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Plant species diversity in a changing agricultural landscape: the case of Kaweri Coffee Plantation, Central Uganda

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Abstract

Plant diversity in Kaweri Coffee Plantation was inventoried in January 2002. The aim was to document the species in the area before establishment of a coffee plantation and to create a database for monitoring changes in the ecosystem. International Forestry Resources and Institutions' (IFRI) method of three concentric circles was used to collect data from 64 sample plots established along transects laid in four major habitats: closed forest, swamp, grassland and farmland. All the plants were identified to species level except two, which were identified to genus level. Nine hundred and ninety nine individuals were identified comprising 215 tree species, four shrub species and 403 species of non-woody plants from 255 genera and 85 families. Most of the plants (98.3%) were Spermatophytes, a few (1.7%) were Pteridophyes and only two were orchids. Some of the species identified were adapted to one or more habitats; the majority was adapted to roadsides and farmlands. A comprehensive survey of plants and establishment of a database for monitoring future changes in the landscape is recommended as part of a planned investment in plantation agriculture.

Key words: Coffee plantation, plant species diversity, agroecosystem, vascular plants

Introduction

One of the most striking features of the conservation movement of the late twentieth-century has been the expanding scope and technical competence for creative conservation of nature. Recently, several conservation organisations have come to the conclusion that there will never be enough protected areas to preserve current levels of wild biodiversity (Paden, 2002). Even intact protected areas lose species when invasive species, pollution and development pressure move in from surrounding areas. For rural people, wild plants and animals provide food, medicine, building materials, income and non-resource benefits. However, instead of producing a sustainable flow of renewable resources provided by nature, with little human input, recent agricultural developments are depleting soils, genetic and species diversity both in managed estates and surrounding habitats (McNeely & Miller, 1984). Past efforts to conserve biodiversity have largely focused on increasing the sizes of Protected Areas (PAs) of different categories that could contain large, undisturbed ecosystems. With increasing pressure and demand for agricultural land, the number and size of such PAs is probably getting close to a maximum. It is now becoming apparent that in order to increase the opportunities to conserve biodiversity, new complementary approaches to PAs must be sought because nearly half of the world's protected areas are surrounded by agricultural land (McNeely *et al.*, 1994).

Although agriculture, pastoralism and forestry and other human-managed ecosystems cover about two-thirds of the terrestrial surface of the planet, the most common type of land use relates to agriculture and pastoralism or a combination of both. Where the population pressure is low, a number of traditional agricultural and pastoral systems have succeeded in attaining a sustainable level of production while at the same time maintaining a high level of biodiversity as well as most functional aspects of the ecosystem. As such, maintaining biological diversity is essential for productive and ecologically sustainable agriculture (Eilu *et al.*, 2003). Fearnside (1997) noted that in order to prevent declines in the ecological carrying capacity of an area, productive systems brought about by development should be sustainable.

Little attention has been given to changes in biodiversity in agroecosystems, even though there is some indication that certain disturbed or managed ecosystems, including agroecosystems, can maintain a high degree of biodiversity (Eilu *et al.*, 2003). Agroecosystems have been defined as a biological and natural resource system managed by humans for the primary purpose of producing food as well as other socially valuable nonfood goods and environmental services (Paden, 2002).

Since it is true that ecosystem functions may be impaired by loss of biodiversity, there is a need to define the conditions under which such impairments would occur and determine the management interventions needed to mitigate the situation. On this basis, the management of Kaweri Coffee Plantation felt that there was a need to develop a database of plant species diversity that would help in monitoring changes in the agroecosystem. The aim of the study was to inventory the plant species diversity before establishment of a coffee plantation. The data generated would help to determine the importance of biodiversity to agro-ecosystem resilience and productivity. The coffee plantation, like any other development, will have some positive and negative impacts on the environment. The negative impacts include reduction of land cover, biodiversity loss and soil erosion. The positive impacts are increase in employment opportunities and income for the local community and a wider tax base for the country.

Materials and methods

Study area

Kaweri Coffee Plantation is located in Naluwondwa parish, Madudu sub-county, Buwekula County, Mubende District between longitudes 31°40' E and latitudes 0°25' N (Rwabwoogo, 1998). The total project area is 2,512 ha of land, of which 80% is arable and can therefore be used for cultivation of coffee (Gissat Techno Consult Ltd, 2001). The land on which the coffee plantation is now being established was previously owned by a local farmer under the freehold land tenure system and used for growing vegetables that were flown out by using an airstrip situated to the north of the estate. The land has been bought by a German firm, Hansetische Natur-und Umweltiniative e.v. (HNU), and is being developed into a coffee plantation.

