Gillison, A. N., N. Liswanti, S. Budidarsono, M. van Noordwijk, and T. P. Tomich. 2004. Impact of cropping methods on biodiversity in coffee agroecosystems in Sumatra, Indonesia. Ecology and Society **9**(2): 7. [online] URL: http://www.ecologyandsociety.org/vol9/iss2/art7

Report

Impact of Cropping Methods on Biodiversity in Coffee Agroecosystems in Sumatra, Indonesia

Andrew N. Gillison[1], *Nining Liswanti*[2], *Suseno Budidarsono*, *Meine van Noordwijk*, and *Thomas P. Tomich*[3]

ABSTRACT. The sustainable management of biodiversity and productivity in forested lands requires an understanding of key interactions between socioeconomic and biophysical factors and their response to environmental change. Appropriate baseline data are rarely available. As part of a broader study on biodiversity and profitability, we examined the impact of different cropping methods on biodiversity (plant species richness) along a subjectively determined land-use intensity gradient in southern Sumatra, ranging from primary and secondary forest to coffee-farming systems (simple, complex, with and without shade crops) and smallholder coffee plantings, at increasing levels of intensity. We used 24 (40 x 5 m) plots to record site physical data, including soil nutrients and soil texture together with vegetation structure, all vascular plant species, and plant functional types (PFTs—readily observable, adaptive, morphological features). Biodiversity was lowest under simple, intensive, non-shaded farming systems and increased progressively through shaded and more complex agroforests to late secondary and closed-canopy forests. The most efficient single indicators of biodiversity and soil nutrient status were PFT richness and a derived measure of plant functional complexity. Vegetation structure, tree dry weight, and duration of the land-use type, to a lesser degree, were also highly correlated with biodiversity. Together with a vegetation, or V index, the close correspondence between these variables and soil nutrients suggests they are potentially useful indicators of coffee production and profitability across different farming systems. These findings provide a unique quantitative basis for a subsequent study of the nexus between biodiversity and profitability.

INTRODUCTION

Sustainable forest management and biodiversity conservation are rarely viable financial propositions. Uncontrolled forest exploitation or deforestation can contribute to major biodiversity loss yet continue to be highly profitable in the short term. The underlying problem of weak incentives for forest management and conservation is of increasing concern and contributes significantly to biodiversity loss. For biodiversity to be managed sustainably, the links between the natural resource base, management systems, and income must be understood in order to develop acceptable tradeoffs. Because biodiversity is consistently undervalued, it is important to know how to allocate a biodiversity value to forested lands, especially those with high "externality" values associated with environmental functions and biodiversity conservation (Richards 1999). Short-term profit incentives in primary production are frequently supported by permanent, intensive cropping systems as an alternative to slash and burn. Where capital is available, this is usually accompanied by the addition of artificial fertilizers, pesticides, and herbicides. These short-term gains can be seriously eroded by a gradual decline in crop yields engendered by increasing soil acidity, pesticide resistance, and herbicide-resistant, invasive exotic weeds. In many tropical countries, the widespread and often uncontrolled removal of land cover continues to deplete soil reserves leading to a significant reduction in environmental services and water quality often with a dramatic loss in biological diversity. Current methodologies severely restrict the kinds of multidisciplinary baseline studies needed to provide a meaningful economic value to biodiversity for policy development.

As one element of a broader effort to redress this

[1]Center for Biodiversity Management; [2]Center for International Forestry Research; [3]Alternatives to Slash and Burn (ASB), World Agroforestry Centre

problem, we report the results of a baseline study using recently developed rapid survey techniques to identify key links and indicators of interactions between biodiversity and cropping systems in a typical, upland, tropical coffee-based agroecosystem. The biophysical baseline data reported here will form the basis for a second report to deal more specifically with dynamic links between biodiversity and profitabilty. Coffee is one of the principal agricultural products in international trade volume, having a market value of almost US$19.5 billion per year; most of it is grown and exported by more than 50 developing countries. Baseline information that can lead to policy changes in the management of coffee agroecosystems over the long term, therefore, has the potential to significantly influence both international trade and natural resource capital, as well as long-term local livelihoods and sustainable biodiversity management.

Biodiversity Indicators in Agroecosystems

In its broadest sense, biodiversity is defined as the "variety of life on earth," otherwise described in terms of gene, species, and ecosystem (*cf*. Heywood and Baste 1995). However, a specific application by Sala et al. (2000) excludes "exotic organisms that have been introduced and communities such as agricultural fields that are maintained by regular intervention." Although conceptually useful, such definitions are inappropriate for management where quantification is vital and where any species, either exotic or indigenous, is an integral part of the bio-ecological landscape. In this paper, we examine the potential value of certain suites of indicators of change in biodiversity under different forms of land use in coffee-based agroecosystems involving both exotic and indigenous plant species. In so doing, we focus on causal rather than correlative links within the context of management scale and purpose.

For logistic, scientific, and management purposes there is a need for cost-efficient methods to identify and locate simple, readily observable indicators of complex sets of biota and related agricultural productivity. In order to be able to monitor and forecast the impacts of land use on biodiversity and, conversely, any potentially negative feedback of biodiversity loss on productivity, it is desirable that such indicators should possess some demonstrable, functional as well as correlative relationship with the physical environment. So far the "ideal" is far from reality and much debate surrounds the definition, measurement, and reliability of biodiversity indicators (cf. Noss 1990, Lawton et al.1998, Watt et al.1998, Lindenmayer et al. 2000). Although there is no "best surrogate" (Margules and Pressey 2000), certain biophysical indicators may be used to estimate both the type and distribution of organisms in time and space. Conversely, it is possible to use taxonomic subsets of species assemblages or functional characteristics as indicators of specific abiotic features of the environment, such as soil quality, potential productivity, profitability, or the state of ecosystem health (e.g., level of pollution or degradation) (Gillison 2001). The use of environmental indices, composite environmental indices, and socio-economic indicators is reviewed by Bakkes et al. (1994) and the role of biodiversity indicators in forested landscapes by Gillison (2001). Apart from managers, policy makers also require indicators for biodiversity management (McNeely 1990, Reid et al.1993).

Despite a continuing search for alternatives, until now the species remains the common currency of biodiversity. Multivariate approaches to the use of composite species sets as indicators commonly include some form of species indicator analysis (Schwartz and Wein 1997, Hobson and Schieck 1999). In Ugandan forests, Howard et al. (1997) applied a range of biological indicator taxa in a wide-ranging study of biodiversity conservation procedures and concluded that practical factors compel their use. In our study, rather than persist solely with taxa as sole indicators in complex, tropical environments where species identification is often problematic, we examine the potential complementary use of plant functional types (PFTs) for which there is at least some evidence for a role in ecosystem function. The relatively recent and novel use of PFTs in biodiversity assessment requires some explication within the context of more traditional species-based, biodiversity indicators.

Diaz (1998) describes functional groups or functional types (FTs) as "sets of organisms showing similar responses to environmental conditions and having similar effects on the dominant ecosystem processes" (see also Cramer 1996, Cramer et al.1999, Tilman, 2001). A more practical definition (Shugart 1996) refers to FTs as "species or groups of species that exhibit similar responses to a suite of environmental conditions." FTs are most commonly described as "guilds" or groups of individuals that exploit an existing resource in a similar way, such as raptors,

folivores, plant parasites, saprophytes, etc. (Gillison 1981, Huston 1994, Smith et al. 1996, Gillison and Carpenter 1997, Gitay et al. 1999, Duckworth et al. 2000). Functional types can help reduce complex species groups to more manageable entities and facilitate comparison of responses of individuals, for example, between geographically remote locations where environments and adaptive morphologies are simlar but where species differ. In this way, FTs achieve a practical and logistic advantage over species as more generic indicators. Nonetheless, field studies suggest measurement of biodiversity impact can benefit from including records of both species and FTs (Gillison 1981, 2002, Cowling et al. 1994, Huston 1994, Martinez 1996, Diaz et al. 1999, Duckworth et al. 2000).

At both local and global scales, there is a generally negative relation between the diversity of plant species and potential agricultural productivity (Huston 1993) and, although agricultural expansion benefits from biodiversity via integrated pest management among other things, it remains one of the greatest contributors to its loss (Miller et al. 1995). A consensus on a functional role for species diversity (richness) remains elusive; however, certain functional groups can significantly influence ecosystem processes (Folke et al. 1996, Tilman et al. 1997, Knops et al. 1999, Tilman 1999). And, although PFT richness itself may be a useful indicator of biodiversity condition, differences in PFT composition can help explain more variation in ecosystem processes, such as production and nitrogen dynamics, than the number of functional groups present (Hooper and Vitousek 1998). Plant functional types based on adaptive morphologies are known to influence soil organic carbon (SOC) distribution in the soil profile (cf. Jobbágy and Jackson 2000). An intensive, multitaxa baseline study in lowland Sumatra showed PFTs and plant species were closely correlated with SOC, soil nutrient availability, above-ground carbon, and land-use intensity (Gillison 2000, Hairiah and van Noordwijk 2000). The same study provided strong statistical support for the use of PFTs in combination with vascular plant species as indicators of certain groups of insects, especially termites, and birds along a lowland, tropical, forested land-use intensity gradient (Bignell et al. 2000, Jepson and Djarwadi 2000, Gillison 2000, Jones et al. 2000, 2002, Gillison et al. 2003).

Traditional farming practices that maintain landscape mosaics rather than monoculture cropping systems are more likely to support natural pest control through maintenance of different types of natural enemies (Abate et al. 2000). The maintenance of landscape complexity can, therefore, help sustain many useful functional aspects of environmental services (Giller et al. 1997, Vandermeer et al. 1998, van Noordwijk and Swift 1999). For this reason, traditional land-use mosaics containing woodlands, forests, and agroforests and other complex agroecosystems, are likely to be more beneficial in the long term for adaptive management and sustainable biodiversity than broadscale agricultural mono-cropping systems. The environmental impacts of traditional, rotational systems involving forest succession, such as shifting cultivation, may be much less on biodiversity and soil erosion, than those from other forest land uses (Angelsen 1995, Tomich et al. 2001). Profitable agroforestry systems are potentially sustainable, controlling erosion, enhancing biodiversity, and conserving carbon, provided nutrient offtake is balanced by nutrient returns via litter and the strategic use of fertilizers, particularly phosphorus (Sanchez 1995). The solution to maintaining biodiversity through an intermediate level of disturbance of the kind found in more complex agroforests is relatively well established, where, through the maintenance of disturbance, an equilibrium is never reached and higher biodiversity is maintained. Forest management can dictate the disturbance regime (frequency, size, and intensity) which must be fitted to the relevant attributes, or life histories, of the organisms to be managed (Attiwill 1994).

The above findings are generally consistent with what is known about coffee agroecosystems, although some field studies provide conflicting evidence for the impact of specific cropping methods on biodiversity. Most studies show biodiversity is enhanced through increasing shade treatments, although short-term profitability may be reduced (Perfecto et al.1996). In Costa Rica, Perfecto and Snelling (1995) found vegetational diversity varies proportionally with the diversity of foraging ants. This is supported by Roberts et al. (2000) who also showed that in western Panama, mid-elevational, traditional shade-coffee plantations provide additional habitat for diverse avifauna that attend army ant swarms—a trend that is reversed when coffee is grown without shade at increasing levels of intensity. On the other hand, in Guatemala, Greenberg et al. (2000) found no evidence for shade-related levels of insectivory.

In a Colombian coffee agroecosystem, Armbrecht et al. (2004) showed plant species diversity of ant nesting resources varied directly with ant species diversity, thus providing experimental evidence that, at least in this case, biodiversity begets biodiversity.

A Typology of Coffee-farming Systems

In order to erect a suitable sampling framework, the research team (comprising ecologists and economists) developed a typology of coffee-farming systems and associated tenure systems (see Methods) through a series of visits to the study region and discussions with local farmers. Related studies elsewhere in Sumatra suggest cropping systems and tenure systems evolve jointly and hence are largely determined simultaneously (Otsuka et al. 2001, Suyanto et al. 2001a,b). Thus, pioneer coffee systems are associated with insecure tenure, complex coffee systems always occur with (at least informal) tenure security, and simple coffee monocultures occur across shades of insecurity in land and tree tenure associated with varying intensities of purchased inputs and other productivity-sustaining investments (Budidarsono et al. 2000). "Pioneer" systems are established by clearing natural forest on State forest land (often gazetted as parks and conservation areas) and hence involve a high degree of tenure insecurity for the smallholders.

Because these "low intensity" systems aim to maximize coffee yields in the short run (over 5–7 years), no shade trees are planted. Absence of shade trees boosts coffee yields in years 4 and 5 but, combined with lack of fertilizer applications, coffee yields drop dramatically after the peak harvest in year 7. Hence, instead of pruning to establish a steady-state coffee system, the plots are fallowed from year 8 in the pioneer system. The pioneer coffee system also represents a shifting cultivation technique of coffee farming that most indigenous Semendonese practiced in the early stage of coffee cultivation in Sumberjaya when land was still abundant. Although it is unusual, this system still occurs in the frontier area, where it is practiced by others as well as Semendonese more or less as a "hit and run" strategy.

Under the simple monocropping system, coffee trees are fertilized and pruned at about year 8 in order to sustain coffee production and avoid reversion to the bush fallow that characterizes the pioneer system. As with pioneer coffee, simple coffee systems with insecure title are derived from conversion of State forest land, but often from watershed protection areas instead of parks and conservation areas. Simple coffee systems with insecure tenure are derived from conversion of State forest land but not necessarily from forested land. In many cases, simple coffee with insecure tenure is derived from an old abandoned coffee garden that belonged to the Semendonese. In this case, the old coffee garden was purchased by an immigrant (mostly Javanese), to establish a new coffee garden (slash and burn), or to just rejuvenate them (by pruning the main stem) to be managed as simple, permanent coffee system. Alternatively, the immigrant, a sharecropper, could be given the old abandoned land to manage. Simple coffee systems with secure tenure are located outside State forest land. Not surprisingly, the greater security of tenure over land and, hence, over trees is associated with increased investment in maintaining tree productivity through application of fertilizer and, occasionally, grafting.

