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From shade- to sun-grown perennial crops in Sulawesi, Indonesia: implications for biodiversity conservation and soil fertility

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Abstract. Traditional, complex forest farming systems are increasingly converted to sun-grown monocultures throughout the tropics. Biophysical, soil and biodiversity effects associated with sun- vs. shade-grown coffee and cacao were investigated in a case study in Sulawesi, Indonesia. Canopy height, tree, epiphyte, liana and bird species diversity, vegetation structural complexity, percent ground cover by leaf litter, and soil calcium, nitrate nitrogen and organic matter levels in the O horizons were all significantly greater in shaded than in sun-grown farms. In contrast, photosynthetic active radiation (PAR), air and soil temperatures, weed diversity and percent ground cover by weeds were significantly greater in sun compared to shade farms. At the landscape level, conversion of shade-grown crops to sun conditions isolates protected areas and remnant primary forest fragments. Local cultivators are cognizant of the agronomic and socioeconomic risks associated with sun-grown perennial monocultures and some are increasing the density and diversity of fruit tree cultivation in an effort to provide shade and organic matter, and increase and diversify crop yields. The maintenance of traditional, complex forest farming systems, particularly shade-grown perennial crops, warrants greater attention in agricultural development and biodiversity conservation efforts.

Introduction

Tropical protected areas are insufficient to preserve biological diversity and ecosystem services, even under the most optimistic scenarios (Janzen 1998; Putz et al. 2000). Indeed, the maintenance of biodiversity is likely to be determined by agricultural and forest (i.e., matrix) land uses outside of formally protected areas (Janzen 1998; Lenne and Wood 1999). Not only do matrix lands provide valuable environmental and biodiversity conservation benefits (e.g., wildlife habitat, linkage between protected areas, watershed protection, C sequestration, etc.), they provide food and cash income for millions of rural households and comprise the basis of regional and national economies in many tropical countries (Lenne and Wood 1999; Fox et al. 2000).

Agricultural and forestlands in the tropics have been subjected to unprecedented development pressures for the past several decades (Collier et al. 1994; Janzen 1998). Millions of hectares of primary forest have been degraded by logging (Putz et al. 2000) and millions more converted to intensive agricultural uses (Lenne and

Wood 1999). At the same time, traditional agroforestry, perennial and long-fallow shifting cultivation systems (i.e., forest farming) have been displaced by technified monocultures (Collier et al. 1994; Perfecto et al. 1996; Thrupp 1998). The role and importance of agricultural lands, particularly traditional forest farming systems, have been neglected in global biodiversity conservation efforts (Thrupp 1998; Lenne and Wood 1999; Fox et al. 2000).

The environmental and biodiversity values of matrix lands vary with their biophysical characteristics and the way in which the lands are used. Gascon et al. (2000) argue that the most important determinants of biodiversity value are the intensity and history of land use, fire incidence, introduction of exotic species and the structure of the vegetation. Thiollay (1995), for example, observed that tree species richness, canopy height, vegetation structure and foliage volume were important determinants of bird species diversity in primary forest and traditional agroforestry systems in Sumatra. Similar relationships have been observed in the Neotropics with birds (Greenberg et al. 1997) and bats (Medellin et al. 2000).

Matrix effects on important ecosystem processes such as light, humidity, litter fall and seed dispersal can extend 300 m into undisturbed primary forests (Laurance 1997). Adverse effects associated with harsh forest–matrix boundaries, growing conflicts between protected areas and land use outside preserves, and the extensive transformation of matrix lands to technified monocultures necessitates addressing the type, intensity and scale of traditional matrix land use.

Any use of tropical forests is likely to alter biophysical conditions and floristic and faunal diversity (Janzen 1998; Putz et al. 2000). Nevertheless, many traditional tropical agricultural practices (e.g., agroforestry, shade-grown perennial cropping and long-fallow shifting cultivation) have proven to be productive, ecologically sustainable, and compatible with the conservation of some native flora and fauna (Perfecto et al. 1996; Moguel and Toledo 1999; Fox et al. 2000; Rice and Greenberg 2000). Furthermore, these systems have operated for centuries and continue to be modified by cultivators in response to local needs and external market opportunities (Thrupp 1998).

Maximizing environmental and biodiversity conservation in matrix lands requires minimizing forest–matrix edge harshness through the promotion of species-rich and structurally diverse land uses (Gascon et al. 2000). Complex agroforestry, traditional perennial farming (i.e., crops grown under shade trees) and long-fallow shifting cultivation exemplify these conditions. These forest farming systems are characterized by abundant primary and secondary forest vegetation, a closed canopy, complex vegetation structure, large leaf biomass, and high floristic diversity (Fox et al. 2000; Rice and Greenberg 2000). Furthermore, traditional forest farming systems create a diverse mosaic of vegetation types and successional stages (from cultivated fields to modified primary forests) across the landscape (Fox et al. 2000).

