflora	*Placodiscus boya*		–
Piptostigma fasciculate			–
Soyauxia velutina			–
Strombosia glaucescens			–
Vitex micrantha			–
Xylopia quintasii			–
16	11	7	0

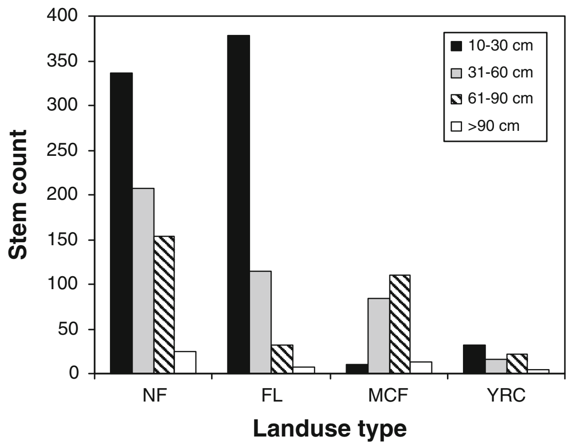

Fig. 3 Stem size distribution of trees ≥10 cm dbh in different landuse systems in the Atwima district of Ghana. *NF* Natural forest, *FL* fallow land, *MCF* mature cocoa farm, *YRC* young replanted cocoa. Plot size = 5 ha

tree functions on cocoa farms: (i) naturally occurring trees that are very useful because of their high timber value, fruit value, medicinal value, soil fertility value, and spiritual value; (ii) naturally occurring species of minor economic use, but accepted because of their shade and/or fuelwood value; and (iii) naturally occurring tree species that are aggressive or incompatible with cocoa because of factors such as being host to cocoa pest and diseases, incompatible rooting habits, above ground competition, allelopathy, etc. (Table 4).

Farmers articulated a good knowledge of the above-ground interactions between shade trees and the cocoa. Several attributes of the shade trees which influence shading were outlined by the farmers, and these included: the crown size, the number of branches, leaf size, leaf number, and crown density. An increase in any of these attributes was believed to cause an increase in shading intensity. Crown size was described in terms of its diameter, while crown density was described in terms of the number of leaves per unit area. They were of the opinion that trees with large broad crowns and extensive branching habits cast more shade than those with small crowns. Trees with dispersed leaves were said to cast less shade than trees with many and closely spaced leaves (Table 5). This knowledge is well supported by a number of scholars, who have pointed out that the level of shading or light interception is influenced by the amount of leaf area and the spatial distribution of the leaf area in the vertical and horizontal inclination, as well as general characteristics of tree crowns (Wang and Jarvis 1990; Stenberg et al. 1994; McCrady and Jokela 1998; Lott et al. 2000). It was apparent that farmers strongly linked aboveground interactions to the shade level in their farms. Indeed, they pointed out that plant density, together with the architecture of the aerial parts of the shade tree species concerned, mainly determined the shade level, which in turn influenced the micro-environmental conditions in the field such as the amount of solar radiation getting to the understorey, humidity and air circulation. Amongst the tree species attributes identified as influencing the shade level in the farm, emphasis was put on crown density and shape, tree height and the extent of canopy closure. The crown density principally referred to tree foliage abundance. Bigger leaf size tended to be associated with higher crown density, and vice versa (Table 4). Farmers said the crowns were importantly shaped by the spatial development of tree branches; they clearly distinguished between the following shapes:

- Wide crown shape: where tree branches had a pronounced plagiotropic development, with few branches developing on the trunk.
- Narrow crown shape: where tree branches had a pronounced orthotropic development, with few branches in general and few developing on the trunk.
- Intermediate crown shape: where there was a somewhat balanced mixture of both plagiotropic and orthotropic branches, with no predominant development of either type.

