

BIODIVERSITY CONSERVATION THROUGH AGROFORESTRY: MANAGING TREE SPECIES DIVERSITY WITHIN A NETWORK OF COMMUNITY-BASED, NONGOVERNMENTAL, GOVERNMENTAL AND RESEARCH ORGANISATIONS IN WESTERN KENYA

Paper presented at the 15th Annual Conference of the Eastern Africa Environmental Network on *Networking for Biodiversity*, 27-28 May 2005, National Museums of Kenya, Nairobi

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ABSTRACT

Biodiversity, or the diversity of life in all its forms and at all levels of organization, has come under serious threat in many places in recent times. Several of the global hotspots of biodiversity are at the same time areas where human population density has increased tremendously, which has contributed to current global species extinction levels paralleling previous mass extinction events. Some researchers have therefore called to develop strategies for ecoagriculture - a new type of agriculture that combines objectives of ensuring food security and conserving biodiversity in the same landscapes - to complement other conservation methods. Agroforestry can be classified as ecoagriculture, since integration of productive woody perennials in farming systems (which is the definition of agroforestry) is one of the ecoagriculture strategies of mimicking natural habitats to conserve some wild biodiversity.

This paper describes how an innovative scheme of networking with community-based organisations (CBOs), non-governmental organisations (NGOs), governmental organisations and research organisations can contribute to biodiversity conservation in farmland and in relict natural ecosystems by diversifying agroforestry systems. The organisations collaborated with farmers in 10 interactive learning sites, which are part of the much larger network of the Consortium for Scaling-up Options for increasing Farm Productivity and incomes in western Kenya (COSOFAP). This consortium was initiated in 2001 and currently has more than 100 member organisations. The key objective of the consortium was to target resource-poor farmers by synergising the efforts of the many organisations that work in western Kenya. This synergy is achieved by establishing interactive learning sites that are strategically dotted all over western Kenya, and by avoiding duplication and fragmentation of efforts of the various organisations. The paper also describes how COSOFAP has linked up with the Ministry of Environment and NEMA to diversity tree species on farms in western Kenya.

The paper makes the case that effective management of biodiversity in agricultural landscapes can only be achieved by methods of adaptive management. One of the requirements for implementing adaptive management is to use appropriate methods of investigating patterns of biodiversity, and especially to train communities on how to use these methods. Since several of the scientifically recommended methods for investigating biodiversity can be mathematically quite complex, the World Agroforestry Centre (ICRAF) has taken the lead in developing appropriate training materials and user-friendly free software to allow its partner organisations to investigate common biodiversity patterns. Results from various methods and their implication for biodiversity management in western Kenya are presented in the paper. One of the methods is using species accumulation curves to study the relationship between sampling scale and species richness. Another method is the use of diversity profiles to rank different sites in biodiversity. A third method is generalised linear modelling to study the relationship between farm and household characteristics and species richness. Some new ordination methods that allow investigating the influence of farm characteristics on species composition are also presented.

INTRODUCTION

Biodiversity, or the diversity of life in all its forms and at all levels of organization (Hunter 2002), has come under serious threat in many places in recent times. Several of the global hotspots of biodiversity are at the same time areas where human population density has increased tremendously, which has contributed to current global species extinction levels paralleling previous mass extinction events (Myers et al., 2001; Woodruff, 2001). Some researchers have therefore called to develop strategies for ecoagriculture - a new type of agriculture that combines objectives of ensuring food security and conserving biodiversity in the same landscapes - to complement other conservation methods (McNeely and Scherr, 2002).

One of the purposes of agroforestry tree domestication is enhancement of stability and productivity of agro-ecosystems by diversifying on-farm tree species composition (presence and abundance). Diversification and intensification of land use through domestication of agroforestry trees is one of the three pillars of the research of the World Agroforestry Centre (Kindt and Lengkeek, 1999; ICRAF, 2000). In this article, methods of studying tree species diversity at various scales (ranging from the individual farm to the complete survey) are presented and discussed. The results are interpreted as options for diversification planning for farm-level tree diversity in landscapes where farmer management dominates the presence of trees, although spontaneous regeneration of trees still occurs.

Diversification at higher scales in the landscape is focused on improving ecosystem functioning. Although studying the effect of biodiversity on ecosystem functioning requires complex ecological experiments or models, studies have shown that there is a positive but conditional relationship between species diversity and ecosystem stability and/or productivity (e.g., Nijs and Roy, 2000; Cottingham et al., 2001; Loreau and Hector, 2001; Loreau et al., 2001; Norberg et al., 2001; Tilman et al., 2001; Whittaker et al., 2001). The conditions include that species have diversity in traits and that the ecosystem has environmental heterogeneity. Therefore not all mixtures of higher diversity will have beneficial effects on ecosystem functioning. One of the challenges of targeting enhancement of ecosystem functioning by increasing biodiversity is therefore to select the identities and traits of the component species. The challenge is also to match the variation in environmental conditions at a specific scale in the landscape with a mixture of species with the appropriate traits for the environmental conditions. However, the studies have shown that on average higher diversity will have beneficial effects. Also on average, having more species in the landscape means that redundancy is higher: losing one species from a diverse landscape will have smaller consequences than losing one species from a species-poor landscape.

One of the methods of achieving landscape diversification is to promote wider distribution of species that are already present somewhere in the landscape. Reasons to adopt such approach could be related to species conservation in a conservation-through-use setting (Kindt and Lengkeek, 1999; Kristensen and Balslev, 2003; Kindt et al, 2004, in press¹, in press²), biosafety precautions, ecological suitability, or fitness of purpose of the species. Agroforestry is uniquely suited to provide ecoagriculture solutions that successfully combine objectives for increased food security and biodiversity conservation gains, especially by promoting greater use of native tree species in agroforestry systems (Atta-Krah et al., 2004; Garrity, 2004; McNeely, 2004; Simons and Leakey, 2004). Diversification could therefore result in improved conservation, although the links between development and conservation goals need to be explored carefully (Adams et al., 2004).

MATERIALS AND METHODS

Study area

Complete tree inventories were made on 219 stratified-randomly selected farms (taken to mean all land managed by a single household) in 10 locations (interactive learning sites belonging to the COSOFAP network, see below) in western Kenya (Figure 1, Table 1). The study area is located within the East and Central African Bimodal Highlands, characterised by altitudes above 1000 m above sea level and bimodal rainfall of more than 1000 mm per annum (Hoekstra, 1988). The highlands of Kenya cover an area of 85,000 km² and accommodate 8 - 10 million inhabitants, corresponding to 15% of Kenya's total land area and 40-50% of its total population (Hoekstra 1988). Of the total area, 59% consists of undulating landscapes with slopes between 2-8%. The soils are erosion prone because of the high land use intensity (Shepherd et al. 1997). Holmgren et al. (1994) described the Bimodal Highlands in Kenya as an area where tree cover on farms is positively correlated with population density and has thus been increasing over the last decades.

The study area belongs to the Victoria Basin forest-savanna mosaic ecoregion (AT0721). This ecoregion is noted for its high species diversity and endemism which results from the mixture of habitat types. These include more than 310 tree species, 280 species of birds, 220 species of butterflies, and 100 species of moths. The forest habitats in the ecoregion have been mostly replaced by savanna, farmland, and pasture (<http://www.worldwildlife.org/wildworld/>).

Within the study area, farming households place more reliance on New World crops such as maize (*Zea mays*), cassava (*Manihot esculenta*), potatoes (*Solanum tuberosum*), sweet potatoes (*Ipomoea batatas*), and beans (*Phaseolus vulgaris*). Trees are retained for fuel in the homestead area, exotic fruit trees are preferably planted in the homestead area, while indigenous and exotic trees are planted on boundaries, in fields and in homesteads. Farmers prefer to plant trees that address several of their needs for poles, construction materials, fuel, and soil fertility enhancement. Selected indigenous trees are retained. In some systems, indigenous trees are expected to grow naturally and should not be planted (Warner, 1993).

COSOFAP network

The Consortium for Scaling-up Options for increasing Farm Productivity and incomes in western Kenya (COSOFAP) was initiated in 2001 and currently has more than 100 member organisations. Funding is provided by the Rockefeller Foundation and by the member organisation. Member organisations include farmer groups and associations, community-based organizations (CBOs), non-governmental organizations (NGOs), the private sector, national research and development organizations (including Kenya Agricultural Research Institute, Kenya Forestry Research Institute, and the extension branch of the Ministry of Agriculture and Rural Development), regional universities, the Regional Land Management Unit (RELMA) of sida, and the Consultative Group for International Agricultural Research (CGIAR) Future Harvest centres and other International Agricultural Research Centres (IARC) present in the region. Effective management of the program across the 23 districts in the region is achieved by three sub-regional co-ordinating committees which report to an overall regional co-ordinating committee that is backstopped by a secretariat hosted by the World Agroforestry Centre (ICRAF).