The high tree species diversity and complex structure of traditional forest farming systems maintains many of the ecosystem functions and processes found in primary forests. This includes low ground-level light intensities, low transpiration rates of understorey plants, reduced wind speed, and diurnal temperature and humidity fluctuations; large and continuous organic matter inputs; efficient nutrient cycling;

and diverse habitat for forest flora and fauna (Young 1989; Perfecto et al. 1996; Beer et al. 1998). These conditions also help sustain agricultural production by minimizing water runoff, soil erosion and nutrient leaching, and extend the productive life of crops while retaining or restoring soil fertility (Purseglove 1968; Young 1989; Beer et al. 1998). Traditional forest farming practices tend to be less susceptible to drought, insect and disease outbreaks, and require less capital and labor (e.g., fertilizers, insecticides and weeding) than technified monocultures (Beer et al. 1998; Fox et al. 2000). Traditional forest farming systems also provide a wide array of locally important goods and services (e.g., food, fuel, timber, medicinal plants, etc.). These farming systems are widely employed by poor households who typically pursue diverse livelihood strategies, lack capital, and cannot afford the risks associated with modern, technified agriculture (Collier et al. 1994; Thrupp 1998).

In this paper, biophysical and biodiversity effects associated with the transition from traditional shade- to sun-grown perennial crop cultivation are explored through a case study in Sulawesi, Indonesia. The specific attributes evaluated include photosynthetic active radiation (PAR), leaf area index (LAI), vegetation height and structure, weed establishment, air and soil temperatures, soil fertility, and floristic and bird species diversity.

Research site and methods

Site

The study was conducted near the forest village of Moa (78 households) in Central Sulawesi, Indonesia (120° E, 1.5° S; elevation 800 m). Environmental and biodiversity effects associated with sun- and shade-grown perennial cropping practices were evaluated in five representative farms. The five farms included: (A) shade-grown cacao (age 2 years) beneath a primary forest canopy (i.e., never cultivated); (B) shade-grown coffee (age 25 years) beneath a well-developed secondary forest canopy (age 30+ years, previously a shifting cultivation farm); (C) shade-grown cacao (age 3 years) beneath a well developed secondary forest canopy (age 25 years, previously a shifting cultivation farm); (D) full-sun-grown cacao (age 1 year) intercropped with *Gliricidia sepium*, previously a shifting cultivation farm; and (E) a complex agroforestry system with shade-grown cacao (age 10 years) intercropped beneath planted fruit trees (age 20 years; previously a shifting cultivation farm). The farms are all located within 1 km of the village, are approximately 1.0 ha in size, and are on Tropohumult soils of 20–40% slope. Precipitation in the region averages 3000–4000 mm annually with a relatively dry period from June to August.

Methods

In each farm 10 sample plots (3 × 3 m) were established along two random transects located 15+ m from parcel boundaries (i.e., to minimize edge effects). The sample plots were three-dimensional and extended from below the soil surface up through the canopy. In each plot the height of the canopy, the number of vegetation layers, the number of epiphytes and lianas, the percent ground covered by leaf litter and/or weeds, and the percent PAR at 1 m height and LAI of all vegetation layers above 1 m height were recorded. The individual PAR and LAI measurements were each an average of 20 ceptometer sensor readings taken between 10 A.M. and 2 P.M..

Floristic diversity was inventoried by identifying all wild and cultivated plant species in each farm (specimens deposited in the Herbarium at Tadulaku University, Palu and at Herbarium Bogoriense, Bogor). All birds observed perched or feeding in one shaded perennial farm (C) and one full-sun farm (D) were recorded for 1 h (between 9 A.M. and noon) each day for 10 consecutive days during August.

Cultivation effects on edaphic characteristics and soil and air temperatures were investigated in each farm. Three random soil samples (each a composite of five subsamples) from the soil surface (O horizon; 0–5 cm depth) and mineral soil (A/E horizon; 10–25 cm depth) were collected in each of the five farms. The soil samples were air dried, nutrients were extracted with Morgan's solution (10% sodium acetate in 3% acetic acid buffered to pH 4.8) and analyzed for nitrate nitrogen (automated hydrazine reduction, NO_3-N reported as mg N kg^{-1}); P (Bray-P colorimetrically by stannous chloride reduction; mg kg^{-1}); K, Ca, and Mg (by atomic absorption; mg kg^{-1}); pH and percent organic matter (by loss on ignition) by the Cornell Nutrient Analysis Laboratory in Ithaca, NY. Maximum daily air temperatures in one shade (A) and one sun (D) cacao farm under both shade (i.e., beneath the perennial crop) and sun conditions (i.e., in gaps in parcel A and in the open in parcel D) were measured on 10 occasions (i.e., for 10 consecutive days). Maximum midday soil temperatures at the soil surface and at 10 cm depth in the same farms (A and D) were also recorded on 10 occasions using a digital temperature probe.