The farmers exhibited an appreciable level of knowledge about the rooting pattern of shade trees and the complementarity or otherwise of various tree species with the cocoa. They had a good understanding of the effect of shallow and deep rooted trees on the cocoa. They pointed out that deep rooted trees do not compete with the cocoa for soil nutrients and water, whereas shallow rooted trees tend to compete with cocoa for these resources. Among tree species cited as having shallow roots were *Triplochiton scleroxylon*, *Terminalia ivorensis*, *Ficus exasperate*, *Cola gigantea*, among others. The shallow rooted trees were said to have extensive lateral roots near the soil surface and this results in serious competition for

Table 4 Farmers' perceptions of tree species as cocoa companion species in Gogoikrom, Atwima

Species	Family	Local Name	Comments
(i) Naturally occurring species that are very useful on cocoa farms because of their high timber value, fruit value, medicinal value, soil fertility value, and spiritual value			
Albizia adianthifolia	Mimosaceae	Pampena	Light crown but shallow roots; good timber
Albizia ferruginea	Mimosaceae	Awiemfosamina	Deep roots, light crown; good timber
Albizia zygia	Mimosaceae	Okoro	Branches brittle; good timber
Entandophragma angolense	Meliaceae	Edinam	Deep rooting, dense shade but high crown; valuable timber
Entandophragma cylindricum	Meliaceae	Penkwa/Sapele	Valuable timber
Entandophragma utile	Meliaceae	Utile	Valuable timber
Ficus capensis	Moraceae	Odoma/Nwamdua	Good timber tree
Funtumia africana	Apocynaceae	Okae	Good timber tree
Funtumia elastica	Apocynaceae	Fruntum	Valuable timber tree; gum used for mending bicycle tyres etc.
Hannoa klainniana	Simaroubaceae	Fotie	Valuable timber tree
Irvingia gabonensis	Irvingiaceae	Besebuo	Seeds used as spice for soup
Khaya anthotheca	Meliaceae	Krubu	Valuable timber tree
Khaya ivorensis	Meliaceae	Dubini	Heavy crown; valuable timber tree
Lophira alata	Ochnaceae	Kaku	Deep rooting, high crown; valuable timber tree
Maesopsis eminii	Rhamnaceae	Onwamdua	Deep rooting; used for timber; seeds processed for edible oil
Milicia excelsa	Moraceae	Odum/Iroko	High crown; very valuable timber tree
Milicia regia	Moraceae	Odum-nua/Iroko	Good timber tree
Morinda lucida	Rubiaceae	Konkroma	Deep rooting, high crown; medicinal value
Myrianthus arboreus	Moraceae	Nyankumabere	Edible fruits
Newbouldia laevis	Bignoniaceae	Sesemasa	Good early shade for cocoa, narrow crown; valuable medicinal plant
Pericopsis elata	Papilionaceae	Kokrodua	Valuable timber species
Piptadeniastrom africanum	Mimosaceae	Dahuma	High wide crown, but shallow rooting; valuable timber tree
Pycnanthus angolensis	Myristicaceae	Otie	High crown, deep rooting, but branches brittle. Valuable timber tree
Rauvolfia vomitoria	Apocynaceae	Kakapenpen	Good early shade species; valuable medicinal plant
Ricinodendron heudelotti	Euphorbiaceae	Wama	Deep rooting, heavy but high crown; branches brittle; good timber tree
Terminalia ivorensis	Combretaceae	Emire	High wide crown; valuable timber tree
Terminalia superba	Combretaceae	Ofram	High wide crown; valuable timber tree
Tetrapleura tetraptera	Mimosaceae	Prekese	Light crown; spice and medicinal value
Tieghemella heckelli	Sapotaceae	Baku/Makore	Valuable timber tree
Turreanthus africanus	Meliaceae	Avodire/Apapaye	Low branching, deep rooting, very valuable timber
(ii) Naturally occurring species of minor economic use, accepted because of their shade and/or fuelwood value:			
Alstonia boonei	Apocynaceae	Nyamedua	Branches brittle; wood used for carving
Celtis mildbreadii	Ulmacaceae	Esa	Good for fuelwood and pestles
Celtis zenkeri	Ulmacaceae	Esakokoo	
Grewia mollis	Tiliaceae	Kyapotoro	Deep rooting; bark used in local brewery
Morus mesozygia	Moraceae	Wonton	Deep rooting, but compact crown