METHODS

Our target area was a coffee-based production system in a relatively remote, upland tropical forested landscape with many similarities to production systems in other areas of the tropics where biodiversity is under increasing threat and where management uncertainties are high. Most studies on coffee agroecosystems focus on impacts within coffee plantations under varying levels of management and rarely consider biodiversity response within a broader land-use context, for example, along regional land-use intensity gradients. Previous studies (Gillison 2000) show that expanding the sample base to include gradient extremes of land use and the biophysical environment greatly improves the value of a baseline survey and the robustness of biodiversity indicators. Gradient-oriented transects or gradsects (Gillison and Brewer 1985, Wessels et al. 1998) also indicate considerable improvements over standard, random sampling methods in detecting biodiversity pattern. The methods used for vegetation assessment in this survey were those applied in other ASB ecoregional baseline studies (Gillison 2000) using gradsect sampling, to which the reader is referred for detail. (The Alternatives to Slash and Burn project operates as an institutional consortium hosted by the International Centre for Research in Agroforestry (ICRAF).)

We selected a series of representative locations within

Sumberjaya, a coffee-farming area within Lampung Province, Sumatra, Indonesia where approximately 115 000 ha of a total 410 000 ha have been converted to coffee plantings. The area lies within one the world's top five biodiversity "hotspots" (Myers et al. 2000). At the beginning of the 20th century, most of Sumberjaya was covered with natural forest (Benoit et al.1989). A sudden surge in population (largely immigrant Javanese) resulted in a change from 57% primary forest cover and 12% secondary forest in 1970 to 12 and 18%, respectively, in 1990. Approximately 60% of the area has been converted to mostly smallholder coffee plantings. Within the range of accessible land-use types, 24 sites (Fig.1) were located along a subjectively determined land-use intensity gradient. These were stratified according to land tenure (secure, insecure) and whether the cropping system was complex or simple. A "complex coffee system" in our study refers to the complexity of vegetation structure in coffee plots in which there are perennials and other tree species that provide financial return for farmers (from fruits and timber); a "simple coffee system" includes coffee monoculture without shade trees or with only a single shade tree species but with no financial return for farmers (no fruits and no valuable wood may be harvested). Simple coffee systems are permanent coffee monocultures, except for intercropping with upland rice and high-value vegetables in the first 2 years. Sites were further stratified according to the use or non-use of shade crops (Tables 1, 2, 3, 4). This sample design created considerable logistic problems because access to some remote village areas with poor road systems and steep terrain was very difficult. For the purposes of this paper, we use the term "land-use type" (LUT) to include both broader-scale natural forest and coffee-based, multi-strata systems for example, and the different cropping systems included under the latter.

Fig. 1. Site locations in Sumberjaya, Lampung Province, South Sumatra.

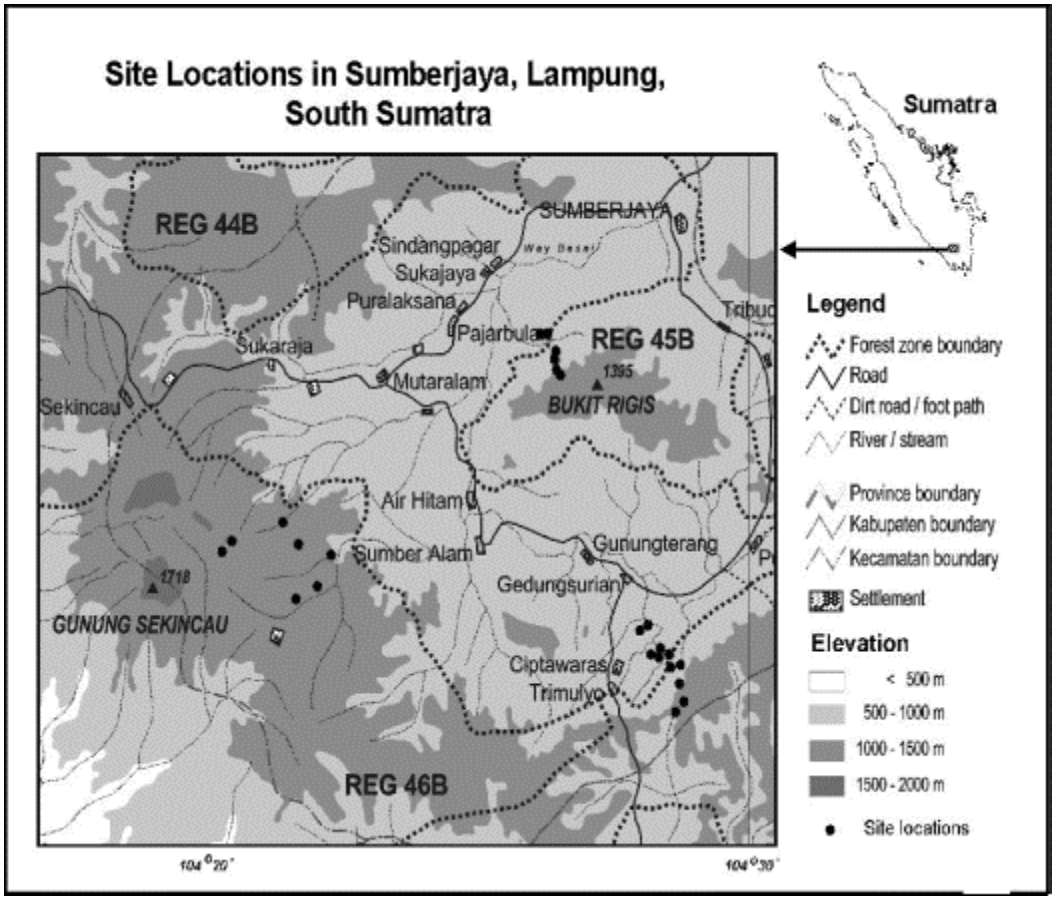


Table 1. Site physical environmental features

Site	Location	Latitude d.m.s	Longitude d.m.s	(m)	Slope %	Aspect Deg.	Terrain Unit
LAM01	Begelung Nature Reserve, Cipta Waras Village	05-08-32 S	104-28-48 E	1034	5	190	Hill crest
LAM02	Begelung Nature Reserve, Cipta Waras Village	05-08-23 S	104-28-55 E	1045	30	160	Upper slope
LAM03	Begelung Nature Reserve, Cipta Waras Village	05-07-41 S	104-28-52 E	925	40	290	Upper slope
LAM04	Cipta Waras Village (Pak Enjang)	05-07-48 S	104-28-40 E	817	10	25	Upper slope
LAM05	Cipta Waras Village (Aki Narja)	05-07-46 S	104-28-51 E	826	37	40	Upper slope
LAM06	Cipta Waras Village (Pak Nana)	05-07-37 S	104-28-40 E	821	45	190	Upper slope
LAM07	Cipta Waras Village (Pak Nanu (Kamaseh)	05-07-31 S	104-28-31 E	835	0	120	Flat
LAM08	Cipta Waras Village (Pak Dede Surachman)	05-07-36 S	104-28-28 E	832	35	280	Upper slope
LAM09	Trimulyo Village (Pak Atip)	05-07-07 S	104-28-12 E	806	0	125	Flat
LAM10	Trimulyo Village (Pak Cion)	05-07-09 S	104-28-07 E	800	40	50	Upper slope
LAM11	Cipta Waras Village (Pak Edy)	05-07-34 S	104-28-19 E	818	3	320	Flat
LAM12	Sekincau Forest, Talang Enam, Beringin Village	05-05-39 S	104-20-13 E	1464	10	170	Upper slope
LAM13	Talang Bukit, Sukaraja Village	05-05-24 S	104-21-12 E	1143	40	300	Upper slope
LAM14	Air Abang II, Sidomakmur Village (Pak Roni)	05-06-40 S	104-21-31 E	1061	0	260	Flat
LAM15	Air Abang II, Sidomakmur Village (Pak Kuyin)	05-06-28 S	104-21-55 E	1091	12	30	Upper slope
LAM16	Air Abang I, Sidomakmur Village	05-05-56 S	104-22-11 E	1050	60	240	Upper slope
LAM17	Air Kelat, Sidomakmur Village	05-05-47 S	104-21-34 E	1026	25	200	Mid slope
LAM18	Bukit Regis, Air Rengkih (Pak Nata)	05-02-46 S	104-26-28 E	901	20	320	Upper slope
LAM19	Air Rengkih, Bukit Regis (Semendo people)	05-02-46 S	104-26-29 E	930	25	340	Upper slope
LAM20	Bukit Regis Nature Preserve	05-02-51 S	104-26-32 E	980	45	300	Upper slope
LAM21	Sukajaya Village (Pak Poniman)	05-02-13 S	104-26-20 E	1010	5	60	Flat
LAM22	Sukajaya Village (Pak Poniman)	05-02-13 S	104-26-15 E	898	15	240	Mid slope
LAM23	Sukaraja Village, Air Ringkih (Pak Pur)	05-02-38 S	104-26-28 E	886	20	250	Mid slope
LAM24	Sukaraja Village, Air Ringkih (ref:Pak Katimin)	05-02-29 S	104-26-30 E	878	40	250	Mid slope

Table 2. Site history and vegetation structural data

Site	Symbols	Vegetation	MHt	CC	CW	CNW	Wdy	Bry	Litt.	BaA	MFI	Fi CV%
LAM01	1 ◆	1-year fallow	1.0	60	0	60	0	0	3	0.01	0.00	0.00
LAM02	□	Natural forest, partially disturbed	30.0	80	30	50	5	7	6	30.67	17.00	174.24
LAM03	20C○	20-year abandoned coffee mixed with *Calliandra* plantation	16.0	60	60	0	1	1	5	17.33	89.75	26.59
LAM04	8C▲	8-year coffee mixed with agroforest plantation	8.0	90	80	10	8	1	3	5.33	75.00	49.09
LAM05	30CΔ	30-year coffee mixed with agroforestry & bamboo	10.0	85	65	20	8	3	5	8.00	69.00	67.27
LAM06	1C●	1-year coffee plantation with mixed crops	0.5	10	10	0	3	0	0	0.10	0.00	0.00
LAM07	30CΔ	30-year coffee mixed with agroforestry plantation	8.0	60	60	0	6	3	3	12.00	44.75	92.31
LAM08	2C●	2-year coffee plantation mixed with fruit trees and crops	1.0	10	10	0	6	1	0	0.10	0.00	0.00
LAM09	8C▲	8-year coffee plantation	3.0	85	85	0	7	3	5	4.00	71.00	59.74
LAM10	8C▲	8-year coffee plantation	3.5	70	70	0	7	1	4	4.00	89.75	34.22
LAM11	8C▲	8-year coffee mixed with agroforestry plantation	8.0	75	75	0	7	2	7	6.33	59.75	68.01
LAM12	□	Natural forest, partially disturbed	25.0	80	60	20	7	8	7	19.33	10.75	157.75
LAM13	20B□	20-year *belukar* (secondary growth)	6.0	90	30	60	8	1	10	6.67	20.25	117.32
LAM14	30CΔ	30-year coffee plantation with shade (*Erythrina subumbrans*)	2.5	95	95	0	8	2	6	9.33	26.50	149.71
LAM15	2C●	2-year coffee plantation with mixed crops	1.0	80	20	60	6	0	1	0.10	0.00	0.00
LAM16	8C▲	8-year coffee plantation	1.6	80	60	20	7	1	3	5.33	72.25	56.60
LAM17	20C○	20-year abandoned coffee	2.5	60	60	0	6	1	10	2.67	91.50	12.67
LAM18	30CΔ	30-year coffee plantation with shade	8.0	60	60	0	6	2	5	12.00	74.50	48.88
LAM19	1◆	1-year fallow	0.6	95	0	95	3	0	10	0.10	4.50	309.90
LAM20	□	Natural forest, partially disturbed	25.0	85	75	10	7	4	3	13.33	9.00	147.10
LAM21	20C○	20-year coffee plantation mixed with agroforestry plantation	5.0	85	85	0	7	2	4	6.67	78.00	34.07
LAM22	20C○	20-year coffee plantation with shade	3.0	70	50	20	7	1	2	7.33	73.75	59.30
LAM23	1C●	1-year coffee plantation mixed	0.6	50	50	0	6	0	0	0.10	0.00	0.00

		with crops										
LAM24	8C▲	8-year coffee plantation	2.5	85	75	10	7	1	3	8.67	76.50	51.56

MHt: Mean canopy height; CC: Crown cover%; CW: Crown cover% woody plants; CNW:Crown cover% non woody plants; Wdy: Woody plants <1.5m tall, cover abundance; Bry: Bryophyte cover abundance; Litt.: Surface litter depth cm; BaA: Mean basal area m^2 ha^{-1}; MFI: Mean furcation index; FICV%: Coefficient of variation % of FI.

Geocordinates for each site were obtained using a Garmin GPS with an estimated accuracy of ± 80m. In each LUT and cropping system, a 40 x 5 m plot (strip transect) was laid out along a contour and according to site biophysical data (Table 5). A field botanist recorded all vascular plant species, for which voucher specimens were collected and later identified at the Herbarium Bogoriense. These were cross-referenced with PFTs (or functional *modi*), recorded using the classification method of Gillison and Carpenter (1997). In the field, these biophysical data were collated and stored in a laptop computer using the public domain CIFOR "VegClass" ® (beta v. 1.5) Windows®-based software package (Gillison 2002). VegClass uses a standard protocol to collate, store, and tabulate proforma data and can be used to generate graphic output of meta-data and to export summary data to a wide range of industry-standard spreadsheet and relational database programs. Estimates of above-ground tree dry weight were obtained from two sources (Brown 1997, Ketterings et al. 2001) and used to quantify above-ground carbon (van Noordwijk et al. 1997).