The observed biophysical and biodiversity characteristics of shade- and sun-grown farms were evaluated by comparing total and mean subplot differences. The significance of differences were analyzed through the use of ANOVA followed by Tukey's *post hoc* tests, where appropriate. It is important to note that sampling was conducted in one farm of each type (i.e., 10 sample plots per farm type for biophysical characteristics and three samples per farm type for soil characteristics). Consequently, it is not possible to make definitive generalizations to farm types across the landscape.

Results

Biophysical differences

Biophysical characteristics differed between shade- (parcels A, B and C) and sun-grown perennial (parcel D) farms (Table 1). Not surprisingly, traditional perennial farms were structurally more complex (e.g., 1.6–1.9 vegetation layers) and had a high, relatively closed canopy (i.e., from 17 to 34 m height), while the

Table 1. Biophysical characteristics of sun- and shade-grown perennial farms.

Site/description	Mean (±SD) based on 10 samples per site				
	Total available PAR (%)	LAI	Vegetation layers (≠)	Ground cover %/type	Canopy height (m)
A: Primary forest/cacao[1] (2 years)	4.9^{a}	1.56^{a}	1.9^{a}(0.6)	100 (0) litter	34.5 (5.2)
B: Secondary forest/coffee[2] (25 years)	13.2^{b}	1.19^{b}	1.6^{a}(0.7)	100 (0) litter	16.7 (13.2)
C: Secondary forest/cacao[1] (3 years)	15.1^{b}	1.07^{b}	1.7^{a}(0.5)	100 (0) litter/weeds	33.8 (15.6)
D: Full-sun cacao/*G. sepium*[3] (1 year)	72.4^{c}	0.18^{c}	0.2^{b}(0.4)	80 (15.7) weeds	Open
E: Agroforestry/cacao[1] (10 years)	2.3^{a}	2.09^{a}	1.5^{a}(0.5)	89 (7.5) litter	12.4 (5.1)

Values followed by the same letter within a column are not significantly different (ANOVA followed by Tukey's *post hoc* tests, $P < 0.05$). [1]Cacao – *Theobroma cacao* L.; [2]coffee – *Coffea canephora* Pierre ex Froehner; [3]*G. sepium* – *Gliricidia sepium* (Jacq.) Warb.

Table 2. Air and soil temperatures in sun- and shade-grown perennial farms.

Site/description	Mean midday temperature (± SD), °C, and significance of difference (ANOVA followed by Tukey's *post hoc* tests; $n = 10$)			
	Air		Soil	
	Shade	Sun	Surface	10 cm depth
Cacao[a] under primary forest canopy (A)	25.4 (1.7)	25.7 (1.9)	22.9 (0.9)	22.1 (0.7)
Cacao[a] with *G. sepium*[b] (D)	31.2 (2.9)	33.5 (3.7)	27.6 (2.9)	24.5 (1.6)
P value	<0.001	<0.001	<0.001	<0.001

[a]Cacao – *Theobroma cacao* L. [b]*G. sepium* – *Gliricidia sepium* (Jacq.) Warb.

Table 3. Soil characteristics in O and A/E horizons of sun and shade perennial farms.

Site/description	Mean (± SD), mg/kg, of three samples, each a composite of five subsamples from the O (0–5 cm) and A/E (10–25 cm) horizons						
	NO_3[d]	P	K	Ca	Mg	pH	OM (%)
A: Primary forest (O)	65 (19)	29 (14)	217 (22)	4794 (596)	428 (16)	7.2 (.1)	9.9 (1.3)
Cacao[a] (2 years) (A/E)	ND	5 (4)	189 (27)	2138 (158)	295 (19)	6.9 (.5)	3.1 (0.4)
B: Sec. forest/ (O)	38 (15)	6 (3)	195 (93)	3113 (284)	512 (19)	6.5 (.3)	8.6 (1.0)
Coffee[b] (25 years) (A/E)	ND	1 (1)	72 (21)	2080 (41)	390 (77)	6.2 (.2)	4.4 (0.3)
C: Sec. forest/ (O)	46 (19)	39 (29)	261 (70)	3037 (519)	470 (24)	7.1 (.4)	7.2 (0.9)
Cacao[a] (3 years) (A/E)	ND	6 (4)	82 (15)	1528 (325)	204 (68)	6.5 (.4)	2.7 (0.3)
D: Full-sun cacao[a] (O)	8 (7)	3 (4)	90 (37)	1565 (256)	549 (7)	6.3 (.4)	3.8 (0.4)
G. sepium[c] (1 year) (A/E)	ND	1 (1)	35 (23)	1480 (276)	646 (65)	6.2 (.3)	2.5 (0)
E: Agroforestry (O)	17 (5)	33 (30)	147 (51)	3105 (414)	443 (89)	7.2 (.1)	7.3 (1.6)
Cacao[a] (10 years) (A/E)	ND	4 (1)	45 (3)	1924 (159)	323 (18)	6.7 (.1)	3.3 (0.5)

ND – values at or below detection limits. [a]Cacao – *Theobroma cacao* L.; [b]coffee – *Coffea canephora* Pierre ex Froehner; [c]*G. sepium* – *Gliricidia sepium* (Jacq.) Warb.; [d]Nitrate nitrogen (mg N kg^{-1}).

sun-grown site (D) had no vegetation layers above the cacao. Total available PAR at 1 m height was 5–15 times greater in the full-sun site than in the shaded farms, while LAI was the reverse (6–9 times greater in shaded farms than in the full-sun

Table 4. Biodiversity characteristics of perennial farms.