Table 4 continued

Species	Family	Local Name	Comments
Myrianthus libericus	Moraceae	Nyankumanini	Deep rooting
Parkia bicolor	Mimosaceae	Asoma	But shallow rooting
Petersianthis macrocarpus	Lecythidaceae	Esia	High crown, deep rooting
Solanum erianthum	Solanaceae	Pepediawuo	Good early shade for cocoa
Spathodea campanulata	Bignoniaceae	Akuakuo-ninsuo	Deep rooting, high and wide crown; keep soil moist
Spondias mombin	Anacardiaceae	Atoa	Deep rooting
Sterculia rhinopetala	Sterculiaceae	Wawabima	High crown
Strombosia glaucescens	Olacaceae	Afena	Deep rooting; good for roofing rafters and transmission poles
Treculia africana	Moraceae	Brebetim	Good early shade for cocoa, short tree, deep rooting
Trema orientalis	Ulmaceae	Sesea	Good early shade for cocoa, small tree
(iii) Naturally occurring tree species that are aggressive or incompatible with cocoa because of factors such as being host to cocoa pests and diseases, incompatible rooting habits, above ground competition, allelopathy etc.			
Bombax buonopozense	Bombacaceae	Akata/Akonkodie	
Ceiba pentandra	Bombacaceae	Onyina	Branches brittle, host to cocoa pest; good timber, kapok used for pillows and mattresses
Cola gigantea	Sterculiaceae	Watapuo	Fruit and seed edible; good fuelwood; found on sandy soils
Ficus exasperate	Moraceae	Nyankyereni	Takes too much water and nutrients from the soil
Lannea welwitschii	Anacardiaceae	Kumanani	Host for cocoa pests; fruits edible
Musanga cecropioides	Moraceae	Odwuma	Shallow rooting, draws too much water from soil; branches brittle; medicinal value
Triplochiton scleroxylon	Streculiaceae	Wawa	Draws too much water from soil, branches brittle, harbours pests; valuable timber

soil moisture and nutrients. The literature is replete with information on the competitive effect of overstorey tree roots on the understorey crop (e.g. Akinnifesi et al. 1998; Jama et al. 1998; Mekonnen et al. 1999). For instance, Akinnifesi et al. (1998) found that the percentage of fine roots in the top 0–30 cm of soil varied from 21% for *Lonchocarpus sericeus* to 84% for *Tetrapleura tetraptera*. Jama et al. (1998) found that the slope of roots of log L_{rv} (root length density) against depth differed significantly between tree species, indicating that some had deeper root distribution. These studies have concluded that deeper rooting trees are better candidates for use when trees and crops are mixed in fields, since they will compete less with the crops.

With regards to soil moisture dynamics the farmers recognised that while certain tree species were capable of bringing up water from deep down the soil to keep the soil surface beneath them moist and cool, there were others that have the characteristics of making the soil beneath them dry and hard. They pointed out that trees with deep roots usually bring up water from deep in the soil to keep the soil surface moist. They cited specific trees which, they say, pump up water from the soil depths to the surface to feed the surrounding cocoa seedlings and/or trees. Tree species such as *Ficus sur*, *Spathodea campanulata*, *Albizia zygia* and oil palm were specifically cited as having the quality of keeping the soil around them cool and moist, in addition to providing good shade, and hence enhancing the growth of the cocoa around them. Other species like *Bombax buonopozense* and *Ceiba pentandra* are also mentioned as having the same soil cooling and moistening abilities, however, they are considered as unsuitable shade for cocoa because they harbour insect pests and diseases

Table 5 Examples of farmers' assessment of tree attributes and their effects on the microenvironmental conditions on multistrata cocoa fields

Tree species	Attributes				Effects on conditions in farm		
	Height	Crown density	Crown shape	Leaf size	Shade	Solar radiation	Humidity
Albizia adianthifolia	Medium	Sparse	Wide	Small	Light	Excessive	Low
Entandrophragma angolense	Tall	Dense	Narrow	Big	Excessive	Low	High
Entandrophragma utile	Tall	Dense	Narrow	Big	Adequate	Adequate	Medium
Khaya anthotheca	Tall	Dense	Wide	Big	Excessive	Low	High
Newbouldia laevis	Short	Dense	Narrow	Big	Light	Adequate	Medium
Terminalia ivorensis	Tall	Medium	Wide	Medium	Adequate	Adequate	Medium
Tetrapleura tetraptera	Medium	Sparse	Wide	Small	Light	Adequate	Medium
Ficus sur	Tall	Dense	Wide	Medium	Excessive	Low	High
Milicia excelsa	Tall	Dense	Narrow	Medium	Excessive	Low	High
Alstonia boonei	Short	Dense	Wide	Big	Excessive	Low	High

