CHAPTER 1 INTRODUCTION

1.1 Background

1.1.1 Zambia's forested areas

Over 69% of Zambia's surface is covered by forest vegetation (Fanshawe, 1971). This forest vegetation is classified into three major categories. The first category is the closed forest which consists of five subtypes: *Cryptosepalum* evergreen forest, *Baikiaea* deciduous forest, and to a limited extent the *Parinari - Marquesia* montane, riparian and swamp forests. The second category is the open forest (savanna woodland) which account for 71% of the total forest area in Zambia. The savanna woodland is dominated by miombo woodland which accounts for 47% of the country's forests. The dominant species in miombo woodland are *Brachystegia* spp, *Pericopsis angolensis, Isoberlinia angolensis*, *Julbernardia* spp and *Pterocarpus angolensis*. This is followed by the Kalahari woodland dominated by *Guibourtia coleosperma*, *Burkea africana* and *Erythrophleum africanum*. Other woodland types with restricted occurrence include mopane woodland dominated by *Colophospermum mopane* and munga woodland dominated by *Acacia* spp. The third category is the thicket. The common type of thickets found include the *Itigi* thicket found in north-eastern Zambia. This dense deciduous thicket is dominated by *Baphia, Combretum,* and *Grewia* species. The other type is the *Pemba* thicket found on the edge of the miombo-dominated plateau in southern-central Zambia. This is also a deciduous thicket dominated by *Byrsocarpus, Canthium, Combretum, Lannea* and *Parinari* species. The last thicket type is the *Termitaria* thicket which occurs on termite mounds in different vegetation types. The dominant plants include *Acacia, Albizia, Commiphora, Cassia, Euphorbia* and *Strychnos* species (White, 1962; Fanshawe, 1971; Chisumpa, 1990).

Zambia's forested areas are a source of many useful wood and non-wood products (Chisanga, 1998). Miombo woodlands in particular produce many species of edible caterpillars, mushrooms, fruits, roots and wild vegetables. Many miombo trees and herbs are used for a variety of medicinal purposes while some miombo trees are exploited commercially for timber, bee-keeping and charcoal (Vernon, 1983; Clauss, 1992; Chidumayo, 1987a). Apart from providing many useful wood and non-wood products, Zambia's forested areas also provide valuable habitats for many faunal species. Miombo and mopane woodlands in particular, host many species of mammals and birds that are of conservation significance both nationally and globally (Benson *et al.,* 1971; Ansell, 1978).

From a protected status perspective, Zambia's forest estate is classified into two categories: National Forests and Local Forest Reserves. The Local Forest Reserves are meant for use by local people and the National Forests are meant to protect and conserve major catchments and biodiversity. Zambia has 481 Protected Forest Areas (PFAs) comprising 181 National Forests and 300 Local Forest Reserves. These cover approximately 74,000km^2 or 9.6% of the country. National Forests and Local Forest Reserves comprise 70% and 30% of the forest estate, respectively. Some of the PFAs are categorized as production forests in which the exploitation of forest products is authorized with license while others are protection forests which are particularly conserved for protection of water catchment areas, wildlife habitat, cultural sites and soil erosion control (Chisanga, 1998; MENR, 1998).

The forest estate is administered by the Forestry Department in the Ministry of Tourism, Environment and Natural Resources (MTENR). However, the Department lacks funds and manpower to effectively manage the estate. As a result, encroachment through settlements and agriculture has reduced the estate by roughly 20% over the past 10 years. Continued encroachment, shifting agricultural practices, uncontrolled tree cutting, charcoal making and fires threaten the country's forested areas. About 1.2% of the country's forested area is lost per annum as a result of the factors mentioned above (Chidumayo & Chidumayo, 1984; World Bank, 1990; Chidumayo, 1993; MENR, 1997; Chidumayo & Njovu, 1998). In heavily populated areas such as Central and Copperbelt provinces, there is considerable pressure to degazette some PFAs. Illegal logging of high value forest species such as *Afzelia quanzensis, Baikiaea plurijuga, Faurea saligna, Guibourtia coleosperma* and *Pterocarpus angolensis* is rampant where vehicle access is possible. In isolated and less accessible areas, forest cover appears to be in reasonably good state irrespective of protected status of the forested area. The alarming rate of the forest ecosystem degradation does not only endanger sustainable timber exploitation but also biodiversity conservation (Chisanga, 1998).

All the land in PFAs is to be used exclusively for the conservation and development of forests with a view to securing supplies of timber and other forest produce, providing protection against floods, erosion and desiccation and maintaining the flow of rivers (MENR, 1998). The forest estate is primarily there for the protection of floral biodiversity, catchment areas and timber supply. Protection of wildlife species and their habitats is secondary. A few PFAs are considered areas of high biodiversity in terms of plant endemism and the variety of bird species, and have been recommended for special protection. One of these areas is the miombo woodland found in Mkushi and Serenje Districts in central Zambia. The area has high rainfall with miombo woodland that is rich in endemic birds. Lack of updated data on the significance of the area to both local and international avifauna conservation has resulted in poor forest resource management in the area (Ferrar, 1998; Leonard, 2005).

Habitat modification and fragmentation are the greatest threats to biodiversity both globally and nationally. This has been recognized by the Zambian Government in the National Environmental Action Plan (MENR, 1994) and the National Biodiversity Strategy and Action Plan (Chidumayo & Aongola, 1998). Shifting cultivation is one of the major causes of habitat modification and fragmentation and yet, the existence of mosaics of regrowth and old growth areas in shifting cultivation regions might in theory promote biodiversity richness and maintenance. To date, little is known about responses of avifauna to protection, traditional land uses and infrastructure development in Zambia.

1.1.2 Zambian avifauna

The avifauna of Zambia is principally that of the Central African Plateau. It belongs to the South Central Highlands District of the Ethiopian zoogeographical subdivision of southern Africa. The district includes and is characterized by the miombo woodland avifauna. The heart of the miombo woodland avifauna lies in Angola, Katanga in Democratic Republic of Congo (DRC) and Zambia, stretching in a slightly impoverished form to Malawi and northern Mozambique (Winterbottom, 1978). There are 112 species of birds that are characteristic of miombo woodland and 23 of these are virtually confined to miombo woodland. A characteristic feature of miombo avifauna is the presence of parties of insectivorous birds of many species which travel through the woodland together (Benson & Irwin, 1966).

In terms of species diversity, there are about 740 species of birds representing 22 orders, 86 families and over 400 genera in Zambia (Benson & Irwin, 1965a; Benson & Irwin, 1965b; Benson & Irwin, 1965c; Irwin & Benson, 1966a; Irwin & Benson, 1966b; Irwin, 1967; Irwin & Benson, 1967; Keith & Vernon, 1969; Benson *et al.,* 1970; Benson *et al.,* 1971; Aspinwall

& Beel, 1998). There are about 64 endemic and near endemic species in Zambia while 76 species are considered to be rare (Leonard, 2005). Bird habitats include miombo, mopane and munga woodlands, forests, thickets, wetlands, dambos and grasslands, rocky places, aquatic habitats and human habitations. There is greater diversity of birds in the northern parts of the country because these areas have higher rainfall and more woodland cover compared to the rest of the country (Ferrar, 1998; Leonard, 2005). The major threats to the birds of Zambia include loss of habitat due to some or all of the following: agriculture; settlements; woodland degradation and uncontrolled bushfires. These threats impose changes in the composition of the species while other activities result in the death of birds (Dowsett, 1973; Konrad, 1980; Collar & Stuart, 1985; Howard, 1988; ZOS, 1990; Dodman, 1994).

1.2 Degradation and fragmentation of the forest ecosystem

Human activities dominate many of the earth's ecosystems. Humans use these ecosystems for agricultural activities, forest products and settlements (Watson *et al.,* 2005). These activities directly diminish the amount of relatively undisturbed habitat available to other species (habitat loss), create islands of undisturbed habitats in a sea of human dominated ones (habitat fragmentation) and, change the characteristics of undisturbed habitats, thereby changing the distribution of resources available to other species (habitat modification/degradation). Habitat loss and fragmentation represent the greatest threat to biological diversity on earth currently (Driscoll & Weir, 2005; Turner *et al.,* 2001; Wiegand *et al.*, 2005). There has been an increasing interest in studying the effects of anthropogenic habitat fragmentation and modification on the spatial dynamics of populations and communities. In particular, the effects of reducing the size of the habitat patches (Area effects), increasing the distance between occupied patches (Dispersal effects) and the creation of habitat edges on patches (Edge effects). The other important aspect of habitat fragmentation is the creation of different, often human dominated, matrix habitats that surround habitat fragments (Matrix effects). How the matrix affects population dynamics is also the subject of current research in habitat fragmentation studies (MacArthur & Wilson, 1967; Forman, 1995; McIntyre, 1995; Berry *et al,* 2005; Harper *et al.,* 2005; Horn *et al.,* 2005; Parker *et al.,* 2005; Schultz & Crone, 2005; Siitonen *et al.,* 2005; Tabarelli & Gascon, 2005; Watson *et al.*, 2005). Habitat fragmentation and modification alters (1) the distribution of populations, (2) the migration rates among populations and, (3) the sizes of local populations. Species characteristics such as trophic level, body size and dispersal ability are some of the factors that determine whether a species will decline after habitat fragmentation or not. Habitat modification and fragmentation often leads to decreased species richness of both plants and animals (Bawa & Sedler, 1998; Lawton *et al.,* 1998). However, species richness does not always decrease with increased habitat modification for certain plant and animal groups (Johns, 1997; Beck *et al.,* 2002).

The forest ecosystem is increasingly threatened by human disturbances such as deforestation caused by agriculture and settlements, selective logging of valuable timber species, habitat fragmentation and fires (Lovejoy *et al.,* 1986; Skole & Tucker, 1993; Johns, 1997; Cochrane *et al.,* 1999; Laurance *et al.,* 2001). Dramatic reduction and fragmentation of forest cover in several parts of the world has prompted many to ask what the impacts of such changes are on animal abundance, species richness and community dynamics (Alo & Turner, 2005; Waltert *et al.,* 2005).

Forest fragmentation is the disruption in the continuity of forest habitat. It is one of the most pervasive and important results of present day human land use dynamics. The rate at which humans are changing the forest ecosystem is thousands of times the background rate of natural forest regeneration. (Chazdon, 2003; Kolb & Diekmann, 2005; Watson *et al.,* 2005; Wiegand *et al.,* 2005; Yates & Ladd, 2005). Results from numerous studies of forest fragmentation show that forest edges represent the main threat for species because of physical and biotic changes associated with edge creation, such as increased wind disturbance to lower soil moisture content. Forest fragmentation and its edge effects reduces plant recruitment because of disruption of seed rain; increases habitat desiccation due to increased insolation and evapotranspiration; increases seedling damage caused by litter fall and tree fall near the edges; increases sapling mortality by competition with creepers, vines and ruderal species and, increases adult tree mortality caused by uprooting and breakage near forest edges. Many environmental changes resulting from the creation of forest edges diminish after some years of edge formation as the forest edges are sealed by regrowth suggesting that simple measures can be taken to stabilize degradation of forest edges over time (Freer & Hingrat, 2005; Mathieu *et al.,* 2005; Radeloff, 2005; Sayre, 2005).

The loss of primary forest results in the creation of a new matrix habitat which promotes additional changes in forest patches such as:

- Species associated with disturbed areas present in matrix habitat may invade forest patches and edge habitats.

- Depending on land use, matrix habitat will take on a different form (pasture or secondary growth forest) which can magnify the severity of edge effects on fragments.

In addition, the position or strata that a species occupies can render it more or less vulnerable to the effects of habitat fragmentation i.e. shade tolerant understorey shrubs are especially extinction prone in isolated forest fragments. Plant position in the understorey may also render the species prone to smothering by invasive creepers (Driscoll & Weir, 2005).

1.3 Role of vegetation in influencing avian community structure

Community organization implies attributes concerned with species occurrence and their interactions such as abundance, diversity, succession, stability and trophic relationships (Haefner, 1981). The role of vegetation in influencing avian community structure came to prominence when MacArthur and MacArthur (1961) published their ground breaking work on the relationship between plant diversity and avian diversity. They concluded that the layering of the vegetation in deciduous forests was more highly correlated with the number of bird species in an area than the number of tree species. They expressed the relationship as a correlation between foliage height diversity (FHD) and bird species diversity (BSD). Further work revealed that the reason why one habitat supports more bird species than another is due to differences in the internal variation of the vegetation profile. Vegetation at many heights above ground will simultaneously support ground dwellers, shrub dwellers and canopy dwellers. The variety of plant species had no direct effect on the diversity of bird species (Mac Arthur *et al.,* 1962). MacArthur (1964) found that the number of breeding bird species is greatest when the three layers have equal amount of foliage in the herbs, shrubs and tree layers. Within homogenous habitats, the number of layers of vegetation is sufficient to account for the diversity of breeding bird species, but when the area includes major differences as those between different habitats of sparse and dense vegetation, then the number of layers of the vegetation is no longer sufficient to account for bird species diversity.

Since the grounding breaking work of MacArthur and MacArthur, other workers have found that different components of the vegetation other than foliage height diversity influence avian diversity. Wilson (1974) found that bird species composition is not related to similarity of foliage distribution and that bird species diversity was linearly correlated with foliage height diversity and curvelinearly with total percentage vegetation cover. Karr and Roth (1971) found that bird species diversity was linearly related to foliage height diversity and sigmoidally related to the % vegetation cover. They found out that the volume of the vegetation in addition to the layering and distribution among the layers is important as a predictor of bird species diversity. The relationship between FHD and BSD has been criticized by James and Wamer (1982) because the concept confounds the effects of species richness and relative abundances of birds and ignores spatial attributes of the vegetation other than vertical distribution. As a function of the number of height categories of the vegetation and how evenly they are distributed among categories, FHD is actually a measure of canopy height, and as such the classic FHD-BSD relationship is not necessarily a function of diversity in either the birds or vegetation. Holmes and Recher (1986) found that the foliar arrangement, positioning and accessibility of available substrates and the types and availabilities of food resources strongly influence how birds forage. Since foliage structure and resource availability change over the vertical profiles of forests and vary with plant species, they act in conjunction with forest stratification to shape the kind of foraging opportunities that can be exploited by birds. In relating avian species diversity to vegetation diversity, the important fact is that it is specific plant species and their different physiognomies and food resources which should be emphasized and not FHD alone. Two physiognometrical factors affecting avian species diversity are first foliage height diversity and secondly spatial heterogeneity. An increase in avian diversity is associated with increased vegetation structural diversity and tends to be more clearly defined in areas with variations in woodland populated with trees of varying leaf types from broad to fine-leaved (Hudson & Bouwman, 2007).

1.4 Responses of birds to forest degradation and fragmentation

Major goals of avian community ecology are to identify recurrent patterns of species composition, guild structure, diversity and other parameters among co-occurring species and to understand the factors promoting those patterns (Holmes & Recher, 1986). The structure and functioning of a biological community are affected by characteristics such as life histories and interactions of its constituent species. Which species actually co-occur in a particular place at a given time is determined by a variety of historical and ecological factors (Holmes *et al.,* 1979). Greater species diversity of plant communities and a higher level of complexity in food chains are the two characteristics of tropical communities that are expected to allow increased avian species richness (Powell, 1989). Habitat characteristics largely determine the number of bird species and individuals that may exploit available resources and survive in that habitat, and biotic interactions may alter individual foraging characteristics and contribute to partitioning of exploitable resources (Landres & MacMahon, 1980). Studies have shown that guild structure varies from site to site and is correlated with particular features of the habitat and resource base. Plant species diversity, plant physiognomy, habitat heterogeneity and differential use of plant species by birds have been shown to strongly influence the structure of bird communities (MacArthur & MacArthur, 1961; Wilson, 1974; Holmes & Robinson, 1981; Karr & Roth, 1971; Hudson & Bouwman, 2007).

An important priority in any species conservation is identifying habitats and landscapes that promote high survival and reproduction and protecting as much area of such as possible (Marini & Garcia, 2005). Landscape effects, such as habitat fragmentation and changing land-use pattern, have important implications for planning bird species conservation. Bird species have been especially useful in demonstrating the effects of landscape change because they are particularly responsive to landscape level alterations and are highly mobile and visible (Herrando *et al.,* 2003). Birds respond differently to habitat alteration. Some species benefit from alteration and increase their populations whereas others have become extinct or threatened (Crick, 2004; Seoane *et al.,* 2005). Studies of birds have demonstrated that simple changes in the amount of edge, as well as habitat area accompanying landscape fragmentation may affect avian diversity. Certain species of birds benefit from an increase in edge habitat whereas in others it has a negative impact. Edge habitat increases the occurrence of brood parasites, predators and competitors. Small habitat patches generally have more edge relative to interior than do extensive habitats, which may expose species characteristic of the forest interior to increased risk of predation, parasitism or competition, as well as, reducing foraging and nesting space. Species loss in smaller forest fragments therefore increases and movements among forest patches decreases in forest interior dependent birds more than in edge dwelling or other types of birds (Marsden & Pilgrim, 2003; Alo & Turner, 2005; Freer & Hingrat, 2005; Jones *et al.,* 2005).

Forest degradation is known to affect birds differently depending on the functional groups they belong to and on the degree of trophic specialization (Forman, 1995; Collinge, 2000; Davis *et al.,* 2001). Understory insectivorous birds have been found to be more sensitive to forest modification than other guilds. The abundance of this guild decreases drastically with habitat fragmentation and modification (Lovejoy *et al.,* 1986; Sieving & Karr, 1997; Stouffer & Borges 2001). Specialist forest interior species and non-migratory species are more likely to be behaviorally inhibited from crossing barriers, such as matrix habitat, compared to generalist, forest canopy and migratory species (Sekercioglu, 2002; Lampila *et al.*, 2005).

Predictions of species loss due to forest degradation and deforestation in tropical areas have been made several times but have been criticized partly because of a failure to acknowledge the ability of many tropical forest species to survive in agricultural production areas. Tropical bird species differ in their likelihood of sustaining populations in tropical forest fragments and these differences are in part attributable to differences in the extent to which forest species use agricultural matrices surrounding forest fragments. Recently, several studies have addressed the conservation value of agricultural landscapes and have shown that a relatively high number of individuals and species can still be found in man-altered systems (Bishop & Myers, 2005). A considerable number of such species are part of the natural forest fauna. However, abundances of such species may be affected by interspecific interactions. Even if species richness may change little with disturbance, trophic structure may be altered and species characteristic of primary and old-growth or secondary forest may be replaced by species associated with disturbed habitats. For birds, general findings have shown that traditional agro-forests with a mix of cultivated and natural shade trees can support a high number of species including many forest specialists, especially in close proximity to natural forest. In contrast, agro-forests with planted shade trees even if composed of many tree species only support a few forest specialist birds in the absence of nearby primary forest. Monocultures of grain crops generally do not support high numbers of bird species in forest regions but the picture is often different if groups of tall trees and forest fragments are left in the agricultural landscape (Lindell *et al.,* 2004; Bradbury *et al.,* 2005; Guenette & Villard, 2005; Nol *et al.,* 2005; Wilson *et al.,* 2005; Wunderle *et al.,* 2005).

The impacts of forest management on birds are difficult to detect because contrast among patches is not as clear as in urban or agricultural landscapes. The mosaic created by forestry is composed of stands of different age, structure and composition which exhibit subtle contrasts in habitat quality or permeability to movement. Silvicultural treatments vary in intensity from clear-cutting over large areas to single tree selection. Some of these forestry practices produce marginal habitat for certain forest bird species. Low intensity practices, such as single tree selection or thinning, seem to have less of an effect on birds of late seral forests than more intensive treatments but they still can significantly reduce the abundance or productivity of certain species associated with closed canopy stands (Borman, 2005; Lampila *et al.,* 2005; Tabarelli & Gascon, 2005).

1.5 Objectives and hypotheses

1.5.1 Objectives

The above review on responses of birds to forest degradation and deforestation suggests that any investigation of effects of such habitat changes needs to consider habitat status, the avian community therein and analysis of how habitat changes impact on avifauna. Therefore this study was based on three broad objectives : (1) to evaluate the habitats in the study area and establish the level of woodland degradation in the study area, (2) to determine the avian community structure in the study area and, (3) to analyze the impact of woodland degradation on the avian community structure.

Under broad objective 1, the specific objectives were:

(i) To determine vegetation composition (species richness, diversity and evenness) in the study sites,

(ii) To determine the vegetation structure (density, basal area cover, height and canopy cover) in the study sites and,

(iii) To assess woodland degradation in the study sites.

Under broad objective 2, the specific objectives were:

(i) To determine avian species composition and bird species groupings in the study area,

(ii) To determine avian species richness in different habitats,

(iii) To determine avian abundance in different habitats,

(iv) To determine avian guild richness in different habitats and,

(iii) To determine habitat range specialization of the avifauna in different habitats.