Site/description	Number of species					
	Trees[a]	Epiphytes	Lianas	Ground[b]	Herbaceous weeds[c]	Birds[d]
A: Primary forest/cacao[e] (2 years)	30	3+	2	7	3	ND
B: Secondary forest/coffee[f] (25 years)	25	2+	1	2	9	22
C: Secondary forest/cacao[e] (3 years)	25	2+	4	3	5	ND
D: Full-sun cacao/*G. sepium*[g] (1 year)	1	0	0	0	16	0
E: Agroforestry/cacao[e] (10 years)	7	0	0	9[h]	5	ND

ND – no data. [a]Includes wild and cultivated species. [b]All non-weed herbaceous and perennial species of the forest floor. [c]As indicated by farmers. [d]As recorded during 10 days in August, 2000. [e]Cacao –*Theobroma cacao* L. [f]Coffee – *Coffea canephora* Pierre ex Froehner. [g]*G. sepium* – *Gliricidia sepium* (Jacq.) Warb. [h]Includes four cultivated crop species.

site). Cacao grown under a secondary forest canopy (site C) received approximately three times the total available PAR in comparison to cacao grown under a primary forest canopy (site A). The agroforestry parcel (E) had a lower canopy (12.4 m) than perennial farms under primary or secondary forest. However, it exhibited high structural complexity (i.e., 1.5 vegetation layers), was the most heavily shaded parcel (2.3% available PAR at 1 m height) and had the highest LAI, 2.09.

Maximum ambient midday air temperatures in the shade and sun, and soil temperatures at the surface and at 10 cm depth, were significantly lower in the shaded farm (A) than in the full-sun farm (D, Table 2). In the O horizon, soil organic matter and Ca levels were significantly greater in all three shade farms (A, B and C) and in the agroforestry site (E) in comparison to the full-sun site (Table 3). Similarly, nitrate nitrogen levels were significantly higher in the O horizons in the three shade farms in comparison to the full-sun parcel, while soil pH levels were significantly greater in parcels A, C and E than in D. No significant differences were observed in P and Mg levels in the O horizons of the five farms.

In comparing soils within each parcel, organic matter and Ca levels were significantly greater in the O than in the A/E horizon in all shade farms (A, B and C) and in the agroforestry farm (E), but not in the full-sun farm (D). Nitrate nitrogen levels were also significantly greater in the O than in the A/E horizons in the three shade farms, but not in the agroforestry or full-sun farms. No significant differences were observed between the O and A/E horizons in the full-sun parcel for any of the soil parameters investigated. Finally, no significant differences in the mineral soil horizons (A/E) were observed between the five farms, with the exception of Mg, which was significantly higher in the full-sun farm compared to the others. All of the above analyses utilized ANOVA followed by Tukey's *post hoc* tests ($P < 0.05$).

Biodiversity differences

In terms of floristic diversity, the three traditional shade farms each contained 25–30 different canopy tree species, several epiphytic and liana species, and a number of herbaceous and fern species common in primary or secondary forests (Table 4,

Appendix 1). In contrast, the only trees in the full-sun farm (D) were planted *Gliricidia sepium*, a naturalized exotic from Central America. Seven tree species, all cultivated fruit trees, were observed in the agroforestry farm. The shaded farms exhibited 100% ground cover, primarily leaf litter, while the full-sun site averaged 80% ground cover, primarily exotic weed species, and lacked a well-developed leaf litter layer. The full-sun site had no epiphytes, lianas or forest floor species, and contained 16 plant species considered to be weeds by local farmers, including large populations of the problem weeds *Imperata cyclindrica* and *Ageratum conyzoides*. The complex agroforestry site (E) lacked epiphytes, lianas and forest floor species, but, in contrast to the full-sun farm, had a well-developed leaf litter layer (89% ground cover) and few problem weed species.

Twenty-two bird species were observed in the shaded farm (B) during the 10-day observation period, including several endemic species (Appendix 2). In contrast, no birds were observed in the full-sun site, even though birds were abundant in adjacent shaded farms and primary forest fragments.

Discussion

The biodiversity value of traditional shade-grown coffee and cacao farms is due to the high canopy tree species diversity, multilayered forest structure, and the presence of lianas and epiphytes. Shaded farms also exhibited low levels of exotic weeds in terms of both the number of species and percent ground cover. The presence of weed species is a useful proxy for disturbance (Gascon et al. 2000) and an indicator of the extent to which native floristic diversity has been retained in the wake of exotic species invasions.