Soil samples were collected (composited from eight sample points per 200 m^2 sampling area) for the 0–5, 5–15, and 15–30 cm depth zone below the litter layer. The samples were passed through a 2-mm sieve and air dried for texture analysis (sand, silt, clay; pipette method), pH (in a 1: 2.5 soil: solution extract with water or 1 N KCl), P_{BrayI}, C_{org} (Walkley and Black), N_{tot} (Kjeldahl), exchangeable K, Ca, Mg, Na, (exchanged with a 1 N NH4-Acetate solution of pH7) and exchangeable Al and H (exchanged with a 1 N KCl solution). Effective cation exchange capacity was obtained by summation of these cations. These measurements were undertaken in the laboratory of the Centre for Soil and Agroclimate Research (CSAR) in Bogor, Indonesia. All mineral contents were expressed per unit soil dried at 105°C. On the basis of texture and pH, the reference organic C (C_{ref}) content was calculated using a regression equation derived from a large data set for Sumatra (van Noordwijk et al. 1997): C_{ref} = EXP(1.333 + 0.00994 * clay% + 0.00699 * silt% - 0.156 * pH(KCl)). Because plant performance along land-use intensity gradients appears to be more closely associated with the physico-chemical nature of the upper rather than lower soil horizons, only data from the top 0–5cm layer are used in this analysis.

The high biophysical complexity inherent in the plot samples, together with difficulties in locating adequate plot replicates, prohibited standard sampling and statistical treatments as a means of detecting meaningful pattern between biodiversity and cropping methods. Instead, we applied a multivariate exploratory data analysis package (PATN©, Belbin 1992) to all plant-based data using a Gower similarity measure (Gower 1967) with an unweighted pair-group averaging fusion strategy to produce classifications and multi-dimensional scaling (MDS) ordinations. Multi-dimensional scaling was also used to extract the single best eigenvector scores for all plant-based variables across all plots. These eigenvector values were then incorporated as an additional predictive variable in subsequent standard regression analyses. Linear (Pearson) and polynomial regressions were used to seek out the most highly correlated variables within the entire data set using the MINITAB© ver.13.2 statistical package. Although diversity indices are traditionally derived from species abundance data, for logistic reasons they are rarely used in species-rich, tropical forests. Instead, we used a more logistically acceptable estimate of the better known indices (Shannon-Wiener, Simpson's, and Fisher's alpha) based on numbers of species per PFT rather than the number of individuals per species (Gillison and Carpenter (unpubl.), Gillison 2000). We also applied a measure of plant functional complexity (PFC) which is the total minimum spanning tree distance in a computed matrix of functional "distance" between all PFTs within a site (Gillison 2000).

Table 3. Typology of coffee farming systems, associated tenure systems, and their transitional sequences

Year	Pioneer-insecure title low intensity	Simple-insecure title medium intensity	Simple-secure title medium to high intensity	Complex-secure title low to medium intensity
0	Forest	Forest	Forest	Forest
1	Vegetables + paddy + coffee	Vegetables + paddy + coffee	Vegetables + paddy + coffee	Vegetables + paddy + coffee
2	Vegetables + coffee	Vegetables+ coffee	Vegetables+ coffee	Vegetables + coffee + shade
3	Coffee (belajar)	Coffee (belajar)	Coffee (belajar)	Coffee (belajar) + shade
4	Coffee (ngagung pangkal)	Coffee (ngagung pangkal)	Coffee (ngagung pangkal)	Coffee (ngagung pangkal) + shade
5	Coffee (ngagung besar)	Coffee (ngagung besar)	Coffee (ngagung besar)	Coffee (ngagung besar) + shade
6	Coffee (ngagung anak)	Coffee (ngagung anak)	Coffee (ngagung anak)	Coffee (ngagung anak) + shade
7	Coffee (ngagung anak)	Coffee (ngagung anak)	Coffee (ngagung anak)	Coffee (ngagung anak) + shade
8	Semak/belukar fallow	Pruned and fertilized coffee	Pruned and fertilized coffee (and some cases grafted)	Pruned and fertilized coffee (and some cases grafted)
9	Fallow	Pruned and fertilized coffee	Pruned and fertilized coffee (and some cases grafted)	Pruned and fertilized coffee (and some cases grafted)
10	Fallow	Pruned and fertilized coffee	Pruned and fertilized coffee (and some cases grafted)	Pruned and fertilized coffee (and some cases grafted)
11	Fallow	Pruned and fertilized coffee	Pruned and fertilized coffee (and some cases grafted)	Pruned and fertilized coffee (and some cases grafted)
24	Semak/Belukar	Coffee	Coffee	Complex coffee
25	Belukar	Coffee	Coffee	Complex coffee

Table 4. Biodiversity sample design based on coffee land-use sequence and tenure classes

	Year 0	Fallow - 1 year	Year 1	Year 2	Year 8	Year 20	Year 30
Pioneer-insecure title							
Low intensity	x	x	x	x	x	x	x
Simple-insecure title							
Low intensity	Forest	LAM19	x	Crops +	Coffee trees	Abandoned coffee	Coffee +

	LAM 02			coffee LAM15	LAM16	LAM17	*Erythrina subrunbrams* shade LAM14 LAM18
Medium intensity	Forest LAM 02	LAM01	x	x	x	Coffee + mix w/*Caliandra* plant. LAM03	x
Simple-secure title							
Low intensity	Forest LAM 12	x	x	x	Pruned coffee trees LAM24	x	x
Medium intensity	Forest LAM 12	x	Crops + coffee LAM06	Fruit + crops + coffee LAM08	Pruned and fertilized coffee LAM09; LAM10	Coffee + shade LAM22	x
High intensity	Forest LAM 12	x	Crops + coffee LAM23	x	x	x	x
Complex-secure title							
Medium intensity	Forest LAM 20	x	x	x	Pruned and fertilized coffee + agroforest shade LAM04; LAM11	x	Complex coffee (mix w/ agroforest) LAM05; LAM07
High intensity	Forest LAM 20	x	x	x	x	Coffee + mixed w/ agroforest plant. LAM21	x
Complex-insecure title							
Low intensity	x	x	x	x	x	Belukar LAM13	x

Table 5. List of data variables recorded for each 40x5m plot (VegClass)

Site feature	Descriptor	Data type
Location reference	Location	Alpha-numeric
	Date (dd-mm-year)	Alpha-numeric
	Plot number (unique)	Alpha-numeric
	Country	Text
Observer/s	Observer/s by name	Text
Physical	Latitude deg.min.sec. (GPS)	Alpha-numeric
	Longitude deg.min.sec. (GPS)	Alpha-numeric

	Elevation (m.a.s.l.) (aneroid and GPS)	Numeric
	Aspect (compass deg.) (perpendicular to plot)	Numeric
	Slope percent (perpendicular to plot)	Numeric
	Soil depth (cm) (sample taken 0–10, 10–20cm)	Numeric
	Soil type (US Soil taxonomy)	Text
	Parent rock type	Text
	Litter depth (cm)	Numeric
	Terrain position	Text
Site history	General description and land-use / landscape context	Text
Vegetation structure	Vegetation type	Text
	Mean canopy height (m)	Numeric
	Crown cover percent (total)	Numeric
	Cover-abundance (Domin Scale)—bryophytes	Numeric
	Cover-abundance (DS) woody plants <1.5m tall	Numeric
	Basal area (mean of 3) (m^2ha^{-1});	Numeric
	Furcation index (mean and cv % of 20)	Numeric
	Profile sketch of 40 x 5 m plot (scannable)	Digital
Plant taxa (vascular)	Family	Text
	Genus	Text
	Species	Text
	Botanical authority	Text
Plant Functional Type	Plant functional elements combined according to published rule set	Text
Photograph	Hard copy and digital image	JPEG

Table 6. Summary data for plant species, PFTs, species/PFT richness ratios, functional diversity indices*, and V-index

No.	Site	Symbols	Total PFTs	Total Species	Species/ PFTs	F. alpha PFTs	Simp. PFT	S/W PFT	PFC	V-Index
1	LAM01	1◆	18	27	1.50	23.60	0.0809	2.71	110	3.50
2	LAM02	□	70	110	1.57	81.33	0.0309	3.95	799	10.00
3	LAM03	20C○	19	24	1.26	42.19	0.0729	2.81	149	1.00
4	LAM04	8C▲	14	15	1.07	100.31	0.0756	2.62	147	1.24
5	LAM05	Δ	24	29	1.21	65.35	0.0606	3.04	250	2.17
6	LAM06	1C●	20	29	1.45	28.48	0.0654	2.87	156	3.17
7	LAM07	30CΔ	19	27	1.42	28.53	0.0672	2.83	183	3.43
8	LAM08	2C○	28	44	1.57	33.14	0.0599	3.10	229	4.25
9	LAM09	8C▲	9	11	1.22	23.15	0.1240	2.15	74	1.65
10	LAM10	8C▲	10	12	1.20	28.23	0.1111	2.25	114	1.62

11	LAM11	8C▲	21	30	1.43	31.09	0.0733	2.86	203	3.34
12	LAM12	□	69	97	1.41	103.75	0.0292	3.99	764	8.34
13	LAM13	20B□	55	93	1.69	55.51	0.0299	3.78	573	6.54
14	LAM14	30CΔ	23	32	1.39	36.64	0.0742	2.91	229	3.09
15	LAM15	2C●	23	34	1.48	31.22	0.0606	2.98	155	3.72
16	LAM16	8C▲	17	26	1.53	21.33	0.0828	2.68	106	3.62
17	LAM17	20C○	19	24	1.26	36.13	0.0624	2.87	112	2.41
18	LAM18	30C○	17	28	1.65	18.34	0.0867	2.65	133	4.57
19	LAM19	1◆	32	39	1.22	83.46	0.0388	3.38	329	2.12
20	LAM20	□	72	115	1.60	81.04	0.0287	3.97	808	8.83
21	LAM21	20C○	25	31	1.24	60.12	0.0468	3.15	232	2.57
22	LAM22	20C○	15	23	1.53	18.71	0.0926	2.55	120	3.68
23	LAM23	1C●	24	34	1.42	36.34	0.0657	2.99	213	3.04
24	LAM24	8C▲	14	18	1.29	28.97	0.0864	2.55	84	2.34

* Diversity indices for PFTs: F. alpha = Fisher's alpha; Simp. = Simpson's; S/W = Shannon-Wiener H'; PFC = Plant Functional Complexity measure (Gillison and Carpenter, unpubl. 1999; Gillison 2000)

Certain key vegetation features (mean height, basal area, species and PFT richness, and species:PFT ratio) can vary predictably with specific measures of biodiversity and LUT (Gillison 2000). In the present study, these features were compared across all plots together with a relative vegetation index ("V"-index, Gillison 2002) that integrates these values for each plot measured as the single best eigenvector score from an MDS. These scores are standardized and used to rank LUTs—in this case, the 24 plots of the present study. The V index is a potentially useful measure of biodiversity relative to LUT and has been shown to be closely correlated with the presence of certain animal groups and their habitats in lowland Sumatra (Gillison 2000, 2002).

RESULTS

Site physical features, site history, and vegetation structural data are summarized in Tables 1 and 2. Typology of coffee-farming systems and associated teunure systems and their transitional sequences are cross-referenced in Table 3 and the sample design based on LUT and tenure class is outlined in Table 4. Richness values for vascular plant species and PFTs and diversity indices for PFTs are listed in Table 6 with richness at plant Family, Genus and Species summarized in Table 7. A complete listing of all plant taxa and PFTs and species coding per quadrat for each site is available from the contact author. The data are generally consistent with those from other ASB ecoregional sites, showing typically high richness values for both species and PFTs in the older, forested plots. Soil analytical data are summarized in Tables 8a and 8b.

Exploratory data analysis shows that species-weighted PFTs (number of species per PFT) alone account for a clear separation of closed forest types (LAM2, 12, 13, 20) but include an 8-year-old site (4) in an agroforestry plantation (Figs 2, 3, 4, 5). Apart from this, the PFTs also clearly identify 30-year-old coffee sites (LAM5, 7, 14, 18) as a tight cluster in the dendrogram (Fig. 2) but in an otherwise loose grouping in the classification of 8-year-old plots with a diverse land-use history. The MDS (Fig. 3) on the other hand reveals close links between the 8-year sites based on PFTs. When species alone are used, apart from older growth sites (LAM2, 12, 13, 20) the pattern tends to be confused, with little if any interpretative value (Figs. 4, 5).

Cluster analysis of mean canopy height, basal area, total species, total PFTs, and species:PFT ratios produced readily observable patterns in transitional

vegetational sequences. Tight clusters in both classification and ordination (Figs. 6, 7) can be seen in early 1- and 2-year fallows (LAM1, 6, 8, 15, 23), mid-stage, 8-year plots (LAM4, 9, 10, 16, 22), and older growth (LAM2, 12, 13, 20). The group with the "noisiest" configuration included the 30-year-old coffee plantations with varying mixtures of species and shade treatments. A simple plot of species against PFTs shows a highly significant linear correlation that tends to correspond with LUT with highest plant-based biodiversity toward the forested plots and plantations with shade treatments (Fig.8).

When ranked against LUT, the V-index values reveal a clear response to shade treatment over otherwise mixed assemblages of different age groups (Fig. 9). The shaded groups include 8-, 20-, and 30-year-old plots. The least biodiverse plots are not the 1- and 2-year fallows but the unshaded, pruned, and fertilized coffee gardens under simple, secure title.