The key objective of the consortium is to synergise the efforts of the many organisations that work in western Kenya. This synergy is achieved by establishing interactive learning sites that are strategically dotted all over western Kenya, and by avoiding duplication and fragmentation of efforts of the various organisations. Interactive learning sites are sites where partners and farmers share their experiences, demonstrate on-going activities and learning of farmers and extension agents takes place.

COSOFAP targets 100,000 resource-poor farmers each year through farmer-to-farmer dissemination and extension activities. The goals of the consortium are to increase the delivery of information and germplasm (reproductive materials such as seeds or seedlings), define the recommendation domains of available technologies, increase the participation of farmers, enhance knowledge and skills of extension workers, increase linkages with the private sector and markets, and enhance cooperation between research and development institutions in planning and production of extension materials. In the first four years, high priority was given to improving soil fertility, since depletion of soil fertility is a major constraint to improve agricultural productivity of the maize-sorghum-millet-based landuse system of western Kenya. Improved soil fertility has increased the demand of farmers for diversification, including the demand for improved cultivars of crops and trees. Recent activities of the COSOFAP have therefore focused on diversification of agroecosystems.

Farm Africa project on accelerating market-led integration of high-value trees into smallholder farms in western Kenya

The study was conducted in 10 focal scaling-up areas of a Farm Africa project (Figure 1, Table 1). This two-year project (April 2003 – March 2005) catalyzed wide-scale technology dissemination in the Western and Nyanza provinces (the COSOFAP region) by promoting collaboration among community-based, NGO, national and international institutions in planning and executing project activities.

The ten locations were selected in a consultative manner based on: (i) existence of relevant baseline data; (ii) match between available agroforestry technologies and farmer interest and priorities; (iii) reasonable road access to markets; (iv) existence of development partners working collaboratively; and (v) feasibility of making significant impact within two years. Other indicators considered were: existing production and marketing potentials, levels of vulnerability to food insecurity and poverty, existing extension staff competencies and performance and current levels of local participation and interests in the technologies available. Selection was carried out together with COSOFAP partners using Geographical Information Systems (GIS) tools, recent development statistics and partner information.

In every location, a change team consisting of farmers (50% women), the area chief or sub-chief, the headmaster of the local school and one development facilitator was formed. The farmers in the committee represent farmer associations or common interest groups in the area. Selection to committees was based on potential of persons to act as change agents within their communities. The selection was carried out with transparency and involvement of partner institutions and communities.

The change teams were taken through practical, field-based and modular training events over the two year project cycle. The primary training goal was efficient technology dissemination through graduating a number of farmer trainers who act as volunteer frontline extension staff in their areas. The secondary goal was to enable extension staff to develop into local facilitators in participatory extension and rural development.

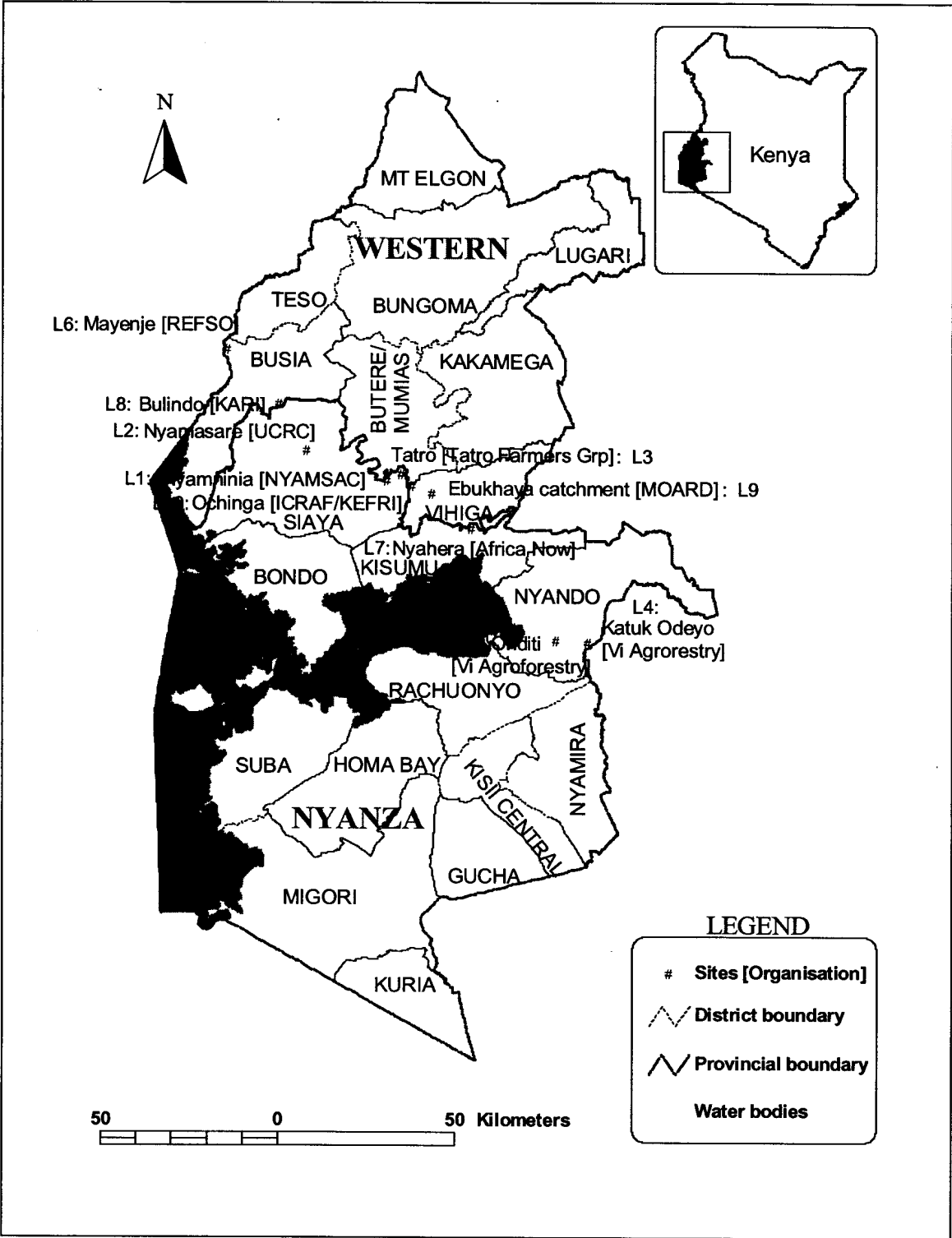


Figure 1. Location of the interactive learning sites (focal scaling-up areas) with organisation within western Kenya. The tree diversity study was done on complete farms within each interactive learning site through the COSOFAP consortium and a Farm Africa project, with co-funding from VVOB (Flanders, Belgium).

Table 1. Organisations and locations of interactive learning sites

Code	Organization	Type	District	Site	N	E
L1	Nyamninia Sublocational Agroforestry Committee	CBO	Siaya	Nyamninia	0.10	34.50
L2	Ugunja Community Resource Centre	NGO	Siaya	Nyamasare	0.18	34.30
L3	Tatro Farmers Group	CBO	Siaya	Yala	0.12	34.54
L4	VI Agroforestry	NGO	Nyando	Karuk Odeyo	-0.31	35.02
L5	VI Agroforestry	NGO	Nyando	Pap Onditi	-0.31	34.93
L6	Rural Energy Food Security Organisation (REFSO)	NGO	Busia	Mayenje	0.44	34.10
L7	Africa Now	NGO	Kisumu	Nyahera	-0.02	34.72
L8	Kenya Agriculture Research Institute (KARI)	Research	Busia	Bulindo	0.30	34.23
L9	Ministry of Agriculture And Rural Development	GO	Vihiga	Ebukhaya	0.07	34.62
L10	World Agroforestry Centre (ICRAF) in collaboration with the Kenya Forestry Research Institute (KEFRI)	Research	Vihiga	Ochinga	0.09	34.57

Data collection methodology

Complete tree censuses were made on farms in 10 locations in western Kenya by each partner organisation (Table 1). After counting the abundance (number of individual trees) of each species occurring on a farm, farm respondents were requested to list all the uses of the different species encountered on their farm. Some information on the farm and household, such as the farm size, the number of children and the type of head of the household, were also recorded. Information was recorded on a questionnaire form in the field, and was entered and checked for errors in a MS Access database. This database generated the datasets that were used as inputs in the subsequent statistical analyses.