that affect the cocoa. On the other hand, some tree species were cited as making the soil around them dry and hard. These include *Ficus exasperate*, *Pterygota macrocarpa*, *Triplochiton scleroxylon*, *Cola gigantea* and the cocoa tree itself. This clearly demonstrated a deep understanding of ecological processes going on within tree-crop systems by the farmers, and tallies with the findings of scientific research which has reported the recycling of nutrients from considerable depths in the soil profile by deep rooted trees (e.g. Singh et al. 1989; Rao et al. 1993).

On cocoa diseases, a number of environmental factors were enumerated as having an influence on disease incidence. These include too much shade, excessive humidity, poor ventilation, all of which encourage the incidence of black pod.

Distribution of species commodities in different land uses

The number of tree species of potential economic importance in the production of non-timber forest products (NTFPs) was highest in the fallow lands (23) followed by the natural forest (21). Mature cocoa farms had a total of 18 NTFP species while the young replanted cocoa plots were the most impoverished, with only five species of importance recorded in the 5 ha (Table 6). However, in terms of overall stem count of all economically important species, stem count was highest in the natural forest and lowest in the young replanted cocoa landscapes (Fig. 4). Thus the fallow lands were the most economically endowed overall, among all the habitat types, followed by the natural forest and the mature cocoa farms, with the young cocoa farms being the least diverse and the poorest in terms of economic importance of the biodiversity (excluding cocoa).

Discussion

Historically, and particularly for small-scale farmers of the tropics, fallows are a major component of the traditional farming system, where they are valued for many purposes such as restoration of ecosystem soil fertility or key reservoirs of non-timber forest products which can generate off-farm income. Our findings concur with other studies in West Africa that show that fallow regrowth is an important reservoir of biodiversity (e.g. Augusseau et al. 2006; Ngobo et al. 2004), having a species diversity greater even than the natural forest. A decline in tree biodiversity occurs with cultivation, but mature cocoa agroforests are still biodiverse, contrasting with the impoverished floral diversity of recently established higher-yielding cocoa varieties in plantations requiring less shade. Combined with decreasing fallow lengths, and associated poorer regeneration, the fallow-agricultural mosaic will likely be less important in the future for biodiversity conservation. If, as suggested by Finegan and Nasi (2004), a key to conservation is landscape level management which maintains a mosaic of shifting land use units, which eliminate some species in the short term only for

Table 6 List of economically promising non-timber forest product (NTFP) tree species found in the different landuse systems in Atwima, Ghana

Species	Local Name	Landuse system [occurrence (+)/absence (−)]				Potential uses
		NF	FL	MCF	YRC	
Alstonia boonei	Nyamedua	+	+	+	−	Medicinal; wood carvings
Blighia sapida	Akye	+	+	−	−	Fruits edible
Ceiba pentandra	Onyina	+	+	−	+	Kapok for mattresses/pillows
Dacryodes klaineana	Adwea	+	+	−	−	Fruits edible
Diospyros canaliculata	Otwabere	+	+	−	−	Fruits edible
Diospyros heudelotii	Omenewabere	+	+	−	−	Fruits edible
Diospyros kamerunensis	Omenewa	−	+	−	−	Fruits edible
Garcinia afzelii	Nsoko	+	+	−	−	Chew sticks
Irvingia gabonensis	Abesebuo	−	−	+	−	Edible oil from fruits
Khaya anthotheca	Kruben	+	+	+	−	Bark for malaria
Khaya grandifoliola	Kruba	−	+	+	−	Bark for malaria
Khaya ivorensis	Dubini	+	+	+	−	Bark for malaria
Klainedoxa gabonensis	Kroma	+	−	+	−	Edible oil from fruits
Lecaniodiscus cupanioides	Dwindwera	+	−	−	−	Fruits edible
Maesopsis eminii	Onwamdua	+	+	+	−	Edible oil from fruits
Monodora myristica	Wedeaba	+	−	+	−	Spice; medicinal
Morinda lucida	Konkroma	−	+	+	−	Fruits edible; medicinal value
Myrianthus arboreus	Nyankumabere	+	+	−	−	Fruits edible
Newbouldia laevis	Sesemasa	+	+	+	+	Bark, leaves, roots: medicinal
Persea americana	Pea	−	+	+	+	Fruits edible
Raphia hookeri	Adobe	+	+	+	−	Edible oil from fruits
Rauvolphia vomitoria	Kakapenpen	−	+	−	+	Medicinal
Ricinodendron heudelotii	Wama	+	+	+	−	Edible oil from fruits
Spondias mombin	Atoa	−	−	+	−	Fruits edible; medicinal
Tetrapleura tetraptera	Prekese	+	+	+	+	Fruits: spice; medicinal
Tieghemella heckelii	Baku	−	−	+	−	Edible oil from fruits
Treculia africana	Brebretim	+	+	−	−	Edible oil from fruits; fruits sold as food
Trichilia monadelpha	Tanuro	+	+	+	−	Medicinal
Uacapa guineensis	Kontan	+	+	−	−	Fruits edible
Voacanga africana	Ofuruma	−	−	+	−	Seeds & bark used as poison, stimulant, aphrodisiac & psychedelic
Totals		21	23	18	5	