Table 7. Summary of plant taxa recorded for Lampung sites

Site No.	Family	Genus	Species
LAM01	12	25	27
LAM02	50	89	107
LAM03	14	24	24
LAM04	12	15	15
LAM05	18	28	29
LAM06	5	11	11
LAM07	16	25	27
LAM08	23	40	44
LAM09	9	11	11
LAM10	9	12	12
LAM11	18	28	30
LAM12	48	69	93
LAM13	47	78	93
LAM14	20	31	32
LAM15	14	29	33
LAM16	10	25	26
LAM17	11	23	24
LAM18	16	28	28
LAM19	21	37	39
LAM20	55	97	115
LAM21	17	28	31
LAM22	11	22	23
LAM23	17	32	34
LAM24	4	10	11
Total	477	817	919
Unique	108	291	460

The soil analytical data (Table 7a,b) show that all sites have very acid soils, with the highest pH(KCl) of 5.0 recorded for the 0–5 cm layer of LAM03 (21-year-old coffee with *Calliandra thyrsifolia*) and the lowest value of 2.5 for LAM12, the forest site in Sekincau, with initial stages of peat soil development (only in the surface 5 cm). Sand content is generally low, and the textures range from loam to clay soils. Aluminum saturation is closely linked to the pH(KCl) values, as expected (Fig.10), with the peaty surface layer of LAM12 as the main outlier. Quite serious aluminum toxicity symptoms may be expected for Al saturation values above 0.2 (0.6), or a pH(KCl) of 4.2 (3.8). Although soil pH(KCl) does not vary with depth within the 0–30 cm layer for the forest soils, the Al saturation increases from 0.35 in the 0–5 cm layer to 0.54 and 0.62 in the 5–15 and 15–30 cm depth layers, respectively. This difference in Al saturation may be related to the higher soil C content in the top 5 cm. All coffee plots, whether monoculture or mixed systems, were derived from forest after slash and burn and this may still be reflected in a slight shift of the relation between pH and Al saturation (which is similar to that for the top layer in the forest sites).

Table 8. (a) Soil texture, pH, organic C, N, and available P for the 24 sample sites in layers 0–5, 5–15, and 5–30 cm depth; (b) soil exchangeable cations and aluminium saturation

Site Number	Years after forest conversion	Depth (cm)	Sand (%)	Silt (%)	Clay (%)	pH H_2O	KCl	Organic C (%)	matter C/Cref	N (%)	C/N	Bray 1 P_2O_5 ppm
Lam01	1	0–5	13	26	61	5.2	4.5	8.85	2.14	0.42	21	4.0
	1	5–15	14	26	60	4.9	4.3	7.07	1.67	0.40	18	3.5
	1	15–30	12	14	74	4.6	4.3	2.87	0.65	0.22	13	5.8
Lam02	0	0–5	12	28	60	4.5	4.0	10.31	2.30	0.63	16	10.7
	0	5–15	12	25	63	4.5	4.2	5.53	1.27	0.54	10	5.8
	0	15–30	11	16	73	4.4	4.3	3.35	0.74	0.25	13	4.6
Lam03	21	0–5	9	22	69	5.4	4.9	4.43	1.09	0.33	13	6.8
	21	5–15	7	22	71	5.6	5.0	2.70	0.66	0.21	13	2.5
	21	15–30	5	13	82	5.3	4.7	1.33	0.30	0.20	7	1.1
Lam04	10+	0–5	20	20	60	4.2	3.8	2.88	0.66	0.25	12	125.3
	10+	5–15	17	20	63	4.2	3.8	2.27	0.50	0.21	11	67.0
	10+	15–30	15	14	71	4.3	3.7	1.36	0.29	0.20	7	11.0
Lam05	30+	0–5	14	25	61	5.3	4.6	3.04	0.75	0.34	9	7.1
	30+	5–15	14	33	53	5.3	4.7	1.82	0.47	0.15	12	2.5
	30+	15–30	11	18	71	5.3	4.6	0.99	0.23	0.13	8	1.1
Lam06	1	0–5	24	19	57	4.6	4.0	2.54	0.62	0.37	7	6.9
	1	5–15	16	27	57	4.5	3.9	1.83	0.42	0.16	11	5.1
	1	15–30	13	20	67	4.4	3.8	0.98	0.21	0.13	8	4.9
Lam07	20+	0–5	4	56	40	4.8	4.1	3.94	0.89	0.39	10	13.1
	20+	5–15	4	30	66	4.6	4.0	4.08	0.84	0.28	15	4.5
	20+	15–30	1	20	79	4.4	3.9	1.16	0.22	0.14	8	1.1
Lam08	2	0–5	9	36	55	5.3	4.6	2.63	0.64	0.30	9	9.1
	2	5–15	11	26	63	5.0	4.2	1.58	0.36	0.15	11	2.9
	2	15–30	11	22	67	4.8	3.9	0.87	0.19	0.11	8	1.6
Lam09	20	0–5	2	47	51	4.8	4.2	3.47	0.76	0.25	14	30.7

	20	5–15	2	44	54	4.7	4.0	2.44	0.51	0.24	10	3.9
	20	15–30	3	20	77	4.5	3.9	1.23	0.24	0.15	8	2.0
Lam10	8	0–5	7	30	63	4.7	3.9	2.55	0.54	0.22	12	75.4
	8	5–15	3	26	71	4.5	3.8	2.04	0.40	0.20	10	16.0
	8	15–30	2	18	80	4.3	3.7	1.08	0.20	0.14	8	10.1
Lam11	8	0–5	1	42	57	5.1	4.3	2.04	0.44	0.21	10	11.3
	8	5–15	2	37	61	4.9	4.2	1.48	0.32	0.20	7	2.8
	8	15–30	1	21	78	4.5	3.9	0.99	0.19	0.12	8	2.0
Lam12	0	0–5	0 (peat)	0 (peat)	0 (peat)	3.1	2.5	30.75	11.90	0.54	57	182.2
	0	5–15	1	68	31	3.6	3.3	11.13	2.26	0.33	34	37.8
	0	15–30	4	42	54	3.9	3.8	4.81	1.00	0.28	17	4.9
Lam13	22	0–5	7	49	44	4.1	3.6	6.32	1.34	0.43	15	3.1
	22	5–15	8	30	62	3.9	3.6	2.03	0.41	0.15	14	10.4
	22	15–30	11	36	53	4.1	3.6	3.31	0.71	0.24	14	0.3
Lam14	30	0–5	8	45	47	4.5	4.0	5.26	1.18	0.42	13	7.6
	30	5–15	17	33	50	4.4	4.0	3.82	0.90	0.32	12	1.1
Lam15	2	0–5	5	43	52	4.8	4.1	4.22	0.94	0.35	12	4.4
	2	5–15	4	34	62	4.4	3.9	2.29	0.47	0.22	10	0.3
	2	15–30	11	28	61	4.2	3.8	1.27	0.27	0.14	9	3.0
Lam16	8	0–5	16	26	58	4.0	3.7	3.42	0.75	0.23	15	8.1
	8	5–15	13	26	61	4.0	3.7	2.74	0.59	0.19	14	23.0
	8	15–30	13	22	65	4.0	3.7	1.37	0.29	0.10	14	13.1
Lam17	20	0–5	12	39	49	4.9	4.2	5.33	1.27	0.43	12	9.8
	20	5–15	14	33	53	4.7	4.1	3.93	0.92	0.31	13	15.6
	20	15–30	15	30	55	4.6	3.9	2.94	0.67	0.26	11	12.8
Lam18	30+	0–5	26	51	23	5.4	4.9	3.83	1.21	0.36	11	5.0
	30+	5–15	24	52	24	5.3	4.6	1.60	0.47	0.18	9	1.1
	30+	15–30	19	31	50	4.8	4.2	0.68	0.17	0.09	8	0.3
Lam19	1	0–5	27	36	37	5.1	4.4	3.21	0.91	0.24	13	2.7
	1	5–15	23	32	45	4.6	3.9	2.01	0.50	0.18	11	1.9
	1	15–30	22	30	48	4.6	3.8	1.19	0.29	0.11	11	0.8
Lam20	0	0–5	18	54	28	4.5	3.9	3.55	0.89	0.29	12	4.4
	0	5–15	24	41	35	4.4	3.8	1.33	0.34	0.15	9	1.9
	0	15–30	20	30	50	4.3	3.7	0.81	0.19	0.08	10	0.8
Lam21	20+	0–5	7	29	64	4.5	3.9	3.00	0.63	0.25	12	14.6
	20+	5–15	10	26	64	4.4	3.9	2.17	0.46	0.17	13	11.5
	20+	15–30	10	26	64	4.4	3.9	2.13	0.45	0.18	12	5.9
Lam22	20	0–5	3	29	68	4.5	3.9	2.14	0.43	0.19	11	12.9
	20	5–15	10	25	65	4.6	3.9	1.66	0.35	0.15	11	2.2
	20	15–30	11	22	67	4.5	3.9	1.31	0.28	0.13	10	0.3
Lam23	1	0–5	13	39	48	4.8	4.1	3.27	0.77	0.26	13	24.7
	1	5–15	14	33	53	4.4	3.9	1.96	0.44	0.17	12	5.8
	1	15–30	9	26	65	4.2	3.7	1.03	0.21	0.10	10	3.6
Lam24	8	0–5	13	28	59	4.3	3.8	3.77	0.82	0.29	13	9.9

8	5–15	8	27	65	4.3	3.8	2.25	0.46	0.19	12	18.5
8	15–30	6	23	71	4.3	3.7	1.38	0.27	0.13	11	5.0

		Exchangeable cations (NH_4-Acetate 1N, pH7) (cmol+kg^{-1})				KCl 1N (cmol+ kg^{-1})				
Site number	Depth (cm)	Ca	Mg	K	Na	Al^{3+}	H^+	ECEC	Al saturation	ECEC/ clay
Lam01	0–5	3.29	0.94	0.40	0.07	0.67	0.18	5.55	0.12	0.09
	5–15	1.14	0.41	0.32	0.12	1.37	0.33	3.69	0.37	0.06
	15–30	1.03	0.36	0.11	0.12	1.26	0.21	3.09	0.41	0.04
Lam02	0–5	1.03	0.70	0.18	0.09	3.57	0.65	6.22	0.57	0.10
	5–15	0.46	0.39	0.11	0.08	2.05	0.56	3.65	0.56	0.06
	15–30	0.45	0.32	0.08	0.13	1.41	0.51	2.89	0.49	0.04
Lam03	0–5	11.51	2.28	0.32	0.06	0.13	0.09	14.39	0.01	0.21
	5–15	8.86	1.50	0.16	0.06	0.19	0.11	10.88	0.02	0.15
	15–30	4.95	1.19	0.08	0.06	0.13	0.09	6.50	0.02	0.08
Lam04	0–5	1.98	0.65	0.20	0.00	2.87	0.66	6.36	0.45	0.11
	5–15	1.45	0.42	0.12	0.00	3.40	0.80	6.19	0.55	0.10
	15–30	0.82	0.43	0.18	0.05	4.35	0.76	6.59	0.66	0.09
Lam05	0–5	6.68	1.41	0.40	0.06	0.21	0.09	8.85	0.02	0.15
	5–15	5.88	1.54	0.24	0.05	0.13	0.09	7.93	0.02	0.15
	15–30	4.70	1.46	0.16	0.06	0.11	0.07	6.55	0.02	0.09
Lam06	0–5	3.42	1.28	0.39	0.08	1.26	0.30	6.74	0.19	0.12
	5–15	2.40	1.09	0.26	0.02	2.34	0.53	6.64	0.35	0.12
	15–30	1.18	0.74	0.18	0.00	3.93	0.79	6.82	0.58	0.10
Lam07	0–5	4.66	1.48	0.33	0.02	1.18	0.23	7.90	0.15	0.20
	5–15	2.79	0.92	0.15	0.02	2.01	0.55	6.44	0.31	0.10
	15–30	1.84	0.75	0.15	0.10	2.63	0.60	6.06	0.43	0.08
Lam08	0–5	8.37	1.89	0.55	0.02	0.19	0.06	11.08	0.02	0.20
	5–15	5.79	1.37	0.28	0.00	0.40	0.11	7.95	0.05	0.13
	15–30	4.60	1.25	0.24	0.06	1.27	0.30	7.72	0.16	0.12
Lam09	0–5	3.81	1.36	0.43	0.05	1.20	0.20	7.05	0.17	0.14
	5–15	3.04	1.13	0.29	0.07	1.37	0.50	6.40	0.21	0.12
	15–30	1.57	0.87	0.17	0.08	2.87	0.60	6.17	0.47	0.08
Lam10	0–5	3.09	1.96	0.42	0.02	1.26	0.33	7.07	0.18	0.11
	5–15	1.82	1.26	0.16	0.03	2.69	0.61	6.58	0.41	0.09
	15–30	1.08	0.92	0.08	0.00	3.79	0.84	6.72	0.56	0.08
Lam11	0–5	4.23	1.20	1.32	0.00	0.39	0.13	7.27	0.05	0.13
	5–15	4.94	1.25	0.41	0.06	0.37	0.11	7.15	0.05	0.12
	15–30	3.72	1.19	0.23	0.13	1.20	0.23	6.70	0.18	0.09