Data analysis methodology

Total and average tree species richness and tree abundance were calculated for the survey and for separate locations. Species accumulation curves were calculated using the exact method for calculating the average number of accumulated species when sites (here: farms) are accumulated in a random pattern, or when individuals (here: trees) are accumulated in a random pattern (Gotelli and Colwell, 2001; Kindt, 2002; Kindt and Coe, 2005; Kindt et al., in press2). Species accumulation curves were calculated separately for each location so that differences in species richness could be analysed.

Diversity (which is influenced by the number of species and the evenness in the abundances of each species) was analysed by rank-abundance curves and Rényi diversity profiles. Rank-abundance curves list species in decreasing order of abundance (number of individuals). Rényi diversity profiles allow for partial ranking of ecological communities in diversity: a community of higher diversity than a second community will have a diversity profile that is everywhere above the profile of the second community. When communities have corresponding diversity profiles that intersect, then this means that one community will have more species but that these species will not be more evenly distributed than the second community (Tóthmérész, 1995; Kindt, 2002; Kindt and Coe, 2005; Kindt et al., in press1). Diversity profiles offer a superior way to investigating differences in diversity than diversity indices, since the latter do not provide sufficient information to order communities in diversity. Since sample size has an influence on diversity, comparison of diversity of the different locations was made on the basis of equal numbers of farms using a new randomisation method for Rényi diversity profiles (Kindt, 2002; Kindt et al., 2001, in press1).

The potential influence of explanatory factors on species richness and abundance of individual farms was analysed by regression models. We fitted Generalised Linear Models (GLM; Hastie and Pregibon, 1993; Jongman et al., 1995) with a log link to the observed

number of species and number of individuals. The log link ensures that predicted values will always be positive, which is a desirable property for count data such as the analyzed species richness data (Kindt and Coe, 2005). We fitted GLM with a negative binomial variance function that has been recommended to analyze datasets with overdispersion or clumped populations (White and Bennets, 1996; Venables and Ripley, 2002). The contribution of each explanatory variable to explained deviance was tested by type-II ANOVA by removing each variable from the model that included all variables.

Differences in species composition were analyzed through the Bray-Curtis distance. This distance coefficient is one of the ecological distance measures that are best suited for analysing differences in species composition and is calculated as (Jongman et al., 1995; Legendre and Legendre, 1998; Quinn and Keough, 2002; Kindt and Coe, 2005):

$$D(A, C) = 1 - 2 \frac{\sum_{i=1}^S \min(a_i, c_i)}{\sum_{i=1}^S (a_i + c_i)}$$

where S indicates the total number of species, a_i the abundance of the i -th species on site A and c_i the abundance of the i -th species on site C . The influence of location on differences in species composition was investigated with two related constrained ordination methods. Distance-based Redundancy Analysis (db-RD; Legendre and Anderson, 1999) was used to estimate the significance of the influence on location on differences in species composition. Constrained Analysis of Principal Coordinates (CAP) was used to provide ordination diagrams (Anderson and Willis, 2003).

All these analyses were made with the *BiodiversityR* software developed by Roeland Kindt (Kindt and Coe, 2005), building on the free *R* 2.1.0 statistical program and its contributing packages such as the vegan community ecology package (Oksanen et al., 2005; R Development Core Team, 2005). More details on the various types of analyses can be found in Kindt and Coe (2005), as space is too limited here for more comprehensive treatments of each method for biodiversity analysis.

RESULTS

Farm characteristics

Table 2 shows the quantitative farm characteristics that were recorded. Information on tree species composition was available for 213 farms from the total of 219 farms. As categorical variable, the type of the household head was recorded, with 116 farms categorised as male-headed, 63 farms characterised as female-headed by a woman without husband, and 24 farms characterised as female-headed by a women with an absentee husband.

Table 2. Quantitative farm characteristics

Variable	Mean	Minimum	Maximum	Median
Farm size (acres)	3.07	0.03	17	2.5
Age of head	49.9	18	89	50
Time under current head	20.4	0	69	18
Number of children	4.8	0	17	5
Education level‡	7.1	0	13	7

‡ Education level: 0 (no education), 1-8 (standards), 9-12 (forms), 13 (higher education)

There was no strong correlation among the farm characteristics. The highest variance inflation factor was 3.5 for locations (respondents were younger in locations 4 and 6 [variance explained by linear regression: 11.9%, $P=0.002$], farms were larger in location 6 [var. 11.7%, $P=0.003$], there were fewer children in locations 2 and 10 [var. 13.7%, $P<0.001$], household heads had higher education levels in locations 5 and 7 [var. 32.1%, $P<0.001$], and farms were for a longer time under the current head in locations 6 and 10 [var. 11.3%, $P=0.006$]). This means that the other characteristics explain 70% of variation among variables. This phenomenon indicates multiple correlation among the explanatory variables, but is not considered to hinder the subsequent regression analyses.

Species richness

In the complete survey, 127 tree species were encountered (Table 3). 87 (67%) of these species were indigenous to Kenya, although species' identities need to be confirmed for a number of species. The total number of trees encountered was 249,138. The average number of species on a farm was 9.92 (minimum: 3, maximum: 26, median: 9) and the average number of trees on a farm was 550.7 (minimum: 8, maximum: 13610, median: 308).

Table 3. Total and average tree species richness and average tree abundance for the survey and for the separate locations. Locations are sorted by total number of species and average number of species.

Location ‡	Number of farms	Species total	Species average	Average abundance
L4	20	67	13.00	475
L6	38	51	11.47	650
L2	20	51	11.30	652
L10	20	42	11.35	392
L9	20	42	10.85	258
L5	16	42	9.88	911
L3	20	39	9.10	271
L1	20	36	8.35	194
L8	19	29	7.21	1672
L7	20	17	5.20	70
(all)	213	127	9.92	551

‡ See Table 1 for full description of each location

Differences can be observed between locations in average number of species (Table 3). These differences will be further scrutinized by regression analysis. The fact that the location with the largest number of species (location 4) only contained 53% of the total number of species shows that locations only contain a subset of all the species that occurred in the survey.

Species accumulation curves show how species richness increases when all tree species that occur on 1, 2, 3, ..., all farms are counted (Figure 2). The curve shows that farms differ in species composition: not every farm has the same species. Many more species are encountered at larger scales in the landscape. The average number of species on a farm thus only provides an underestimation of the total number of species in the landscape. The individual-based species accumulation curve shows that species are clustered within farms – if individuals were randomly distributed over farms, then the average number of species on a farm would be 44.2.