The floristic and structural diversity of shade-grown coffee and cacao farms provides habitat for native fauna, as is evident by the observed diversity of bird guilds and species. Local farmers also reported that small mammals, deer, wild pigs, macaques and other forest fauna are regularly observed and occasionally hunted in these farms. In contrast, no birds were observed in the full-sun farm and forest animals were reported to be rare in these sites, even where adjacent to shade farms and remnant primary forest patches (farmers, personal communications).

Vegetation (i.e., canopy) height and structural complexity (i.e., number of layers) are often associated with increased bird species diversity due to the increased foraging and nesting opportunities such vegetation provides (Greenberg et al. 1997). A diversity of vegetation types and structure also modifies microclimatic conditions, thereby providing a wide range of niches for other plant, animal and insect communities. In addition, flora and fauna may interact to maintain and even enhance biological diversity. For example, birds and bats are known to be important dispersers of pioneer and primary forest tree, shrub, herb and epiphyte species (Galindo-Gonzales et al. 2000). Structurally diverse forest farms that provide sites for birds and bats to feed and perch may enhance seed dispersal and establishment of woody vegetation. They may also provide connectivity between isolated primary forest fragments (Galindo-Gonzales et al. 2000). It is important to note, however, that both native and exotic weed species could be established in this manner.

Canopy height is a function not only of forest age, but also of the history and intensity of cultivation. The relatively low canopy height and structural complexity of the fruit-based agroforestry farm (E) suggests that the diversity and abundance of insects and birds may be lower than in farms under primary or secondary forests. However, some of the fruit trees planted in agroforestry farms are long-lived species that can reach 20–40 m in height (e.g., jackfruit, durian and coconut). Thus, both canopy height and structural diversity may increase with time, enhancing the biodiversity conservation value of these farms. Furthermore, even when young and relatively low in height and structural complexity, agroforestry farms provide a much more diverse range of biophysical conditions (i.e., niches) than full-sun farms.

The establishment of permanent full-sun perennial crops in former long-fallow shifting cultivation fields will reduce landscape-level diversity by eliminating secondary forests on fallowed lands. This will simplify the current diverse mosaic of vegetation types and successional stages found in the region. Increased full-sun farming will also isolate protected primary forests and remnant primary forest fragments.

The people of Moa have lived, farmed and collected forest products in this region for centuries. Until recently, local people relied primarily on long-fallow shifting cultivation for the production of staple food. Coffee was first planted in the 1950s and has been widely grown since under primary or secondary forest canopies without use of petrochemical fertilizers or pesticides. Shifting cultivation and perennial cash cropping were prohibited over large areas with the establishment of Lore Lindu National Park (LLNP) in 1982. Households have responded to the loss of traditional land and forest resources by intensifying cultivation on lands outside of the park. Long-fallow shifting cultivation and shade-grown coffee production are being replaced by short-fallow or permanent annual farming and intensive, full-sun perennial crop cultivation, particularly of cacao. In Moa, for example, cacao cultivation increased from a single household in 1990 to 100% of households in 1999 and 82% of the new plantings were under full-sun conditions in former shifting cultivation farms (Siebert, unpublished data).

Widespread establishment of full-sun perennial crops in former shifting cultivation farms may adversely affect soil fertility and long-term agricultural production. When a short cultivation period (1–2 years) is followed by a long-fallow (10–20 years), shifting cultivation can be productive and sustainable; the fallow restores soil fertility and suppresses weed infestation (Nye and Greenland 1960).

All of the farms investigated in this study (with the exception of parcel A) were swiddens within the past several decades. Thus it is noteworthy that soil nutrient and physical characteristics followed similar patterns in all of the farms, with the exception of the full-sun parcel D. Soil calcium and organic matter levels were greater in the organic layer (O horizon) than in the mineral soil (A/E horizon) in all of the shade parcels. In addition, soil nutrient, organic matter and pH levels in the O and A/E horizons were not significantly different between parcels A, B, C and E, even though parcel A is a primary forest. In contrast, there were no significant differences in soil characteristics between the O and A/E horizons in the full-sun farm, suggesting that cultivation is occurring on exposed mineral soils.

These data suggest that coffee and cacao cultivated beneath primary or secondary forest vegetation may maintain soil organic matter levels and help retain soil productivity. Care must be taken in extending these conclusions to farms throughout the region due to the limited number of parcels sampled (i.e., definitive conclusions can only be drawn about the five farms sampled). There may be significant differences in biophysical, soil and biodiversity attributes between farms of the same general type throughout the landscape. Nevertheless, the data suggest the existence of important trends and relationships that warrant more detailed study.

For example, it appears that secondary forest farms may exhibit comparable soil fertility, organic matter and low weed infestation levels as primary forest farms. If this is the case, their higher light levels (i.e., available PAR) might be conducive to greater coffee and cacao yields in comparison to primary forest farms. Secondary forest farming could thus be advantageous for reasons of economic yield, long-term productivity and biodiversity conservation. This would argue for investing development assistance in enhancing secondary forest farming productivity and sustainability, and conserving remnant primary forests for biodiversity conservation.