Under objective 3, the specific objectives were:

(i) To identify habitat factors that significantly influence avian community structure,

(ii) To develop models to predict how the avian community structure responds to habitat factors and,

(ii) To predict avian responses to woodland degradation.

1.5.2 Hypotheses and assumption

The study tested six hypotheses and these were:

(i) Vegetation characteristics are correlated with avian species richness, avian guild richness and avian abundance,

(ii) Avian species richness decreases with increased woodland degradation,

(iii) Avian species composition changes along the woodland degradation gradient with species from disturbed woodland gradually replacing those of intact woodland,

(iv) The number of avian guilds decreases with increased woodland degradation,

(v) Different bird guilds respond differently to woodland degradation and,

(vi) Avian abundance decreases with increased woodland degradation.

The assumption in the study was that the study area had different levels of woodland degradation.

1.6 Study design

An ecological study was undertaken over a period of one and half years in order to model avifauna responses to miombo woodland degradation. The study was divided into two parts. The first part was the inventory or survey part. An inventory of the vegetation, habitat types and avian community structure was undertaken in the study sites. The second part then investigated how habitat characteristics influenced avian community structure by using statistical analyses to develop models of the responses of the avifauna to woodland structure and degradation.

1.7 Significance of the study

The goal of the study was to evaluate the impact of miombo woodland degradation on the avifauna community structure in Serenje District. The study yielded data on (i) vegetation composition and structure, and woodland degradation in the study area and (ii) species diversity, abundance and guild structure of the avifauna. The data obtained from the study were used to (1) highlight the significance of the avifauna in the area to both local and international conservation, (2) quantify the impact of woodland degradation on the avifauna and (3) make recommendations for an integrated approach to forest resource utilization and management that does not only concentrate on securing timber supply and other forest produce, protection of catchment areas and floral biodiversity but also emphasizes faunal conservation.

CHAPTER 2 STUDY AREA

2.1 Location and topography

The study area is located in Serenje District of north-central Zambia. Serenje District lies between longitude 30° and 31° east and latitude 13° and 14° south on the Central African Plateau between the Lake Bangweulu-Luapula swampy depression (Lake Basin) to the north and the Central African Rift comprising the valleys of the Luangwa and Lukusashi Rivers to the south, and is elsewhere bounded by the Democratic Republic of Congo (DRC) frontier and Mkushi and Mpika districts (Figure 2.1). Most of the district lies on the plateau that is drained by many perennial streams that flow into shallow lakes. In general, the elevation of the plateau varies from over 1680 metres above sea level in the north to 1000 metres in the south. Ranges of ridges and hills arise from the edges of the plateau. The Muchinga Escarpment divides the plateau from an area of lower relief, the Luangwa and Lukusashi valleys in the south. Specific topographic features of Serenje District include the plateau in the central region, the Lukusashi and Luangwa valleys in the south, the Muchinga Escarpment in the south and south east and the Lake Basin in the north (Peters, 1974).

2.2 Climate

The climate in Zambia is characterized by the alternation of dry and wet seasons. The dry season can be divided into two parts. The cool season extends from April to mid August when the minimum night temperatures may fall to below freezing point, particularly in the valleys and on lower woodland slopes, and the day temperatures rises to 21 - 28°C. The hot season lasts from mid August to October when night temperatures do not fall below 10 - 15°C and day temperatures reach 33 - 37°C. There is a single rainy season which lasts about five months from November to March-April but it can rain at any time of the year at any place. The average annual rainfall ranges from 700 – 1400 mm. Latitude 14ºS roughly divides the country into a high rainfall region in the north and a low rainfall region in the south (Hutchinson, 1974).

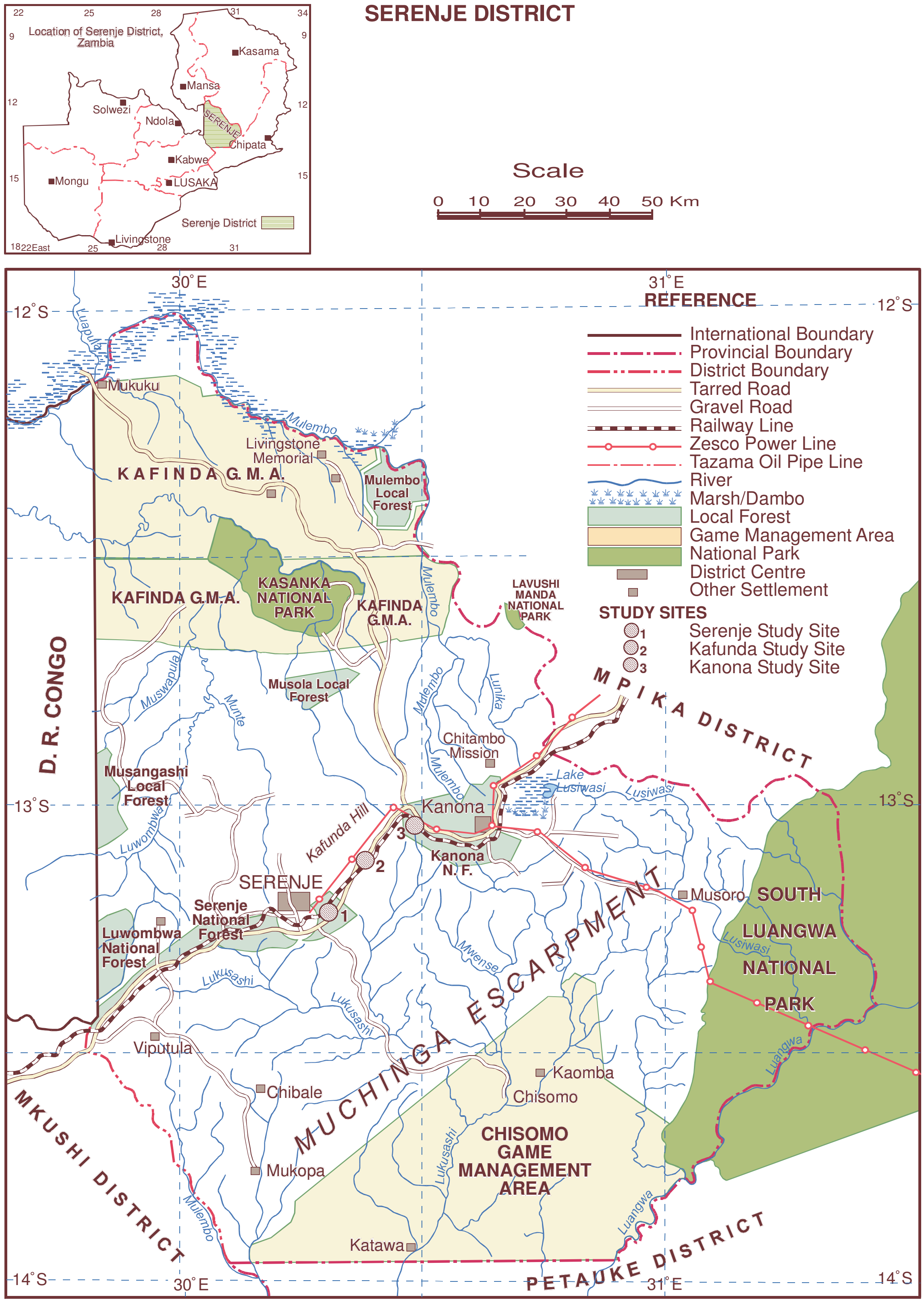
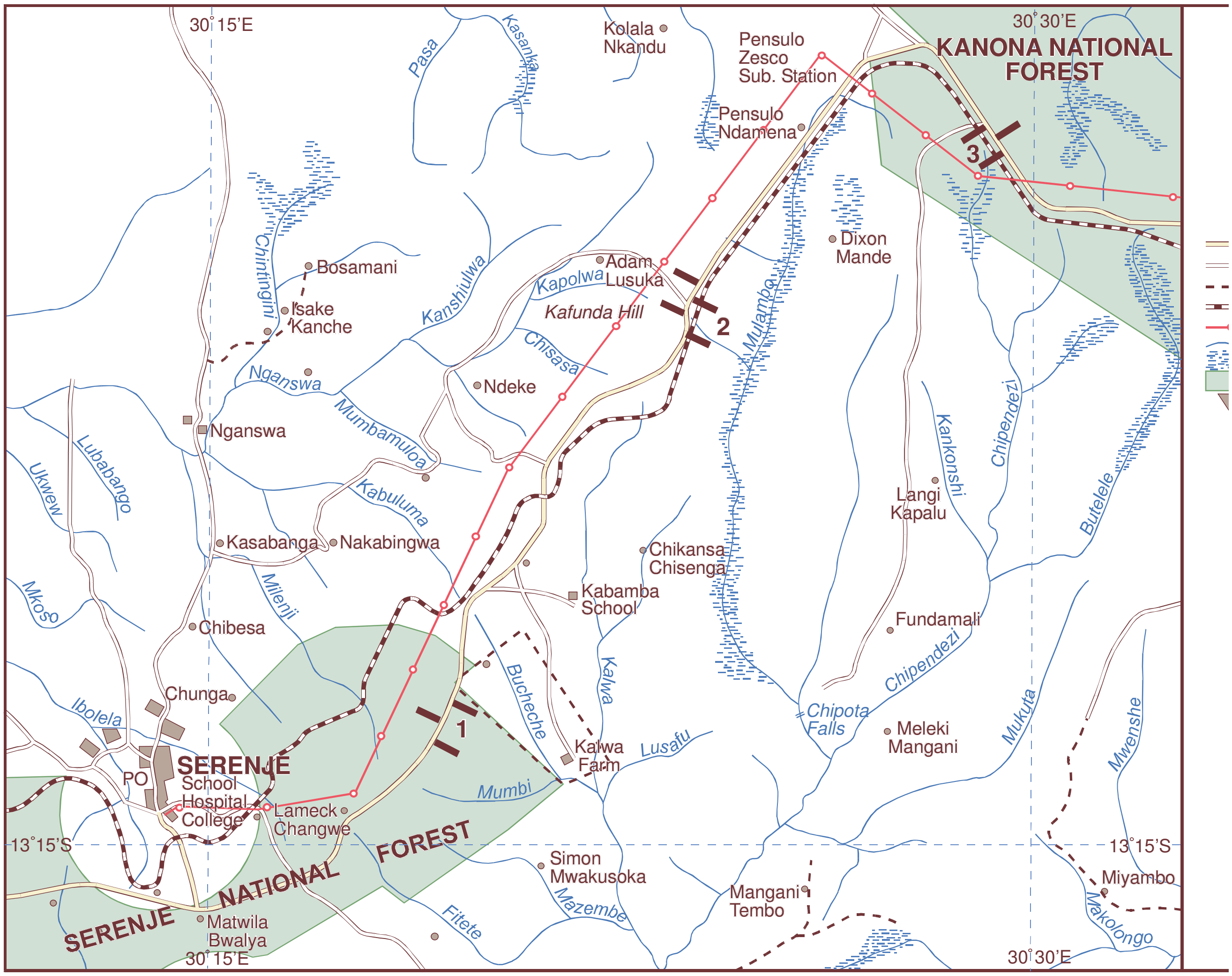


Figure 2.1a Map of the study area showing the location of Serenje District in Zambia and the location of protected areas, study sites, topographical features and infrastructure in Serenje District.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Kapolwa
Adam Lusuka
Kafunda Hill
Mulambo
Chisasa
Nganswa
Ndeke
Mumbamuloa
Nganswa
Lubabango
Ukwew
Kabuluma
Kasabanga
Nakabingwa
Chikansa Chisenga
Langi Kapalu
Kankonshi
Chipendezi
Butelele
Mkoso
Milenji
Kabamba School
Chibesa
Fundamali
Chipendezi
Chunga
Ibolela
Bucheche
Kalwa
Chipota Falls
Meleki Mangani
Mukuta
Mwenshe
SERENJE
PO
School
Hospital
College
Lameck Changwe
Kalwa Farm
Lusafu
Mumbi
13°15'S
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FOREST
NATIONAL
SERENJE
Simon Mwakusoka
Mangani Tembo
Miyambo
Matwila Bwalya
Fitete
Mazembe
Makolongo
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2
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The climatic data for Serenje District are summarized in Table 1. The mean annual rainfall for the District is 1100 ± 50 mm and is based on the period 1976 - 1991 and 2005 – 2007.

Table 2.1 Climatic seasons at Serenje in the Central Province of Zambia based on the period 1977 - 1991 and 2005 - 2007 for mean monthly rainfall; 1976 - 1991 and 2005 - 2007 for average monthly temperature and 1981 - 1991 and 2005 - 2007 for minimum and maximum mean monthly temperature.

			Mean monthly air temperature (°C)		
Season	**Duration**	**Mean monthly rainfall (mm)**	***Minimum***	***Maximum***	***Average***
Hot and dry	Sep - Oct	11 ± 4.0	14 ± 0.3	30 ± 0.3	22 ± 0.3
Hot and wet	Nov - Mar	200 ± 12.0	16 ± 0.1	27 ± 0.2	21 ± 0.1
Cool and dry	Apr - Aug	16 ± 5.0	11 ± 0.4	25 ± 0.2	18 ± 0.3

2.3 Soils

Serenje District lies in an area which is part of an ancient land mass believed to date from the Miocene. It lies in the structural stratigraphic province known as the Kibaran belt. This is composed of the pre-Katangan rocks generally grouped as the Basement Complex. The area is underlain by an interfolded and sheared sequence of granite-gneisses, schists and quartzites of pre-Katangan age (Reeve, 1962; Cordiner, 1968; Astle, 1968-9; Drysdall *et al.,* 1972). The soils derived from these formations are known as Red-yellow latosols (oxisols) or ferruginous earths (Red Earths). These are mainly sandy and silty soils although sandy loams and clayey loams also occur, particularly in the alluvial soils of the Bangweulu Basin. On the plateau, the soils are deep (Figure 2.2a) while on hilly escarpment they are shallow with surface rock boulders (Figure 2.2b).

(a) (b)

Figure 2.2 (a) Red earths are the common soil type on the plateau and (b) Rocky outcrops in hill miombo in Serenje District.

2.4 Vegetation types

The study area lies within the Sudano-Zambezian phytogeographical region, Zambezian domain and the Katango-Zambian subdomain of White (1983). The vegetation types found in Serenje District are miombo woodland, chipya woodland, dry evergreen forest (mateshi), swamp forest (mushitu) and dambos (Trapnell, 1953). The vegetation types found in the study sites are miombo woodland and dambo.

2.4.1 Miombo woodland

Miombo is a term used to describe woodlands in central, southern and eastern Africa dominated by the genera *Brachystegia*, *Julbernardia* and/or *Isoberlinia*. The woodland typically comprise an open canopy of semi deciduous trees usually 12 - 15 m tall, a discontinuous understorey, a scattered shrub layer and saplings, and a patchy layer of grasses, forbs and suffrutices (Fanshawe, 1971). Miombo species regenerate largely through sucker shoots from felled trees and resprouts from suppressed saplings. Shoot suckers dominate the regeneration because felled trees give rise to multistemmed plants while regeneration from suppressed saplings gives rise to single stemmed plants. Within regrowth miombo with each successive clearing, stem density increases due to the dual recruitment from the coppice of cut trees and suppressed saplings. During the development period, the number of shoots decreases due to inter-shoot competition and therefore stem density per plant declines slowly with age of regrowth. As a result, stem density in regrowth miombo woodland is higher than in mature woodland (Chidumayo, 1988b; Chidumayo, 1989; Chidumayo, 2002; Chidumayo, 2004). Canopy species are deciduous for a short period of time during the cool and dry season usually in July and August and flush by September. *Brachystegia* spp, *Julbernardia paniculata* and *Isoberlinia angolensis* are the common canopy species. Other co-dominants are *Erythrophleum africanum, Syzygium guineense, Uapaca* spp*, Parinari curatellifolia, Pterocarpus angolensis* and *Monotes* spp. Smaller trees and shrubs are also widespread like *Anisophyllea boehmii, Byrsocarpus orientalis, Ochna pulchra, Protea angolensis, Strychnos* spp and *Swartzia madagascariensis*. The common species in the ground layer are *Nephrolepis cordifolia, Pteridium aquilinum, Erythrocephalum zambesianum* and *Vernonia* spp. Under an open tree canopy and regrowth woodland, grasses can be found growing in the ground layer. The most widespread miombo woodland grasses include *Andropogon, Brachiaria, Digitaria, Eragrostis, Setaria,* and *Panicum*. *Hyparrhenia* sp is found in open places in the woodland but is more characteristic of woodland edges and woodland in decline (White, 1962; Vesey-FitzGerald, 1963; Fanshawe, 1971; Chidumayo, 1993). The structure of miombo woodland is distinctive, a result of the characteristics of the dominant trees. Most species of the key genera have slender boles with initially sharp ascending branches which eventually spread out to support the light shallow, often umbrella-shaped canopy. The diversity of canopy tree species is low although overall species richness of the flora is high (Frost, 1996). Although miombo is dominated by a few characteristic species, their contribution to numbers and biomass varies widely between and within communities.

Serenje District lies in a transition zone between the plateau (Central African Plateau) and the Muchinga Escarpment. As a result, there are two variants of miombo woodland in the district; plateau miombo and escarpment/hill miombo. Trees in escarpment miombo are usually small because of the shallow soils with rocky boulders on which they grow (see Figure 2.2b). The ground layer in hill miombo is dominated mainly by ferns such as *Nephrolepis cordifolia* while the shrub layer is dominated by xerophytic plants such as *Xerophyta equisetoides* (Figure 2.3). Trees in plateau miombo are of variable sizes with old growth (undisturbed) woodland having large trees while in regrowth miombo, the size depends on the history of human disturbance.

(a) (b)

Figure 2.3 Escarpment miombo with (a) A ground layer dominated by *Nephrolepis cordifolia* and (b) A shrub layer dominated by *Xerophyta equisetoides* in Serenje District. The photographs were taken in the hot and wet season.

2.4.2 Dambo

Dambos are small valley grasslands occurring in the upper reaches of drainage lines (Vesey-FitzGerald, 1963). Valley grasslands are assemblages of edaphic grasslands associated with drainage lines. Edaphic grasslands occur in the headwater reaches of many drainage lines on the Zambian plateau above the 1200 metre contour (Garlick, 1961). Dambos are found interspersed within the miombo woodlands in areas of low seepage. Soils of the dambos usually belong to the illuvial complex, in the superficial horizon. They are black, very dark grey to neutral grey or occasionally dark brown. In texture, they vary from sand to clay but always have a high colloidal content and become very sticky when wet. In structure, the surface soil is single grain, spongy when moist but becoming very compact when dry. These soils are normally acidic (Trapnell, 1953). Dambos have low relief either gently sloping towards the drainage line or actually lying at the bottom of the drainage line. The water table in dambos is usually high and this coupled with the bad drainage means dambos tend to become flooded during the rains (Garlick, 1961). The vegetation of the dambo is usually a medium dense, mixed herb mat of rather uniform appearance and height. The mat is composed of grasses like *Andropogon, Hyparrhenia* and *Loudetia simplex* which together afford a 100% ground cover (Figure 2.4a). Other species include *Eragrostis, Panicum, Echinochloa* and *Brachiaria* (Trapnell, 1953). Dambos are zoned in relation to the drainage. At the perimeter, the contact with the tree line is normally very distinct (Figure 2.4b). The size and shape of dambos reflect the type and depth of weathering of bedrock. Dambos over granite are long, wide and gently curving following major fractures whereas those over schists are usually small and arranged in a reticulate pattern (Garlick, 1961).

(a) (b)

Figure 2.4 (a) Dambo surrounded by plateau miombo woodland and (b) Sharp boundary between dambo and miombo woodland in the background in Serenje District.

2.5 Land use and human impacts on miombo woodland

In tropical open woodlands such as miombo woodland, there is a complexity in determining human impacts because human activities often only degrade woodland by diminishing canopy cover and biomass instead of removing them entirely as in deforestation. Deforestation is the clearance of forest for agriculture or other purposes while degradation is the temporary or permanent reduction in density, structure, species composition or productivity of the vegetation (Grainger, 1999). Degradation describes changes in woodland quality and it can be monitored by such indicators as canopy cover, biomass, density and biodiversity. Land use includes activities that humans use to exploit land resources (Chidumayo, 2002).

2.5.1 Shifting cultivation

Shifting cultivation is the most widespread agricultural system in miombo areas where ample land is available. Woodland sites are cut over, the vegetation debris is burned and the site is abandoned after 3-4 years of farming because of the decline in soil fertility under cultivation. Because the level of fertility in miombo soils is low, the gain of nutrients from wood ash is sufficient to make the difference between a useless crop and a reasonable one (Boaler & Sciwale, 1966).