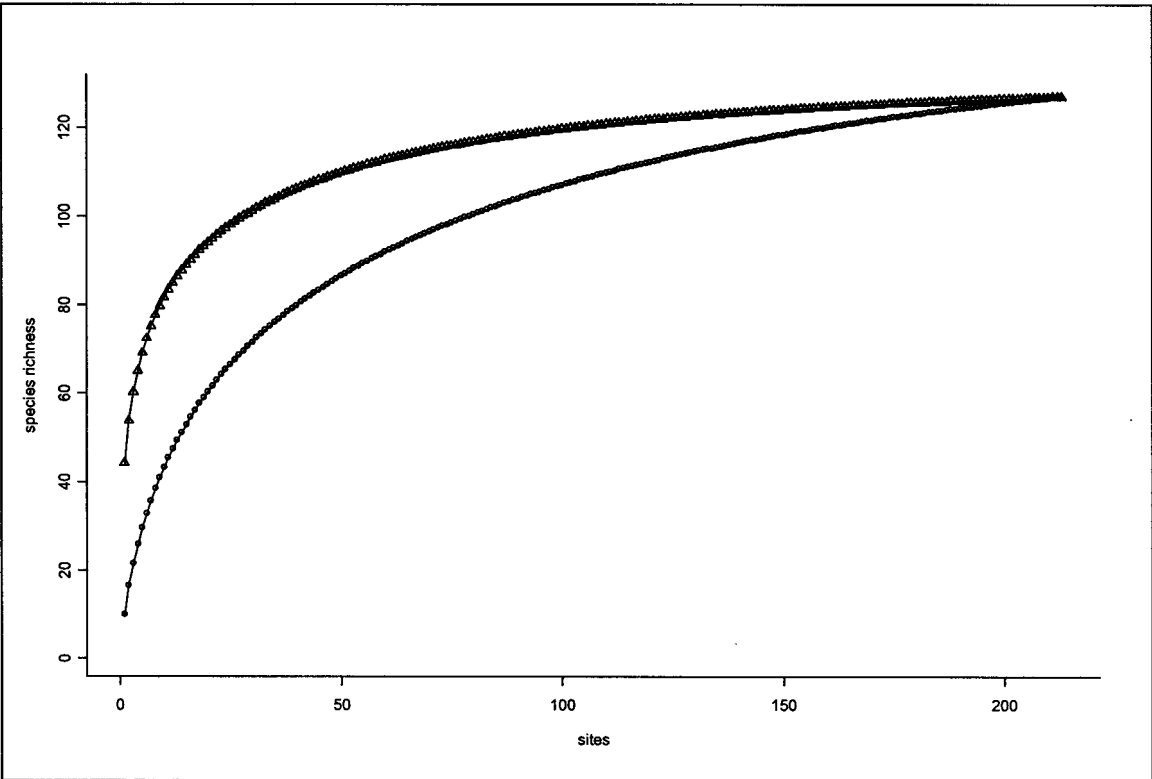


Figure 2. Species accumulation curve observed in the survey (O: random accumulation of sites; Δ: random accumulation of individuals).

The same methodology of species accumulation curves was used to compare species richness between the various locations (Figure 3). Species richness is greatest in the fourth location, and lowest in the seventh location. A ranking of the other locations can also be observed: for example, locations can be ranked as 4 > 2 > 5 > 3 > 1 > 8 > 7.

The previous species accumulation curves did not consider differences in total farm size of the various locations. When farms are scaled by this criterion, a different pattern was observed (Figure 4). No information was available on farm sizes from location 6. Farm size differences did not have a large influence on the differences in species richness as similar patterns are observed (Figure 3). Location 9, however, shows a larger richness for

equal area sampled than for equal number of farms sampled. In this location, farms have the highest richness for 6 or fewer combined farms, when taking farm size into account.

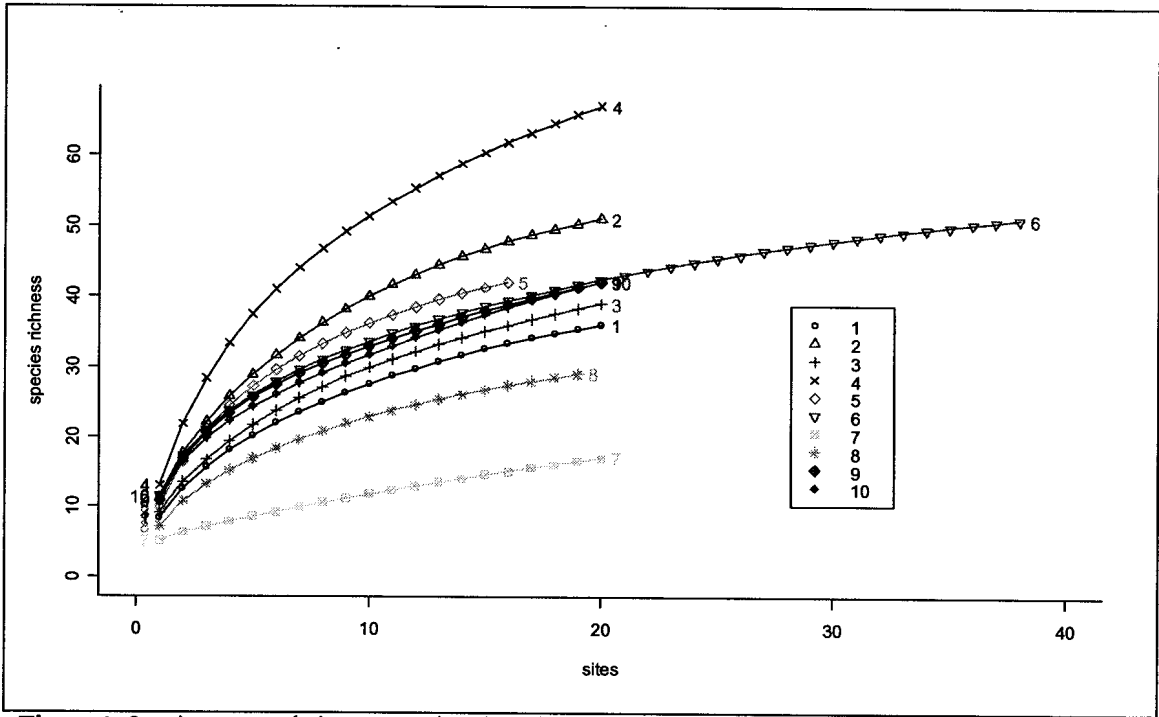


Figure 3. Species accumulation curves (site-based accumulation) for the separate locations.

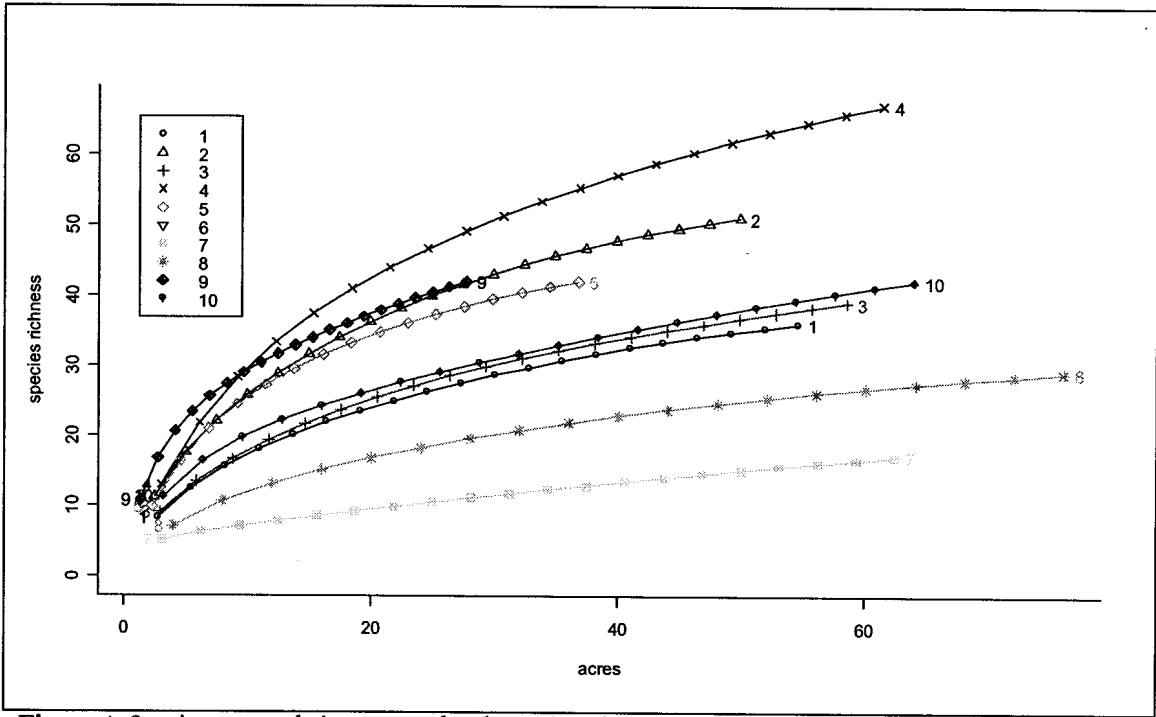


Figure 4. Species accumulation curves for the various locations. The horizontal axis is scaled on the farm sizes recorded for each farm.

When considering differences in total number of individuals per farm (Figure 5), location 7 does not obtain the lowest species richness as in previous figures (Figures 3-4). Location 4 has the highest richness at all scales in figures 3 and 5. Location 5 of the same district that had relatively high levels of species richness in figures 3 and 4, showed low levels in Figure 5.