The long-term viability of cacao cultivation under full-sun conditions is questionable (Beer et al. 1998). Furthermore, the conversion of shifting cultivation to sun-grown cacao will prevent restoring soil nutrient and organic matter levels through fallowing. This switch could eliminate the possibility of switching from cacao back to annual food crops without chemical inputs, should the need arise (i.e., if cacao crops fail or international market prices drop; current cacao prices are near record lows).

Farmers in Moa are aware of the agronomic and socioeconomic vulnerability of sun-grown cacao and have begun to modify their cultivation practices. Following a series of droughts and widespread mortality of sun-planted cacao seedlings in the late 1990s, many Moa farmers cultivating full-sun cacao increased the density of *G. sepium* planting and began incorporating bananas in their farms. This was undertaken to increase shade and organic matter levels and thereby reduce soil moisture losses and increase soil water-holding capacity (farmers, personal communications). The owner of parcel E (the complex agroforestry farm), a respected traditional leader, has encouraged other farmers to intercrop fruit trees in sun farms to reduce drought risk, enhance long-term sustainability, and to increase and diversify yields.

Traditional forest farms are being converted to intensive, full-sun monocultures in Sulawesi and elsewhere in the humid tropics, despite their valuable ecological and socioeconomic attributes. The retention of shade-grown farms is particularly important in matrix lands surrounding protected areas and primary forest remnants, and warrants conservation and development support.

Conclusions

The widespread transformation of traditional, complex forest farming systems to sun-grown monocultures of coffee or cacao may adversely affect long-term agricultural productivity, simplify forest environments, increase habitat fragmentation, lead to exotic weed species invasions, and isolate primary forest in protected areas and remnant fragments. In contrast, shade-grown perennial farms provide valuable economic and biodiversity conservation benefits and appear to have been productive for decades.

The future of biodiversity in the tropics will depend largely upon what occurs on agricultural and forestlands outside of protected areas (Janzen 1998; Lenne and Wood 1999). Agricultural development and forest conservation efforts should seek to maintain and enhance traditional shade-grown forest farming systems on matrix lands, as these practices are integral to local livelihood strategies and complement biodiversity conservation objectives. As Aldo Leopold (1935, p. 216) cogently observed over six decades ago:

''Parks are overcrowded hospitals trying to cope with an epidemic of esthetic rickets; the remedy lies not in hospitals, but in daily rations. The vast bulk of land beauty and landlife, dispersed as it is over a thousand hills, continues to waste away under the same forces as are undermining land utility''.

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Appendix 1

Plant species recorded in perennial farms.[a]

Tree species	Family	Site[b]				
		A	B	C	D	E
Arenga pinnata Merrill	Palmae	×		×		×
Arenga sp.	Palmae	×		×		
Cocos nucifera L. (p)	Palmae					×
Pinanga sp.	Palmae	×		×		
Polyscias nodosa Seem.	Amaryllidaceae	×	×	×		
Leea aequata Linn.	Ampelidaceae	×				
Dracontomelon mangiferum Blume	Anacardiaceae	×				
Koordersiodendron pinnatum Merrill	Anacardiaceae		×			
Mangifera indica Blume	Anacardiaceae		×			
Alstonia scholaris R.Br.	Apocynaceae	×	×	×		

Appendix 1. (*continued*)