The average population density in Mubende is about 8 persons per km^2 (Rwabwoogo, 1998); the Baganda, Banyoro and Bagungu sub-tribe are the major ethnic groups in the area. Agriculture is the major land use and economic activity in the surrounding areas. Crops such as beans, maize, coffee, tea, sweet potatoes, bananas, groundnuts, sugar cane and others are interspersed with settlements. The livestock reared include cattle, goats, sheep, pigs and poultry. The farming system in the area is the banana-coffee-cassava system (NEMA, 2001). Bush burning is very common in the dry season.

The annual rainfall varies between 875 and 1,250 mm, with an average of 1,125 mm per annum and varies from year to year. The mean minimum temperature is 15 °C and mean maximum temperature is 25 °C. The area is made up of Pre-Cambrian and Cainozoic rocks overlain by red ferralitic soils and sandy loams characterised by large amounts of iron oxides. The land is part of the Ugandan plateau and the altitude varies between 1,245 and 1,350 m above sea level (Kaweri Coffee Plantation Ltd, 2001). There are several streams and two major rivers in the area namely, Katabalanga and Kiiye. These are the sources of water to be used for irrigation in the coffee plantation.

The coffee plantation site and surrounding areas are dominated by savanna vegetation with a moderate cover of *Acacia* and *Albizia* species varying in height from 4.5 to 12 meters and the undergrowth dominated by perennial grass. *Acacia polyacantha* Willd., sub-sp. *Campylacantha* ([Hochst. Ex] Brenan), *Acacia sieberana* DC var *vermoesenii* (De Wild.) Keay & Brenan and *Albizia coriaria* [Welw. Ex] Oliv. dominate the tree layer (Langdale-Brown *et al.*, 1964).

Assessment of trees, shrubs and grasses

Transects 500 m apart were established in each section of the estate namely Luwunga, Kitemba, Kitagweta, Nonve and Kyamutuma. Using IFRI's method of three concentric circles (Ostrom, 1993), data were collected from 64 sample plots established along transects at 150 m intervals and originating from a road that ran through the estate in the north–southwest direction. The outermost circle (10 m radius) was used to collect information on mature trees and shrubs >10 cm diameter at breast height (DBH). The middle circle (3 m radius) was used to collect information on saplings (1-2 m height; 2.5-10 cm DBH) and poles (>2 m height; 2.5-10 cm DBH). The innermost circle (1 m radius) was used to collect information on climbers, grasses and sedges and tree and shrub seedlings (< 1m height; <2.5 cm stem diameter at root collar). All the plants encountered in the plots were identified to species level except two, which were identified to genus level. The DBH was measured using a caliper, height of mature trees and shrubs measured using a suunto clinometer, a tape measure was used to measure the distance between sample plots and transects and an altimeter to determine elevation.

Specimens of woody climbers, creeping, twining and epiphytic plants species that could not be immediately identified in the field were collected for subsequent verification of the identifications in the Makerere University Herbarium. The nomenclature of grasses, climbers and other herbs was based on the Flora of Tropical East Africa (Polhill *et al.*, 1952) which was used to confirm the identifications. The trees and shrubs were identified using keys developed by Blundell (1987) and Hamilton (1991). The habitat type where the three concentric circular sample plots were established was recorded as closed forest, swamp, grassland or farmland.

To maximise the number of species encountered in the estate, plant species were also recorded using the opportunistic method. This involved moving around the site in the unsampled areas, around sampled plots and along the transect lines, listing species that were not encountered in the sample plots. Opportunistic surveys were also conducted in patches of vegetation that showed visible differences in structure from those in which sample plots were laid. Isolated ecosystems such as thickets, heavily shaded areas, cultivated areas and swamps were also surveyed. These data were included in the species list but not used in the analysis of plot data.

Data analysis

DAFOR - an acronym for Dominant, Abundant, Frequent, Occasional and Rare (Forest Department, 1996) was used to show the rating of species occurrence. Although other methods e.g. Pitman *et al.* (1999) exist, DAFOR was used because it is suitable for data generated by rapid assessment of plant species. The following criteria were used to rate the occurrence of tree and shrub species in the study: rare (1-10), ocassional (11-25), frequent (26-40), abundant (41-70) and dominant (>70). The following relative frequencies were used to rate the occurrence of grasses and herbs: common (75-100%), frequent (50-75%), occasional (25-50%), and rare (0-25%). Sorensen similarity coefficient (Causton, 1988; Kent and Coker, 1992; Magurran, 1987) was used to show tree/shrub species similarity. Sorensen species similarity coefficient was chosen and used because it gives weight to plots or samples rather than to species that only occur in either sample. It is represented as:

$$S_s = \frac{2a}{2a + b + c}$$

Where S_S=Sorensen similarity coefficient, a=number of species common to both sample plots, b=number of species in sample plot A, and c=number of species in sample B. The coefficient was multiplied by 100% to give the percentage species similarity. McIntosh diversity index (Kent and Coker, 1992; Magurran, 1987) was used to show tree/shrub species diversity. It is represented as:

$$U = \sqrt{\sum_{i=1}^{s} n_i^2}$$

Where U=McIntosh diversity index, s=the number of species, and n=number of individuals or abundance of the i^{th} species in the sample.