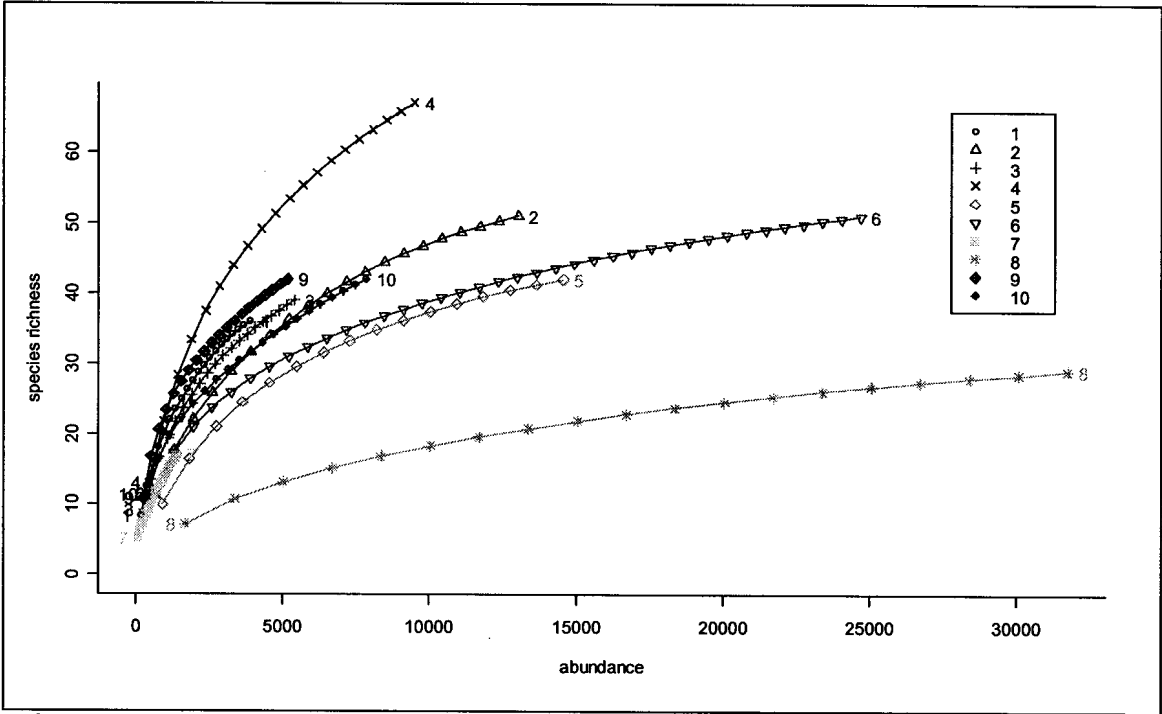


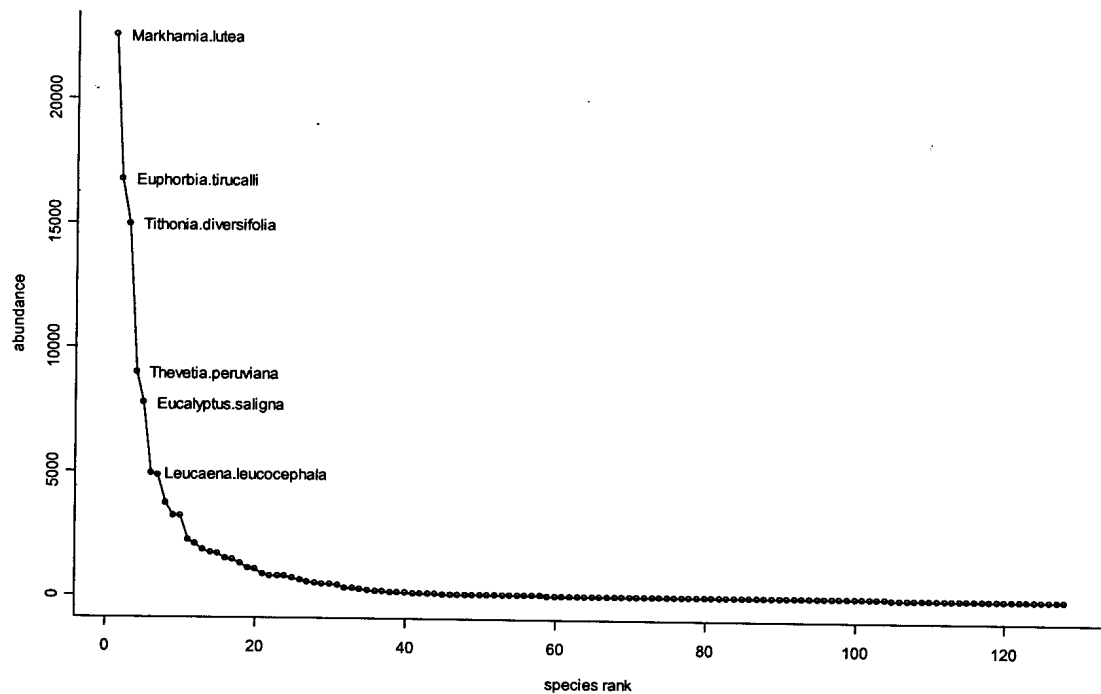
Figure 5. Species accumulation curves for the various locations. The horizontal axis is scaled by the number of trees recorded for each farm.

Diversity

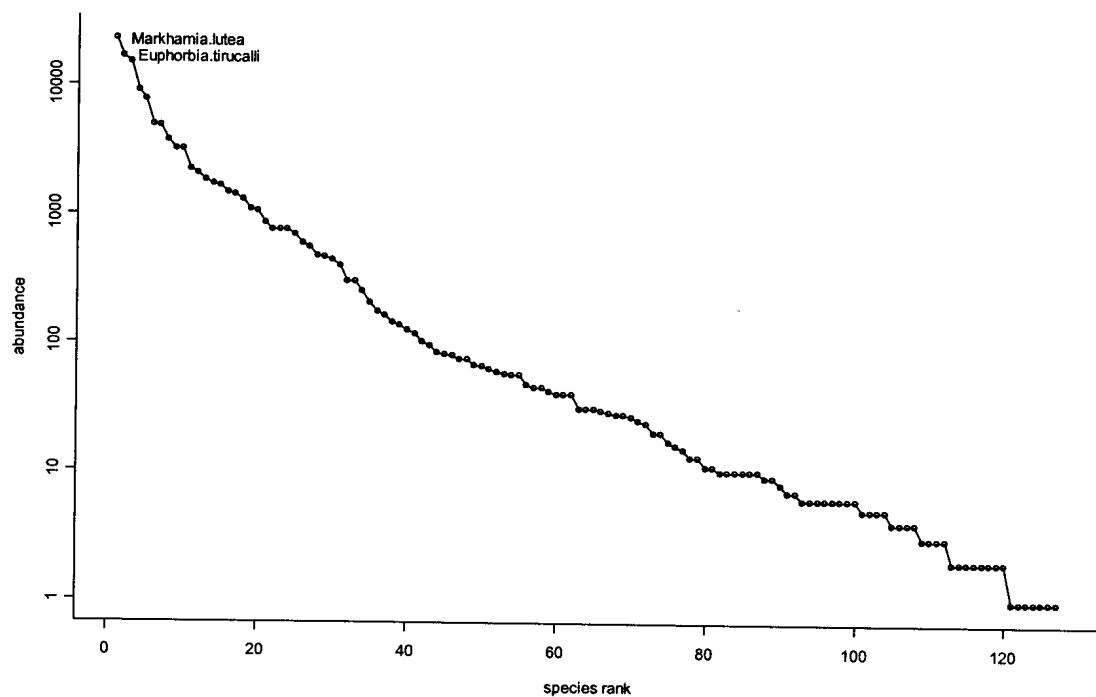
Diversity is not only influenced by richness (the number of species), but also by evenness (similar numbers of trees for each species). A rank-abundance curve is based on the total number of trees for every species ranked in descending order. Few species dominate the landscape (Figure 6). The 10 most dominant species contain 77.5% of all the trees that were encountered, although they only constitute 7.9% of the species (Table 4). Most of the dominant species are exotics, although the most dominant species, *Markhamia lutea*, is an indigenous species. Almost one in five of all trees belong to this species.

Table 4. Abundances (numbers of trees) for the 10 most dominant species in the survey.

Species	Rank	Abundance	% total number	Accumulated %
<i>Markhamia lutea</i>	1	22583	19.3	19.3
<i>Euphorbia tirucalli</i>	2	16763	14.3	33.5
<i>Tithonia diversifolia</i>	3	14960	12.8	46.3
<i>Thevetia peruviana</i>	4	8989	7.7	54.0
<i>Eucalyptus saligna</i>	5	7755	6.6	60.6
<i>Leucaena leucocephala</i>	6	4920	4.2	64.8
<i>Lantana camara</i>	7	4833	3.2	68.9
<i>Cassia siamea</i>	8	3708	2.7	72.1
<i>Tephrosia candida</i>	9	3200	2.7	74.5
<i>Eucalyptus grandis</i>	10	2214	1.9	77.5



(a)



(b)

Figure 6. Rank-abundance curves for the survey. (a) vertical axis on linear scale; (b) vertical axis on logarithmic scale.