Serenje District is currently populated by the Lala tribe who also live in the neighbouring district of Mkushi and in the adjacent Katanga Pedicle of the DRC. The Lala are a Bantu tribe that migrated from Katanga and the Congo forests in the DRC between 200 - 250 years ago. They are forest people and practice a form of woodland-based shifting cultivation known as chitemene (Trapnell, 1953; Peters, 1974). Chitemene is a traditional cultivation system found in northern Zambia (Trapnell, 1953). There are two types of chitemene; northern large circle chitemene and southern small circle chitemene. In the northern large circle chitemene, tree crowns are cut during the dry season (May - September) by men and the branches are stacked in the centre of a circular clearing by women for burning just before the onset of rains. In the southern small circle chitemene, trees are normally felled at breast/knee height and the felled trees are carried and stacked into small circles or in long narrow circular strips (Figure 2.5a). The stacked branches/trees are burnt to ash just before the rains (Figure 2.5b). Chitemene plots are planted with millet *Eleucine coracana* at the onset of rains (Figure 2.5c) and the millet is ready for harvesting by March/April (Figure 2.5d). The type of chitemene practiced in Serenje District is the small circle chitemene (Peters, 1974).

Trees are cut from a large area than is actually planted in chitemene and miombo woodland is used as an agricultural fallow crop (Strømgaard, 1985; Oyama, 1996). Except for a negligible fraction of the burned area which is used for a second time, chitemene plots are used for only one year and then rested until the woodland is regenerated. Under ideal conditions, people practicing shifting cultivation moved through alternative sites finally returning to the original site after a period that gave the woodland sufficient time to recover and be ready for the next chitemene cycle. Data obtained by Peters (1974) in Serenje District indicate that under average conditions on the plateau, it takes about 35 years for the woodland to fully regenerate after cutting at breast height. Perpetuation of the chitemene system depends upon an availability of fully regenerated woodland. Once the human population exceeds the carrying capacity of the system, the period allowed for woodland regeneration is reduced. The chitemene system worked well as long as the population remained low, but with increased population, the system has come under pressure (Lawton, 1982). Peters (1974) found that in

Serenje District over 75% of chitemene plots were being cut from trees that were not fully regenerated and that the average age of growth being cut had fallen from 35 to 17 years.

(a) (b)

(c) (d)

Figure 2.5 Small circle chitemene in Kafunda area in Serenje District.

The main cause of woodland degradation in the study area is the declining fallow period in shifting cultivation which has led to regrowth woodland being felled for chitemene (Figure 2.5). There is little old growth woodland left for people to use in shifting cultivation. Those that cannot find old growth woodland are forced to use regrowth woodland for slash and burn agriculture. The trees being felled have small stems and most of them are multi-stemmed, an indication that the woodland is regenerating from coppice (Figure 2.6).

Figure 2.6. Regrowth miombo cut for shifting cultivation in Serenje District.

Because regrowth woodland is being used for chitemene, large areas of woodland have to be cut in order to supply the amount of ash needed to increase soil fertility (Oyama, 1996). Chitemene is indiscriminate when it comes to its impact on the woodland, in that all the trees in the farm lot are cut down irrespective of species or size. Within the chitemene, woodland regeneration occurs by resprouting of suckers on the stem of cut trees or germination of seeds and results in an even-aged/size regrowth woodland. Maize, *Zea mays,* is also grown on the plateau (Figure 2.7a). However, maize is grown under permanent cultivation with the same field used every year. Maize yields are usually poor if chemical fertilizers are not used to improve soil fertility.

Figure 2.7 (a) Maize, *Zea mays,* is cultivated on the plateau and (b) Mango, *Mangifera indica,* tree (left) and *Euphorbia* sp (right) in an abandoned settlement in Kafunda area in Serenje District.

Shifting cultivation practiced by the Lala people of Serenje District results in many abandoned settlements in miombo woodland. The length of time it takes for the people to return to such abandoned settlements depends on the amount of old growth woodland available which in turn is influenced by the population size. Some of the abandoned settlements are very old and have become covered by regrowth woodland. The only indication that such areas were once inhabited by humans is the presence of fruit trees such as Mango, *Mangifera indica* and *Euphorbia* sp commonly used as a hedge (Figure 2.7b). There has been a sociological change in the practice of chitemene in that nowadays people are unwilling to move their settlements from one area to another. As a result, the woodland near the permanent settlements is used over and over without the woodland fully regenerating.

2.5.2 Charcoal production

Charcoal production is another cause of woodland degradation in the District. Most of the people living in the vicinity of Serenje Town and Kanona sub-Boma use charcoal as a source of fuel. The commercialization of charcoal means that charcoal produced in the district is used to supply the demands of far flung areas. The scarcity of old growth woodland means regrowth woodland is being exploited for charcoal production (Figure 2.8). In order to produce a charcoal kiln that will yield good economic returns, large areas of regrowth woodland are cut. The impact of charcoal production on the woodland is selective in that bigger trees are usually cut down as they yield a lot of charcoal from one cutting as opposed to smaller trees where one needs to cut several of these to produce an economic yield. Apart from bigger trees being imparted more than smaller ones, certain species of trees are selected because they produce charcoal that does not spark and does not produce a lot of ash. Tree species which produce charcoal that burns too quickly do not have a high demand on the market. Almost all the charcoal in Zambia is produced by the traditional earth-kiln method with very little capital investment in the form of hand tools such as axes, shovels, hoes and machetes. This means that only a small area of woodland is cleared for charcoal production at a time. The selective nature of charcoal production results in woodland with a disjointed structure in that within an even aged woodland, one would find scattered patches of newly cut areas or regenerating woodland.

(a) (b) (c) (d)

Figure 2.8 (a) Charcoal kiln ready for carbonization in regrowth woodland in Kanona National Forest (b) Wood billets neatly packed inside a charcoal kiln (c) Charcoal kiln being carbonized in Kafunda area and (d) Abandoned kiln in Kanona National Forest after the charcoal has been collected.

2.5.3 Infrastructure development

For the woodland in Serenje District, infrastructure development, such as the Great North Road (GNR), TAZAMA oil pipeline, ZESCO power lines and the TAZARA railway line, also degrade and fragment the woodland (see Figure 2.1). The vegetation under the infrastructure or along the infrastructure is constantly cleared to prevent the advancement of regeneration. This has resulted in the creation of permanent woodland edges (Figure 2.9).

(a) (b)

(c) (d)

Figure 2.9 Permanent woodland edges created by (a) ZESCO power lines (b) Great North Road (c) TAZARA railway line and (d) TAZAMA oil pipeline in Serenje District.

The presence of the railway line and road makes accessing the woodland in the area easy, thereby making it vulnerable to exploitation. It also makes the transportation of woodland products to other areas very easy which in turn encourages more exploitation. Lay-bys along the Great North Road and railway stations along the TAZARA railway line are points of encroachment into PFAs. What starts off as trading posts/stations to cater for the needs of road/railway users eventually end up as permanent settlements. With settlements, come shifting cultivation to provide food for the settlers and this is usually accompanied by charcoal production, a source of income for the local population. Apart from shifting cultivation, charcoal production and the presence of infrastructure, the woodland in the study area has also been affected by small scale harvesting of trees for timber and firewood. The land-use and infrastructure development have modified and fragmented the woodland of the area.

2.6 Protected areas

Serenje District has different categories of Protected Areas (PAs) which include; National Parks, Game Management Areas (GMAs), National Forests and Local Forest Reserves. National Parks and GMAs are managed for the conservation of wildlife and wildlife habitats (Zambia Wildlife Act, Cap 12 of 1998). Human settlements and exploitation of wildlife other than for tourism purposes are not allowed inside National Parks and entrance into National Parks is restricted without a permit. In GMAs, human settlements are allowed and controlled hunting and/or capture of wildlife is permitted with the purchase of a licence. Serenje District has two National Parks; Kasanka and South Luangwa National Parks, and two GMAs; Kafinda and Chisomo (Figure 2.1a). Kasanka National Park lies wholly in the district whereas South Luangwa National Park is shared with other districts in Zambia. Both National Parks are adequately stocked with wildlife with Kasanka being managed by a private trust whereas South Luangwa is managed by the Zambia Wildlife Authority. Kafinda and Chisomo GMAs are depleted of wildlife due to poaching and killing of problem animals arising from humans and animals living in close proximity. Kasanka National Park and South Luangwa National Park have been identified by BirdLife International as Important Bird Areas in Zambia (Leonard, 2005). Apart from the above PAs, the district also has Protected Forest Areas (PFAs). There are three National Forests; Serenje, Kanona and Luombwa and three Local Forest Reserves; Mulembo, Musangashi and Musola (Figure 2.1a). All the PFAs in the district are exploited both legally and illegally for their natural resources. Others like Kanona and the three local forest reserves have been encroached by humans who are illegally settled there and practicing shifting cultivation.

CHAPTER 3 WOODLAND STRUCTURE AND DEGRADATION

3.1 Introduction

This chapter presents the results of woodland surveys conducted in the study area in order to describe qualitatively and quantitatively woodland structure, composition and degradation at study sites in Serenje District. The results answer to the overall objective stated in 1.5.1: to evaluate the habitats in the study area and to establish the level of woodland degradation in the study area. The specific objectives were:

(i) To determine vegetation composition (species richness, diversity and evenness) in the study sites,

(ii) To determine the vegetation structure (density, basal area cover, height and canopy cover) in the study sites and,

(iii) To assess woodland degradation in the study sites.

3.2 Methodology

The study was carried out in miombo woodland found in Serenje District (Figure 2.1b). The study sites included the Serenje study site located in Serenje National Forest, Kanona study site located in Kanona National Forest and Kafunda study site located in the open area between the two National Forests. The coordinates for the midpoint of the Serenje study site are 13º13'S; 30º18'E whereas those of Kanona study site are 13º02'S; 30º29'E. Coordinates for the midpoint of Kafunda study site are 13º06'S; 30º22'E. The study sites were located about 14.5 km apart. An inventory of the vegetation was undertaken in March 2006 in order to determine the vegetation composition and structure and to establish the level of woodland degradation in the study sites.

3.2.1 Sampling design

Using the Great North Road that passes through the study area (Figure 2.1), line transects were established on either side of the road in the study sites in March, 2006. The transects originated from the edge of the road and were 1.0 km long. The first transect was randomly located along the road. The other transects were systematically placed 500 metres apart in an alternating pattern, such that transects established on one side of the road were spaced 1 km apart (Figure 3.1). The beginning and the end of each transect were geo-referenced with a

Global Positioning System (GPS) instrument and recorded. Ten transects were established in the study area. Three transects were established in each of the National Forests and the other four were established in the open area between them. The original study design was to have 12 transects in total, with six transects in the National Forests and the other six in the open area between them. However, due to the presence of human settlements and cultivated fields in the open area, only four transects could be established in woodland that was not used for either settlements or fields in the open area. The Great North Road, ZESCO power lines and TAZARA railway line all pass through the study sites. Transects were located along the Great North Road because it was easier to access (Figure 2.1b).

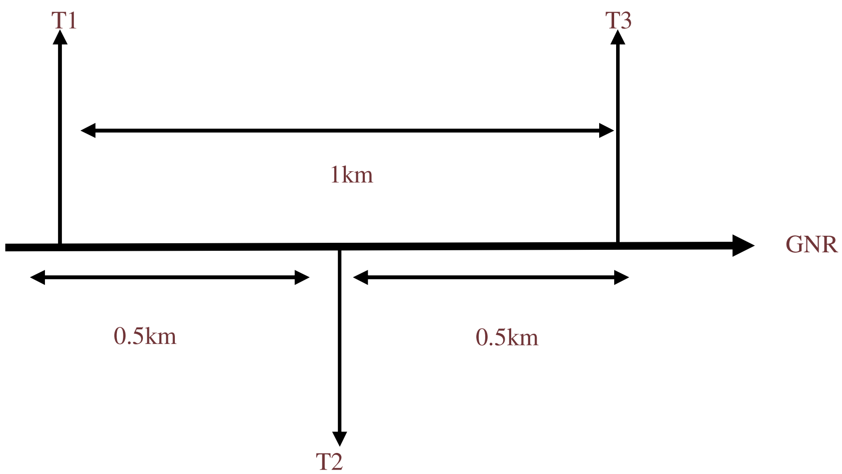


Figure 3.1. The layout of transects along the Great North Road (GNR). T1, T2 and T3 stand for transect 1, 2 and 3.

Along each transect, circular plots with a radius of 50 metres were established. The first circular plot was placed 50 metres from the origin of the transect while the last plot was placed 50 metres from the end of the transect. The other circular plots were spaced 100 metres apart, such that each line transect had 5 circular plots (Figure 3.2). The centre of each circular plot was geo-referenced with a Global Positioning System (GPS) instrument and recorded. Flagging material tied to plants was used to mark the path of the line transects. The circular plots will be referred to as bird census plots. Within each circular plot, a 10 m X 10 m (0.01ha) square subplot was established. The subplot was located in an area that was representative of the vegetation within the circular plot. The square subplots will be referred to as plant census plots.

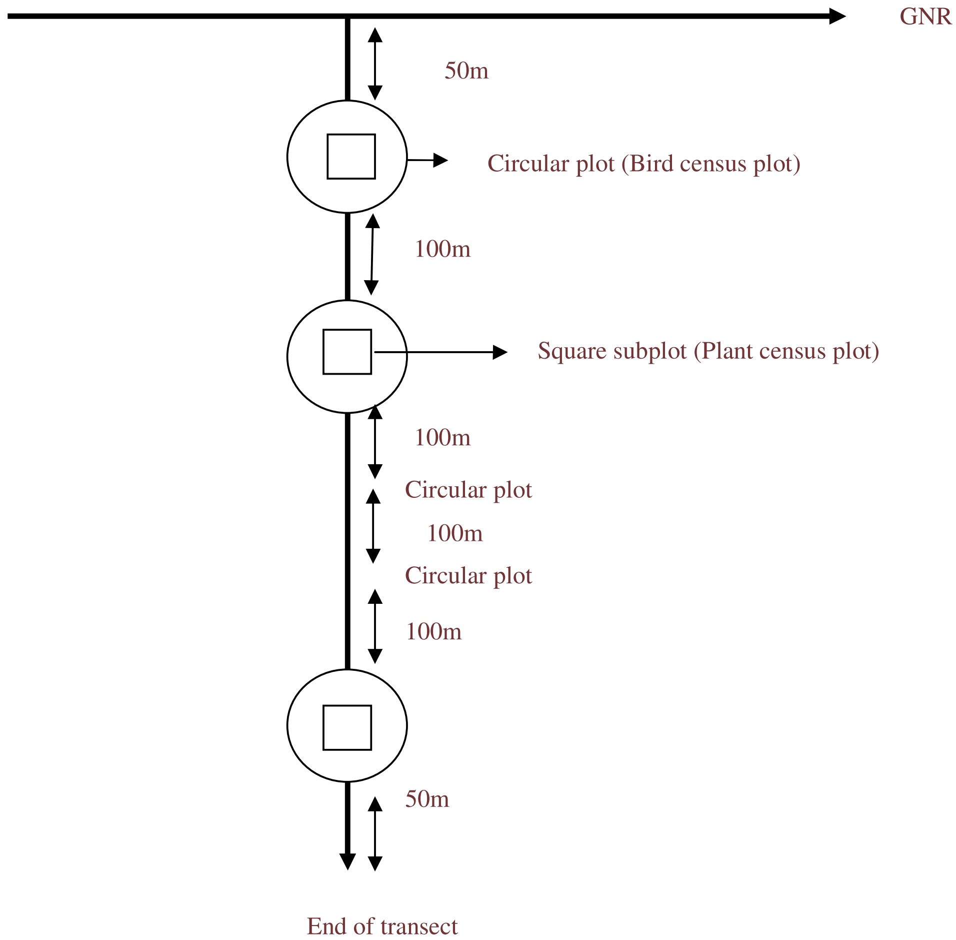


Figure 3.2 Layout of study plots along a transect.

3.2.2 Vegetation composition and structure

Vegetation composition refers to the floristic characteristic of the vegetation and can be measured by species richness, diversity and evenness (Begon *et al.,* 1990). Species richness is the total number of species in an area while species evenness is the relative abundance or proportion of individuals among species. Species diversity is an index that incorporates both species richness and the relative abundances of species (Begon *et al.,* 1990). Vegetation structure is the horizontal and vertical distribution of plant biomass (Heady & Heady, 1982). Horizontal distribution of plant biomass refers to the pattern of spacing of plant stems on the ground. It can be described by plant density and basal area cover. Plant density is the number of plant stems in a unit area while basal area cover is the area or proportion of the soil surface occupied by bases of plants. The vertical distribution of plant biomass refers to the height distribution of plants. It can be described by plant height and canopy cover. Canopy cover is the proportion of ground covered by the vertical projection of the tree canopy (Heady & Heady, 1982).

All the woody and non-woody plants within the plant census plots were identified and recorded in order to determine plant species composition in the plots. For those plant species whose identification could not be done in the field, specimens were collected and taken for identification at the University of Zambia Herbarium. For woody plants with a height of 1.5 metres and above (trees), the diameter at 1.3 metres or breast height (DBH) of each individual tree or each stem for multistemmed trees was measured by tape to the nearest centimetre (cm) and recorded. The breast height of the coppiced stems was measured from the point where the stems originated on the tree stump. As a result, only multistemmed trees that had stems coppicing at knee height or below were measured. The DBH data was then used to estimate stem density and basal area cover of trees within the plots. All woody plants with a height below 1.5 metres (sapling) in each plot were also counted in order to determine sapling density. The percentage canopy cover in each plot was determined visually using reference diagrams for estimating canopy cover (Appendix 3.1).

The tree height was estimated from the DBH data using a regression model developed from DBH and height data of miombo woodland trees felled in 1988 and 1990 supplied by Prof Chidumayo of the University of Zambia. In order to obtain the best model that fitted the scatter plot of tree height (y) and tree diameter (x), five curves were fitted to the data using Grapher Software (Golden Software, 2003). The five curves were linear, log, exponential, power and polynomial. Of these, the power model showed the best fit with a coefficient of determination (r^2) = 0.79. The scatter plot of tree height and DBH of these data is shown in Figure 3.3. The power model $\ln(y) = 0.6739\ln(x) + 0.3551$ was therefore selected for estimating tree height from the DBH data obtained from the plant census plots.

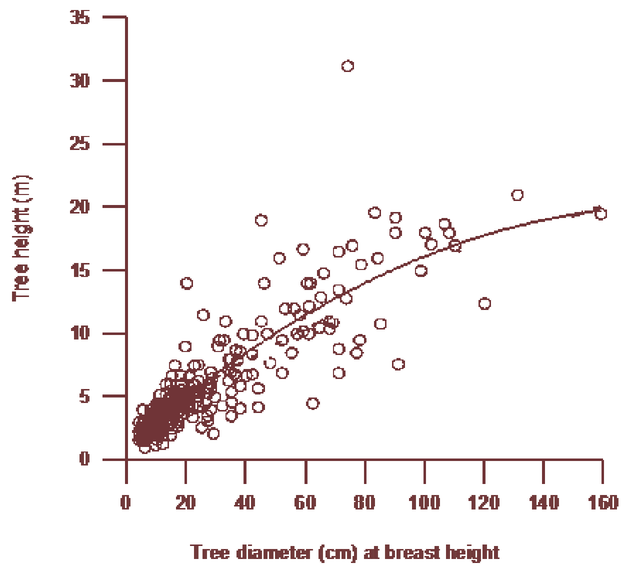


Figure 3.3 Scatter plot of tree height and DBH of miombo woodland trees using data collected by E.N. Chidumayo and the fitted power model curve: $\ln(y) = 0.6739 \ln(x) + 0.3551$.

3.2.3 Indicators of woodland degradation

This study was originally developed on the assumption that the woodland in National Forests being legally protected areas would represent undisturbed vegetation (control) and that the vegetation in the open unprotected area would represent various stages of woodland degradation (treatments). However, investigations made during the first visit to the study area in March 2006 revealed that woodland degradation was widespread both in protected National Forests and unprotected areas. It therefore became necessary to assess each plant census plot for evidence of degradation and classify each plot along a degradation gradient or scale. To do this, four plots representing relatively undisturbed woodland were identified at the study sites: two plots were in Serenje study site and one each in Kanona and Kafunda study sites. Four plots representing severely degraded woodland were also identified: two plots in Kanona study site while the other two were in Kafunda study site. Examples of relatively undisturbed woodland and severely degraded woodland are shown in Figure 3.4. The vegetation characteristics of these plots were used as the basis for classifying the plant census plots along a degradation gradient using Principal Component Analysis (PCA) followed by Cluster Analysis. Principal Component Analysis was used in factor analysis to identify the main vegetation characteristics that were responsible for the variation among the plant census plots. The factors identified by PCA were then used in Cluster Analysis to assign the samples plots into clusters based on their overall similarity. Discriminant Function Analysis was then used to determine whether the sample plots were classified correctly. The different clusters of miombo woodland types will be referred to as habitats as defined by Hall *et al.,* (1997) which defines habitat as the resources and conditions present in an area that produce occupancy including survival and reproduction by a given organism.