Lam12	0–5	1.10	2.23	0.69	0.29	7.40	5.94	17.66	0.42	*
	5–15	0.33	0.37	0.15	0.16	9.58	2.56	13.15	0.73	0.42
	15–30	0.21	0.21	0.04	0.02	7.07	0.98	8.54	0.83	0.16
Lam13	0–5	2.64	0.74	0.34	0.06	5.06	0.75	9.59	0.53	0.22
	5–15	0.70	0.16	0.15	0.02	9.01	1.15	11.19	0.81	0.18
	15–30	1.23	0.24	0.17	0.02	6.60	0.77	9.03	0.73	0.17
Lam14	0–5	3.28	0.81	0.41	0.06	1.48	0.52	6.55	0.23	0.14
	5–15	2.05	0.39	0.17	0.08	2.54	0.52	5.75	0.44	0.12
	15–30	1.36	0.18	0.09	0.05	3.63	0.66	5.97	0.61	0.10
Lam15	0–5	5.58	1.14	0.34	0.06	0.96	0.17	8.25	0.12	0.16
	5–15	2.65	0.67	0.23	0.02	2.45	0.56	6.58	0.37	0.11
	15–30	1.17	0.42	0.19	0.00	3.74	0.77	6.29	0.59	0.10
Lam16	0–5	0.37	0.12	0.13	0.03	6.37	0.85	7.87	0.81	0.14
	5–15	0.37	0.05	0.08	0.00	5.80	0.78	7.08	0.82	0.12
	15–30	0.27	0.03	0.06	0.00	6.32	0.71	7.39	0.86	0.11
Lam17	0–5	7.71	1.78	1.17	0.05	0.59	0.13	11.43	0.05	0.23
	5–15	5.89	1.19	0.51	0.03	1.01	0.22	8.84	0.11	0.17
	15–30	4.53	1.06	0.32	0.06	1.98	0.53	8.49	0.23	0.15
Lam18	0–5	8.24	1.80	0.61	0.05	0.04	0.02	10.76	0.00	0.47
	5–15	4.50	1.00	0.34	0.02	0.00	0.00	5.86	0.00	0.24
	15–30	3.33	0.83	0.21	0.02	0.39	0.11	4.89	0.08	0.10
Lam19	0–5	6.79	2.04	0.61	0.08	0.06	0.02	9.60	0.01	0.26
	5–15	4.68	1.33	0.32	0.02	1.25	0.30	7.90	0.16	0.18
	15–30	3.71	1.05	0.17	0.00	3.03	0.60	8.56	0.35	0.18
Lam20	0–5	2.11	1.81	0.34	0.05	1.22	0.32	5.85	0.21	0.21
	5–15	0.74	1.00	0.17	0.02	2.65	0.55	5.14	0.52	0.15
	15–30	0.37	0.92	0.13	0.02	4.66	0.78	6.87	0.68	0.14
Lam21	0–5	2.21	1.00	0.45	0.03	1.69	0.48	5.86	0.29	0.09
	5–15	1.35	0.49	0.17	0.05	2.66	0.61	5.33	0.50	0.08
	15–30	1.07	0.46	0.15	0.02	3.07	0.61	5.38	0.57	0.08
Lam22	0–5	2.15	0.74	0.32	0.05	1.52	0.47	5.25	0.29	0.08
	5–15	2.00	0.53	0.17	0.02	1.90	0.52	5.14	0.37	0.08
	15–30	1.83	0.40	0.09	0.05	1.90	0.56	4.83	0.39	0.07
Lam23	0–5	4.68	1.09	0.38	0.06	0.77	0.15	7.13	0.11	0.15
	5–15	2.67	0.73	0.17	0.00	1.88	0.51	5.96	0.32	0.11
	15–30	0.74	0.28	0.11	0.25	4.00	0.69	6.07	0.66	0.09
Lam24	0–5	1.59	0.78	0.21	0.05	2.70	0.60	5.93	0.46	0.10
	5–15	0.85	0.47	0.15	0.02	3.37	0.69	5.54	0.61	0.09
	15–30	0.53	0.31	0.08	0.02	4.15	0.77	5.86	0.71	0.08

Fig. 2. Classification of species-weighted plant functional types (PFTs) for all sites (ref: Tables 1 and 2 for explanation of symbols).

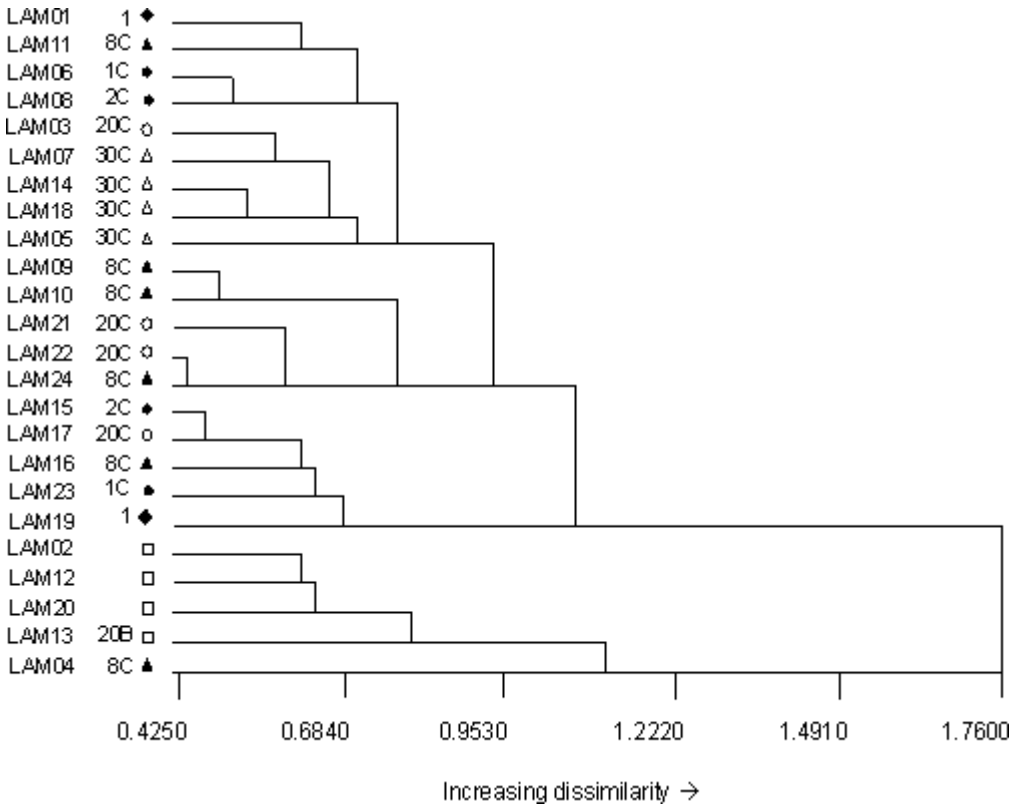


Fig. 3. Multi-dimensional scaling (MDS) of species-weighted plant functional types (PFTs) for all sites (ref: Tables 1 and 2 for explanation of symbols).

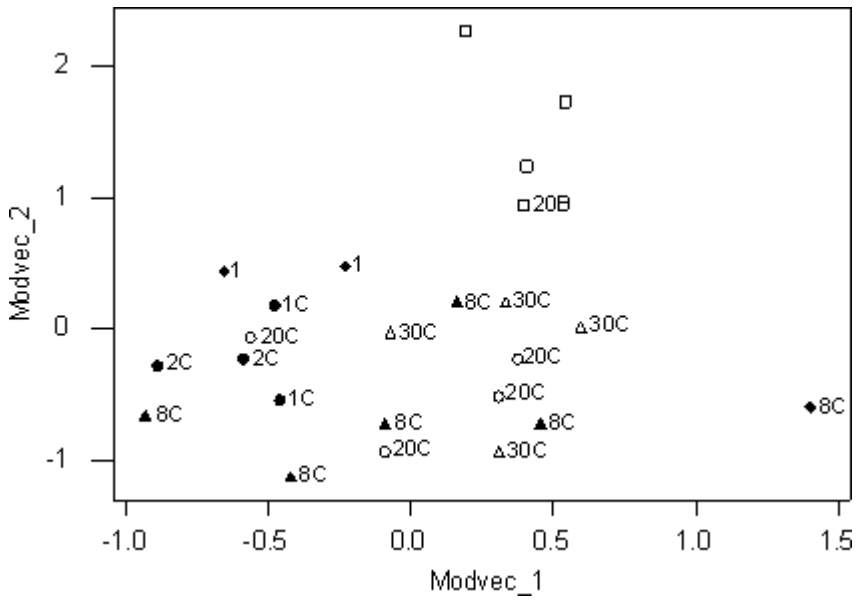


Fig. 4. Classification of sites according to presence or absence of all vascular plant species.

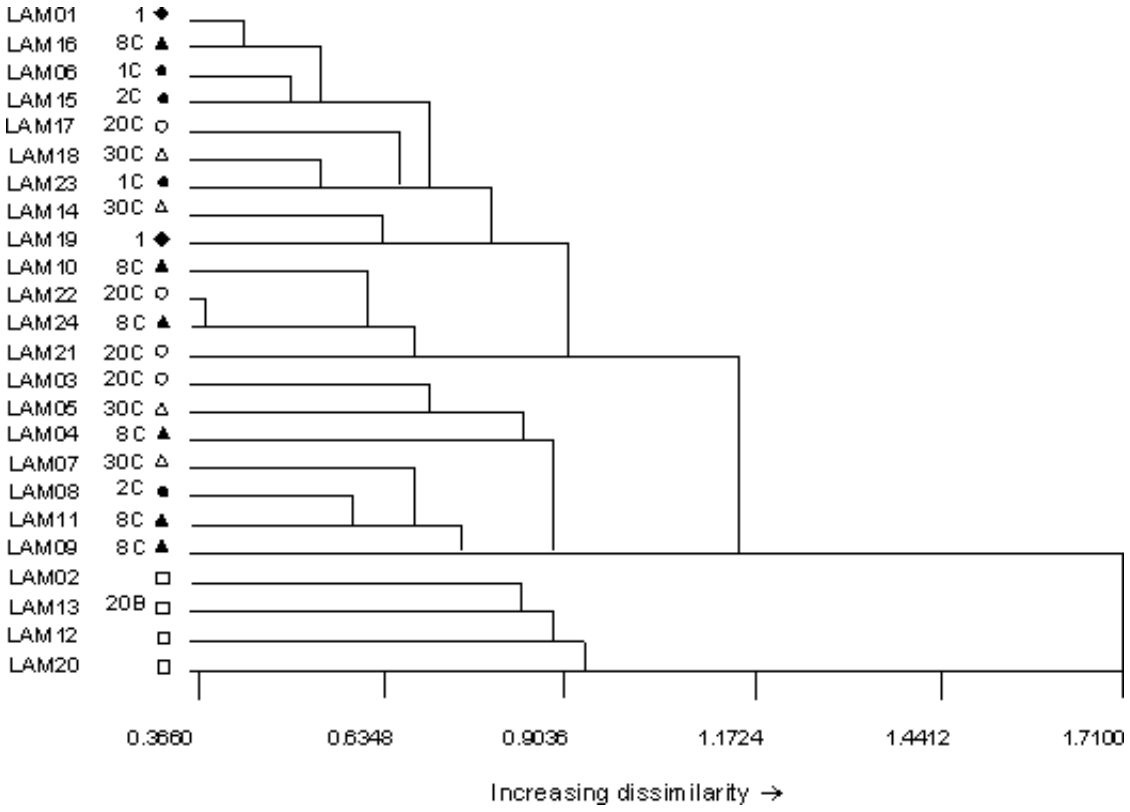


Fig. 5. Multi-dimensional scaling (MDS) according to presence or absence of all vascular plant species; best two eigenvectors plotted.

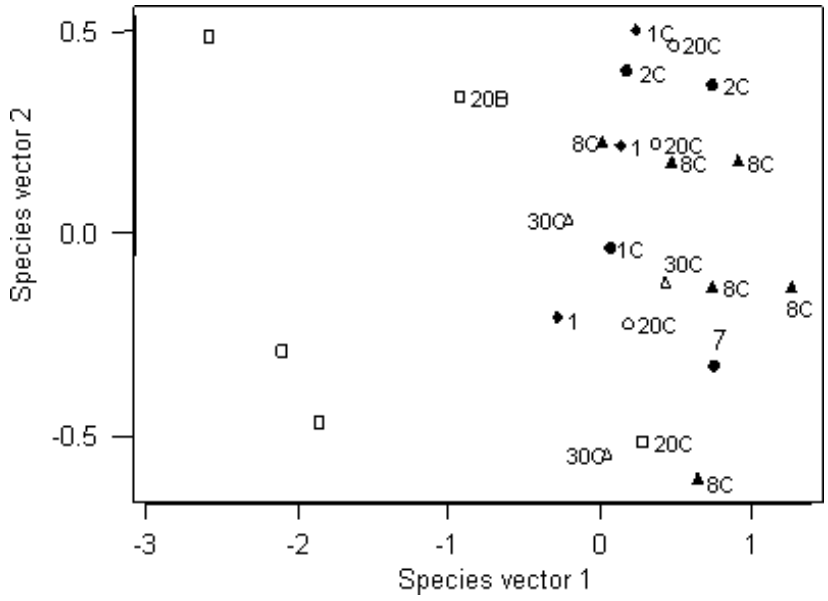


Fig. 6. Classification of all sites using mean canopy height, basal area, total plant species, total PFTs, and species:PFT richness ratios (attributes used to calculate V-index).

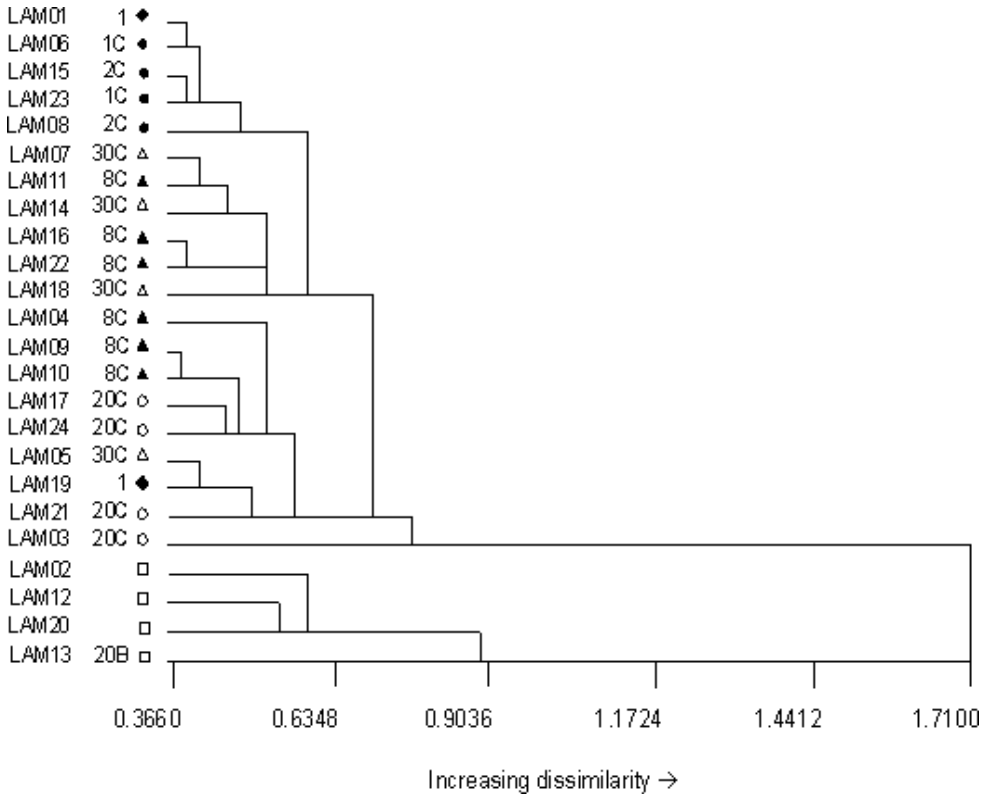


Fig. 7. Multi-dimensional scaling (MDS) of all sites using mean canopy height, basal area, total plant species, total PFTs, and species:PFT richness ratios (attributes used to calculate V-Index); best two eigenvectors plotted.