An alternative method to investigate patterns of diversity is to construct Rényi diversity profiles. A profile that has greater values corresponds to higher diversity. The results were rarefied to sample sizes of 16 farms to remove the influence of sample size of the results. The fourth location is the most diverse (this location also had the highest species richness at all scales in the landscape) (Figure 6). Location 7 has the lowest richness, but has quite an even distribution exemplified by the most horizontal profile. Diversity is low in locations 8, 1 and 3. Location 2 that has second highest richness has a very uneven species abundance distribution.

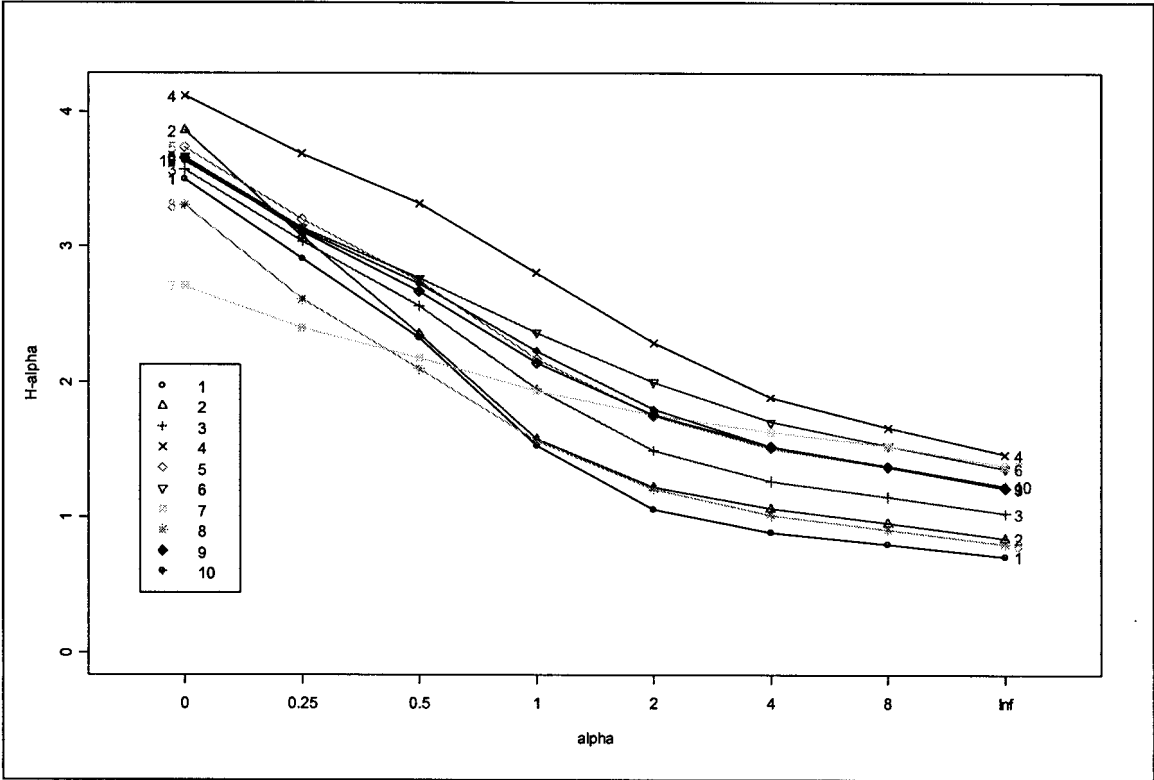


Figure 7. Rényi diversity profiles comparing the diversity of the 10 locations. Location 4 has the highest diversity as it has a profile above all the others.

Regression analysis

We fitted a regression model to explain differences in species richness among the various farms (Table 5). Although there was no strong evidence for a clumped distribution (dispersion estimated from quasi-Poisson GLM = 1.08; theta = 56.9), diagnostic analysis of regression results indicated that more reliable results were obtained with a GLM with a negative binomial variance distribution.

Although the regression only explained about 31.5% of total deviance, these results show that farms of larger size have more species (this is indicated by a positive and significant regression coefficient). There is evidence that farms in Kisumu district contained fewer species than farms in Busia district (chosen as reference district), but there was no evidence for farms in the other districts to differ in average species richness. A similar analysis with locations as explanatory factors instead of districts showed that location 7 contained fewer species, and that locations 2, 4, 5, 6, 8 and 10 contained more species than location 1 (chosen as reference). The ANOVA table provided some evidence that male-headed households contained more species, but this was not supported by

significance levels of the regression coefficients and this variable only explained a very small percentage of deviance.

Table 5. Results of regression of species richness on farm characteristics.

Variable	Coefficient	Significance	
(intercept)	2.17	<0.001	***
Kisumu district	-0.71	<0.001	***
Siaya district	-0.03	0.751	
Vihiga district	0.14	0.114	
Nyando district	0.14	0.126	
Farm size	0.03	0.003	**
Age of head	0.00	0.448	
Number of children	-0.02	0.145	
Education level	0.00	0.882	
Female headed (husband absent)	-0.13	0.217	
Male headed	0.08	0.348	
Duration under current head	0.00	0.616	

	Deviance % (ANOVA II)	Significance	
District	4.9	<0.001	***
Farm Size	3.7	0.004	**
Age of head	0.3	0.454	
Number of children	0.9	0.152	
Education level of head	0.0	0.884	
Type of head	1.7	0.024	*
Duration under current head	0.1	0.620	
Residual	68.5	-	-

In analogy to the investigations for species richness, we fitted a regression model to explain differences in tree abundance among the various farms (Table 6). Because dispersion was large (the quasi-poisson GLM calculated a dispersion of 369.5), a negative binomial model was fitted with theta estimated as 1.21. The model explained 29.2% of deviance.

Table 6. Results of regression of tree abundance on farm characteristics.

Variable	Coefficient	Significance	
(intercept)	6.94	<0.001	***
Kisumu district	-2.47	<0.001	***
Siaya district	-0.89	<0.001	***
Vihiga district	-0.87	<0.001	***
Nyando district	-0.70	0.005	**
Farm size	0.08	0.006	**
Age of head	0.01	0.357	
Number of children	-0.03	0.302	
Education level	-0.02	0.351	
Female headed (husband absent)	-0.45	0.092	.
Male headed	-0.32	0.168	
Duration under current head	-0.01	0.065	.

	Deviance % (ANOVA II)	Significance	
District	3.7	<0.001	***
Farm size	2.4	0.015	*
Age of head	0.3	0.414	
Number of children	0.3	0.384	
Education level of head	0.3	0.397	
Type of head	0.5	0.305	
Duration under current head	1.1	0.090	.
Residual	70.8	-	-

These results show that larger farms contain more trees. Farms in Busia district contained most trees on average (shown by significant negative regression coefficients for the other districts). There are also differences among locations, with fewer trees in location 7 than location 1 (chosen as reference), and more trees in locations 2, 4, 5, 6, 8

and 10. There was some indication that female-headed households where the husband was absent had fewer trees, and some indication that farms that were longer under the current head had fewer trees, although these variables explained low percentages of deviance.

Differences in species composition

Differences in species composition were investigated by ordination models that investigated whether location explained differences in species composition. A permutation test revealed that differences among villages were significant (pseudo- $F=4.16$, $P=0.001$ for distance-based Redundancy Analysis). The Constrained Analysis of Principal coordinates provided the best discrimination results for 37 Principal Coordinates Analysis axes, with 67.6% correct predictions, and these results were therefore used to construct the ordination diagrams.

The ordination diagram provides further evidence for compositional differences among locations (Figure 8). The symbols in the graph correspond to the farms. Farms that are more similar in species composition are closer together on the graph. The ellipses indicate where 90% of farms of a location are expected to be placed on the graph. Since the ellipses do not overlap much, we have other evidence of compositional differences. Species composition is especially different for locations 4, 5, 7 and 9. Of these four locations, farms of locations 4 and 5 (which are the two locations from Nyando district), were ordinated in the same region of the graph, indicating similarity of species composition of both locations.

Information on species can be added to an ordination diagram (Figure 9). The vectors show the species that contribute most to differences in composition (Figure 8). Some of the species names have been provided for the species that contributed most to the graph. The direction of the vectors indicate where farms are located that are expected to contain more trees of the specific species. For instance, locations 4 and 5 contain farms with higher presence of *Balanites aegyptiaca*, *Terminalia brownii*, *Euphorbia tirucalli*, *Albizia coriaria* and *Citrus sinensis*.