(a) (b)

Figure 3.4 (a) Relatively undisturbed woodland in Serenje National Forest and (b) Severely degraded woodland in Kanona National Forest in Serenje District.

Four phases have been identified in regenerating miombo woodland: initial regrowth; dense coppice; tall sapling; and mature woodland (Trapnell, 1959). The vegetation following a disturbance is relatively open with cover dominated by grasses. Most woody plants in the initial regrowth phase are less than 1 m tall. Regular, intense, late hot and dry season fires can suppress woodland recovery, restricting vegetation to this phase. Protection from fire or relatively early cool and dry season fires enables a dense coppice phase to emerge, with 1 - 3 m tall woody plants. Uninterrupted growth of coppice leads eventually to the development of a tall sapling phase with woody plants 3 - 6 m high. Closure of the canopy suppresses grass production and allows fire-sensitive species to establish. Finally a mature woodland phase develops, marked by thinning of the intermediate size classes and the suppression, but not the elimination, of saplings. Fire alone does not divert the development of woodland though it may retard it (Frost, 1996; Martin, 1996; Figure 3.5).

Figure 3.5 Regrowth miombo with evidence of (a) A recent fire (absence of grass cover) and (b) An old fire (presence of green grass) in Kafunda area, Serenje District. Both photographs were taken in the hot and dry season.

3.3 Data analysis

3.3.1 Vegetation composition

Data on the presence and abundance of tree species within the plant census plots was used to estimate tree species richness, evenness and diversity using the PC-ORD analytical program (McCune & Mefford, 1999). Presence and abundance data of sapling species within the plant census plots was used to estimate sapling richness, evenness and diversity using PC-ORD. Data on the presence of all plant species in the plant census plots was used to determine total plant richness and total plant diversity. Often, not all species present in the field are actually detected and recorded. The jackknife estimator is a procedure that considers that there are species that are not actually recorded but whose presence can be inferred from the pattern of observed species. The first order jackknife method was therefore used to estimate the expected number of species at the plant census plots. The diversity index estimated by the PC-ORD program is the Shannon diversity index (H').

3.3.2 Vegetation structure

PC-ORD was used to estimate stem density and stand basal area cover from the DBH data for each plant census plot. The stand basal area cover data and stem density plot data were then used to calculate the mean tree basal area cover for each plot. Stem density plot data and DBH plot data were also used to calculate the mean tree DBH per plot. Tree height was estimated from the DBH data using the power model calculated by the Grapher program (see Figure 3.3). The mean tree height was then calculated for each plot. Abundance data of saplings was used to estimate sapling density within the plots.

Within each plant census plot, 15 vegetation characteristics were determined and these were (i) total plant species richness, (ii) total plant species diversity, (iii) tree species richness, (iv) tree species evenness, (v) tree species diversity, (vi) stand basal area cover, (vii) mean tree basal area cover, (viii) mean tree size, (ix) mean tree height, (x) stem density, (xi) % canopy cover, (xii) sapling species richness, (xiii) sapling species evenness, (xiv) sapling species diversity and (xv) sapling density.

3.3.3 Classification of plant census plots on the basis of woodland degradation

Principal Component Analysis was conducted on the 15 vegetation variables obtained in the plant census plots in order to determine which vegetation variables were responsible for the variation among the plots using SPSS© analytical software (SPSS, 2005). In the initial analysis, partial correlations between variables were summarized as Kaiser-Meyer's Measure of Sampling Adequacy (MSA) for each variable. All variables that had MSA values below 0.5 were deleted prior to the PCA. After extracting the principal components that explained the greatest variance in vegetation variables among the plots, the variables identified in each of the principal components were then used to group the sample plots into clusters based on their overall similarity by hierarchical cluster analysis using SPSS©. The data matrix consisted of 50 plant census plots (rows) by the vegetation characteristics (columns) identified in the principal components. All the column data were standardized to bring the means to 0 and variances to 1 before the analysis. The effect of this standardization was to weigh all categories equally. Similarity among plant census plots was based on Squared Euclidean distances. The distance matrix was subjected to a hierarchical cluster analysis using the k-means splitting method to produce a dendrogram showing degree of similarity in vegetation structure and composition among plant census plots. The k-means clustering was carried out by varying the number of clusters from 2 up to 6 and observing the changes in the variables' significant probability. K-means clustering was chosen because it has an ANOVA table output which shows the significance levels of the variables in the clustering process. The number of clusters which had the highest number of significant variables used in the clustering was chosen among the different options. Discriminant Function Analysis using SPSS© was performed on the 15 vegetation variables obtained in different plot clusters in order to determine the combination of variables that separated the cluster of plots and to determine whether the plots were classified into clusters correctly or not.

3.3.4 Variation in vegetation composition and structure

Analysis of Variance (ANOVA) using the Statistix analytical software (Analytical Software, 2003) was used to determine whether there were significant differences ($\alpha = 0.05$) in vegetation characteristics among clusters of plant census plots with different levels of woodland degradation. Where there were significant differences among the cluster of plots, comparison of means using the Bonferroni test was used to determine which of the cluster of plots were significantly different from one another. For canopy cover data, which was recorded in percentage, the data was arcsine transformed before carrying out ANOVA.

3.3.5 Vegetation structural diversity

Vegetation structural diversity was determined in each plant census plot using the Shannon – Weiner index (MacArthur & MacArthur, 1961). Vegetation structural diversity was based on the vertical stratification of the woody vegetation or foliage height diversity (FHD). The woody vegetation in the plant census plots was divided into three height classes based on Trapnell (1959) where woody plants in the range 0 – 5 m were classified as small trees and shrubs; those between 5 and 10 m were classified as understorey trees while those over 10 m were classified as canopy trees. Within each plot, the proportion of small trees and shrubs, understorey and canopy trees was calculated. Foliage height diversity within plant census plots was calculated as:

$$FHD = - \Sigma_i \, p_i \, ln \, p\mathrm{i}$$

where p_i is the proportion of the total woody vegetation which belongs to the i^{th} height class, *ln* is the natural logarithm and Σ is summation across height categories. Foliage height diversity for clusters of plant census plots with different levels of woodland degradation was determined from the mean FHD values of the plant census plots within the cluster.

3.4 Results

3.4.1 Floristic diversity

The total number of species recorded in the plant census plots was 107, representing 90 genera and 45 families (Appendix 3.2). A first order jackknife estimate using PC-ORD yielded 118 species. Of these species, 74% were dicotyledonous while 24% were monocotyledonous. Two percent of the total species recorded were pteridophytes. The largest family was Fabaceae which constituted 23% of the total plant richness followed by Poaceae with 15%. The five dominant plant species based on their importance values as determined by PC-ORD were *Julbernardia paniculata*, *Brachystegia spiciformis, Parinari curatellifolia, Uapaca kirkiana* and *Brachystegia floribunda*.

3.4.2 Woodland status at plant census plots

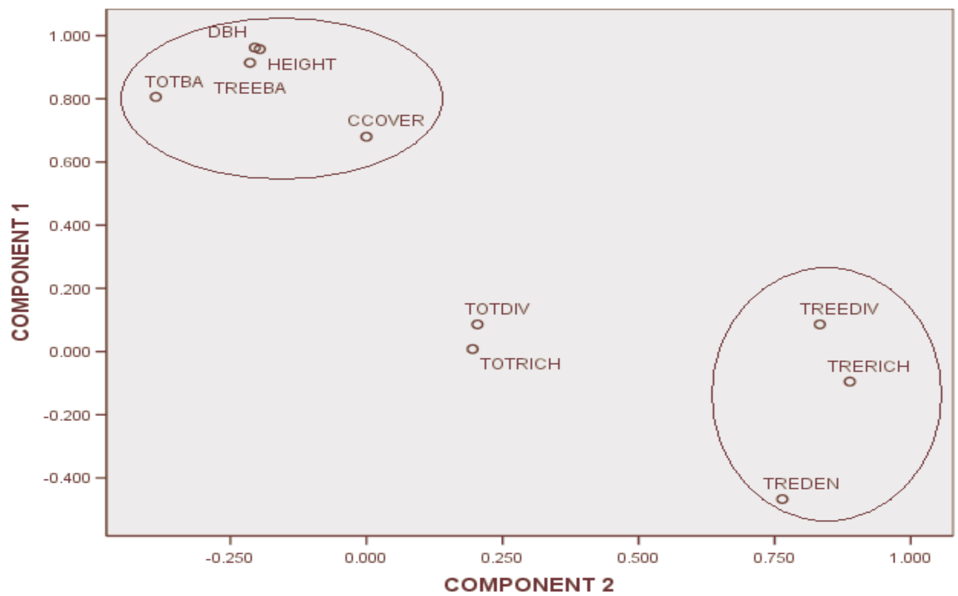
3.4.2.1 Principal Component Analysis of vegetation variables

Of the 15 vegetation variables obtained in the plant census plots, ten had MSA values over 0.5 (Appendix 3.3). Tree evenness, sapling species richness, sapling species evenness, sapling species diversity and sapling density were the vegetation variables excluded from further analysis in PCA because their MSA values were below 0.5. The overall MSA value computed across all the ten significant variables from the PCA was 0.640. The correlation matrix of the 10 variables is summarized in Appendix 3.3. Principal Component Analysis extracted ten components and of these, only three had eigenvalues over 1.0. The three components cumulatively accounted for 84.79% of the total variance. The rotated sums of squared loadings indicated that the first component accounted for 40.30% of the variance while the second and third component accounted for 24.22% and 20.28%, respectively. The rotated component matrix is given in Table 3.1.

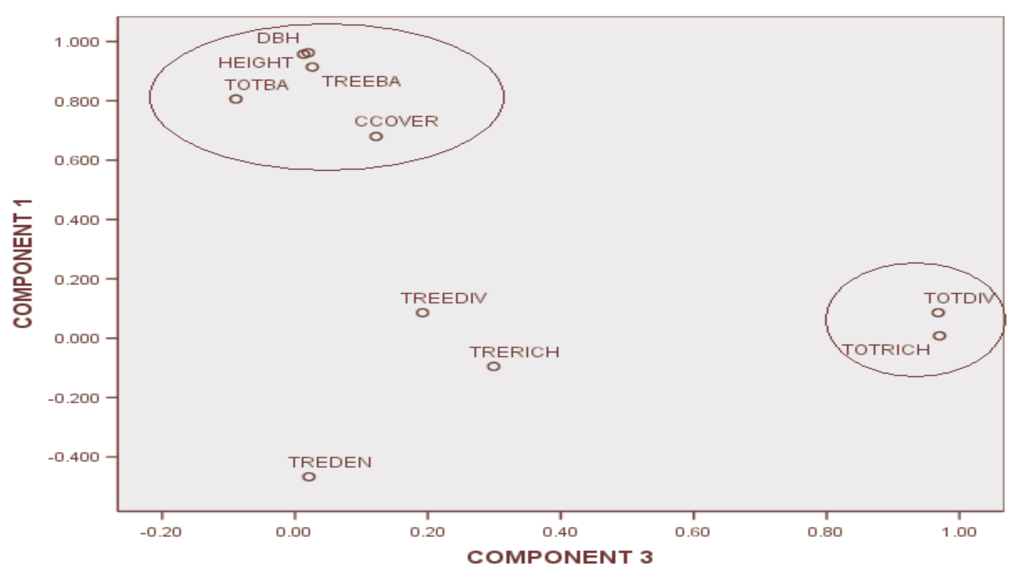
Table 3.1 Rotated component matrix of the ten significant vegetation variables. The values indicate the Pearson's correlation coefficient between the component and the variable

Variable	COMPONENT		
	1	2	3
DBH	0.962	-0.205	0.02
Mean tree height	0.957	-0.196	0.013
Mean tree basal area cover	0.914	-0.214	0.026
Stand basal area cover	0.806	0.387	-0.089
% canopy cover	0.68	0.00	0.122
Tree species richness	-0.095	0.888	0.299
Tree species diversity	0.086	0.833	0.192
Stem density	-0.467	0.764	0.021
Total species richness	0.008	0.195	0.97
Total species diversity	0.086	0.204	0.968

The first component is characterised by vegetation variables that describe the vegetation structure. The variables include tree height, tree size, basal area cover and canopy cover (Figure 3.6a). All the variables that loaded well on the first component are positively correlated with each other. The second component is characterised by variables that describe tree species composition and stem density (Figure 3.6a). All the variables in the second component are positively correlated with each other. The third component is characterised by variables that describe the total species composition. All the variables in the third component are positively correlated with each other (Figure 3.6b). The three principal components are summarized in Figure 3.7.



(a)



(b)

Figure 3.6 2D scatter diagrams representing the principal components of vegetation structure and composition among plant census plots (a) Component 1 versus component 2 (b) Component 1 versus component 3. Vegetation abbreviations: DBH - Diameter at breast height, HEIGHT - Mean tree height, TOTBA – Stand basal area cover, TREEBA – Mean tree basal area cover, CCOVER - % canopy cover, TREEDIV – Tree species diversity, TRERICH – Tree species richness, TREDEN – Stem density, TOTDIV – Total species diversity and TOTRICH – Total species richness

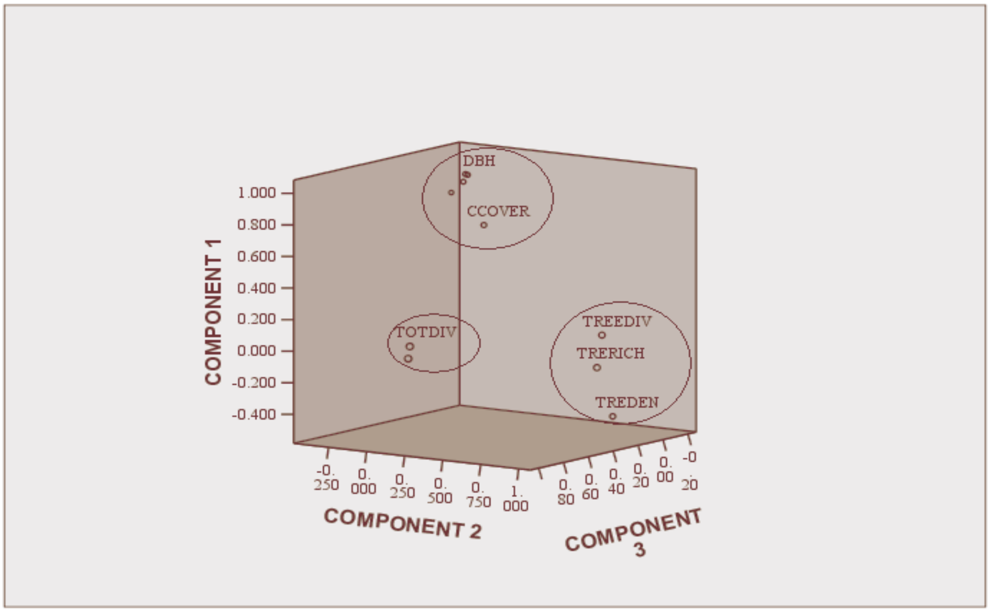


Figure 3.7 3D scatter diagram representation of all principal components of vegetation structure and composition among plant census plots

3.4.2.2 Cluster analysis of plant census plots

Cluster Analysis using different numbers of clusters yielded different significant levels for various vegetation characteristics. When two and three clusters were used in the analysis, five out of ten variables showed a probability significance level of less than 0.05. The five variables were stand basal area cover, mean tree basal area cover, canopy cover, DBH and mean tree height. A four cluster analysis yielded 8 significant variables which included the five variables identified under the 2 cluster and 3 cluster analysis as well as stem density, tree species richness and tree species diversity. The significance probability of stand basal area cover, mean tree basal area cover, canopy cover, DBH, mean tree height and stem density were less than 0.001 while tree species richness and diversity had probabilities of 0.01 and 0.023 respectively. A five cluster analysis also yield 8 significant variables which were similar to those identified in the four cluster analysis. The only difference was that the significance probability for tree species richness and diversity were 0.013 and 0.043 respectively. A six cluster analysis yielded 7 significant variables and included the 8 variables identified in the 4 cluster and 5 cluster analysis without the tree species diversity. The cluster analysis that was selected was the four cluster analysis (Figure 3.8). The first cluster had 9 plots (18%), the second cluster had 16 plots (32%) while the third and fourth clusters had 7 plots (14%) and 18 plots (34%), respectively (Appendix 3.4). The first cluster of plots contained the four plots identified as relatively undisturbed woodland while the third cluster contained the four plots identified as severely degraded woodland. The first cluster of plots was classified as old growth miombo while the second cluster was classified as degraded old growth miombo. The third and fourth clusters were classified as young regrowth and old regrowth miombo, respectively.

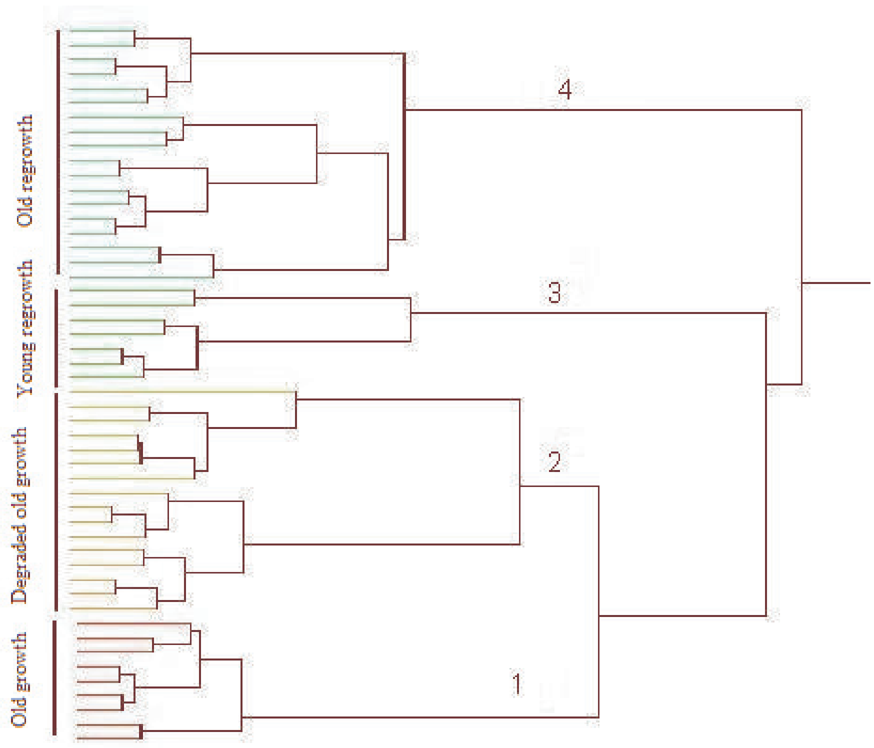


Figure 3.8 Classification of plant census plots using hierarchical cluster analysis into degradation groups: (1) Old growth miombo, (2) Degraded old growth miombo, (3) Young regrowth miombo and (4) Old regrowth miombo.

Young regrowth miombo is regenerating miombo that is in the initial, dense coppice phase and tall sapling phase (Figure 3.9a,b). Old regrowth miombo is regenerating miombo which is just maturing with a canopy that is not fully developed while the thinning of the intermediate size classes is not complete (Figure 3.9c). Degraded old growth woodland is mature woodland where there has been selective harvesting of trees for various purposes leaving other trees intact (Figure 3.9d). In the gaps where selective harvesting has taken place, there is regenerating miombo in the initial regrowth, dense coppice or tall sapling phases depending on when the harvesting had taken place. Degraded old growth miombo has a disjointed structure because of the mixed age nature of the woodland and it has a more open canopy. Old growth miombo is relatively undisturbed mature woodland with a fully developed canopy. Canopy trees are large with a height of about 15 - 17 m with a sparse understorey and grass layer (Figure 3.4a).

(a) (b) (c) (d)

Figure 3.9 Some phases in miombo woodland degradation and regeneration in Serenje District: (a) Regenerating miombo in the initial regrowth phase in the foreground and dense coppice phase in the background (b) Miombo woodland in the tall sapling phase. Most of the saplings are multistemmed, an indication that regeneration was from tree resprouts (c) Old regrowth miombo with a canopy that is not fully developed and (d) Degraded old growth miombo with evidence of an old charcoal kiln in the foreground and a coppicing tree stump on the left probably cut down to produce charcoal. In the background, the other big trees have been left intact

3.4.2.3 Discriminant Function Analysis of plant census plot clusters

Discriminant Function Analysis identified three discriminant functions as explaining the separation among sample plots belonging to different clusters. The first function accounted for 51.1% of the separation while the second and third function accounted for 31.1% and 17.8%, respectively. The correlation coefficients and tests of significance of the three discriminant functions are summarized in Table 3.2. All the three discriminant functions were statistically significant and correlations between the plot clusters and the identified discriminant functions were high.