Results

Trees and shrubs

Nine hundred and ninety individuals comprising 215 tree species and four shrub species were identified and recorded in 64 sample plots established in four major habitats namely, closed forest, swamp, grassland and farmland. The number of tree and shrub species found in Luwunga, Kitagweta, Kitemba, Kyamutuma and Nonve are given in Table 1.

Table 1. Tree and shrub species per habitat type in each sampling site

Habitat type.	Luwunga	Kitagweta	Kitemba	Kyamutuma	Nonve
Closed forest	25	21	12	32	21
Grassland	15	0	0	2	5
Farmland	20	10	1	4	7
Swamp	5	7	3	2	17
Total	65	38	16	40	50

Luwunga had the highest number of species (65) followed by Nonve (50), Kyamutuma (40), Kitagweta (38), and Kitemba (16).

The average height and DBH of the trees and shrubs are given in Table 2. The table shows that trees and shrubs in Kitagweta were the tallest (average height = 11.2 m) and trees and shrubs in Kitemba had the biggest stems (average DBH=14.97). The average height and DBH were much lower in Luwunga than in the other sections of the estate because most of the plants enumerated were seedlings and saplings.

Table 2. Tree/shrub sizes at the sampling site

Sampling site	Average height (m)	Average DBH (cm)
Luwunga	3.03*	3.99*
Kitagweta	11.22	12.65
Kitemba	10.82	14.97
Kyamutuma	8.46	14.51
Nonve	7.56	7.71

* Values are very low because most of the plants were seedlings and saplings

Species similarity and diversity

Sorensen similarity index (U=0.014 or 1.4%) shows that the tree and shrub species in Kaweri coffee estate were not similar (dissimilarity index S_S=0.986 or 98.6%). The average McIntosh diversity index was 73.896. The two values indicate that the tree and shrub species were more diverse than similar. The highest species diversity was noted in Luwunga (U=104.32) and the lowest in Nonve (U=41.56) as shown in Table 3. This finding is not surprising because a large part of Nonve was heavily degraded by human settlement. It was noted that at one time the area had an army barracks and the soldiers used much of the woody biomass in and around their settlement as a source of energy and building poles. In the process many tree and shrub species were cut or destroyed hence the low species diversity.

Table 3. Tree and shrub species diversity indices for the five sampling sites

Sampling site	McIntosh species diversity index (U)
Luwunga	104.32
Kitagweta	98.51
Kitemba	65.18
Kyamutuma	59.91
Nonve	41.56

Species occurrence rating using DAFOR

Figure 1 shows that more than 60% of the tree and shrub species were rare (R). In Luwunga, 60% of the species were rare, Kyamutuma 66%, Kitagweta 67%, Nonve 76% and Kitemba 92%. There were few species rated as occasional (O) and frequent (F) in all the sections of the estate. No abundant (A) and dominant (D) species was noted in Kyamutuma and Nonve.