them to recover when land is abandoned, then the prospects within this agricultural landscape are not encouraging. However, the situation is complex and Sonwa et al. (2007) showed trends in the increasing prevalence of exotic food tree species at the expense of valuable non-timber forest products along a gradient of market access, population density and resource use intensity in southern Cameroon. Oke and Odebiyi (2007) also found in Nigeria that cocoa agroforests are less diverse than natural forest but more enriched with exotic and indigenous fruit tree species. In general, Gockowski and Sonwa (2008) confirm an increasing gradient in shade levels from West to East across the cocoa belt of West Africa. Also, farmers are likely to become more ambivalent about the presence of shade for cocoa, given the now widespread availability of higher yielding cocoa varieties which require less shade, and will only

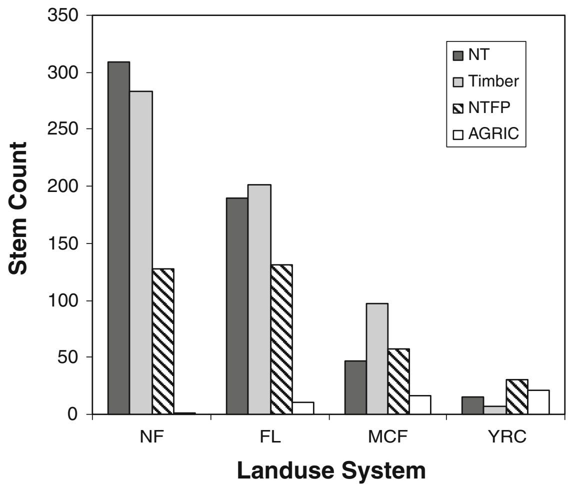

Fig. 4 Distribution of non-timber (NT), timber, non-timber forest products (NTFP) and agricultural (AGRIC) tree crops in four landuse systems in Atwima District, Ghana. *NF* Natural forest, *FL* fallow land, *MCF* mature cocoa farm, *YRC* young replanted cocoa. Plot size = 5 ha

incorporate trees giving greater economic return than in previous modes of cultivation. The effect of shading level on cocoa yield was well articulated by the farmers. They pointed out that too much shade had a negative effect on cocoa yield, as well as causing an increase in the incidence of diseases especially the black pod disease. In their opinion, dense shade, which is caused by too many shade trees or trees with heavy canopies, makes the farm 'dark' and 'silent'. This, they believe, causes low yields directly by cutting the sun's energy to the cocoa crop underneath, and indirectly by causing disease outbreaks. Height of the shade tree was also considered very important and was linked to below canopy micro-climatic factors such as air circulation and humidity. They were clear in their understanding that short, heavy-crowned trees tend to prevent proper circulation of air beneath them. This, in their opinion, causes high temperature, as a result of improper ventilation, and high humidity, which in turn encourages the development of the black pod disease. This is in consonance with the views of Bellow and Nair (2003) who have pointed out that yields of understorey crops grown in areas where soil nutrients and water are not limiting are likely to be reduced due to reduced solar radiation. Monteith (1990) also stated that tree shading affects understorey crops by reducing temperature and the amount of light, thus affecting the amount of photosynthetically active radiation intercepted by the crop canopy and the efficiency with which this radiation is converted into plant matter. Rao et al. (1998) also found a link between understorey microclimatic conditions and tree species' canopy characteristics and size and density of the trees in the system.