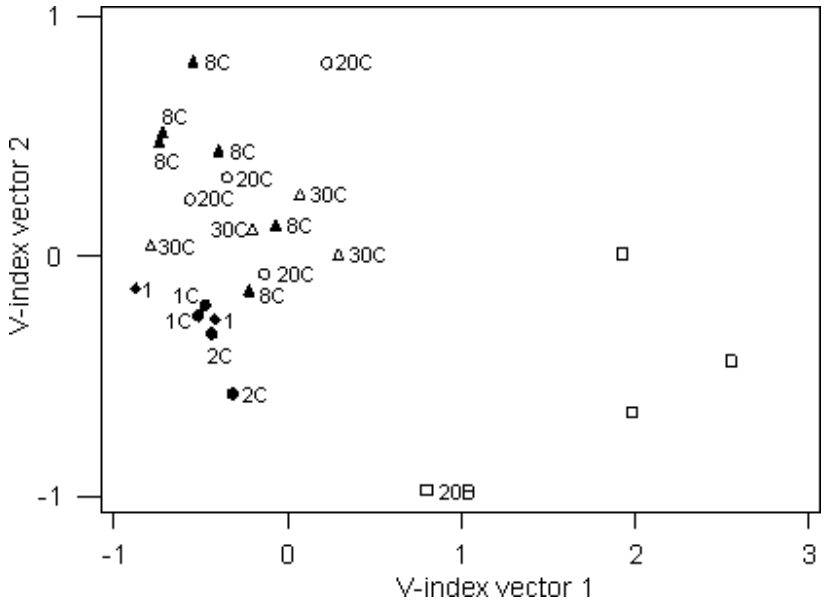


Fig. 8. Relationship between vascular plant species richness and PFT richness across all sites.

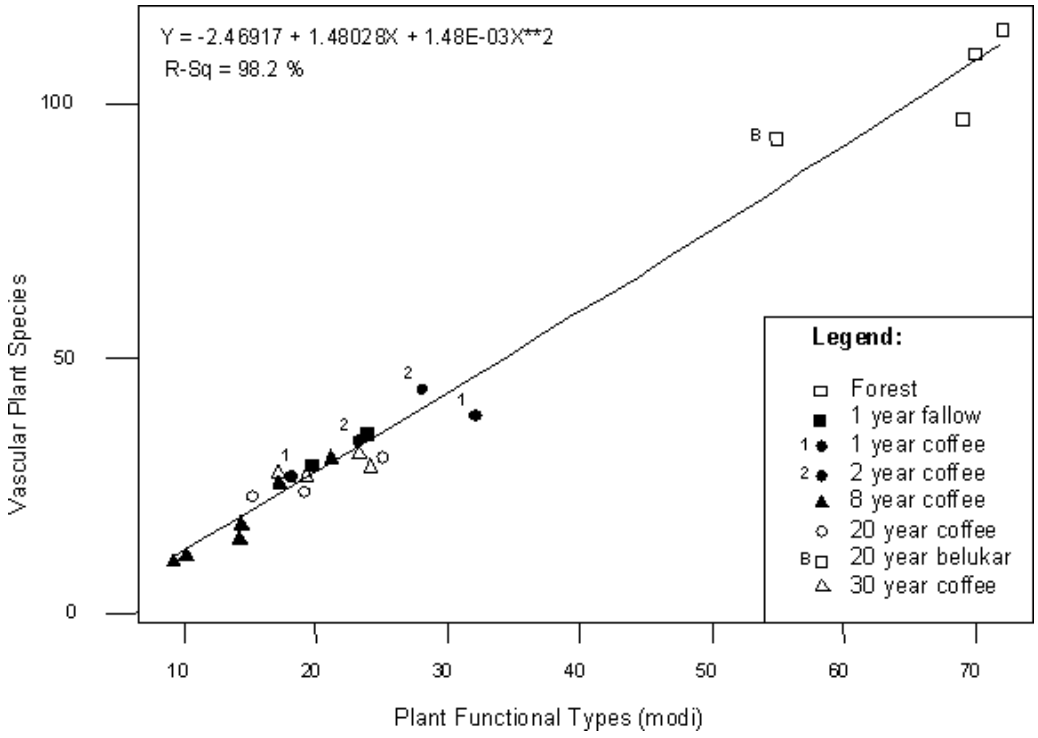


Fig. 9. Land-use types (LUTs) ranked against vegetation or "V"-index.

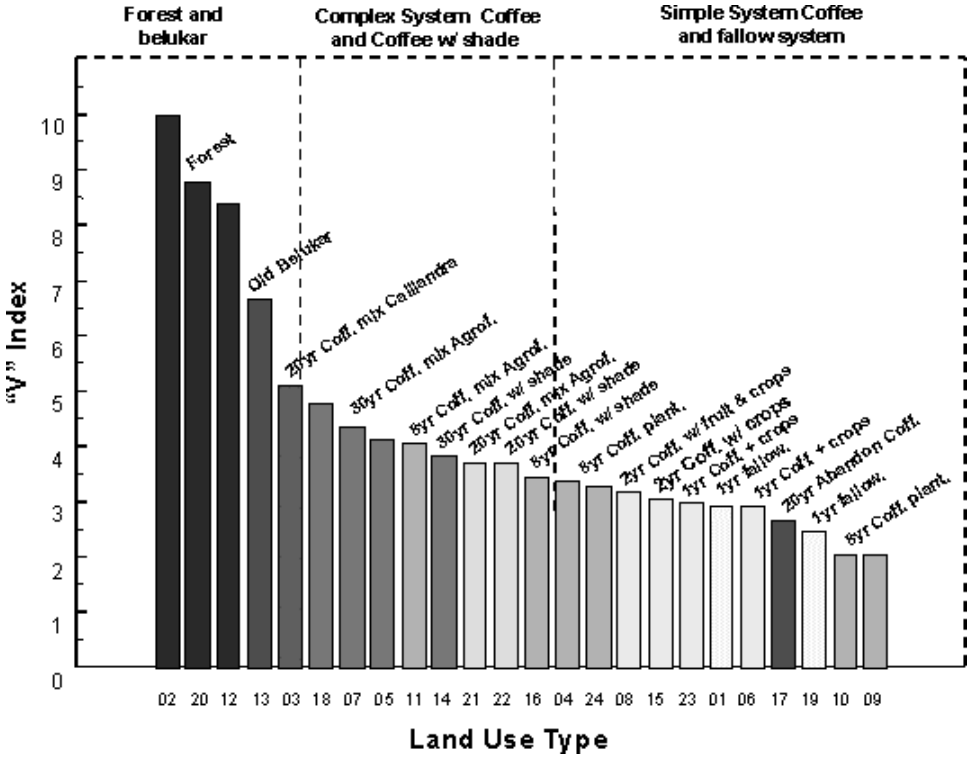
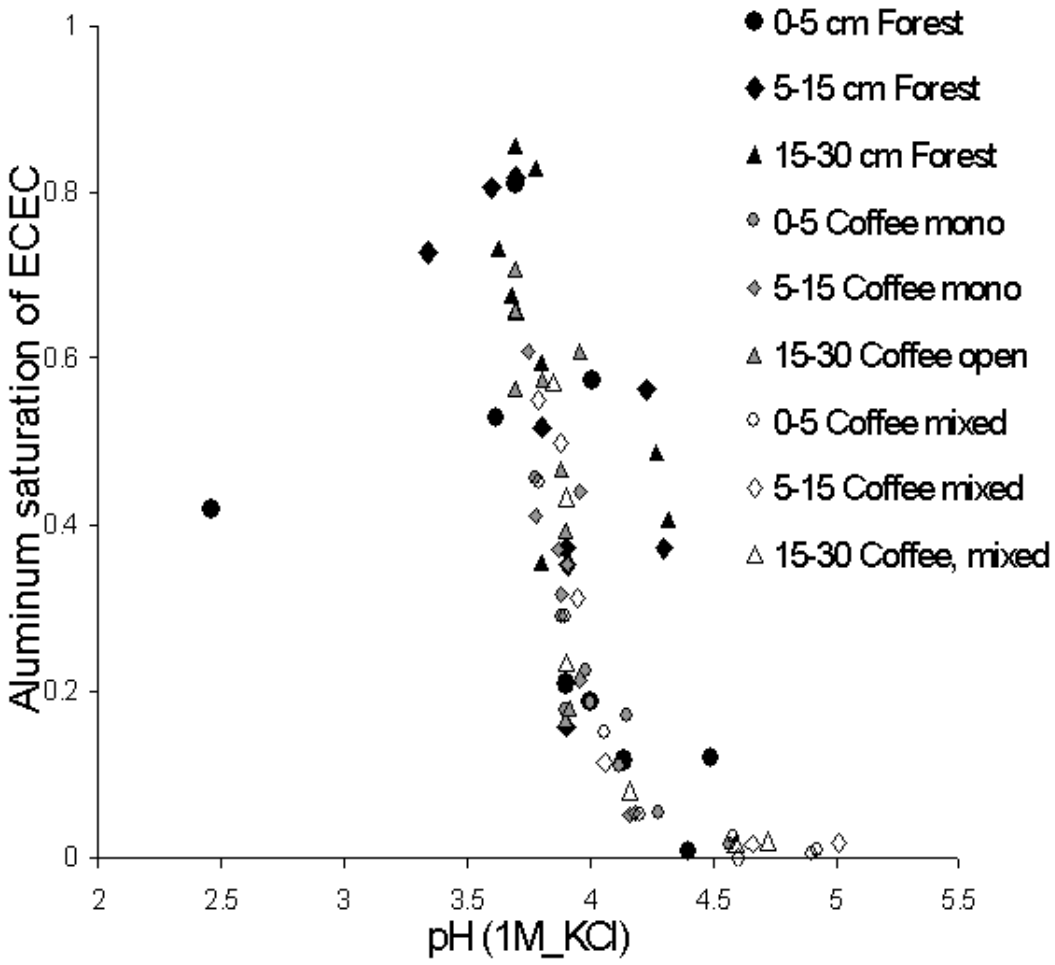


Fig. 10. Relationship between pH and Al saturation of soil classified by depth and land-use type.



In the coffee gardens, soil pH tends to decrease slightly with depth but, due to the strong relationship between soil pH and Al saturation, this implies an increase of Al saturation from 0.19 to 0.31 to 0.48, respectively, for the coffee monoculture in the 0–5, 5–15 and 15–30 cm layers, and from 0.14 to 0.22 to 0.29 in the mixed coffee systems, respectively. Any (further) loss of topsoil is thus likely to increase Al toxicity of crops and increase drought sensitivity caused by shallow root development. When soil texture and soil pH are taken into account in the C_{ref} value, soil organic matter contents for the forest sites are in the range expected for Sumatra (van Noordwijk et al. 1997). As expected, the relative soil C content (C/C_{ref}) varies with depth (1.3 for 0–5 cm, 0.75 for 5–15, and 0.45 for the 15–30 cm layer in the forest sites, except for LAM12), but is higher than than for the mixed coffee gardens (on average 0.93, 0.62, and 0.33, respectively) and monoculture coffee (0.69, 0.46, and 0.26, respectively). When plotted against the time since forest conversion, there is an indication of decline of the C/C_{ref} value with time in the coffee monocultures, and a possible recovery toward forest values in the mixed coffee gardens (van Noordwijk et al. 2002).

The differences between forests and coffee gardens in total N content are smaller than those in C_{org} because the C/N ratio is higher for the forest soils than for the coffee gardens. Available P, as measured by the Bray I method, varies over a wide range in this data set: from <1 to 182 mg kg^{-1} for the topsoil of LAM12 in the peat

layer. High values in the some of the coffee gardens (125 in LAM04 and 75 in LAM10) indicate heavy P fertilizer use, at rates that are probably not justified by the yield response. Other coffee gardens, however, have a P_{Bray} index of less than 10 for the 0–5 cm depth layer and probably operate in the P deficiency range. Across all land-use types, the top 5 cm of soil has a P_{Bray} index that is 3.5 times higher than that of the 5–15 cm depth and 9 times higher than that of the 15–30 cm depth layer. Loss of topsoil may lead to P shortage in the crops, unless compensated for by high P fertilizer rates. The exchangeable cation concentrations are less variable than the available P values and, as such, are not limiting to growth.

Tree dry weight shows highly significant linear correlations with all of the attributes used in the calculation of the V-Index, with the exception of species:PFT ratio (Table 9). Of all of the plant-based variables, tree weight is also most closely correlated with soil (Table 10). Closer inspection shows this may be artificially high given a skewed distribution of the data, with the highest values associated with a relatively few older forest sites. From a biodiversity standpoint, PFT richness is marginally more closely related to C%, N%, C/N% Na and H+ than species richness. Not surprisingly, diversity indices based on PFT data are highly correlated with species, PFTs, and species:PFT ratios (Table 11). Nonetheless, they are also strongly correlated with vegetation structure (mean canopy height and basal area), age of LUT, and tree dry weight, as well as soil KCL,C%, N%, C/N%, Na and H+ (Table 12).

Results overall indicate that, whereas plant biodiversity is highest in closed canopy rain forest and late secondary forest, among the more intensive cropping systems for coffee, highest biodiversity is to be found under the more complex agro-forest systems and coffee grown with shade. This is consistent with response patterns in other crops, such as rubber and cocoa, where “jungle” rubber and “jungle” cocoa rank highest in biodiversity in tree crop systems across all LUTs (cf. Kotto-Same et al. 2000). Co-located site tree dry weight data were highly correlated with age and with mean canopy height. Correlations between PFTs and tree dry weight were marginally higher than with vascular plant species. Soil data were more closely correlated with tree dry weight than with any other plant-based variable, including basal area estimates of all woody plants. The “V” index is also highly correlated with tree dry weight.