Tree species	Family	Site[b]				
		A	B	C	D	E
Schizostachyum brachicladum Kurz	Bambusaceae	×				
Pangium edule Reinw.	Bxaceae	×		×		
Durio zibethinus Murr. (p)	Bombacaeae		×			×
Canarium balsamiferum Moon	Burseraceae		×			
Acalypha cuturus Bl.	Euphorbiaceae	×				
Glochidion sp.	Euphorbiaceae		×			
Macaranga hispida Muell.Arg	Euphorbiaceae	×	×	×		
Macaranga triloba Muell.Arg	Euphorbiaceae			×		
Gnetum gnemon Linn	Gnetaceae			×		
Litsea sp.	Lauraceae	×	×			
Persea americana Mill. (p)	Lauraceae					×
Erythrina sp.	Leguminosae		×	×		
Gliricidia sepium (Jacq.) Walp.	Leguminosae				×	
Pleomele angustifolia N.E. Brown	Liliaceae	×	×			
Strychnos axillaries Blume	Loganiaceae		×	×		
Disoxillum sp.	Meliaceae		×	×		
Lansium domesticum Correa	Meliaceae		×	×		
Artocarpus heterophyllus Lam. (p)	Moraceae					×
Artocarpus teysmannii Miq.	Moraceae	×	×	×		
Artocarpus vriescana Miq.	Moraceae		×	×	×	
Ficus geoharis Corner	Moraceae	×		×		
Ficus minahasae Miq.	Moraceae			×		
Ficus sp.	Moraceae		×	×	×	
Knema tomentella Warb	Myristicaceae	×				
Eugenia sp.	Myrtaceae	×	×			
Carallia brachiata Merrill	Rhizophoraceae	×		×		
Ixora sp.	Rubiaceae	×				
Morinda bracheata L.	Rubiaceae		×			
Musaendopsis beccariana Baill.	Rubiaceae	×				
Nauclea sp.	Rubiaceae			×		
Citrus sp. (p)	Rutaceae					×
Evodia sp.	Rutaceae	×		×		
Evodia sp.	Rutaceae			×		
Pometia tomentosa Kurz.	Sapindaceae	×		×		
Nephelium lappaceum L. (p)	Sapindaceae					×
Palaquium sp.	Sapotaceae	×		×		
Sarcosperma paniculatum Stapf. & King	Sapotaceae		×			
Firmiana malayana Kosterm.	Sterculiaceae	×				
Pterospermum celebicum Miq.	Sterculiaceae	×	×	×		
Sterculia macrophylla Vent	Sterculiaceae	×				
Grewia sp.	Tiliaceae	×				
Laportea stimulans Miq.	Urticaceae	×	×			
Clerodendron sp.	Verbenaceae		×			
Vitex quinata Druce	Verbenaceae		×			
Ground, epiphyte and liana species						
Curculigo latifolia Dryand. (w)	Amarylidaceae	×	×	×	×	×
Asplenium macrophyllym Sw. (e)	Aspleniaceae	×				
Asplenium nidus Linn. (e)	Aspleniaceae	×	×	×		

Appendix 1. (*continued*)

Tree species	Family	Site[b]				
		A	B	C	D	E
Pothos sp.	Araceae	×				
Philodendron sp. (l)	Araceae	×	×	×		
Scheffelera elliptica (Blume) Horns (l)	Araceae			×		
Ceiba pentandra Gaertn.	Malvaceae		×			
Ageratum conyzoides Linn. (w)	Compositae		×		×	×
Blumea balsamifera DC (w)	Compositae				×	
Mikania sp. (w)	Compositae				×	
Veronica arborea J. Buch. (w)	Compositae		×		×	
Codiaeum variegatum Blume	Euphorbiaceae		×			
Eleusine indica Gaertn. (w)	Gramineae		×		×	
Imperata cylindrica Beauv. (w)	Gramineae			×	×	
Pityrogramma calomelanos (Hook) Bailey	Heminitidaceae	×				
Hyptis capitata Jacq. (w)	Labiatae		×		×	×
Calopogonium sp. (w)	Leguminosae				×	
Cordyline fruticosa A. Cheval.	Liliaceae	×				
Sida rhombifolia Linn. (w)	Malvaceae		×		×	
Urena lobata Linn.	Malvaceae			×		
Mimosa invisa Mart. (w)	Leguminoseae		×		×	×
Musa sp.	Musaceae			×		
Musa sp. (p)	Musaceae					×
Helminthostachys zeylanica L. Hook	Ophioglossaceae	×				
Coelogyne sp. (e)	Orchidaceae	×	×	×		
Other orchids	Orchidaceae	×	×	×		
Piper sp. (l)	Piperaceae			×		
Crypsinus stenophyllus (Bl.) Holltum	Polipodiaceae	×				
Nephrolepis exaltata Schott.	Polipodiaceae				×	
Pyrrosia lanceolata Farwell (w)	Polipodiaceae				×	
Pteris venula Bl. (w)	Pteridaceae				×	
Lasianthus sp. (w)	Rubiaceae	×	×	×	×	×
Lycopodium circinatum (Burn.) Sw. (l)	Schizaeaceae	×		×		
Christella papilio (Hope) Holltum	Thelypteraceae	×				
Stachytarpheta indica Vahl. (w)	Verbenaceae			×	×	
Antrophyum reticulatum (Forst.) Kaulf.	Vittariaceae	×				
Costus speciosus (Koenig) Smith (w)	Costaceae	×	×	×	×	×
Salacca edulis Reinw. (p)	Palmae					×
Zingiber officinale Rosc. (p)	Zingiberaceae					×

e – epiphyte; l – liana; p – planted crop species; w – weed (farmers, personal communications). [a] From: Index Kewensis (1997); Jarvie and Ermayanti (1996); Piggott (1988); Tralau (1969). [b]Sites include: A – primary forest with cacao (age 2 years), B – secondary forest with coffee (age 25 years), C – secondary forest with cacao (age 3 years), D – full-sun cacao with *G. sepium* (age 1 year), and E – agroforestry with cacao (age 10 years).

Appendix 2

Bird species observed in a shade-grown cacao farm (B).