Conversely, trees were also shown to be of enormous importance in the farming systems. The farmers had a strong belief that the presence of trees on their farms greatly enhances soil fertility. This fertility enhancement, they know, is brought about by increase in soil organic matter through litter fall and accumulation. They eloquently described how the tree leaves formed black layers in the soil and how the percolating rain water takes the rotting leaves into the soil. A number of tree species were identified as indicators of soil fertility. Shade trees were also described according to their socio-economic values. The majority of them however, were valued for their sawn wood (timber) quality, fruit and/or medicinal value. Others were also retained/desirable either for their soil nutrient/moisture enhancing qualities or purely for the quality of shade they provide. The decision to classify a tree as a good shade tree appeared however, to be greatly influenced by the socio-economic value of the tree, such as its value as a timber species, fruit tree, medicinal properties as well as some other value. Timber trees appeared to be valued the most because of their socioeconomic value; though past forest policies in the country, which vested total right of harvesting such trees in the government through the Forestry Service, served as a great disincentive for retaining/planting such trees on cocoa farms, as such a practice invariably led to the destruction of cocoa farms by commercial timber companies, who were granted timber harvesting rights by the Forestry Service, with little or no payment of compensation for the damaged cocoa crop. Positive policy instruments will be critical in enhancing biodiversity on cocoa farms, including perhaps price premiums for organic or shade-grown cocoa.

Tree conservation priorities

From the IUCN conservation rating of plant species, all the underlisted tree species (Table 7), found in the study area, are under threat of extinction from over-

Table 7 Threatened tree species, according to the IUCN (2006) criteria

Scientific name	Local name	Use	Species guild	IUCN conservation rating
Albizia ferruginea	Awiemfosamina	Timber	Non-pioneer	Vulnerable[a]: A1cd[b]
Antrocaryon micraster	Aprokuma	Timber	Non-pioneer	Vulnerable: A1cd
Anopyxis klaineana	Kokote	Timber	Non-pioneer	Vulnerable: A1c; B1 + 2c[c]
Berlinia occidentalis	Kwatafompaboa	Timber	Non-pioneer	Vulnerable: A1d
Copaifera salikounda	Entedua	Timber	Non-pioneer	Vulnerable: A1d
Cordia platythyrsa	Tweneboabere	Timber	Pioneer	Vulnerable: A1c
Cussonia bancoensis	Kwaebrofre	Non-timber	Pioneer	Vulnerable: A1c
Drypetes pellegrinii	Opahakokoo	Non-timber	Non-pioneer	Vulnerable: A1cd
Entandrophragma angolense	Edinam	Timber	Non-pioneer	Vulnerable: A1cd
Entandrophragma candollei	Penkwa-akoa	Timber	Non-pioneer	Vulnerable: A1cd
Entandrophragma cylindricum	Penkwa	Timber	Non-pioneer	Vulnerable: A1cd
Guarea cedrata	Kwabohoro	Timber	Non-pioneer	Vulnerable: A1c
Guarea thompsonii	Kwadwuma	Timber	Non-pioneer	Vulnerable: A1c
Heretiera utilis	Nyankum	Timber	Non-pioneer	Vulnerable: A1cd
Khaya anthotheca	Krumben	Timber	Non-pioneer	Vulnerable: A1cd
Khaya ivorensis	Dubini	Timber	Non-pioneer	Vulnerable: A1cd
Khaya grandifoliola	Kruba	Timber	Non-pioneer	Vulnerable: A1cd
Lovoa trichilioides	Dubinibiri	Timber	Non-pioneer	Vulnerable: A1cd
Milicia regia	Odumnua	Timber	Pioneer	Vulnerable: A1cd
Nauclea diderrichii	Kusia	Timber	Pioneer	Vulnerable: A1cd
Nesogordonia papaverifera	Danta	Timber	Non-pioneer	Vulnerable: A1cd
Placodiscus boya	Kafuoso	Non-timber	Non-pioneer	Vulnerable: B1 + 2c
Terminalia ivorensis	Emire	Timber	Pioneer	Vulnerable: A1cd
Tieghemella heckelii	Baku	Timber	Non-pioneer	Endangered[d]: A1cd[e]