Table 3.2 Results of Significance Tests of Discriminant Functions

Function	Wilks Lambda	Canonical coefficient	Chi square	df	p
1	0.028	0.888	1786.569	42	0.000
2	0.132	0.834	1009.431	26	0.000
3	0.434	0.752	416.091	12	0.000

The standardized discriminant coefficients of various vegetation variables are summarized in Table 3.3. High values of standardized coefficients indicate greater discriminating quality. Total species richness, mean tree basal area cover and stand basal area cover were highly positively correlated with the first function while diameter at breast height, total species diversity, tree species richness and stem density were highly negatively correlated with the first function. Stem density, total species richness and mean tree basal area cover were highly positively correlated with the second function while total species diversity was highly negatively correlated with the second function. Sapling density, sapling species diversity, total species diversity, tree species diversity, canopy cover and mean tree basal area cover were highly positively correlated with the third function while tree species richness was highly negatively correlated with the third function.

Table 3.3 Standardized Discriminant Coefficients of various vegetation variables

Vegetation variable	Function 1	Function 2	Function 3
Canopy cover	0.295	-0.335	0.726
Diameter at breast height	-1.947	-0.087	-0.1059
Sapling density	-0.147	0.275	1.322
Sapling species diversity	0.096	-0.217	0.565
Sapling species evenness	-0.471	-0.055	-0.347
Sapling species richness	0.531	0.495	-0.1088
Stand basal area cover	1.561	-0.109	-0.336
Total species diversity	-0.822	-0.579	0.767
Total species richness	1.421	1.059	0.078
Stem density	-0.820	0.931	-0.119
Mean tree basal area cover	1.106	0.699	0.686
Tree species diversity	0.264	0.294	0.777
Tree species evenness	0.546	-0.036	-0.061
Tree species richness	-0.994	0.069	-0.549

Classification results of the Discriminant Function Analysis indicate that 95.3 % of the plant census plots were classified correctly (Table 3.4). An indepth analysis of different miombo woodland types indicates that all old growth miombo plots were correctly classified while 89.5% of degraded old growth miombo plots were correctly classified. 5.8% of degraded old growth miombo plots were misclassified and should have been classified as old regrowth miombo while 4.7% of the plots should have been classified as young regrowth miombo. For old regrowth miombo, 96.9% of the plots were correctly classified while 3.1% of the plots should have been classified as old growth miombo plots. All the plots under young regrowth miombo were correctly classified.

Table 3.4 Classification results of Discriminant Function Analysis. Values in parentheses indicate the actual count.

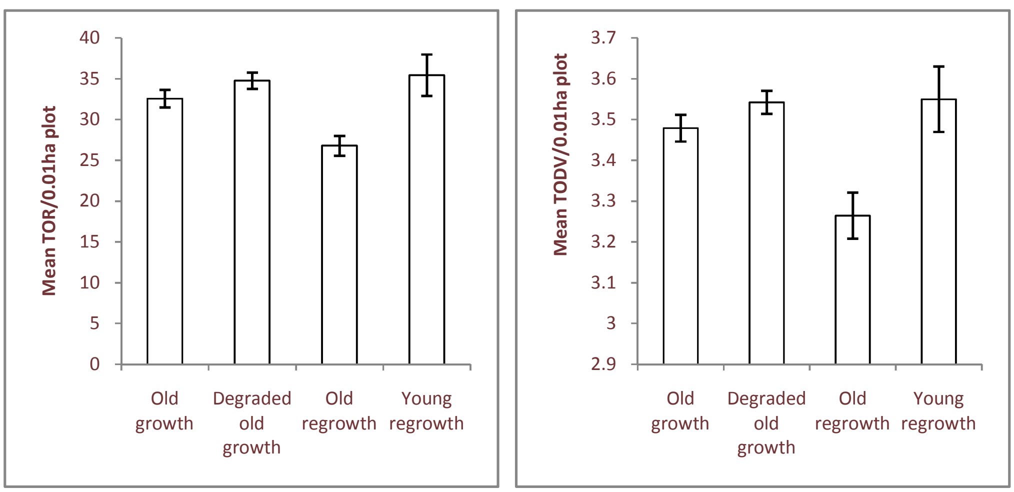
	Prescribed group membership				
	Old growth miombo	Degraded old growth miombo	Old regrowth miombo	Young regrowth miombo	Total
Old growth miombo	100% (87)	0	0	0	100% (87)
Degraded old growth miombo	0	89.5% (154)	5.8% (10)	4.7% (8)	100% (172)
Old regrowth miombo	3.1% (6)	0	96.9% (187)	0	100% (193)
Young regrowth miombo	0	0	0	100% (57)	100% (57)

3.4.3 Variation in vegetation composition and structure among habitats

Within each plant census plot, 15 vegetation characteristics were determined. The means and SE of the vegetation characteristics per plot for the four habitat types are summarized in Appendix 3.5.

3.4.3.1 Vegetation composition

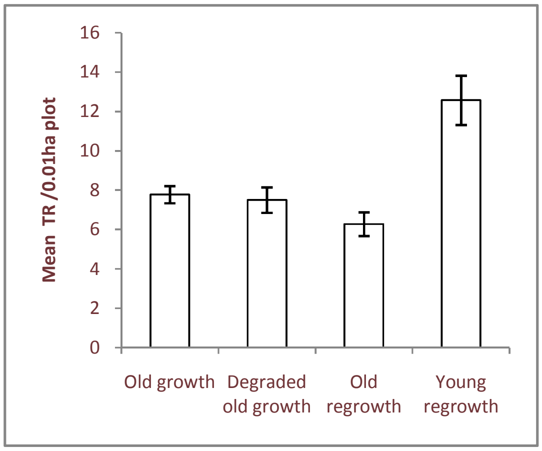
Analysis of variance revealed that there were significant differences in the mean total plant species richness (TOR) among the habitats ($F_{3,46}$ = 10.029; p < 0.0001). Comparison of means using the Bonferroni test however, revealed that the means of old growth, degraded old growth and young regrowth woodland were not significantly different from one another. Average TOR in old regrowth woodland of 26.78 ± 0.801 was significantly different from that of 34.28 ± 1.220 in the other habitats (Figure 3.10a). Analysis of variance also revealed significant differences in the mean total plant species diversity (TODV) among the habitats ($F_{3,46}$ = 8.257; p = 0.0002). However, comparison of means revealed the means of old growth, degraded old growth and young regrowth woodland were not significantly different from one another. Average TODV in old regrowth woodland of 3.26 ± 0.057 was significantly different from that of 3.53 ± 0.024 in the other habitats (Figure 3.10b).

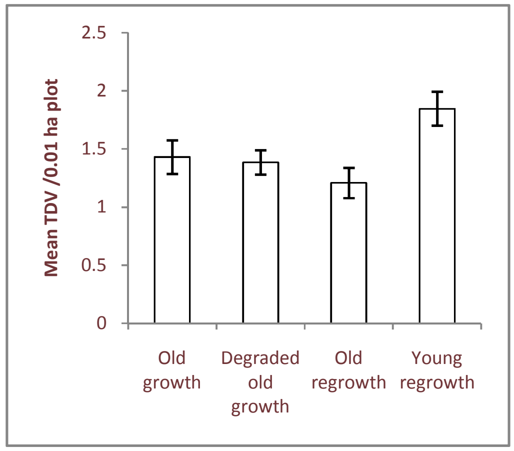


(a) (b)

Figure 3.10 (a) Total plant species richness and (b) Total plant species diversity in four miombo woodland habitat types in Serenje District. The vertical lines indicate SE of the mean.

There were significant differences in the mean tree species richness (TR) among the habitats ($F_{3.46}$ = 10.674; p < 0.0001). Comparison of means however, revealed that the means of old growth, degraded old growth and old regrowth woodland were not significantly different from one another. Average TR in young regrowth woodland of 12.57 ± 1.251 was significantly different from that of 7.05 ± 0.367 in the other habitats (Figure 3.11a). Analysis of variance revealed significant differences in the mean tree species diversity (TDV) among the habitats ($F_{3,46} = 3.116$; $p = 0.035$). Comparison of means revealed that the average TDV in young regrowth miombo was significantly different from that in old growth, degraded old growth and old regrowth miombo. The other miombo types were not significantly different from one another (Figure 3.11.b).





(a) (b)

Figure 3.11 (a) Tree species richness and (b) Tree species diversity in four miombo woodland habitat types in Serenje District. The vertical lines indicate SE of the mean.

Analysis of variance revealed significant differences in the mean sapling species richness (SAR) among the habitats ($F_{3,46} = 3.62$; $p = 0.02$). However, comparison of means revealed that the average SAR of old growth, degraded old growth and young regrowth woodland were not significantly different from one another. Average SAR in old and young regrowth woodland were also not significantly different from each other whereas average SAR in old growth and degraded old growth woodland were significantly different from that in old regrowth woodland (Figure 3.12). There were no significant differences in the mean sapling species diversity (SADV) among habitats ($F_{3,46} = 1.477$; $p = 0.233$). The mean SADV in all plant census plots combined was 1.09 ± 0.061.

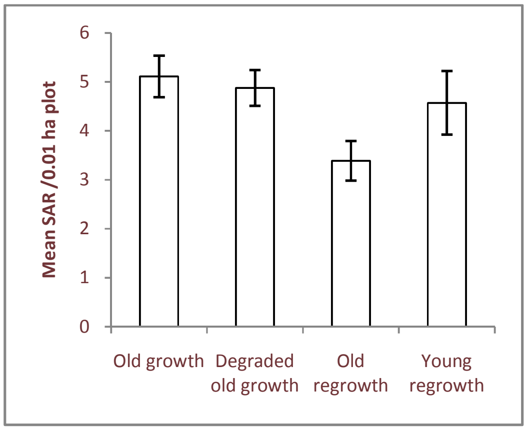
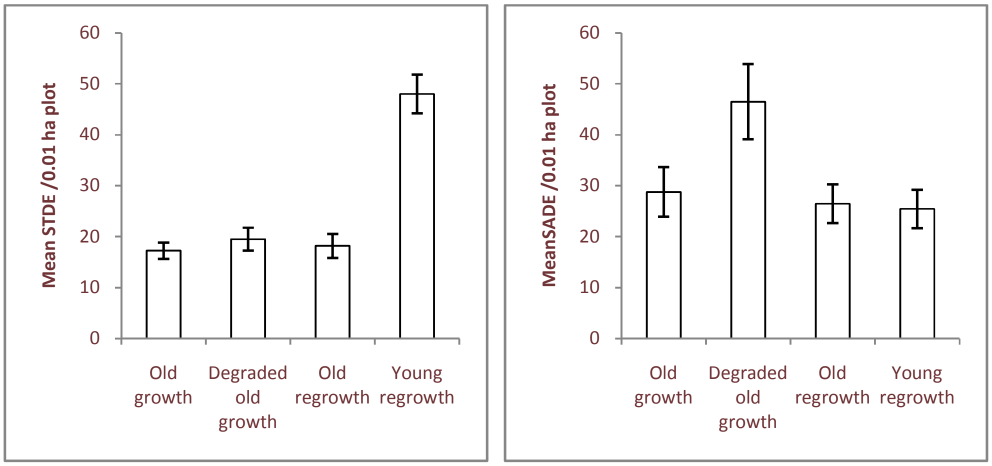


Figure 3.12 Sapling species richness in four miombo woodland habitat types in Serenje District. The vertical lines indicate SE of the mean.

Differences in mean tree species evenness (TEV) among the habitats were insignificant ($F_{3,46}$ = 0.525; p = 0.6674). The mean TEV in all plant census plots was 0.69 ± 0.026. There were also no significant differences in the mean sapling species evenness (SAEV) among habitats ($F_{3,46}$ = 0.292; p = 0.831). The mean SAEV in all plant census plots combined was 0.74 ± 0.030.

3.4.3.2 Vegetation structure

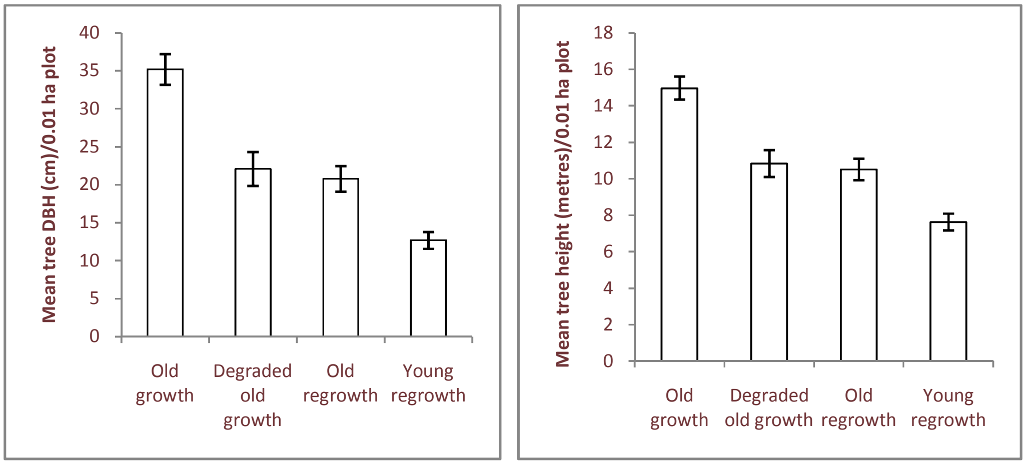
There were significant differences in the mean stem density (STDE) among habitats ($F_{3,46}$ = 21.756; $p < 0.0001$). Comparison of means however, revealed that there were no significant differences in the average STDE of old growth, degraded old growth and old regrowth woodland. However, the average STDE in young regrowth woodland of 48.0 ± 3.786 was significantly different from that of 18.47 ± 1.322 in the other habitats (Figure 3.13a). Analysis of variance revealed significant differences in the mean sapling density (SADE) among habitats ($F_{3,46}$ = 3.298; p = 0.029). Comparison of means revealed that the average SADE of degraded old growth woodland was different from that of the other three habitats. Average SADE in degraded old growth woodland of 46.50 ± 7.373 was significantly different from that of 26.85 ± 2.456 in the other habitats (Figure 3.13b).



(a) (b)

Figure 3.13 (a) Stem density and (b) Sapling density in four miombo woodland habitat types in Serenje District. The vertical lines indicate SE of the mean.

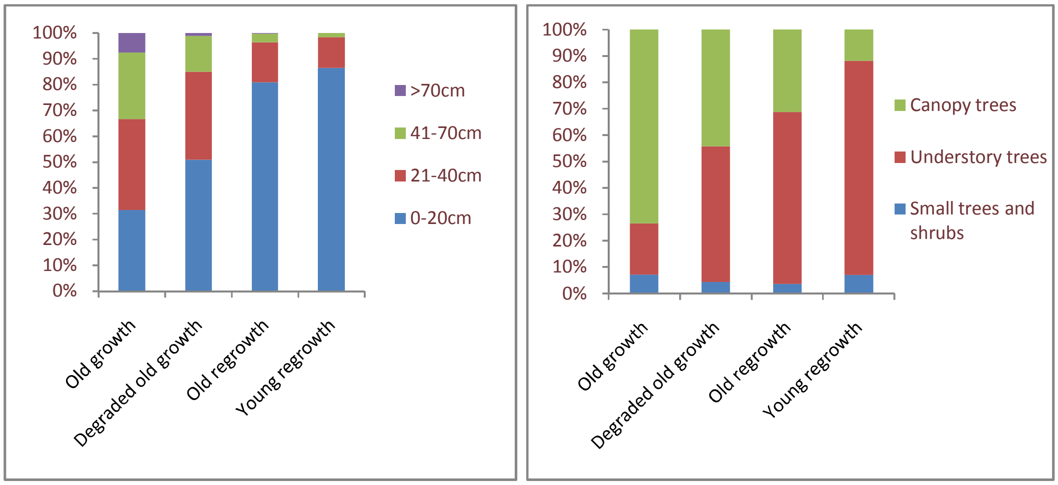
Differences in mean tree size (DBH) among habitats were significant ($F_{3,46} = 13.878$; $p < 0.0001$). Comparison of means revealed that the average tree sizes in old and young regrowth woodland were not significantly different from one another while those in degraded old growth and old regrowth woodland were also not significantly different from one another. Average tree size in degraded old growth woodland was significantly different from that in young regrowth woodland. Tree sizes in old growth woodland were significantly bigger than those in the other three habitats (Figure 3.14a). There were significant differences in the mean tree height among the habitats ($F_{3,46} = 12.714$; $p < 0.0001$). Comparison of mean tree heights revealed that trees in old growth woodland were significantly taller than those in the other habitats. Average tree height in degraded old growth woodland was significantly different from that in young regrowth woodland. Average tree heights in old and young regrowth woodland were not significantly different from one another. Average tree heights in degraded old growth and old regrowth woodland were also not significantly different from one another (Figure 3.14b).



(a) (b)

Figure 3.14 (a) Tree size and (b) Tree height in four miombo woodland habitat types in Serenje District. The vertical lines indicate SE of the mean.

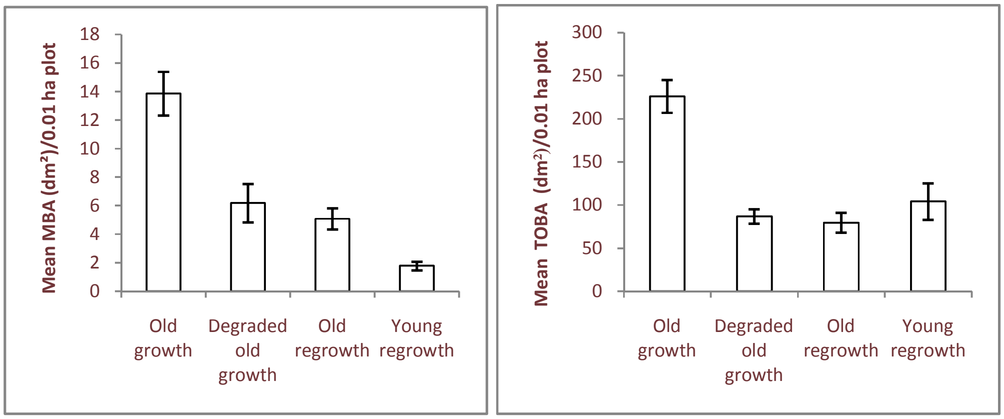
In terms of the distribution of tree sizes, regrowth woodland had over 80% of its stems in the 0 – 20 cm DBH class whereas in old growth woodland only 30% of the stems were in the smallest size class. In degraded old growth woodland about 50% of the stems were in the smallest size class (Figure 3.15a). When the trees were grouped into three height classes, old growth woodland had more than 70% of its trees in the canopy category whereas degraded old growth woodland had 44% of its trees constituting canopy trees. Degraded old growth woodland had 51% of its trees constituting understorey trees. Old and young regrowth woodlands were dominated by understorey trees with over 60% of the trees falling within this category (Figure 3.15b).



(a) (b)

Figure 3.15 (a) Proportion of stems in four DBH size classes and (b) Proportion of trees in three height classes in four miombo woodland habitat types in Serenje District.

Analysis of variance revealed significant differences in the mean tree basal area cover (MBA) among habitats ($F_{3,46} = 13.426$; $p < 0.0001$). Comparison of means revealed that the means of degraded old growth, old regrowth and young regrowth woodland were not significantly different from one another (Figure 3.16a). Average MBA in old growth woodland of 13.86 ± 1.527 dm^2 was significantly different from that of 4.95 ± 0.656 dm^2 in the other habitats. There were significant differences in the mean stand basal area cover (TOBA) among habitats ($F_{3,46} = 22.137$; $p < 0.0001$). Comparison of means revealed that the means of degraded old growth, old regrowth and young regrowth woodland were not significantly different from one another (Figure 3.16b). Average TOBA in old growth woodland of 226.11 ± 18.947 dm^2 was significantly different from that of 86.66 ± 6.926 dm^2 in the other habitats.



(a) (b)

Figure 3.16 (a) Tree basal area cover and (b) Stand basal area cover in four miombo woodland habitat types in Serenje District. The vertical lines indicate SE of the mean.

Differences in the average canopy cover among the habitats were significant ($F_{3,46} = 10.123$; $p < 0.0001$). Comparison of means revealed that there was no significant difference in average canopy cover in old growth and degraded old growth woodland. There were also no significant differences in average canopy cover between degraded old growth and old regrowth woodland, and between old regrowth and young regrowth woodland. However, there were significant differences between average canopy cover values for old growth woodland and that of old and young regrowth woodland, and between that of degraded old growth and young regrowth woodland. Old growth woodland had the highest canopy cover of 51.11 ± 4.985% while the lowest canopy cover of 6.43 ± 0.922% was in young regrowth woodland (Figure 3.17).