Table 9. V-Index, species and PFT indicators of vegetation structure, plot age and tree biomass

Variable	Mean Height	Basal area	Plot age	Tree wt^1	Tree wt^2
V-Index	0.752	0.633	0.802	0.805	0.788
	0.000	0.001	0.000	0.000	0.000
Species richness	0.766	0.587	0.788	0.815	0.792
	0.000	0.003	0.000	0.000	0.000
PFT richness	0.782	0.592	0.814	0.848	0.824
	0.000	0.002	0.000	0.000	0.000

First line = linear “r” correlate; second line = “P” value.
Tree wt^1 and tree wt^2 = tree biomass based on allometric equations of Ketterings et al. (2001) and Brown (1997), respectively.

Table 10. Correlations between soil, plant-based variables, and age of land-use type

Variable*	pH–H_2O	pH–KCl	C%	N%	C/N%	Na	Al3	H+	C/Cref
PFT richness	-0.448	-0.459	0.586	0.592	0.497	0.568	0.465	0.503	0.542
	0.028	0.024	0.003	0.002	0.013	0.004	0.022	0.012	0.006
Species richness	-0.424	-0.427	0.529	0.585	0.435	0.503	0.458	0.441	0.478
	0.039	0.037	0.008	0.003	0.033	0.012	0.024	0.031	0.018
Mean Height	-0.358	-0.331	0.559	0.530	0.477	0.457	0.379	0.480	0.521
	0.086	0.114	0.005	0.008	0.019	0.025	0.068	0.018	0.009
Basal Area	-0.331	-0.260	0.482	0.572	0.383	0.375	0.400	0.402	0.427
	0.114	0.219	0.017	0.003	0.064	0.071	0.053	0.052	0.037
V-Index	-0.433	-0.432	0.550	0.622	0.448	0.495	0.486	0.457	0.496
	0.034	0.035	0.005	0.001	0.028	0.014	0.016	0.025	0.014
Tree wt^1	-0.588	-0.586	0.777	0.566	0.722	0.700	0.570	0.755	0.767
	0.002	0.003	0.000	0.004	0.000	0.000	0.004	0.000	0.000
Tree wt^2	-0.576	-0.568	0.753	0.557	0.697	0.668	0.558	0.73	0.743
	0.003	0.004	0.000	0.005	0.000	0.000	0.005	0.000	0.000
LUT age	-0.421	-0.410	0.613	0.566	0.528	0.569	0.390	0.546	0.584
	0.041	0.046	0.001	0.004	0.008	0.004	0.060	0.006	0.003

* First line = linear "r" value; second line = P value; Tree wt^1 and Tree wt^2 = tree biomass based on the allometric equations of Ketterings et al. (2001) and Brown (1997), respectively; only variables with P <0.020 listed. Complete correlation matrix available on request. Soil data from top 0–5 cm.

Table 11. Correlations between PFT-based diversity indices, PFC, plant-based variables, and age of LUT

Variable	Fisher's alpha	Simpson	Shannon-Wiener	PFC
PFT (richness)	0.677	-0.833	0.956	0.991
	0.000	0.000	0.000	0.000
Species (richness)	0.598	-0.801	0.935	0.978
	0.002	0.000	0.000	0.000
Spp:PFT	-0.238	-0.315	0.417	0.391
	0.263	0.134	0.043	0.059
Mean ht (cm)	0.589	-0.504	0.656	0.808
	0.002	0.012	0.000	0.000

Basal Area (m^2ha^{-1})	0.373	-0.326	0.471	0.622
	0.072	0.120	0.020	0.001
V-Index	0.413	-0.657	0.818	0.893
	0.045	0.000	0.000	0.000
LUT age (years)	0.588	-0.505	0.682	0.841
	0.003	0.012	0.000	0.000
Tree wt^1	0.680	-0.600	0.753	0.866
	0.000	0.000	0.002	0.000
Tree wt^2	0.675	-0.577	0.729	0.847
	0.000	0.003	0.000	0.000

*Diversity indices for PFTs and PFC (Plant Functional Complexity) (Gillison and Carpenter, unpubl. 1999; Gillison 2000); First line = linear "r" correlate; second line = "P" value. Tree wt^1 and tree wt^2 = tree biomass based on allometric equations of Ketterings et al. (2001) and Brown (1997), respectively.

Table 12. Correlations between PFT-based diversity indices, PFC, and key soil variables over all LUTs

Soil variable	Fisher's alpha	Simpson	Shannon-Wiener	PFC
pH_KCl	-0.427	0.297	-0.381	-0.469
0.037	0.158	0.066	0.020	
C%	0.486	-0.409	0.527	0.574
0.016	0.047	0.008	0.003	
N%	0.312	-0.510	0.574	0.563
0.138	0.011	0.003	0.004	
C/N%	0.458	-0.308	0.430	0.488
0.024	0.143	0.036	0.015	
Na	0.453	-0.424	0.533	0.549
0.026	0.039	0.007	0.005	
H+	0.493	-0.335	0.442	0.504
0.014	0.110	0.031	0.012	
C/Cref	0.485	-0.378	0.489	0.533
0.016	0.068	0.015	0.007	

First line = linear "r" correlate; second line = "P" value.
Correlates selected from matrix where $P < 0.050$

DISCUSSION

Despite sampling limitations caused by highly dissected, lowland, tropical terrain with difficult access, experience by the same team members in other areas of Central and Southern Sumatra suggests that, although certain LUTs could not be included (e.g., some of the more intact but more remote forests), key land-use and tenurial combinations were covered in this study. The team was fortunate in having the services of a qualified field botanist with rapid follow-up identification through a herbarium. Such facilities are rarely available in many tropical developing countries and their absence can influence data quality as a result. Where formal species identification is not feasible, the use of PFTs facilitates rapid and uniform data collection that is largely independent of the need for identification of a scientific name, provided morphospecies are recognizable. Recent studies (Gillison 2002) suggest composition rather than richness of PFTs or species determines ecosystem behavior and this is consistent with other views (cf. Folke et al. 1996). Only PFT and species richness were analyzed in this study and found useful for predicting site and soil condition. By association, these are testable predictors of coffee production and profitability. Both PFTs and plant functional compexity (PFC) emerge as the most potentially useful indicators overall of both biodiversity (expressed in terms of both species and PFTs) and soil nutrient status.

The Shannon-Wiener, Simpson's and Fisher's alpha diversity indices performed less efficiently as indicators than the PFC measure, which is not, strictly speaking, a true diversity index. The closer correlations between PFTs and soil variables may be interpreted in part as a plant morphological adaptive response to available soil nutrients. The species:PFT richness ratio, although found useful as a predictor of faunal diversity in other surveys (Gillison 2000), provided no useful correlation with LUT, land tenure class or soil condition in the present study. In this study, we investigated only linear and polynomial regressions with single variables. Additional analysis (not reported here) suggests that, although there would be some improvement in predictors using multiple regression, complex predictors of this kind are likely to be counter-productive where simple indicators are needed in the field. Our study shows that age of the particular land-use sequence is a potentially useful and simple indicator of biodiversity and soil nutrients within the context of the sites chosen. Tree dry weight is also a strong predictor of site condition and biodiversity, but this may be due in part to a sampling artifact that produced highly polarized data distributions. Although mean canopy height and basal area are also potentially useful indicators within a sub-region, there can be no guarantee that they will carry the same predictive capacity between regions where vegetation structure can be similar but where the ecological conditions differ. Under such circumstances, e.g., in inter-regional and inter-country comparisons, PFTs are of greater generic indicator value.

The V-index data produced a readily interpretable relationship between biodiversity and LUT (Fig. 9). As with vegetation structure, the V-index values are locally useful but may be regionally limiting in under-sampled situations. Studies in other tropical countries (Gillison 2000) indicate a high level of congruence between similar LUTs and V-index along similar land-use intensity gradients. If such congruence can be shown to hold across a variety of tropical agroforests, this would enhance its relative value as a simple integral measure of vegetation components and as an indicator of biodiversity and corresponding land-use impact. As such, it could be useful in a matrix analysis of tradeoffs, as already described by Tomich et al. (1998, 2001). Using GIS-based spatial analytical tools, it should be possible to test the indicators derived here by field survey. In this way, a model could be developed to help refine indicators and pave the way for supervised remote sensing applications for regional planning purposes.

CONCLUSIONS

Within the range of LUTs examined, plant biodiversity was lowest under simple, non-shaded, intensive farming systems and increased progressively through shaded and more complex agroforests to late secondary and closed-canopy forests. The most efficient single indicators of biodiversity and soil nutrient availability were PFT richness and a derived measure of plant functional complexity. Vegetation structure, tree dry weight, and age of the land-use type were also highly correlated with biodiversity. The close correspondence between these variables together with a vegetation or V index and soil nutrient values suggests they are potentially useful indicators of coffee production and profitability across different farming systems within the region. The present baseline study

now makes possible a study of links between biodiversity, profitability, and tenure; this will be the subject of a forthcoming paper. Baseline information of this kind is an essential component in the construction of a tradeoffs matrix for assessing policy options and for aiding in decision support for urgently needed adaptive management in some of the world's biodiversity hotspots.

Responses to this article can be read online at: http://www.ecologyandsociety.org/vol9/iss2/art7/responses/index.html

Acknowledgments:

The botanical assistance provided by Afriastini and staff of the Herbarium Bogoriense is much appreciated, as is the assistance from Praktikno and Hendrik of ICRAF-Lampung. Two anonymous referees provided valuable comments on the manuscript.

LITERATURE CITED

Abate, T., A. van Huis, and J. K. O. Ampofo. 2000. Pest management strategies in traditional agriculture: an African perspective. *Annual Review of Entomology* **45**:631–659.

Angelsen, A. 1995. Shifting cultivation and "deforestation": a study from Indonesia. *World Development* **23**:1713–1729.

Armbrecht, I., I. Perfecto, and J. Vandermeer. 2004. Enigmatic biodiversity correlations: ant diversity responds to diverse resources. *Science* **304**:284–286.

Attiwill, P. M. 1994. Ecological disturbance and the conservative management of eucalypt forests in Australia. *Forest Ecology and Management* **63**:301–346.

Bakkes, J. A., G. van den Born, J. C. Helder, R. J. Swart, C. W. Hope, and J. D. E. Parker. 1994. *An overview of environmental indicators: state of the art and perspectives.* National Institute of Public Health and Environmental Protection, Bilthoven, the Netherlands.

Belbin, L. 1992. *PATN pattern analysis package: technical reference.* Division of Wildlife and Ecology, Commonwealth Scientific and Industrial Research Organization, Canberra, Australia.

Benoit, D., M. Pain, P. Levang, and O. Sevin. 1989. *Transmigration en spontanées en Indonésie.* (Transmigration and spontaneous migrations in Indonesia: Lampung Province.) ORSTOM and Transmigration Department, Jakarta, Indonesia.

Bignell, D. E., E. Widodo, F.-X Susilo, and H. Suryo. 2000. Soil macrofauna: ground-dwelling ants, termites, other macroarthropods and earthworms. Pages 91–127 *in* A. N. Gillison, coordinator. *Above-ground biodiversity assessment working group summary report 1996–1999 impact of different land uses on biodiversity.* Alternatives to Slash and Burn Project. International Center for Research in Agroforestry, Nairobi, Kenya.

Brown, S. 1997. Estimating biomass change of tropical forest, a primer. FAO Forestry Paper 134, Food and Agriculture Organization, Rome, Italy.

Budidarsono, S., S. A. Kuncoro, and T. P. Tomich. 2000. *A profitability assessment of robusta coffee systems in Sumberjaya Watershed, Lampung, Sumatra, Indonesia.* Southeast Asia Policy Research Working Paper No. 16. International Center for Research in Agroforestry, Bogor, Indonesia.

Cowling, R. M., P. J. Mustart, H. Laurie, and M. B. Richards. 1994. Species diversity: functional diversity and functional redundancy in fynbos communities. *South African Journal of Science* **90**:333–337.

Cramer, W. 1996. Using plant functional types in a global vegetation model. Pages 271–288 *in* T. M. Smith, H. H. Shugart, and F. I. Woodward, editors. *Plant functional types: their relevance to ecosystem properties and global change.* Cambridge University Press, Cambridge, UK.

Cramer, W., H. H. Shugart, I. R. Noble, F. I. Woodward, H. Bugmann, A. Bondeau, J. A. Foley, R. H. Gardner, W. K. Lauenroth, L. F. Pitelka, and R. W. Sutherst. 1999. Ecosystem composition and structure. Pages 190–228 *in* B. H. Walker, W. L. Steffen, J. Canadell, and J. S. I. Ingram, editors. *The terrestrial biosphere and global change.* International Geosphere–Biosphere Programme Book Series No. 4. Cambridge University Press, Cambridge, UK.

Diaz, S. 1998. The effects of global change on functional group diversity. Page18 *in* E. Huber-Sanwald, and V. Wolters, editors. *Effects on global change on biodiversity and ecological complexity.* Report of EU/TERI-IGBP/GCTE-DIVERSITAS Workshop, October 20–22,

1997. GCTE International Project Office, Canberra, Australia.

Diaz, S., M. Cabido, M. Zak, E. Martinez-Carretero, and J. Aranibar. 1999. Plant functional traits, ecosystem structure and land use history along a climatic gradient in central-western Argentina. *Journal of Vegetation Science* **10**:651–660.

Duckworth, J. C., M. Kent, and P. M. Ramsay. 2000. Plant functional types: an alternative to taxonomic plant community description in biogeography? *Progress in Physical Geography* **24**:515–542.

Folke, C., C. S. Holling, and C. Perrings. 1996. Biological diversity, ecosystems and the human scale. *Ecological Applications* **6**:1018–1024.

Giller, K. E., M. H. Beare, P. Lavelle, A-M. N. Izac, and M. J. Swift. 1997. Agricultural intensification, soil biodiversity and agroecosystem function. *Applied Soil Ecology* **6**:3–16.