[a] A taxon is vulnerable when it is not critically endangered or endangered but is facing a high risk of extinction in the wild in the medium-term future

[b] Population reduction in the form of either of: (1) An observed, estimated, inferred or suspected reduction of at least 20% over the last 10 years or three generations, whichever is the longer, based on c: a decline in area of occupancy, extent of occurrence and/or quality of habitat; (d) actual or potential levels of exploitation

[c] Extent of occurrence estimated to be less than 20,000 km^2 or area of occupancy estimated to be less than 2000 km^2; Severely fragmented or known to exist at no more than ten locations; Continuing decline, inferred, observed or projected, in area, extent and/or quality of habitat

[d] A taxon is endangered when it is not critically endangered but is facing a very high risk of extinction in the wild in the near future

[e] Population reduction in the form of either of: An observed, estimated, inferred or suspected reduction of at least 50% over the last 10 years or three generations, whichever is the longer, based on: (c) a decline in area of occupancy, extent of occurrence and/or quality of habitat; (d) actual or potential levels of exploitation

exploitation and forest degradation through clearance for agriculture and logging activities. Cocoa farms provide a particularly valuable potential niche for threatened species, almost a third of trees recognized as valuable cocoa companion trees (Table 4) are considered vulnerable, and the mature cocoa farms are the main remaining habitat for the sole endangered species, *Tieghemalla heckellii*. The vulnerable species are clearly retained for their multiple benefits, e.g. the *Khaya* spp which provide medicinal products (Table 6) as well as being valuable timber trees. However, the replanted cocoa farms contain no threatened species, and little of the diversity of the mature cocoa farms, and fallows. Vulnerable tree species' protection will therefore require special conservation measures, including active integration into the cocoa landscape through enhancement of natural regeneration and planting in multi-species cocoa agroforestry systems. Valuable indigenous non-timber forest product species will lose importance with increasing resource use intensification without specific efforts to promote them (Sonwa et al. 2007) which integrate farmers' species selectivity (Asare 2006).

However, as pointed out by Tchoundjeu et al. (2002) the domestication of these, and other, species needs to take into consideration the requirements and knowledge of small-scale, resource-poor farmers and their subsistence farming systems. They recommend a more participatory approach to the domestication of high-value agroforestry tree species based on: priority setting by farmers; germplasm collection; low-technology vegetative propagation in village nurseries; the genetic characterization of the marketable products for consumption and processing; the integration of these species into agroforests managed by subsistence farmers; and the expansion of markets for the products. Agroforestry is increasingly providing on-farm sources of cultivated timber and non-timber forest products for domestic use and for marketing, in ways that potentially should reduce poverty and also provide some important environmental services, such as biodiversity conservation and carbon sequestration (Leakey 2001). McNeely and Schroth (2006) highlight the importance of linking forests, agroforests and wild biodiversity through adaptive, participatory management that recognizes local knowledge. Our findings emphasise the validity of exploiting the depth of local knowledge, of both ecological and economic interactions, to provide the most pragmatic solutions to conservation of biodiversity.

Conclusions and implications

The fallows and mature cocoa farms of this part of Ghana are an important reservoir of biodiversity which can provide a conservation focus for some of the vulnerable and endangered tree species of this agro-ecological zone. Trees in the landscape are valued by the farming community for a variety of reasons and there is a strong tradition of their management for cocoa shade which has promoted regeneration and species recovery in fallow lands. Regeneration in mature cocoa farms is restricted by cultivation, and proactive management will be required to ensure continued survival. The more recent tradition of planting new cocoa lands with hybrid varieties requiring less shade means that new cocoa plantations are much less diverse than the mature plantations and do not have the same conservation value. Successful biodiversity conservation, particularly of key threatened species, in this landscape will require a process of agroforestry development, involving tree improvement and the development of niches in the agricultural market. There is a vast knowledge amongst the farming community which should underpin any future developments.

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