Common name	Scientific name
House Swift	*Apus affinus*
Pacific Swallow	*Hirundo tahitica*
Ivory-backed Woodswallow	*Artamus monachus*
Yellow-sided Flowerpecker	*Dicaeum aureolimbatum*
Grey-sided Flowerpecker	*Dicaeum celebicum*
Crimson Sunbird	*Aethopyga siparaja*
Citrine Flycatcher	*Culicicapa helianthea*
Common Dollarbird	*Eurystomus orientalis*
Sulawesi Cicadabird	*Coracina abbotti*
Ornate Lorikeet	*Trichoglossus ornatus*
Yellow-billed Malkoha	*Rhamphococcyx calorhynchus*
Finch-billed Myna	*Scissirostrum dubium*
Drongo	*Dicrurus hottentottus*
Black-napped Oriole	*Oriolus chinensus*
Slender-billed Crow	*Corvas typicus*
Grey-headed Imperial Pigeon	*Ducula radiata*
Stephan's Dove	*Chalcophaps stephani*
Eurasian Tree Sparrow	*Passer montanus*
Sulawesi Woodpecker	*Dendrocopos temminckii*
Brahminy Kite	*Haliastur Indus*
Sulawesi Hanging Parrot	*Loriculus stigmatus*
Red-knobbed Hornbill	*Aceros cassidix*

References

Beer J., Muschler R., Kass D. and Somarriba E. 1998. Shade management in coffee and cacao plantations. Agroforestry Systems 38: 139–164.

Collier G., Mountjoy D. and Nigh R. 1994. Peasant agriculture and global change. BioScience 44: 398–407.

Fox J., Truong D., Rambo T., Tuyen N., Cuc L. and Leisz S. 2000. Shifting cultivation: a new old paradigm for managing tropical forests. BioScience 50: 521–528.

Galindo-Gonzales J., Guevara S. and Sosa V. 2000. Bat- and bird-generated seed rains at isolated trees in pastures in a tropical rainforest. Conservation Biology 14: 1693–1703.

Gascon C., Williamson C. and Da Fonseca G. 2000. Receding forest edges and vanishing reserves. Science 288: 1356–1358.

Greenberg R., Bichier P. and Sterling J. 1997. Bird populations in rustic and planted shade coffee plantations of eastern Chiapas, Mexico. Biotropica 29: 501–514.

Index Kewensis (1997) Oxford University Press, Oxford, UK.

Janzen D. 1998. Gardenification of wildland nature and the human footprint. Science 279: 1312–1313.

Jarvie J. and Ermayanti 1996. Tree Genera of Borneo – Descriptions and Illustrations. http://django.harvard.edu/users/jjarvie/Borneo.htm

Laurance W. 1997. Introduction: edge effects in fragmented forests. In: Laurance W. and Bierregaard R. Jr (eds), Tropical Forest Remnants. University of Chicago Press, Chicago, Illinois, pp. 29–31.

Lenne J. and Wood D. 1999. Optimizing biodiversity for productive agriculture. In: Wood D. and Lenne J. (eds), Agrobiodiversity: Characterization, Utilization and Management. CABI Publishing, Wallingford, UK, pp. 447–470.

Leopold A. 1935. Land Pathology. In: Flader S. and Callicott J. (eds), The River of the Mother of God and Other Essays. University of Wisconsin Press, Madison, Wisconsin, pp. 212–217.

Medellin R., Equihua M. and Amin M. 2000. Bat diversity and abundance as indicators of disturbance in Neotropical forests. Conservation Biology 14: 1666–1675.

Moguel P. and Toledo V. 1999. Biodiversity conservation in traditional coffee systems of Mexico. Conservation Biology 13: 11–21.

Nye P. and Greenland D. 1960. The soil under shifting cultivation. Technical Communication 51. Commonwealth Agricultural Bureau, Harpenden, UK.

Perfecto I., Rice R., Greenberg R. and Van der Voort M. 1996. Shade coffee: a disappearing refuge for biodiversity. BioScience 46: 598–608.

Piggott A. 1988. Ferns of Malaysia in Colour. Tropical Press, SDN BHD, Kuala Lumpur, Malaysia.

Purseglove J. 1968. Tropical Crops: Dicotyledons. Longman, Harlow, UK.

Putz F., Redford K., Robinson J., Fimbel R. and Blate G. 2000. Biodiversity and conservation in the context of tropical forest management. Biodiversity Series Impact Studies #1. The World Bank, Washington, DC.

Rice R. and Greenberg R. 2000. Cacao cultivation and the conservation of biological diversity. Ambio 29: 167–173.

Thiollay J. 1995. The role of traditional agroforests in the conservation of rain forest bird diversity in Sumatra. Conservation Biology 9: 335–353.

Thrupp L. 1998. Cultivating Diversity: Agrobiodiversity and Food Security. World Resources Institute, Washington, DC.

Tralau H. 1969. Index Holmensis. The Scientific Publishers Ltd, Zurich, Switzerland.

Young A. 1989. Agroforestry for Soil Conservation. CAB International, BPCC Wheatons Ltd, Exeter, UK.