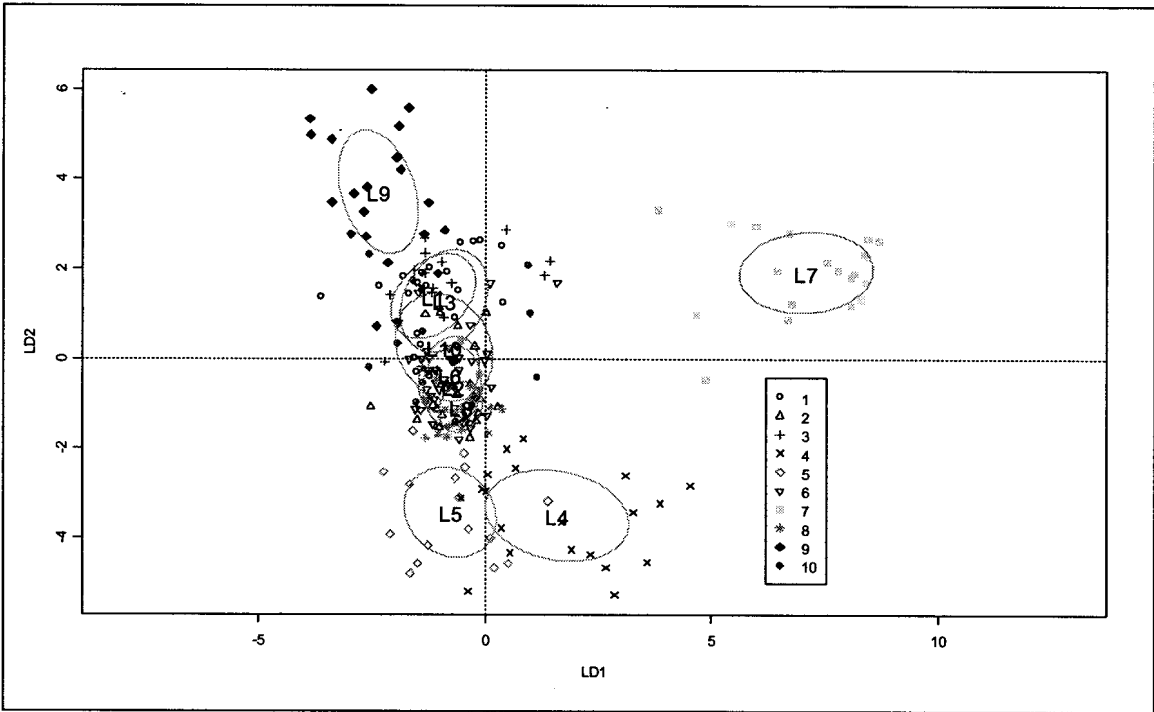


Figure 8. Compositional differences between locations derived by CAP. Ellipses indicate where 90% of farms (symbols show the actual ordination of each farm) are expected to occur from each location.

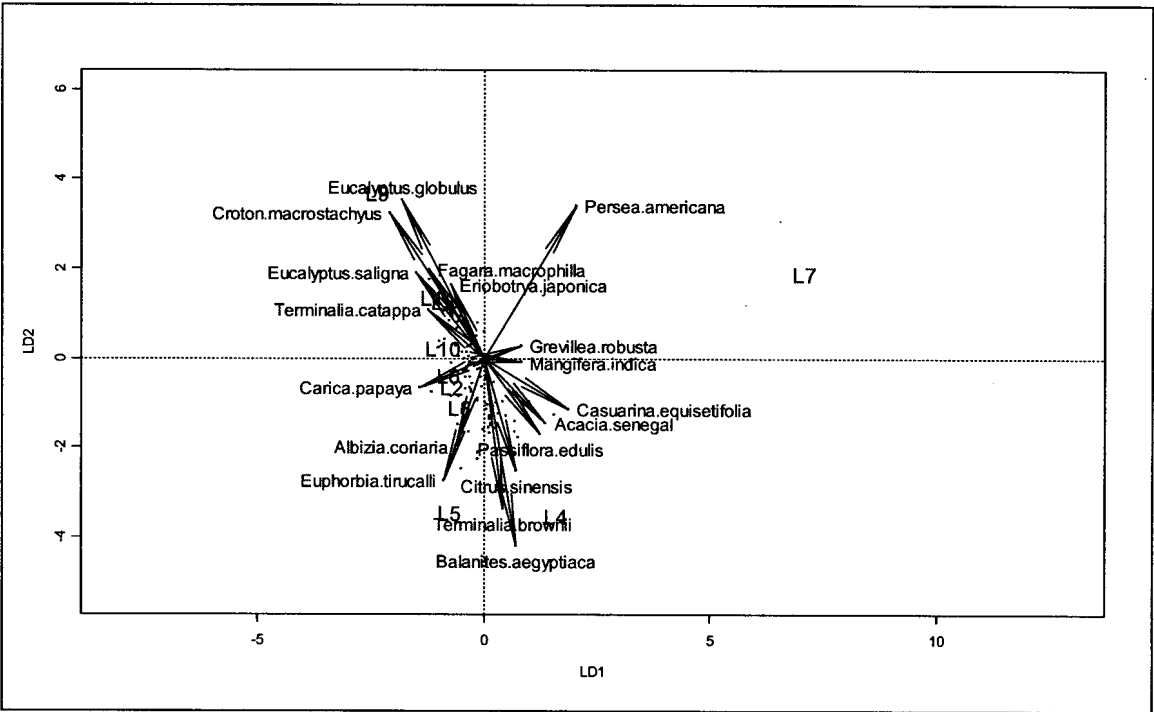


Figure 9. Compositional differences between locations derived by CAP. Circles correspond to farms, vectors or crosses to species. The centroid of each location and the identity of the prominent species are provided.

DISCUSSION

Biodiversity patterns

The results show that there is statistical evidence for differences in biodiversity between locations. Different types of analysis were conducted that investigated different aspects of biodiversity, such as differences in species richness at various scales in the landscape, differences in richness related to farm characteristics, differences in diversity or differences in species composition. The length of this paper does not allow for a thorough interpretation of the results in the face of options for diversification, but a few remarks can be made. The interested reader can consult papers that used similar methodologies, such as Kindt et al. (2004, in press1, in press2).

The results show that tree diversity can be increased in the studied agroecosystem without the need of introducing new species into the area, but by distributing species that are present in some locations more widely. A wider distribution would especially be useful for indigenous tree species, because although the majority of tree species that were encountered were indigenous, the abundance of most indigenous species was low (as shown by the rank-abundance curves) and evenness of each location could be improved substantially (as shown by the Rényi diversity profiles). A wider distribution of indigenous species could be achieved by distributing species more widely over farms (as shown by species accumulation curves) and/or a wider distribution over locations (as shown by the ordination results).

The small abundances of many indigenous species could indicate that genetic diversity and population sizes could be too low to sustain several indigenous tree species within the agroecosystem if their abundance is not increased (O'Neill et al., 2001; Atta-Krah et al., 2004). Since genetic diversity is required for long-term survival of species, tree diversification with native species in agroforestry system could be one of the avenues for conservation. Genetic diversity considerations may also indicate that corridors in farmland are required to connect fragmented populations in the remaining natural ecosystems. It may therefore be beneficial to conduct landscape-level molecular diversity studies, as currently conducted by ICRAF for some indigenous medicinal and timber species, to develop landscape-level conservation strategies. These studies could provide evidence for the need of constructing corridors and increasing population sizes in farmland.

To investigate pathways for diversification, it may be beneficial to investigate diversity patterns for trees that are used for the same purpose separately (Kindt 2002; Kindt et al., 2004, in press1, in press2). To achieve diversification of a landscape, diffusion between farmers of tree germplasm and/or information on species usage could be promoted. The fact that either distribution of trees or distribution of knowledge could increase use-group diversity is caused by the fact that the same species is not used for the same purposes on each and every farm. In various instances, some farmers did not use a species for a particular product or service, although it was present on their farm and other farmers were using it for that purpose. It is likely that there are particular reasons why certain farmers have no trees or low diversity of trees for a specific purpose. For example, richer households had fewer medicinal species in another survey that was conducted in four villages in Vihiga and Kakamega districts (Kindt et al., 2004), which could indicate that richer households opt to purchase medicine from off-farm sources and are not interested in having medicinal trees on their farm. Another reason for the difference between species presence and species use could be the erosion of ethnobotanical knowledge. Obviously, the reason why some species are used on some farms and not on other farms should be investigated with communities, as it is possible

that some species were only used as a last resort and are not preferred for a particular purpose.