Gillison, A. N. 1981. Towards a functional vegetation classification. Pages 30–41 *in* A. N. Gillison and D. J. Anderson, editors. *Vegetation Classification in Australia.* Commonwealth Scientific and Industrial Research Organization and Australian National University Press, Canberra, Australia.

Gillison, A. N. 2000. Summary and overview. Pages19–24 *in* A. N. Gillison, coordinator. *above-ground biodiversity assessment working group summary report 1996–1999 impact of different land uses on biodiversity.* Alternatives to Slash and Burn Project. International Center for Research in Agroforestry, Nairobi, Kenya.

Gillison, A. N. 2001. *A review of the impact of climate change on forest biological diversity.* Report prepared for the Secretariat of the Convention on Biological Diversity. United Nations Environmental Programme/CBD/AHTEG-BDCC/1/2.

Gillison, A. N. 2002. A generic, computer-assisted method for rapid vegetation classification and survey: tropical and temperate case studies. *Conservation Ecology* **6**:3. [online] URL: http://www.consecol.org/vol6/iss2/art3.

Gillison, A. N., and K. R. W. Brewer. 1985. The use of gradient-directed transects or gradsects in natural resource surveys. *Journal of Environmental Management* **20**:103–127.

Gillison, A. N., and G. Carpenter. 1997. A generic plant functional attribute set and grammar for dynamic vegetation description and analysis. *Functional Ecology* **11**:775–783.

Gillison, A. N., D. T. Jones, F-X. Susilo, and D. E. Bignell. 2003. Vegetation indicates diversity of soil macroinvertebrates: a case study with termites along a land-use intensification gradient in lowland Sumatra. *Organisms, Diversity and Evolution* **3**:111–126.

Gitay, H., I. R. Noble, and J. H. Connell. 1999. Deriving functional types for rain-forest trees. *Journal of Vegetation Science* **10**:641–650.

Gower, J. 1967. A comparison of some methods of cluster analysis. *Biometrics* **23**:623–637.

Greenberg, R., P. Bichier, A. Cruz Angon, C. MacVean, R. Perez, and E. Cano. 2000. The impact of avian insectivory on arthropods and leaf damage in some Guatemalan coffee plantations. *Ecology* **6**:1750–1755.

Hairiah, K., and M. van Noordwijk. 2000. Soil properties and carbon stocks. Pages 143–154 *in* A. N. Gillison, cordinator. *Above-ground biodiversity assessment working group summary report 1996–1999 impact of different land uses on biodiversity.* Alternatives to Slash and Burn Project. International Center for Research in Agroforestry, Nairobi, Kenya.

Heywood, V. H., and I. Baste. 1995. Introduction. Pages 3–19 *in* V. Heywood, editor, and R. T. Watson, chair, *Global biodiversity assessment.* United Nations Environmental Programme, Cambridge University Press, Cambridge, UK.

Hobson, K. A., and J. Schieck. 1999. Changes in bird communities in boreal mixedwood forest: harvest and wildfire effects over 30 years. *Ecological Applications* **9**:849–863.

Hooper, D. U., and P. M. Vitousek. 1998. Effects of plant composition and diversity on nutrient cycling. *Ecological Monographs* **68**:121–149.

Howard, P., T. Davenport, and F. Kigeny. 1997. Planning conservation areas in Uganda's natural forests. *Oryx* **31**:253–262.

Huston, M. A. 1993. Biological diversity, soils, and economics. *Science* **262**:1676–1680.

Huston, M. A. 1994. *Biological diversity: the coexistence of species in changing landscapes.* Cambridge University Press, Cambridge, UK.

Jepson, P., and Djarwadi. 2000. Birds. Pages 41–53 *in* A. N. Gillison, coordinator. *Above-ground biodiversity assessment working group summary report 1996–1999 impact of different land uses on biodiversity.* Alternatives to Slash and Burn Project. International Center for Research in Agroforestry, Nairobi, Kenya.

Jobbágy, E. G., and R. B. Jackson. 2000. The vertical distribution of soil organic carbon and its relation to climate and vegetation. *Ecological Applications* **10**:423–436.

Jones, D. T., F-X. Susilo, D. E. Bignell, and H. Suryo. 2000. Terrestrial insects: species richness, functional diversity and relative abundance of termites under different land use regimes. Pages 128–139 *in* A. N. Gillison, coordinator. *Above-ground biodiversity assessment working group summary report 1996–1999 impact of different land uses on biodiversity.* Alternatives to Slash and Burn Project. International Center for Research in Agroforestry, Nairobi, Kenya.

Jones, D. T., F.-X. Susilo, D. E. Bignell, S. Hardiwinoto, A. N. Gillison, and P. Eggleton. 2002. Termite assemblage collapse along a land-use intensification gradient in lowland central Sumatra, Indonesia. *Journal of Applied Ecology* **40**:380–391.

Ketterings, Q. M., R. Coe, M. Van Noordwijk, Y. Ambagau', and C. A. Palm. 2001. Reducing uncertainty in the use of allometric biomass equations for predicting above-ground tree biomass in mixed secondary forest. *Forest Ecology and Management* **146**:201–211.

Knops, J. M. H., D. Tilman, N. M. Haddad, S. Naeem, C. E. Mitchell, J. Haarstad, M. E. Ritchie, K. M. Howe, P. B. Reich, E. Siemann, and J. Groth. 1999. Effects of plant species richness on invasion dynamics, disease outbreaks, insect abundances and diversity. *Ecology Letters* **2**:286–293.

Kotto-Same, J., A. Moukam., R. Njomgang, T. Tiki-Manga, J. Tonye, C. Diaw, J. Gockowski, S. Hauser, S., Weise, D. Nwaga, L. Zapfack, C. A. Palm, P. Woomer, A. N. Gillison, D. E. Bignell, and J. Tondoh. 2000. *Summary report and synthesis of Phase II in Cameroon.* Alternatives to Slash and Burn Project, International Center for Research in Agroforestry, Nairobi, Kenya.

Lawton, J. H., D. E. Bignell, B. Bolton, G. F. Bloemers, P. Eggleton, P. M. Hammond, M. Hodda, R. D. Holt, T. B. Larsen, N. A. Mawdsley, N. E. Stork., D. S. Srivastiva, and A. D. Watt. 1998. Biodiversity inventories, indicator taxa and effects of habitat modification in tropical forest. *Nature* **391**:72–76.

Lindenmayer, D. B., C. R. Margules, and D. B. Botkin. 2000. Indicators of biodiversity for ecologically sustainable management. *Conservation Biology* **14**:941–950.

McNeely, J. A. 1990. Climate change and biological diversity: policy implications. Pages 406–429 *in* M. M. de Boer, and R. S. de Groot, editors. *Landscape ecological impacts of climate change.* IOS Press, Amsterdam, the Netherlands.

Margules, C. R., and R. L. Pressey. 2000. Systematic conservation planning. *Nature* **405**:243–253.

Martinez, N. D. 1996. Defining and measuring functional aspects of biodiversity. Pages 114–148 *in* K. J. Gaston, editor. *Biodiversity: a biology of numbers and difference.* Blackwell Science Ltd., Oxford, UK.

Miller, K., M. H. Allegretti, N. Johnston, and B. Jonsson. 1995. Measures for conservation of biodiversity and sustainable use of its components. Pages 915–1061 *in* V. Heywood, editor, and R. T. Watson, chair. *Global biodiversity assessment.* United Nations Environment Programme, Cambridge University Press, Cambridge, UK.

Myers, N., R. A. Mittermeier, C. G. Mittermeier, G. A. B. da Fonseca, and J. Kent. 2000. Biodiversity hotspots for conservation priorities. *Nature* **403**:853–845.

Noss, R. F. 1990. Indicators for monitoring biodiversity: a hierarchical approach. *Conservation Biology* **4**:355–364.

Otsuka K., S. Suyanto, T. P. Tomich, and T. Sonobe. 2001. Evolution of customary land tenure and agroforestry: evidence from Sumatra. *Agricultural Economics* **15**:85–101.

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

Perfecto, I., and R. Snelling. 1995. Biodiversity and transformation of a tropical agroecosystem: ants in coffee

plantations. *Ecological Applications* **5**:1084–1097.

Reid, W. V., J. A. McNeely, D. B. Tunstall, D. A. Bryant, and M. Winograd. 1993. *Biodiversity indicators for policy makers.* World Resources Institute, Washington, D.C., USA.

Richards, M. 1999. *"Internalising the externalities" of tropical forestry: a review of innovative financing and incentive mechanisms.* European Union Tropical Forestry Paper.

Roberts, D. L., R. J. Cooper, and L. J. Petit. 2000. Flock characteristics of ant-following birds in premontane moist forest and coffee agroecosystems. *Ecological Applications* **10**:1414–1425.

Sala, O. E., F. S. Chapin III, J. J. Armesto, E. Berlow, J. Bloomfield, R. Dirzo, E. Huber-Sanwald, L. F. Huenneke, R. B. Jackson, A. Kinzig, R. Leemans, D. M. Lodge, H. A. Mooney, M. Oesterheld, N. L. Poff, M. T. Sykes, B. H. Walker, M. Walker, and D. H. Wall. 2000. Global biodiversity scenarios for the year 2100. *Science* **287**:1770–1774.

Sanchez, P. A. 1995. Science in agroforestry. *Agroforestry Systems* **30**:5–55.

Schwarz, A. G., and R. W. Wein. 1997. Threatened dry grasslands in the continental boreal forests of Wood Buffalo National Park. *Canadian Journal of Botany* **75**:1363–1370.

Shugart, H. H. 1996. Plant and ecosystem functional types. Pages 20–43 *in* T. M. Smith, H. H. Shugart, and F. I. Woodward, editors. *Plant functional types: their relevance to ecosystem properties and global change.* Cambridge University Press, Cambridge, UK.

Smith, T. M., H. H. Shugart, and F. I. Woodward. 1996. Preface. Pages xii–xiv *in* T. M. Smith, H. H. Shugart, and F. I. Woodward, editors. *Plant functional types: their relevance to ecosystem properties and global change.* Cambridge University Press, Cambridge, UK.

Suyanto S., K. Otsuka, and T. P. Tomich. 2001a. Land tenure and farm management efficiency: the case of smallholder rubber production in customary land areas of Sumatra. *Agricultural Systems* **52**:145–160.

Suyanto S., T. P. Tomich, and K. Otsuka. 2001b. Land tenure and farm management efficiency: the case of paddy and cinnamon production in customary land areas of Sumatra. *The Australian Journal of Agricultural and Resource Economics* **45**:411–436.

Tilman, D. 1999. The ecological consequences of change in biodiversity: a search for general principles. *Ecology* **80**:1455–1474.

Tilman, D. 2001. Functional diversity. *Encyclopedia of Biodiversity* **3**:109–120.

Tilman, D., J. Knops, D. Wedin, P. Reich, M. Ritchie, and E. Siemann. 1997. The influence of functional diversity and composition on ecosystem processes. *Science* **277**:1300–1305.

Tomich, T. P., M. van Noordwijk, S. Budisarsono, A. N. Gillison, T. Kusumanto, D. Mudiyarso, F. Stolle, and A. Fagi. 1998a. *Alternatives to Slash and Burn in Indonesia. Summary report and synthesis of Phase II.* Alternatives to Slash and Burn Project. ASB-Indonesia Report No. 8. International Center for Research in Agroforestry, Bogor, Indonesia.

Tomich, T. P., M. van Noordwijk, S. Budidarsono, A. N. Gillison, T. Kusumanto, D. Murdiyarso, F. Stolle, and A. Fagi. 2001. Agricultural intensification, deforestation and the environment: assessing tradeoffs in Sumatra, Indonesia. Pages 221–244 *in* D. R. Lee and C. B. Barrett, editors. *Tradeoffs or synergies? Agricultural intensification, economic development and the environment.* CAB International, Wallingford, UK.

Tomich, T. P., M. van Noordwijk, S. A. Vosti, and J. Witcover. 1998b. Agricultural development with rainforest conservation: methods for seeking best bet alternatives to slash-and-burn, with applications to Brazil and Indonesia. *Agricultural Economics* **19**:159–174.

van Noordwijk, M., and M. J. Swift. 1999. Belowground biodiversity and sustainability of complex agroecosystems. Pages 8–28 *in* A. Gafur, F-X. Susilo, M. Utomo, and M. van Noordwijk, editors. *Management of Agrobiodiversity in Indonesia for Sustainable Land Use and Global Benefits.* ASB-Indonesia Report No. 9. Agency for Agricultural research and Development, Ministry of Agriculture and University of Lampung, Indonesia.

van Noordwijk, M., P. Woomer, C. Cerri, M. Bernoux, and K. Nugroho. 1997. Soil carbon in the humid tropical forest zone. *Geoderma* **79**:187–225.

van Noordwijk, M., R. Subekti, H. Kurniatun, Y. C. Wulan, A. Farida, and B. Verbist. 2002. Carbon stock assessment for a forest-to-coffee conversion landscape in Sumber-Jaya (Lampung, Indonesia): from allometric equations to land-use change analysis. *Science in China* (Series C) **45** Supp.75–86.

Vandermeer, J., M. van Noordwijk, J. Anderson, C. Ong, and I. Perfecto. 1998. Global change and multi-species agroecosystems: concepts and issues. *Agriculture, Ecosystems and Environment* **67**:1–11.

Watt, A. D., G. Argent, C. Bibby, J. Carter Lengeler, P. Eggleton, N. Garwood, A. N. Gillison, W. Hawthorne, J. Healey, J. Jones, V. Kapos, C. Lyal, D. Moss, A. C. Newton, O. Philips, and D. Sheil. 1998. *Evaluation and development of methods of rapid biodiversity assessment in relation to the conservation of biodiversity in tropical moist forests* . Report to Department for International Development, Oxford, UK.

Wessels, K. J., A. S. van Jaarsveld, J. D. Grimbeek, and M. J. van der Linde. 1998. An evaluation of the gradsect biological survey method. *Biological Conservation* **7**:1093–1121.