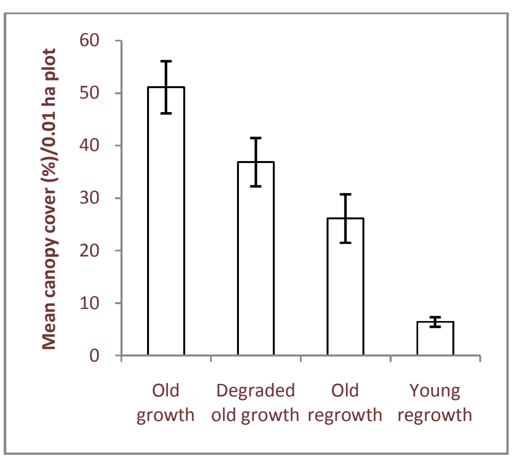


Figure 3.17 Woody plant canopy cover in four miombo woodland habitat types in Serenje District. The vertical lines indicate SE of the mean.

3.4.4 Vegetation structural diversity

Degraded old growth miombo was the most structurally diverse of the four habitats followed by old regrowth miombo (Table 3.5). Young regrowth miombo was the least structurally diverse of the four habitats.

Table 3.5 Proportion of woody vegetation in three height classes and the foliage height diversity in four miombo woodland habitat types in Serenje District, Zambia. Values given are mean ± SE.

	Proportion of shrubs and small tree (%)	Proportion of understorey trees (%)	Proportion of canopy trees (%)	Foliage height diversity (FHD)
Old growth miombo	7.1 ± 2.44	19.5 ± 6.14	73.4 ± 6.63	0.734 ± 0.111
Degraded old growth miombo	4.3 ± 1.45	51.4 ± 5.58	44.2 ± 6.40	0.838 ± 0.050
Old regrowth miombo	3.7 ± 1.58	65.1 ± 4.86	31.2 ± 4.96	0.763 ± 0.060
Young regrowth miombo	7.0 ± 1.92	81.1 ± 2.22	11.9 ± 3.61	0.609 ± 0.030

3.5 Discussion

3.5.1 Vegetation composition

Miombo woodland has been estimated to contain 650 woody species of which 140 species are said to be common (White, 1962; Fanshawe, 1971; Chidumayo, 1987b). Differences in species composition are more apparent at a local scale. Species diversity was higher in young regrowth woodland compared to the other habitats (Figures 3.10 and 3.11) while the lowest floristic species diversity was in old regrowth woodland. Studies on species diversity in miombo woodland have yielded different results with Chidumayo (1987c) finding greater species diversity in small coppice plots than in similar old growth woodland plots while other studies indicate greater decline in species diversity in regenerating miombo than in old growth miombo woodland (Chidumayo, 1987b). Strømgaard's (1986) survey on abandoned shifting cultivation plots after various periods of abandonment found that woody diversity was lowest in the middle of the succession cycle because the distribution of individuals among species was highly uneven and that early and late stages of succession were more similar than intermediate ones. The similarity in species diversity between early and late successional stages might be the result of miombo woodland regenerating largely through sucker shoots of cut tree stumps and suppressed saplings instead of seeds (Frost, 1996).

Results from this study indicate that young regrowth woodland and old growth woodland had high species diversity while the intermediate old regrowth woodland had low species diversity. Zambian miombo woodland exhibits no significant regional differences in the distribution of dominance and species evenness (Chidumayo, 1987b). Results from this study did not yield any significant difference in species evenness among different miombo woodland types.

3.5.2 Vegetation structure

The mean stem densities in the different habitats ranged from 180 - 480 stems ha^{-1} (Figure 3.13a). Studies done elsewhere indicate stem densities ranges from 380 - 5810 stems ha^{-1} (Trapnell, 1959; Boaler & Sciwale, 1966; Strang, 1974; Malaisse, 1978; Chidumayo, 1988a). Within regrowth miombo with each successive clearing, stem density increases due to the dual recruitment from the coppice of cut trees and suppressed saplings (see Figure 3.10). During the development period, the number of shoots decreases due to inter-shoot competition and therefore stem density per plant declines slowly with age of regrowth. As a result, stem density in regrowth miombo woodland is higher than in mature woodland (Chidumayo, 1988b; Chidumayo, 1989; Chidumayo, 2002; Chidumayo, 2004). Results from this study indicate that stem density was higher in young regrowth woodland while the other three habitats did not show any significant difference in stem density (Figure 3.13a). Apart from tree cutting, fire can either slow or accelerate the regeneration process in miombo woodland. Chidumayo (1988b) found that early dry season burnt plots had a higher stem density than protected plots in both coppiced and old growth woodlands. Late dry season burnt plots were found to have a higher stem mortality than early burnt plots (Trapnell, 1959; Chidumayo, 1989; Chidumayo, 1997). In the study area which includes two National Forests, burning is done haphazardly and a lot of the fires that occur are accidental (Figure 3.5). Repeated cutting of regrowth miombo results in unusually dense stands. Stump survival rates have been found to be higher at sites that are sprouting from previous felling than at sites that were mature woodland before clearing (Strang, 1974; Chidumayo, 2004). In this study, sapling density was higher in degraded old growth woodland compared to the other habitats (Figure 3.13b). The cutting history of the woodland in the study area is not well documented. Interviews with staff at Serenje District Forestry Office revealed that most of the woodland in the PFAs in the district was clear-felled in the early 1970s for Tsetse fly control.

Basal area cover in an area is the result of the combination of tree size (DBH) and stem density. The highest stand basal area cover was in old growth woodland followed by young regrowth woodland while the lowest stand basal area cover was in old regrowth woodland (Figure 3.16b). For old growth woodland, the larger trees compared to the other habitats contributed to the overall high stand basal area cover (Figure 3.14a). Although young regrowth woodland had the smallest trees of the four habitats, the higher stem density in young regrowth woodland contributed to the higher stand basal area cover overall compared to degraded old growth and old regrowth woodland (Figures 3.13a & 3.14a). Chidumayo (1988b) found that there is a high basal area increment in coppice as a result of increasing stem density and a higher DBH increment during the early growth phase. Stem density decline in older coppice has a negative effect on basal area increment.

The relative stand basal area cover obtained in the different habitats ranged from 7.9 – 22.6 m^2 ha^{-1} (Figure 3.16b). The mean stand basal area cover estimate for the study area is 12.66 ± 3.6 m^2 ha^{-1}. This compares well with the basal area cover estimates in Serenje District obtained by Chidumayo (1987a) for old growth stands with a range of 6.0 to 62.3 m^2 ha^{-1} and mean basal area cover of 11.73 ± 0.736 m^2 ha^{-1}.

Aridity ratio is a measure of the relative amount of water gained from rainfall and that lost by evaporation and transpiration (Chidumayo, 1987a). It is a biologically suitable measure of the amount of moisture available to vegetation particularly in climates with contrasting seasons. It is calculated as:

Aridity ratio = P/ETP

where P is mean annual precipitation and ETP is annual potential evapotranspiration.

Zambia can be conveniently divided into four aridity zones. Zone I has an aridity ratio under 0.7, Zone II has an aridity ratio of 0.7 – 1.0, Zone III has an aridity ratio of 1.0 – 1.3 and Zone IV has an aridity ratio of 1.3 - 1.6. Serenje District belongs to aridity zone III. The basal area mean for aridity zone III is 13.02 ± 0.443 m^2 ha^{-1} (Chidumayo, 1987a). This value lies within the mean range value obtained in this study which is 12.66 ± 3.6 m^2 ha^{-1}. Elsewhere in the miombo biome, the recorded basal area of trees in old growth and mixed-age stands of miombo woodland ranges from 7 m^2 ha^{-1} at about 650 mm mean annual precipitation in southern Malawi to 22 m^2 ha^{-1} in wet miombo woodland on deep soils in the Democratic Republic of Congo at 1270 mm rainfall (Malaisse, 1978; Lowore *et al.,* 1994). Higher values

(25 - 50 m^2 ha^{-1}) have been recorded locally on small plots (Chidumayo, 1988a; Grundy, 1995). Most stands have basal areas of 7 - 19 m^2 ha^{-1} (Boaler & Sciwale, 1966; Strang, 1974; Chidumayo, 1987a & c; Malimbwi *et al.,* 1994). Miombo woodland has been found to be similar to many other forest types that exhibit biomass variability in space due to variability in species composition, stem density and age/size structure. Large sample plots have been found to be more appropriate in sampling biomass variability than small plots because depending on the siting of the plots, small plots are likely to represent a uniform stand than large plots. Consequently, data from small plots will tend to either underestimate or overestimate biomass (Chidumayo, 1990).

Miombo stands have crowns diffused at all heights and rarely is the vertical structure well-developed. This makes it difficult to distinguish between canopy and understory species because some stems of traditionally recognized understorey species at some sites form part of the canopy stem population while those of the traditionally recognized canopy species can belong to both strata (Fanshawe, 1971; Chidumayo, 1987b). In this study, the height of the trees was crudely used to stratify the vegetation without considering whether the species had attained their full development or not. Canopy and understorey species as defined by Fanshawe (1971) attain different heights at maturity and as such, the terms canopy/understorey species were not used in this study. Height growth of understorey and canopy species in miombo woodland stagnates at about 5 m and 8 - 9 m respectively. During the early stages of miombo woodland recovery, understorey species grow relatively faster than canopy species. However, because understory species attain maturity at a lower height they ultimately become over shadowed by canopy species (Chidumayo, 1988c). The average canopy cover in the different habitats ranged from 6 - 51% (Figure 3.17). The lowest canopy cover was in young regrowth woodland which had the largest proportion of trees constituting the understorey while the highest canopy cover was in old growth woodland which had the largest proportion of trees constituting the canopy (Figure 3.15b). Stem height increments in regrowth miombo woodland are highest in the first or second year and decline thereafter. Mean stem height may reach 4-5 m by 15-18 years in regrowth dry miombo (Chidumayo 1993; Grundy, 1995).

3.5.3 Woodland degradation and regeneration

Different land uses and infrastructure development in miombo woodland found in Serenje District have led to woodland in different stages of degradation and regeneration (Figure 2.5, 2.8 & 2.9). Cluster Analysis identified four types of miombo woodland in the study area based on the level of degradation. The four miombo woodland types are old growth, degraded old growth, old regrowth and young regrowth miombo (Figures 3.8). Old growth miombo is a relatively undisturbed woodland while old regrowth miombo is a recovering woodland. Young regrowth miombo and degraded old growth miombo are the woodland types which show the impact of different degradation factors. Young regrowth miombo results from clear - felling of trees mainly for shifting cultivation whereas degraded old growth miombo results from selective felling of trees for charcoal making and timber. The impact of woodland degradation include reduced canopy cover, basal area cover and tree size (Grainger, 1999). Low intensity forestry practices such as charcoal production and timber harvesting do not lead to drastic changes in woodland structure whereas clear-felling of trees for agriculture and infrastructure development changes the woodland structure completely.

Clustering of plant census plots into different miombo woodland types was mainly based on vegetation structure characteristics. Six out of the 10 significant variables used in the cluster analysis describe vegetation structure (Table 3.1). Old growth miombo and young regrowth miombo plots were correctly classified according to the results of Discriminant Function Analysis (Table 3.4). These two woodland types had the lowest vegetation structural diversity among the four miombo woodland types being dominated by either canopy trees or understorey trees (Table 3.5). The low structural diversity made it easy to separate the two miombo woodland types from the other types because their vegetation structure was distinctively different. Some plots under degraded old growth miombo and old regrowth miombo were incorrectly classified. Degraded old growth miombo has a disjointed vegetation structure consisting of old growth miombo interspersed with regrowth miombo in various stages of regeneration (Martin, 1996). This disjointed structure of degraded old growth miombo led to some plots that should have been grouped under old regrowth miombo or young regrowth miombo being misclassified as degraded old growth miombo. Degraded old growth miombo had the highest vegetation structural diversity of the four miombo woodland types (Table 3.5). The high structural diversity made it difficult to classify all the plots in this woodland type accurately. Old regrowth miombo is a recovering woodland. The vegetation structural diversity in this woodland type was also high because some of the plots were almost fully regenerated mature woodland whereas others were not. Results of the Discriminant Function Analysis revealed that some of the plots classified as old regrowth miombo should have been classified as old growth miombo. Overall classification of plant census plots along the woodland degradation gradient was over 95% correct.

Apart from infrastructure development, the main cause of woodland degradation in the study area is the declining fallow period in shifting cultivation practiced in the area. It takes about 35 year for miombo woodland to regenerate to a mature woodland after being felled at breast height in Serenje District (Peters, 1974). The prevailing situation is that chitemene fields are being cut down from trees that are not fully regenerated and the average age of growth being cut has fallen to 17 years (Figures 2.5 and 2.6). The population increase and some aspects of sociological change where people are now reluctant to move from site to site means that regrowth miombo does not fully recover to become old growth before it is cut down again (Lawton, 1982). There were few areas that had old growth miombo in the open area study site. Even in the Forest Reserves, most of the woodland was old regrowth or degraded old growth.

3.6 Conclusions

Four miombo woodland types were identified based on their level of woodland degradation. These are old growth miombo, degraded old growth miombo, old regrowth miombo and young regrowth miombo.

3.6.1 Vegetation composition

Young regrowth miombo had the highest total plant species richness and diversity, tree species richness and diversity and tree evenness. Old regrowth miombo had the lowest total plant species richness and diversity, tree species richness and diversity and tree evenness. Sapling species richness and diversity was highest in old growth miombo while old regrowth miombo had the lowest sapling species richness and diversity. Degraded old growth miombo had the highest sapling evenness while the lowest sapling evenness was in old growth miombo. Of the four habitats, old regrowth miombo was the most deficient in terms of species richness and diversity while young regrowth miombo was the most rich and diverse.

3.6.2 Vegetation structure

Old growth miombo had the highest stand basal area cover, tree basal area cover, tree size, canopy cover and tree height. Old growth miombo also had the lowest stem density of the four habitats. Young regrowth miombo had the lowest canopy cover, tree height, tree basal area cover, tree size and sapling density. However, young regrowth miombo had the highest stem density. Degraded old growth miombo had the highest sapling density. In terms of vertical distribution of plant biomass, degraded old growth miombo was the most structurally diverse having canopy and understory trees in almost equal proportions while young regrowth miombo was the least structurally diverse as it was dominated by understorey trees.

3.6.3 Response of miombo woodland to degradation

The response of miombo woodland to four degradation indicators is summarized in Figure 3.18. Tree size, tree height, canopy cover and tree basal area cover showed a clear decreasing trend from old growth miombo to young regrowth miombo. Other degradation indicators such as stem density, stand basal area cover and sapling density did not show any clear trend along the woodland degradation gradient in this study.

	Trend across habitat		
Degradation Indicator	***Old growth → Degraded old growth → Old regrowth → Young regrowth miombo***		
Tree size	⟶	Decreasing	⟶
Tree basal area cover	⟶	Decreasing	⟶
Tree height	⟶	Decreasing	⟶
Canopy cover	⟶	Decreasing	⟶

Figure 3.18 Overview of the trend in indicators of woodland degradation in different miombo woodland types found in Serenje District.

CHAPTER 4 MIOMBO AVIAN COMMUNITY STRUCTURE

4.1 Introduction

This chapter presents the results of bird surveys that were conducted in order to describe the avian community structure in the study area. The results answer to the overall objective stated in 1.5.1: to determine the avian community structure in the study area. The specific objectives of the study were:

(i) To determine avian species composition and bird species groupings in the study area,

(ii) To determine avian species richness in different habitats,

(iii) To determine avian abundance in different habitats,

(iv) To determine avian guild richness in different habitats and,

(v) To determine the habitat range specialization of the avifauna in different habitats.

The study tested the following hypotheses:

(i) Avian species richness decreases with increased woodland degradation,

(ii) The number of avian guilds decreases with increased woodland degradation and,

(iii) Avian abundance decreases with increased woodland degradation.

4.2 Methods

4.2.1 Sampling design and bird censuses

The general sampling design has been described in section 3.2.1 of chapter 3. Censuses of birds were conducted in circular plots with a radius of 50 m referred to as bird census plots (Figure 3.2). The principal techniques used for censusing birds fall into two categories: (i) counting techniques and (ii) mist netting (Bibby *et al.,* 1992; Whitman *et al.,* 1997). The difference between the two techniques is that mist netting detects birds by capture, whereas counting techniques rely on an observer to detect birds by sight or sound. Counting techniques require skilled observers familiar with songs or calls of sometimes hundreds of bird species. Secretive non-vocal species which may be an important component of the avifauna are easily missed by counting techniques. When skilled observers are not available, mist netting is an alternative for surveying birds. However, mist netting is ineffective in surveying species that are large and/or inactive within 2 m of the ground. The point count method (Hutto *et al.,* 1986) was used to survey birds in this study because miombo woodland is relatively open and it easy to observe birds in all strata of the vegetation. The technique assumes that all the birds are detected either audibly or visually and that birds occurring at the point are not missed and that each bird is counted only once. The advantages of the technique are that it can be used at any time of the year, is less time consuming than mist netting and it is easier to complete. Nine bird surveys were conducted. Four surveys were done in the cool and dry season (May 2006, July 2006, May 2007 & July 2007), three in the hot and wet season (March 2006, December 2006 & March 2007) while two were done in the hot and dry season (October 2006 & September 2007).

Bird censuses were conducted in bird census plots using the point count method. Each plot was marked with coloured flagging material at 20 m intervals along the perimeter in order to ensure that birds outside the census plots were not included in the count. Bird counts in the plots commenced at sunrise and were completed by 11.00 hrs the same morning. Two transects, each with 5 plots, were surveyed each day making up 10 survey points per day. The birds counted were those using the plot for foraging, nesting, roosting and intra - and inter-specific aggressive or territorial behaviour. Birds flying over the plot were excluded from the count but birds flushed while approaching the centre of the plot were included. The count started 3 minutes after reaching the centre of the plot in order to give birds time to settle down and it lasted for 10 minutes. The counting was done by one observer (F. Lumbwe) to avoid biases in observer performance (Rosenstock *et al.,* 2002). During the cool and dry, and hot and wet seasons, point counts were conducted on mornings when the sky was clear. Censuses were not done on mornings when the sky was cloudy or overcast as bird activity tended to be reduced in such conditions. In each plot, the species, the number of individuals within a species and mode of detection (song, call, or visual) of all birds seen or heard within each plot were recorded. For foraging and feeding birds, the type of food taken was recorded including the height of the vegetation the birds were foraging in. The foraging height classes were ground (found on or near the ground); understorey, the first 6 metres above ground and canopy, over 6 metres (Wilson & Comet, 1996; Sigel *et al.,* 2006).

Databases of bird sound recordings by Claude Chappius (2001) *African Bird Sounds* which contains 15 CDs covering 1460 species and Guy Gibbon (1995) *Southern African Bird Sounds* which contains 6 CDs covering 900 species were used prior to the study to train in identifying birds by sound apart from the visual identification. For birds that could not be identified visually in the field, details of the plumage, bill, legs and other outstanding characteristics were noted and these were used in taxonomic keys and field guides to aid in identification. For bird calls and/or songs that could not be identified in the field, recordings were made and these were compared with Chappius and Gibbon databases.

4.2.2 Avian guilds and distribution categories

Birds were assigned to guilds using two criteria; (1) primary food habit based on the type of food they consume and (2) vegetation height commonly used for foraging and feeding. Primary food habit categories were (i) insectivorous which describes birds that eat entirely or essentially only insects, spiders and other small invertebrates, (ii) carnivorous birds which eat vertebrates, carrion or both vertebrates and insects, (iii) vegetarian are birds that only eat plant materials, such as fruit, seeds, nectar and leaves and (iv) omnivorous are birds that feed on both plant and animal based foods (Frost & Frost, 1980; Larsson & Hemborg, 1995; Sigel *et al.,* 2006). For foraging and feeding height, the categories were ground, understory and canopy. Foraging and feeding height was only assigned if the species was observed foraging and feeding in that stratum in at least five out of the nine sampling events. When conflicts arose, as with species which were recorded but their foraging and feeding height could not be determined with certainty in the field, literature on habitats used by birds for various activities were consulted in making the assignments of species to guilds. The main sources of literature were seven volumes of Fry *et al.,* (1982 – 2004), Mackworth – Praed & Grant, (1962 - 63) and Benson *et al*., (1971). The dietary and foraging height data were combined to determine the guild of each bird species recorded on study plots. Species that were recorded in more than two height categories were considered as generalists. The total number of guilds and bird abundance by guild were recorded in each plot.

Bird species were also assigned to 3 groups based on their habitat range distribution. The categories were (1) endemic species which are species whose entire global distribution lies within the defined boundaries of miombo woodland, (2) habitat-restricted species which are species that occur in miombo woodland more frequently than in other habitats or vegetation and breed in miombo woodland, and (3) habitat generalists which are species that are common in most of the vegetation and habitat types (Benson *et al.,* 1971; Leonard, 2005).

4.3 Data analysis

4.3.1 Avian species occurrence

In order to determine which species were common or rare, species abundance data for each plot were treated as presence and absence data and the frequency of detection of each species was calculated as:

$$FD = P/N$$

where FD is the frequency of detection, P is the total number of plots in which the species was observed during the whole study and N is the number of plots x sampling events or 450.