Warner (1993) stated that farmers, confronted with deforestation, were most likely to establish trees for products for which non-tree alternatives were not available. Construction wood and timber could be such groups, whereas herbs could provide medicine, or crop residues could provide firewood. Diversification of the former use-groups may therefore be more relevant, although expected relevance will need to be tested with communities in the first place.

Biodiversity conservation through agroforestry

McNeely and Scherr (2002) describe that a new type of agriculture is needed that leads to increased food security and conservation gains since human population density and biodiversity are positively correlated in many areas. Their book provides examples of innovative landscape management strategies that successfully combined both objectives by applying ecoagriculture strategies. Our study documented that many tree species have been integrated in farming systems already (conform Ecoagriculture Strategy 4 of mimicking natural habitats by integrating productive perennial plants). As much of 90% of biodiversity resources in the tropics are located in human-dominated landscapes (Garrity, 2004). Agroforestry can reduce the exploitation of protected areas, increase biodiversity within working landscapes, and/or the diversity of trees in farming systems (Garrity, 2004). Diversification of agroforestry systems could therefore result in improved biodiversity conservation, although the links between development and conservation goals need to be explored carefully since community-involvement is not a sufficient requirement for biodiversity conservation (Attwell and Cotterill, 2000; Salafsky et al., 2001; Adams et al., 2004).

To conserve biodiversity through agroforestry in western Kenya poses several challenges, however. The small population sizes of many indigenous species in farmland, and the question whether population sizes can be increased to allow for long-term conservation of species, were mentioned earlier. It also seems that some perceptions of farmers about indigenous species need changing. For instance, many farmers believe that indigenous species will reproduce naturally and do not require raising, are slow growing and can not be marketed. Many indigenous species show good growth rates and can be marketed within acceptable time scales when treated with the same management that is given to exotic species, however. Cultural issues may also need tackling, since women are often not allowed to plant indigenous trees, whereas a large number of farms is female-headed (43% in our survey).

In response to these challenges, as part of the activities of the Farm Africa project that targeted the 10 locations described here, farmers were trained in the value of indigenous tree species, especially for the provision of medicine, fruit and ecosystem services. Training of change teams (see materials and methods) also focused on seed collection, tree establishment and tree management methods for indigenous tree species. Demonstration sites were created that showed the potential of indigenous species such as *Warburgia ugandensis*, *Prunus africana*, *Maesopsis errinii*, *Vitex doniana* and *Trichilia eretica* in diversifying farming systems and providing alternative products that could be marketed.

Ecological reasons for diversification of agroforestry systems include minimizing the chances of pest and disease outbreaks. Promotion of single species for a particular use-group should especially be avoided since several pest outbreaks on agroforestry species have been experienced after large-scale promotions of monoculture agroforestry

technologies (Atta-Krah et al., 2004). Ecological research has also indicated that biodiversity can affect ecosystem function, but that differences in species function are conditions for positive effects of biodiversity on ecosystem stability and productivity (e.g., Nijs and Roy, 2000; Cottingham et al., 2001; Loreau and Hector, 2001; Loreau et al., 2001; Norberg et al., 2001; Tilman et al., 2001; Whittaker et al., 2001). The ecological consequences of increasing the diversity or evenness of trees on farms can therefore not be predicted and thus needs to be evaluated on a case-by-case basis, although natural communities can provide some clues on potential richness and composition (e.g., Van Noordwijk and Ong, 1999).

Adaptive and community-based management of biodiversity

Whereas this work identifies where to intervene in an agroecosystem, diversification should be farmer driven and not merely an exercise in curve shifting. Various authors have indicated that effective management of biodiversity in (agricultural) landscapes can only be achieved by methods of adaptive management (Wood and Lenné, 1997; Meffe et al., 2002; McNeely 2004). Adaptive management is required in most situations since traditional knowledge cannot prepare communities to work in new situations, trial-and-error methods of learning are not readily transferable to other places and people and scientific experiments only work in relatively simple situations. Adaptive management combines the advantages of trial-and-error and scientific learning (Meffe et al., 2002).

Evidence is building to support the view that very few areas in the world have never been influenced by humans, and that the “pristine” or “virgin” forest is above all a myth of urban-dwelling people (McNeely, 2004). Human interventions may therefore enhance forest diversity, but the type of management will determine the positive or negative effect on biodiversity. The best methods of maintaining biodiversity in forest ecosystems seem to be a combined approach of strict protection of strategically selected protected areas, extensive management of forests for logs and other commodities by forestry professionals, intensive management of forests for other products by society and intensive and adaptive management of local people of multiple-use agroforestry areas (McNeely, 2004).

One of the requirements for implementing adaptive management is to use appropriate methods of investigating patterns of biodiversity, and especially to train communities on how to use these methods. Since several of the scientifically recommended methods for investigating biodiversity can be mathematically quite complex (as shown by the methods and results in this paper), the World Agroforestry Centre (ICRAF) has taken the lead in developing appropriate training materials and user-friendly free software to allow its partner organisations to investigate common biodiversity patterns. These training materials were compiled into the *Tree Diversity Analysis: A manual and software for some common statistical methods for biodiversity and ecological analysis* manual and software that will be published by ICRAF later this year (Kindt and Coe, 2005). Both materials will be available free of charge and allow for scientifically-sound and user-friendly analyses of common questions about biodiversity patterns that can be used to monitor the effects of management and are therefore especially suited for methods of adaptive management.

As part of the tree diversity studies that were conducted in the 10 locations and towards monitoring of the impact of interventions on biodiversity (as part of adaptive management), partners were trained in biodiversity analysis with a draft version of the Tree Diversity Analysis manual and software, as part of a VVOB (Flanders, Belgium) project on Testing Options and Training partners in participatory Domestication and

marketing in eastern Africa (TOTDOMEA). Partners were trained in the various methods that are presented in this paper, and the results that are presented here were generated in a participatory workshop that was held in Maseno (September 2003). Similar training events were held in Uganda and Mali, which are other locations of the TOTDOMEA project.

Networking for biodiversity conservation in western Kenya

In its short period since coming into existence, the Consortium for Scaling-up Options for increasing Farm Productivity and incomes in western Kenya (COSOFAP) has already shown the benefit of synergising efforts when various organisations target farmers in the same agroecosystems, especially by avoiding the duplication of efforts and by establishing interactive learning sites.

As the National Environment Management Authority (NEMA) is one of the members of the COSOFAP and the World Agroforestry Centre (ICRAF) is another member, various activities geared at increasing tree diversity have already been undertaken. These activities have focused on the promotion of indigenous tree species in western Kenya and were planned with provincial and district environmental officers of NEMA. A few examples are provided here. One of the activities was on tree planting with farming communities around gullies in Nyando district. Another activity was on enrichment planting of the Guasi forest by a collaboration of NEMA, ICRAF, Osienala and KEEP. Various activities have been undertaken jointly by ICRAF and NEMA on environmental education with schools, including aspects of the value of biodiversity of indigenous flora and fauna. Yet another activity is underway on Rusinga island on the planting of the indigenous *Albizia coriaria* for boat building.

The ongoing tree diversification and biodiversity conservation activities offer a unique possibility to monitor the potentials for agroforestry as a system of ecoagriculture. We advocate that these activities are monitored for their effectiveness in achieving these dual goals, especially because monitoring is a crucial element of adaptive management strategies that may be required to achieve biodiversity conservation and enhanced livelihoods through agroforestry as an ecoagriculture strategy. Some of the methods that were presented here and are available through the new manual and software on biodiversity analysis (Kindt and Coe, 2005) could be used during monitoring as an integral part of adaptive management of tree diversity in western Kenya.

ACKNOWLEDGEMENTS

We are very grateful for all farmers and collaborators that participated in the survey, with special thanks to Walter Adongo, Willis Atiang, James Ayuoyi, George Etindi, Gordon Kojo, Michael Odongo, Charles Ogada, Paul Okongo, Mark Otieno, Vincent Otieno, Daniel Rotich and Michael Wamalwa for coordination the survey in the various locations. We highly appreciate the support from Farm Africa through the project on Accelerating Market-led Integration of High-Value Trees into Smallholder Farms in Western Kenya and from VVOB (Flanders, Belgium) through the ICRAF-TOTDOMEA project.

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