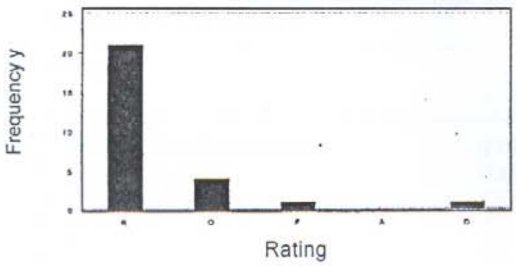


Figure 1. spcies occurrence rating for Luwunga

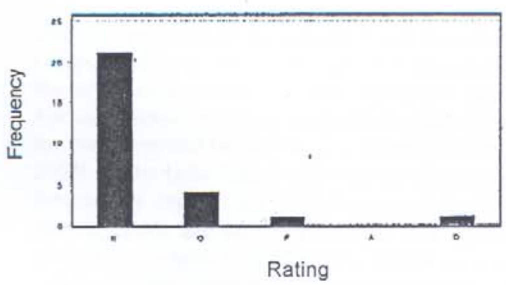


Figure 2. species occurrence rating for Kitagweta

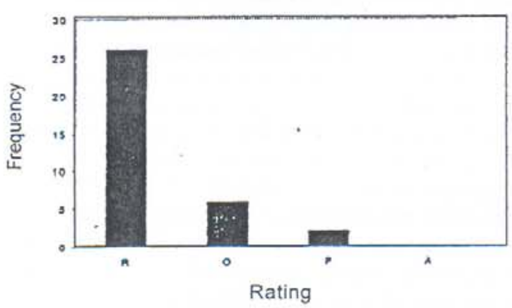
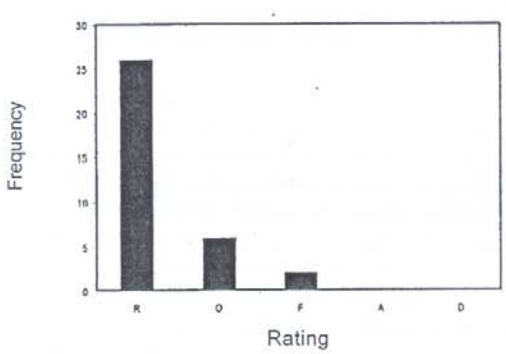


Figure 3 occurrence rating for Kyamutuma



Dominant (D), abundant (A), frequent (F), occasional (O) and rare (R)

A total of 403 species of non-woody plants from 255 genera and 85 families were recorded (Table 4). All the plants were identified to species level except two, which were identified to genus level. Most of the plants (98.3 %) were Spermatophytes, a few (1.7%) were Pteridophytes (ferns) and only two orchids were recorded.

Table 4. Plant species composition of Kaweri Coffee Plantation in Mubende District

Plant type	Families	Genera	No. of species	% of spicies
Spermatophytes	79	247	396	98.3
Pteridophytes	6	7	7	1.7
Total	85	254	403	100

Growth Forms

Table 5 shows that 60.7% of the taxa recorded were herbs, more than 75% of them being erect herbs. Twenty five per cent were twinners or epiphytes. Other growth forms like grasses e.g. *Digitaria abyssinica* (A. Rich.) Stapf, *Eleusine* spp., *Eragrostis* spp., *Panicum maximum* Jacq., *Pennisetum* spp. and sedges e.g *Cyperus* spp., *Kyllinga* spp., and *Lipocarpha chienesis* were also recorded.

Table 5. Relative frequency of the growth forms of the species recorded

Growth forms	No. of species
Herbs	245
Erect	186
Climbing	41
Creeping	6
Twining	5
Epiphytic	7
Grasses	46
Sedges	10
Shrubs	38
Trees	57
Woody climbers7	
Total	**403**

Ecological adaptations

Table 6 shows that some of the species recorded were adapted to one or more habitats. However, it appeared that many of these species were adapted to roadsides and farmlands. These species were mainly weeds such as *Acanthus pubescens* (Thomson ex. Olive) Engl., *Justicia exigua* S. Moore, *Amaranthus dubius* Mart. Ex. Thell. and *Aspilia conyzoides* L. which have taken advantage of human activities in the estate. In fact, the clearing of the original plant cover for coffee cultivation and construction of roads in this area favoured the establishment of these species. In addition, there were species identified and recorded in the closed forest, grassland, and farmland.

Table 6. Ecological adaptation of grass/herb species* in Kaweri Coffee Plantation

Habitat	No. of species
1. Wasteland and roadsides	219
2. Secondary forest	100
3. Mature forest	72
4. Swamps	17
5. Grassland	85
6. Cropland	21

*Some species grow in more than one habitat

Discussion

Over the past decade, agricultural researchers and rural communities have jointly concluded that the poor state of the natural resource base on which agriculture depends is a primary factor limiting agricultural development both in the near term and for future generations (Barrett *et al.*, 2002). At the same time, it has become clear that global food supply depends on intensive agriculture (Lee and Barrett, 2000) and yet it is assumed that agricultural intensification leads to biodiversity decline which could lead to eventual extinction of species if no measures are taken to minimise biodiversity loss. Such losses reduce ecosystem function and the ability of agricultural systems to withstand unexpected periods of stress.