4.3.2 Avian community structure

In order to determine bird species groupings in the study area, multivariate statistics were performed on the avian community data. Multivariate techniques fall into two main groups; classification and ordination. Classification is the placement of species and/or sample units into groups based on their overall similarity while ordination is the arrangement or ordering of species and/or sample units along a gradient (SPSS, 2005). Cluster analysis was used in classification while Principal Component Analysis was the ordination method used in gradient analysis.

4.3.2.1 Cluster analysis of bird species and sample plots

Bird abundance data from the nine censuses were pooled by species for each plot and the pooled data was subjected to a Hierarchical Cluster Analysis (SPSS, 2005) in order to determine bird species groupings in the study area. The data matrix consisted of bird species (rows) by their pooled bird abundance data in the plots (columns). Similarity among the bird species was based on their abundance in the plots. The clustering method used was the Ward's method while the distance measure was the Squared Euclidean distance measure. Since the column data consisted of bird abundance data only, there was no need to standardize the data before the cluster analysis. In addition, bird census plots were also subjected to a Hierarchical Cluster Analysis using the pooled bird abundance data by species in order to determine how bird census plots were related with regards to their selection by bird species. The plot clusters from bird abundance data were then compared with the plot clusters obtained using vegetation structure and composition data (Figure 3.8) in order to determine if the clustering was similar or not.

4.3.2.2 Principal Component Analysis of avian species

Principal Component Analysis was conducted on the bird abundance data obtained in the bird census plots in order to identify the principal bird groupings using SPSS© analytical software (SPSS, 2005). The columns in the data matrix consisted of bird abundance data by species while the rows consisted of the 50 bird census plots. The purpose of the PCA was to determine whether there were similarities in bird species grouping obtained by cluster analysis and those identified by PCA which also ordinates the bird groupings along a gradient.

4.3.3 Avian abundance along the woodland degradation gradient

The abundance data for each plot were summarized in terms of abundance of birds per plot calculated for different bird groups: (i) overall bird abundance, (ii) abundance of miombo habitat endemics, (iii) abundance of habitat-restricted birds, (iv) abundance of habitat generalists, (v) abundance of omnivores, (vi) abundance of vegetarians, (vii) abundance of insectivores and (viii) abundance of nectarivores. Individual species abundance and individual guild abundance estimates per plot were not used because some species and guilds were not recorded in many of the plots. Analysis of variance (Analytical Software, 2003) was used to determine whether there were significant variations in bird abundance among different habitats at a significance level of 0.05. Where there were significant differences, comparison of means using the Bonferroni test was used to show which pair of means were different from each other. Before ANOVA was done, the plot data were subjected to spatial autocorrelation analysis in order to assess whether the plot data for each transect were randomly distributed or not. This was done by regressing data at subsequent plots on data on the previous plot on the same transect. Where significant autocorrelation was observed in the distribution of the transect data, Geostatistics (Gamma Design Software, 2004) was used to determine the range at which spatial autocorrelation in the data ended. The autocorrelated data was then detrended using Berryman's equation (Berryman, 1997). When trends are observed in temporal or spatial data, they can be detrended by rotating the data around the mean. The difference between the expected value computed from a linear regression model through the series and the data point is added to the mean of the series to give the detrended data as shown below.

$$X'(d) = X(d) - (a+b*d) + \overline{X}$$

where $X'(d)$ is the detrended data point at distance d along the transect; $X(d)$ is the original data point at distance d along the transect, $\overline{X}$ is the mean of the transect data, a is the regression intercept, and b is the regression slope. The purpose of detrending the data was to meet the conditionality of random distribution of data before using a parametric test like ANOVA.

All calculations for bird abundance measures were based on pooled data per plot from nine censuses. Seasonal bird community measures were based on four censuses per plot for the cool and dry season, three censuses per plot for the hot and wet season, and two censuses per plot for the hot and dry season. Before the seasonal data were pooled, the census data were subjected to ANOVA in order to determine whether there were significant variations in seasonal data obtained in different years.

4.3.4 Avian species richness and guild richness along the woodland degradation gradient

All the bird species recorded in each plot during the nine censuses were pooled as well as the number of guilds recorded in each plot. The pooled plot data for avian species richness and avian guild richness were separated according to miombo woodland type (Figure 3.8) and ANOVA was performed on the data in order to determine if there were significant differences in avian species richness and guild richness among different miombo woodland types. Before ANOVA was performed, the pooled data was subjected to spatial autocorrelation as outlined under section 4.3.3 above.

4.4 Results

4.4.1 Composition of the avian community

The total number of birds counted was 2637 from 450 points in 9 sampling events. Sixty-seven species of birds were recorded in the bird census plots (Appendix 4.1). Of these, 56 species (84 %) are resident breeders while 10 species (15%) are migrant breeders and 1 species (1%) is a Palaearctic breeder. In terms of habitat range distribution, 44 species (66%) are habitat generalists while 13 species (19%) are habitat-restricted and 10 species (15%) are miombo habitat endemics. In terms of primary food habit, two species are carnivorous, 19 species are omnivorous, 39 species are insectivorous while 7 species are vegetarian. Of the species that are omnivorous, 9 are mostly insectivorous with plants/plant products constituting a minor part of their diet, while 5 are mostly nectarivorous with insects/invertebrates constituting a minor part of their diet. Four species are mostly frugivorous with insects/invertebrates constituting a minor part of their diet while 1 species is mostly granivorous with insects/invertebrates constituting a minor part of its diet. Of the 7 species that are vegetarian, 4 are granivorous while 3 are mixed feeders of both fruit and seeds. Five commonest bird species in the study plots were Shelley's Sunbird *Nectarinia shelleyi* with a frequency of detection of 0.32, followed by the Common Bulbul *Pycnonotus barbatus,* with a frequency of detection of 0.28. Tawny-flanked Prinia *Prinia subflava* and Miombo Double-collared Sunbird *Nectarinia manoensis* both had a frequency of detection of 0.18, while the Fork-tailed Drongo *Dicrurus adsimilis* had a frequency of detection of 0.17. Frequencies of detection of all species recorded in the study are summarized in Appendix 4.1 and these ranged from 0.002 to 0.32. Sixteen guilds based on diet and foraging height stratum were identified (Appendix 4.2). The largest guild was made up of canopy specialized omnivores which constituted 19% of the avifauna richness followed by understorey and canopy insectivores with 18%. Canopy specialized insectivores constituted 15%. Carnivorous guilds and generalist guilds were among the least common guilds in the study area.

4.4.2 Cluster analysis of avian species

Of the 67 species recorded in the study area (Appendix 4.1), only 63 species were used in hierarchical cluster analysis. Four species were excluded from further analysis because they were only recorded during one census and in one plot. Cluster analysis identified two broad groups of birds based on their abundance in different plots (Figure 4.1). The first cluster consisted of bird species that were identified as common using their frequency of detection (Appendix 4.1) and most abundant while the second group consisted of bird species that ranged from moderately common and abundant to those that were infrequently encountered and few. According to the cluster analysis, the Common Bulbul, Shelley's Sunbird, Miombo Double-collared Sunbird and Tawny-flanked Prinia were similar to each other, being the most common and abundant species of birds in the study area. The second cluster was subdivided into two with the Swallow-tailed Bee-eater *Merops hirundineus*, Chinspot Batis *Batis molitor*, Red-headed Quelea *Quelea erythrops*, Green-capped Eremomela, *Eremomela scotops*, Fork-tailed Drongo, White Helmetshrike *Prionops plumata* and Olive thrush *Turdus olivacea* being grouped in subgroup 2b of the second cluster while the rest were in subgroup 2a (Figure 4.1). Subgroup 2b included the Fork-tailed Drongo, a species that was among the top five frequently encountered species in the study area.

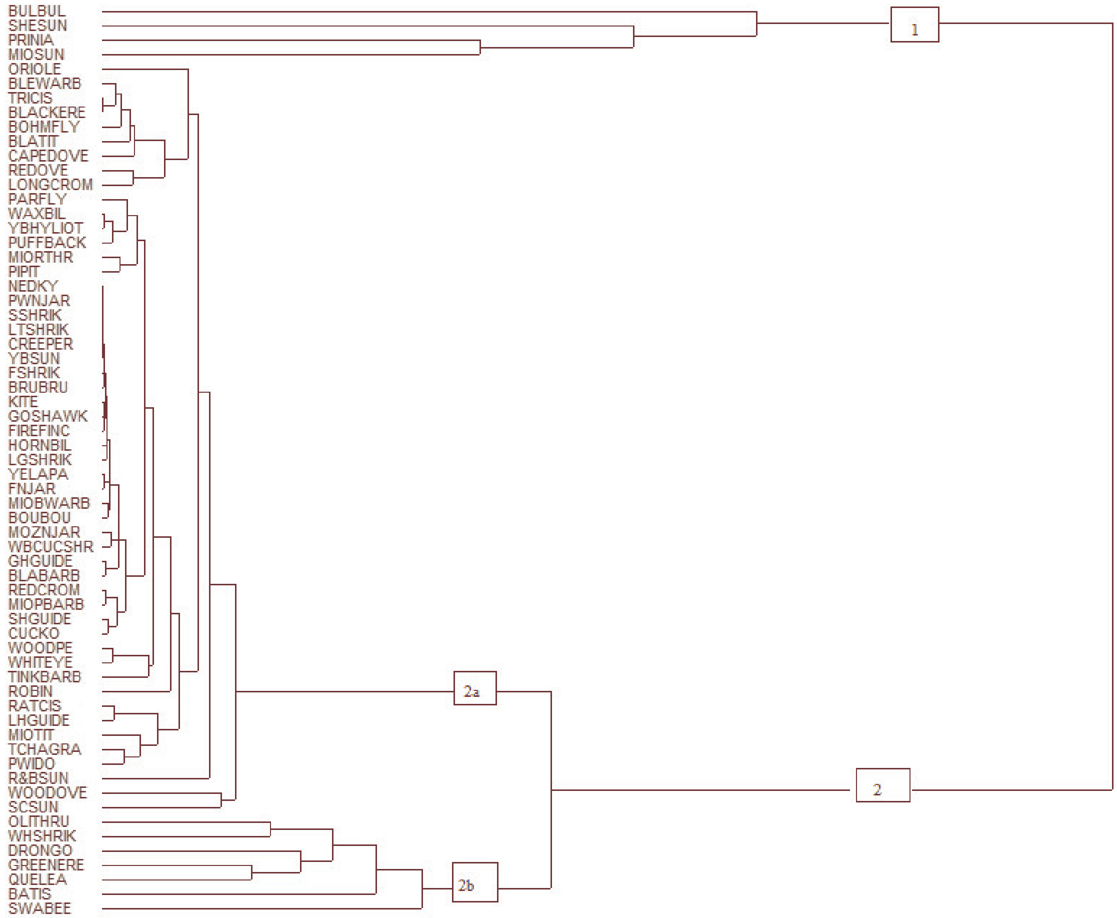


Figure 4.1 Community dendrogram of Euclidean distances between bird species indicating an abundance relationship in 50 census plots in Serenje District in Zambia. Bird species abbreviations are given below.

BULBUL – Common Bulbul, SHESUN – Shelley's Sunbird, PRINIA – Tawny-flanked Prinia, MIOSUN - Miombo Double-collared Sunbird, ORIOLE- Eastern Black-headed Oriole, BLEWARB – Bleating Bush Warbler, TRICIS – Trilling Cisticola, BLACKERE – Black-capped Eremomela, BOHMFLY – Böhm's Flycatcher, BLATIT – Southern Black Tit, CAPEDOVE – Cape Turtle Dove, REDOVE – Red-eyed Dove, LONGCROM – Long-billed Crombec, PARFLY – Paradise Flycatcher, WAXBIL – Fawn-breasted Waxbill, YBHYLIOT – Yellow-bellied Hyliota, PUFFBACK – Southern Puffback, MIORTHR – Miombo Rock Thrush, PIPIT – Long – billed Pipit, NEDKY – Neddicky, PWNJAR – Pennant-winged Nightjar, SSHRIK – Souza's Shrike, LTSHRIK – Long-tailed Shrike, CREEPER – Spotted Creeper, YBSUN – Yellow-bellied Sunbird, FSHRIK – Fiscal Shrike, BRUBRU – Brubru, KITE – Black (Yellow-billed) Kite, GOSHAWK – Dark Chanting Goshawk, FIREFINC – Jameson's Firefinch, HORNBIL – Pale-billed Hornbill, LGSHRIK – Lesser Grey Shrike, YELAPA – Yellow-breasted Apalis, FNJAR – Fiery-necked Nightjar, MIOBWARB – Miombo Barred Warbler, BOUBOU – Tropical Boubou, MOZNJAR – Mozambique Nightjar, WBCUCSHR – White-breasted Cuckoo-shrike, GHGUIDE – Greater Honeyguide, CUCKO – African Grey Cuckoo, WOODPE – Bennett's Woodpecker, WHITEYE – Yellow White-eye, TINKBARB – Yellow-fronted Tinkerbird, ROBIN – Central bearded Scrub Robin, RATCIS – Rattling Cisticola, LHGUIDE – Lesser Honeyguide, MIOTIT – Miombo Grey Tit, TCHAGRA – Black-crowned Tchagra, PWIDO Long-tailed Paradise Widow, R&BSUN – Red – and – Blue Sunbird, WOODOVE – Emerald-spotted Wood Dove, SCSUN – Scarlet-chested Sunbird, OLITHRU – Olive Thrush, WHSHRIK – White Helmetshrike, DRONGO – Fork-tailed Drongo, GREENERE – Green-capped Eremomela, QUELEA – Red-headed Quelea, BATIS – Chinspot Batis, SWABEE – Swallow-tailed Bee-eater

4.4.3 Cluster analysis of bird census plots

Five groups of plots were identified by cluster analysis as explaining the variance in bird abundance by species data (Figure 4.2). The first cluster had 21 plots while the second and third cluster had 6 plots and 4 plots respectively (Appendix 4.3). The fourth and fifth clusters had 12 plots and 2 plots respectively. Cluster 1 included plots identified as being old growth miombo, old regrowth miombo and young regrowth miombo while the second cluster included plots identified as degraded old growth miombo, old regrowth miombo and young regrowth miombo (Appendix 3.4). The third cluster was made up of old growth miombo and degraded old growth miombo plots while the fourth cluster included old growth miombo plots, degraded old growth miombo plots and old regrowth miombo plots. The fifth cluster included one degraded old growth miombo plot and one old regrowth miombo plot (Appendix 3.4).

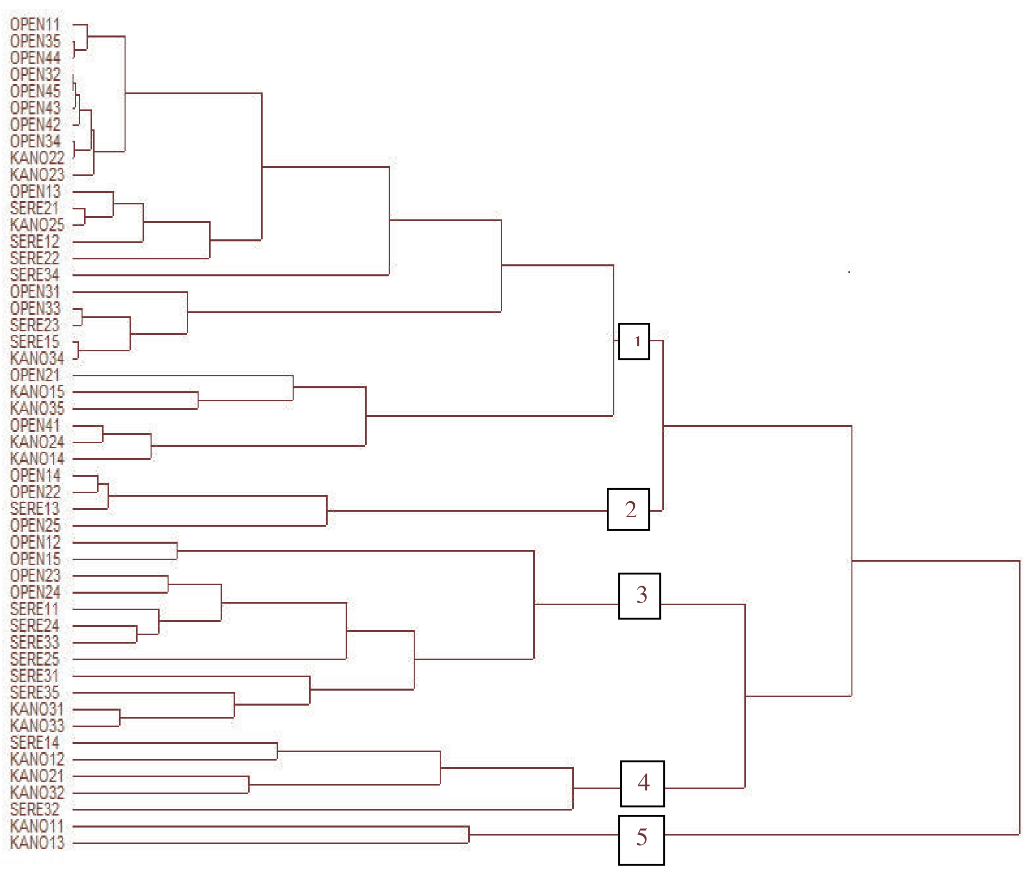


Figure 4.2 Community dendrogram of Euclidean distances between plant census plots indicating a bird abundance by species relationship in 50 census plots in Serenje district in Zambia. Plot abbreviations are given as follows: SERE – Serenje National Forest study site, KANO – Kanona National Forest study site and OPEN – Kafunda study site in the open area. the first number after the name of the study site represents the transect number while the second number represents the plot number along the transect.

4.4.4 Principal Component Analysis of avian species

Principal Component Analysis identified twenty-two principal components in the bird abundance data by species that had eigenvalues greater than 1 and cumulatively accounted for 84.7% of the variance among bird species. Scatter diagrams of the first eight components are summarized in Figure 4.3.

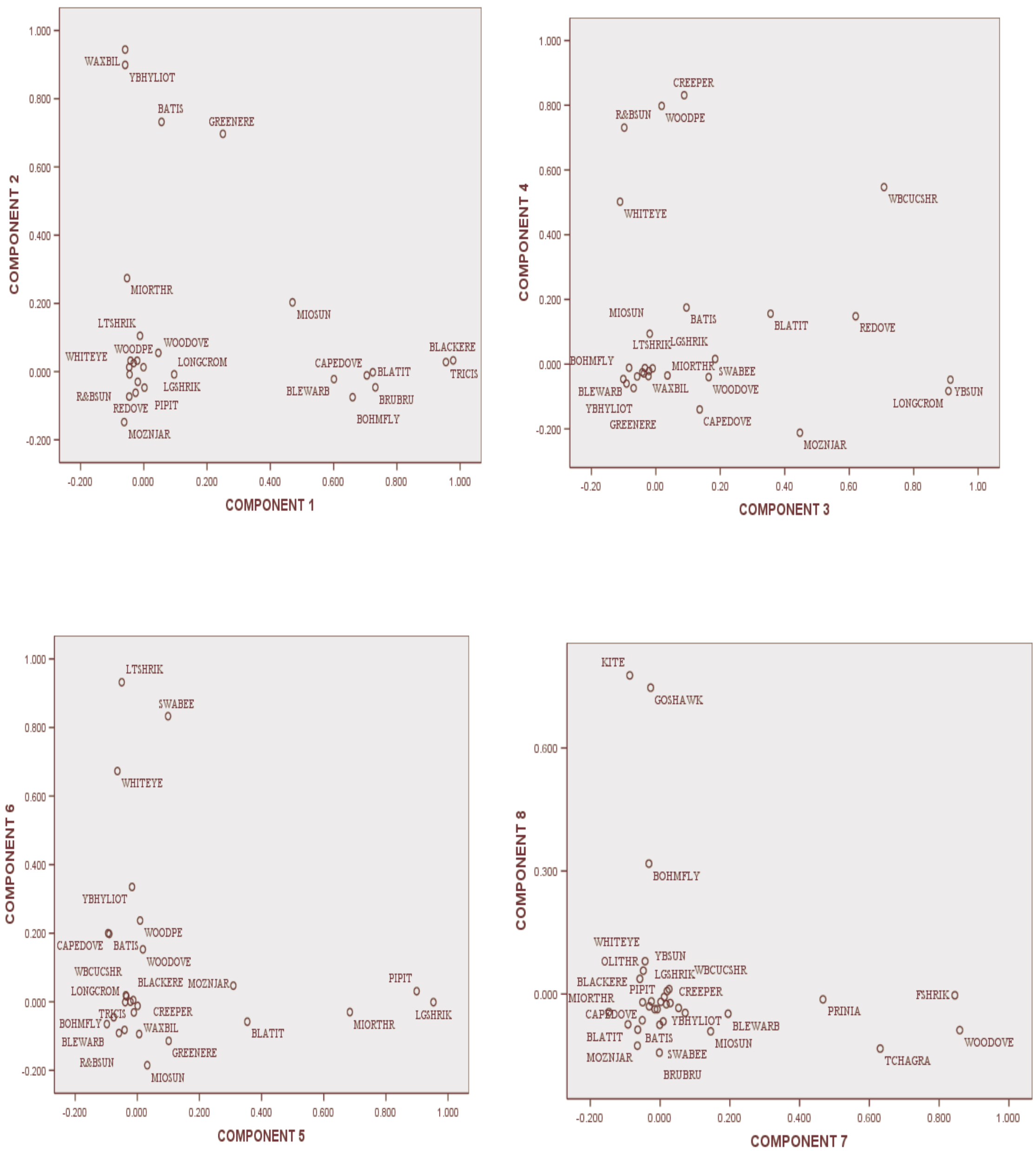


Figure 4.3 Scatter diagrams of the first eight principal components of bird species groupings in 50 plots. For bird species abbreviations see Figure 4.1.