It is believed that agricultural diversification enhances ecosystem resilience and sustained productivity is possible if most of the natural biological diversity is not lost and key functional groups of organisms are not reduced below thresholds that impair agro-ecosystem function. This is unlikely to be the case in Kaweri because of monoculture. However, there are still some questions to be answered in a future study. For example, what are the key functional groups, the loss of which is detrimental to agroecosystem resilience and productivity? Can the appearance or extinction of key functional group(s) or individuals within a group be an indicator of ecosystem degradation? Does reduced biodiversity result in loss of function? Is biodiversity a prerequisite for ecosystem resilience and long-term productivity? These questions should not be ignored if the Kaweri Coffee Plantation project is to remain a showcase for planned investments in large-scale agriculture even if it is monoculture.

Trees and shrubs

Trees and shrubs offer potential advantages over other taxa as biodiversity indicators. Because they are the primary producers, their abundance and diversity is likely to influence the species richness of organisms belonging to other tropic levels. As such they provide a suitable surrogate for all these groups and provide a good measure of overall diversity. The purpose of the plant inventory was to compile a comprehensive species list for the Kaweri Coffee Plantation.

This would facilitate reaching a decision on the biodiversity "hot spots" in the area and to know whether or not the agroecosystem of Kaweri is a place of high conservation value for plants, and draw attention to those species that need special consideration. The inventory has provided baseline data for future monitoring of changes in the plant communities in the uncultivated areas and to enable timely application of mitigation measures. This is particularly useful for evaluating the effectiveness of the coffee plantation management programme, especially where the species concerned was subject to harvesting or other human activities.

The high percentage of rare tree and shrub species in the plantation raises concern on the status of the species over time as clearing for coffee establishment continues. As noted by Sheail *et al.* (1997) to leave nature alone would defeat the purpose of nature conservation. Therefore, there is a need for the managers of the Kaweri Coffee Plantation to consider leaving at least 50% of the present forest cover in order to conserve the tree and shrub species. Although the trees and shrubs may not have high commercial value, their existence is of high conservation importance since the forest fragments are habitats to several species of birds and mammals. The concept of ecoagriculture is relatively new and most ecoagriculture projects (Paden, 2002). Widespread adoption of ecoagriculture would require the support of national policies.

Grasses and herbs

The study has also revealed that grasses and herbs occur mostly in the cultivated and old farmlands where families have been evicted although they grow in other habitats as well. In cultivated areas, these plants are referred to as weeds (Ivens, 1971; Fryer, 1982). The occurrence of these species in Kaweri Coffee estate is obviously due to human activities. The clearing of the natural forest for establishment of coffee plantation has created favourable conditions for these species to grow. They are generally noxious and troublesome to agricultural crops. They are known to compete with crops for soil nutrients, soil moisture, light and carbon dioxide. All these are likely to result in reduction of coffee yields. It is therefore important to identify these plants and to understand their biology and ecology in order to control them.

The current study allowed us to identify these species and to come up with a checklist that can be used for further biological and ecological studies for weed management and control. In order to come up with good management and control strategies of these weed species, there is a need to study their biology e.g. germination, reproduction and dispersal mechanisms, and ecology e.g. life forms, distribution and communities which were not covered in the study. Although it is generally desirable to control weeds, recent studies (e.g. Eilu *et al.*, 2003) have shown that these species are important in terms of biodiversity conservation on agricultural landscapes. Local people eat a number of these species e.g. *Amaranthus*. In addition, there is a need to apply the agroforestry methods in which trees may be planted together with coffee and the shade created would inhibit the growth of weed species since they are light demanding. It would be advisable to use multipurpose-leguminous trees and shrubs that can also improve soil fertility. For this purpose, *Sesbania sesban* (L.) Merill, *Cajanus cajan* and *Albizia* spp could be also used (Katende *et al.*, 1995). Some creeping legumes such as *Puraeria phaseoloides* var. *javaniva* (Benth.) Bak., *Vigna* spp., and *Colopogonium mucunoides* found in the area could be used. Lastly, there is a need to conduct a comprehensive survey of plants prior to establishment of a plantation crop. In this way the data generated would be used to monitor changes in plant species diversity and to apply mitigation measures in time.

Conclusions

A total of 403 species of non-woody plants from 255 genera and 85 families are found in Kaweri coffee plantation. Ninety eight percent of the plants are spermatophytes and 2% per cent are pteridophytes; 25% are twinners or epiphytes interesting tree and shrub species are more diverse than similar as a large part of the coffee plantation has been cleared and degraded by settlement. More than 60% of the tree and shrub species are rare and few are occasional and frequent. Many species are adapted to roadsides and farmlands. Together there is a need for creation of a database for monitoring changes in plant species composition and diversity in Kaweri coffee plantation. The management should prepare a biodiversity-monitoring framework to prevent loss of species. Above all, managment of Kaweri coffee plantation should consider leaving at least 50% of the present forest cover to conserve tree and shrub species above all, management

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