Bird species which were correlated with the various principal components either positively or negatively are given in Table 4.1. Only bird species with correlation coefficient values of 0.5 and above are shown in the table.

Table 4.1 Bird species correlated with various principal components in 50 plots in Serenje District Zambia. The values in parentheses indicate Pearson's correlation coefficients.

Component 1	**Component 2**	**Component 3**	**Component 4**
Black-collared Eremomela (0.978)	Fawn-breasted Waxbill (0.944)	Yellow-bellied Sunbird (0.914)	Spotted Creeper (0.831)
Trilling Cisticola (0.955)	Yellow-bellied Hyliota (0.899)	Long-billed Crombec (0.908)	Bennett's Woodpecker (0.798)
Brubru (0.732)	Chinspot Batis (0.732)	White-breasted Cuckoo-shrike (0.708)	Red - and - Blue Sunbird (0.731)
Southern Black Tit (0.724)	Green-capped Eremomela (0.697)	Red-eyed Dove (0.620)	
Cape Turtle Dove (0.705)			
Bohm's Flycatcher (0.660)			
Bleating Bush Warbler (0.601)			

Component 5	**Component 6**	**Component 7**	**Component 8**
Lesser Grey Shrike (0.953)	Long-tailed Shrike (0.932)	Emerald-spotted Wood Dove (0.859)	Black Kite (0.777)
Long-billed Pipit (0.899)	Swallow-tailed Bee-eater (0.833)	Fiscal Shrike (0.845)	Dark Chanting Goshawk (0.747)
Miombo Rock Thrush (0.684)	Yellow White-eye (0.673)	Black-crowned Tchagra (0.631)	Olive Thrush (0.576)

Component 9	**Component 10**	**Component 11**	**Component 12**
White Helmet Shrike (0.724)	Lesser Honeyguide (0.963)	Yellow-breasted Apalis (0.897)	Souza's Shrike (0.931)
Southern Puffback (0.684)	Rattling Cisticola (0.691)	Jameson Firefinch (0.680)	Eastern Black-headed Oriole (0.772)
Tropical Boubou (0.608)	Common Bulbul (0.617)		
Paradise Flycatcher (0.563)			

Component 13	**Component 14**	**Component 15**	**Component 16**
African Grey Cuckoo (0.893)	Red-headed Quelea (0.919)	Red-capped Crombec (0.944)	Miombo Grey Tit (0.885)
Yellow-fronted Tinkerbird (0.728)	Fiery-necked Nightjar (0.659)	Miombo Pied Barbet (0.651)	Long-tailed Paradise Widow (0.684)

Component 17	**Component 18**	**Component 19**	**Component 20**
Black-collared Barbet (- 0.781)	Central Bearded Scrub Robin (0.731)	Miombo Barred Warbler (0.807)	Pennant-winged Nightjar (0.915)
Greater Honeyguide (- 0.771)		Scaly-throated Honeyguide (0.649)	Fork-tailed Drongo (0.565)
		Scarlet-chested Sunbird (0.618)	

Component 21	**Component 22**
Pale-billed Hornbill (0.931)	Neddicky (- 0.611)

4.4.5 Avian community structure

Bird species that were grouped in the first cluster were those identified as being common and abundant in the study area. Principal Component Analysis revealed that these species were not highly correlated with any component except the Common Bulbul which was positively correlated with Component 10 (Figure 4.1 and Table 4.1). Bird species identified in Component 1 to be closely related were also grouped together by Cluster Analysis in subgroup 2a. The only species identified in the first component which was not next to the other species in the dendrogram was the Brubru. The second component was made up of birds belonging to subgroup 2a and 2b of the second cluster. Yellow-bellied Hyliota and Fawn-breasted Waxbill were ordered next to each other in subgroup 2a while Chinspot Batis and Green-capped Eremomela were ordered near each other in subgroup 2b. The third component is made up of bird species belonging to subgroup 2a, however members of this component are separated from one another in the cluster analysis. It is only the Red-eyed Dove and Long-billed Crombec that are ordered next to each other in the cluster analysis. From the cluster analysis, the two species are more closely related to members of component 1 than the other two members of the third component. The fourth component is made up bird species belonging to subgroup 2a, however, members of this group are separated by some distance in the dendrogram. Bird species belonging to the fifth component belong the subgroup 2a, however, it is only Miombo Rock Thrush and Long-billed Pipit that are ordered next to each other in the dendrogram. The Lesser Grey Shrike is separated from the other two species. The sixth component is made up of bird species belonging to both subgroup 2a and 2b. The two species belonging to subgroup 2a are separated from each other in the dendrogram. Members of the seventh component belong to subgroup 2a but the species are widely separated from each other in the dendrogram. The eighth component is made up of species belonging to both subgroup 2a and 2b. The Black Kite and Dark Chanting Goshawk belonging to subgroup 2a are also ordered next to each other in the dendrogram. For bird species belonging to the ninth component, it is only the Southern Puffback and Paradise Flycatcher that are closely related according to the cluster analysis. Component 10 is made up of the Common Bulbul belonging to cluster 1 and Lesser Honeyguide and Rattling Cisticola belonging to subgroup 2a. The bird species belonging to subgroup 2a are also ordered next to each other in the dendrogram. Bird species belonging to the 11^{th} component are closely related to each other according to the cluster analysis. The same applies to members of component 13. Souza's Shrike and Eastern Black-headed Oriole which belong to the 12^{th}

component also belong to subgroup 2a, but the two species are separated from each other in the dendrogram. Members of the 14th component belong to both subgroup 2a and 2b. Bird species in the 15th component are closely related to each other and are ordered next to each other in the dendrogram and the same applies to bird species in component 17. Members of the 16th component are also closely related and are ordered near each other in the dendrogram. Members of the 19th component belong to subgroup 2a but the bird species are separated from one another in the dendrogram. Members of the 20th component belong to both subgroup 2a and 2b.

4.4.6 Avian abundance along the woodland degradation gradient

Carnivorous birds were excluded from further analysis because they were either recorded in only one habitat during a census or only recorded in one plot in several habitats during the whole study. Sunbirds feed mainly on nectar and supplement their protein requirements with insects and therefore fall into the omnivore category. However, this group of birds was very abundant and common and this necessitated the creation of the nectarivore category to separate sunbirds from other omnivores.

4.4.6.1 Spatial autocorrelation results

Five out of 10 transects revealed significant spatial autocorrelation in transect data for abundance of omnivores and abundance of nectarivores while 4 out of 10 transects revealed significant spatial autocorrelation for overall bird abundance and abundance of miombo endemics (Appendix 4.4). Three out of 10 transects revealed significant spatial autocorrelation in transect data for abundance of habitat restricted birds and abundance of insectivores while 2 out of 10 transects revealed significant spatial autocorrelation for abundance of habitat generalist birds and abundance of vegetarians (Appendix 4.4). The autocorrelated data was detrended using Berryman's equation before ANOVA was performed.

4.4.6.2 Avian abundance along the woodland degradation gradient

The pooled mean avian abundance variables per plot for different miombo woodland habitat types as well as the seasonal mean avian abundance variables per plot for different habitats are summarized in Appendix 4.5. Analysis of variance revealed insignificant differences in the pooled avian abundance variables per plot among different miombo woodland types (Table 4.2).

Table 4.2 Results of between habitat ANOVA of pooled avian abundance variables in Serenje District, Zambia.

Avian variable	$F_{3,46}$	*p-value*
Overall avian abundance	0.220	0.882
Abundance of miombo habitat endemics	0.901	0.448
Abundance of habitat restricted birds	0.496	0.687
Abundance of habitat generalists	0.120	0.948
Abundance of vegetarians	0.713	0.549
Abundance of omnivores	0.904	0.446
Abundance of nectarivores	1.335	0.274
Abundance of insectivores	0.853	0.472

4.4.6.3 Seasonal avian abundance along the woodland degradation gradient

Seasonal data collected in different years revealed insignificant mean differences in pooled avian abundance by plot for March 2006/07 ($F_{1,98} = 0.049$; $p = 0.826$), May 2006/07 ($F_{1,98} = 0.021$; $p = 0.894$), July 2006/07 ($F_{1,98} = 0.032$; $p = 0.841$), and Oct 2006/Sept 2007 ($F_{1,98} = 0.002$; $p = 0.961$). Analysis of variance of seasonal data collected in different years also revealed insignificant mean differences in avian abundance by species for March 2006/07 ($F_{1,52} = 0.015$; $p = 0.903$), May 2006/07 ($F_{1,67} = 0.008$; $p = 0.931$), July 2006/07 ($F_{1,58} = 0.013$; $p = 0.916$) and Oct 2006/Sept 2007 ($F_{1,80} = 0.001$; $p = 0.977$).

There were insignificant seasonal mean differences in all avian abundance variables per plot among different habitats except for the abundance of omnivores in the hot and dry season (Table 4.3). Comparison of means using the Bonferroni test found that the average abundance of omnivores per plot in old regrowth miombo was significantly different from that of the other three habitats.

Table 4.3 Results of between habitat ANOVA of avian abundance variables in different seasons in Serenje District, Zambia.

Avian variable	Hot and wet season		Hot and dry season		Cool and dry season	
	$F_{3,46}$	*p-value*	$F_{3,46}$	*p-value*	$F_{3,46}$	*p-value*
Overall avian abundance	0.205	0.892	0.516	0.673	1.477	0.233
Abundance of miombo habitat endemics	0.317	0.813	0.3	0.825	1.76	0.168
Abundance of habitat restricted birds	0.726	0.541	0.267	0.849	1.767	0.167
Abundance of habitat generalists	0.303	0.823	0.509	0.678	0.286	0.835
Abundance of vegetarians	1.024	0.39	0.719	0.545	0.581	0.63
Abundance of omnivores	0.331	0.803	3.659	0.019	0.608	0.613
Abundance of nectarivores	0.852	0.472	0.365	0.779	1.772	0.166
Abundance of insectivores	0.79	0.506	0.798	0.502	1.303	0.285

4.4.7 Avian species richness and guild richness along the woodland degradation gradient

Four out of 10 transects revealed significant spatial autocorrelation in both avian species richness and avian guild richness (Appendix 4.4). The autocorrelated data was detrended before ANOVA was performed on avian species richness and guild richness among different miombo woodland types.

Analysis of variance revealed insignificant differences in the average avian species richness per plot ($F_{3,46} = 0.315$; $p = 0.814$) among different miombo woodland habitat types. Average avian species richness per plot for the study area is 2.76 ± 0.089 species. Analysis of variance also revealed insignificant seasonal mean differences in avian species richness per plot among different habitats in the hot and wet season ($F_{3,46} = 0.529$; $p = 0.665$), hot and dry season ($F_{3,46} = 0.178$; $p = 0.910$) and the cool and dry season (($F_{3,46} = 1.422$; $p = 0.248$).

There were insignificant differences in the average number of guilds per plot among different miombo woodland habitat types ($F_{3,46} = 0.608$; $p = 0.613$). The average number of guilds per plot for the study area is 2.50 ± 0.095 guilds. Analysis of variance also revealed insignificant seasonal mean differences in number of guilds per plot among different habitats in the hot and wet season ($F_{3,46} = 0.477$; $p = 0.699$), hot and dry season ($F_{3,46} = 0.209$; $p = 0.890$) and the cool and dry season (($F_{3,46} = 0.926$; $p = 0.436$).

The pooled mean avian species richness and avian guild richness per plot for different miombo woodland habitat types as well as the seasonal mean avian species richness and guild richness per plot for different habitats are summarized in Appendix 4.4.

4.5 Discussion

4.5.1 Avian community structure

Community organisation implies attributes concerned with species occurrence and their interactions such as abundance, diversity, succession and trophic relationship (Haefner, 1981). The aim of avian community ecology is to identify recurrent patterns of species composition, guild structure and diversity among co-occuring species and to understand the factors promoting those patterns (Holmes & Recher, 1986). The avian community in the study area is made up of mainly a resident insectivorous group of birds although the most abundant species were the nectarivorous sunbirds. The abundance of food resources such as caterpillars and other invertebrates in miombo woodland and the occurrence of plants that produce copious amounts of nectar might be the reason for this particular community structure (Vernon, 1983; Clauss, 1992; Chisanga, 1998; Mbata *et al.,* 2002). Although the avifauna is mainly insectivorous, different species are able to co-exist with each other without competitively excluding each other by belonging to different foraging height guilds. Studies done by Holmes *et al.* (1979) on the guild structure of a bird community revealed that the most important factors dividing bird communities into foraging guilds relates to the height of the vegetation which separate ground foragers from other species and behavioural characteristics of bark probing and gleaning which divide species into those that feed on the bark of the tree trunk from those that feed on outer parts of branches and among foliage. In this study, only the height was used in separating different guilds, the type of foraging behaviour was not incorporated in the separation of different guilds. Future research on the community structure of miombo avifauna will focus on this aspect in order to investigate further how the mainly insectivorous birds are able to co-exist.

Cluster analysis yielded two main bird groups whereas PCA yielded 22 bird groupings. Component 1, 11, 13, 15, 16 and 17 (Table 4.1) support the cluster analysis results (Figure 4.2) and therefore constitute groups of birds that are closely associated together in terms of their habitat requirements. Bird species normally associate with other species because it increases their foraging opportunities as well as offering protection because spotting predators is made easier by having many eyes. Mixed species bird parties consisting of mainly insectivorous birds are a common occurrence in miombo woodland (Benson & Irwin, 1966). The species composition of such bird parties varies with some bird parties consisting of many bird species whereas other are made up of few species. Incorporation of more characteristics that lead to separation among bird species such as information on food preference, body size and foraging technique might have resulted in more distinctive separation in the cluster analysis. Cluster analysis and PCA in this study was based on bird abundance data and bird occurrence in the study plots. Future research on patterns of bird groupings in miombo avifauna should focus on including detailed information on species characteristics mentioned above other than just using bird abundance data and presence/absence data.

4.5.2 Cluster analysis of plots

The cluster analysis of sample plots using vegetation characteristics yielded results that are different from those obtained using bird abundance data by species. Avian species selection of sample plots does not correspond with the woodland degradation categories identified in chapter 3. Using bird abundance data by species, sample plots were grouped together irrespective of their woodland degradation status. The abundance and distribution of birds is not only influenced by vegetation characteristics, but it is also influenced by biotic interactions with other species such as competition, predation and parasitism (Landres & MacMahon, 1980). The outcome of these biotic interactions between species can lead to the exclusion of some species from areas that have resources necessary for survival, growth and reproduction and force them into marginal habitats.

4.5.3 Avian abundance along the woodland degradation gradient

Humans use the earth's ecosystems for agricultural activities, harvesting forest products and settlements (Watson, *et al.,* 2005). These activities can change the characteristics of such habitats thereby changing the distribution of resources available to other species. Modification of habitats alters (i) the distribution of populations (ii) the migration rates among populations and (iii) the sizes of local populations. Species characteristics such as trophic level, body size and dispersal ability are some of the factors that determine whether a species will decline after habitat modification or not (McIntyre, 1995; Watson, *et al.,* 2005). Bird species respond differently to habitat alteration. Some species benefit from alteration and increase their populations whereas others have become extinct or threatened (Crick, 2004; Seoane *et al.,* 2005). Specialist forest interior species and non migratory species are more likely to be behaviourally inhibited from crossing matrix habitats compared to generalist, forest canopy and migratory species (Sekercioglu, 2002; Lampila *et al.,* 2005). In this study, there were no significant differences in bird abundance along the woodland degradation gradient. The reason might be the predominance of habitat generalist species in the study area. Sixty-six percent of the species recorded in the study area were habitat generalists, and degraded woodland might not be totally inhabitable for such species compared to endemic and habitat restricted birds. Tropical bird species differ in their likelihood of sustaining populations in modified habitats and these differences are attributable to differences in the extent to which such birds utilize agricultural matrices surrounding the forest. Recent studies have shown that a relatively high number of individuals and species can still be found in man-altered systems (Bishop & Myers, 2005). However, abundances of such species may be affected by interspecific interactions such as increased brood parasitism and predation associated with modified habitats. For birds, general findings have shown that a mix of cultivated and natural forests can support a high number of species including many forest specialists as long as there is undisturbed old growth forest nearby (Lindell, *et al.,* 2004; Wilson *et al.,* 2005). Shifting cultivation practiced in the study area does not lead to extensive fragmentation of the woodland because the cultivated fields are usually small in size (Figure 2.5). The largest edge habitat created by infrastructure development in the study area was that created by powerlines and was about 50m from one edge to the next (Figure 2.9). This means that bird species are able to access undisturbed woodland easily, therefore they can still persist in areas where the habitat has been modified.

4.5.4 Avian species richness and guild richness along the woodland degradation gradient

Plant species diversity, plant physiognomy, habitat heterogeneity and differential use of plant species by birds have been shown to strongly influence the structure of bird communities (MacArthur & MacArthur, 1961; Karr & Roth, 1971; Wilson, 1974; Holmes & Robinson, 1981; Hudson & Bouwman, 2007). Greater species diversity of plant communities and a higher level of complexity in food chains are the two characteristics of tropical communities that are expected to allow increased avian species richness (Powell, 1989). Physiognometrical factors affecting avian diversity are first foliage height diversity and secondly spatial heterogeneity (Holmes & Recher, 1986). An increase in avian diversity is associated with increased vegetation structural diversity, although the outcome of biotic interactions among avian species may influence avian diversity and abundance (Landres & MacMahon, 1980). In this study, avian species richness is not affected significantly by woodland degradation. There was no decreasing or increasing trend in bird species richness along the woodland degradation gradient. Woodland types with increased vegetation structural diversity were degraded old growth miombo and old regrowth miombo. These woodland types had intermediate levels of degradation and their avian species richness were not significantly different from those of woodland types with low vegetation structural diversity such as old growth miombo and young regrowth miombo (Table 3.5). Understorey bird species richness in Tanzanian forests over the short term (2 years) were found not to vary significantly among disturbance levels and on the long term (16 years), observed species richness was found to be nearly identical in primary forest, slightly disturbed forest and moderately disturbed forest (Newmark 2005). Primary forest in that study was defined as forest in which there was minimal human disturbance and forest disturbance was the result of natural tree falls or limited cutting of building poles and firewood while slightly disturbed forest was that in which the principal form of human disturbance was intermittent pit-sawing and cutting of building poles and firewood. Moderately disturbed forest was that in which the main human disturbance was mechanized logging in which timber harvesting resulted in clear-cuts over large areas. The reason why there was no significant difference in avian species richness over the disturbance gradient was due to a significant increase in granivore richness following disturbance where as insectivore richness declined significantly. Overall species richness therefore did not change over the disturbance gradient although the species composition was different.

The reason there were no significant differences in the number of guilds along the woodland degradation gradient is similar to the reason why species richness along the degradation gradient did not vary. Some guilds respond positively to woodland degradation and increase in abundance, whereas others are negatively affected and their abundance decreases. The number of guilds lost as a result of degradation (negatively affected) is often offset by the number of guilds gained as a result of degradation (positively affected), such that the overall situation appears as though woodland degradation does not affect guild richness although the guild composition might be different. Studies of the response of avian feeding guilds to tropical forest disturbance by Gray *et al.,* (2007) found that granivore numbers increased significantly in abundance following disturbance whereas frugivores, insectivores and omnivores decreased in abundance. Carnivore and nectarivores abundance showed no significant change following disturbance. In that study, undisturbed forests were primary or old secondary mature forests while disturbed forests were selectively logged forests, secondary regrowth or cultivated forests. Although the guild richness did not show significant differences among the different forest types, the guild composition changed.

The impact of woodland degradation on birds can be difficult to detect if the contrast in woodland structure among different woodland types is not that clear. The mosaic created by different levels of woodland degradation is often composed of stands of different ages, structures and composition which might exhibit subtle contrasts in habitat quality or permeability to movement. Such subtle contrast might not result in drastic changes in avian abundance, species richness and guild richness. Low intensity practices such as single tree selection or thinning seem to have less of an effect on birds associated with old growth woodland than more intensive treatment such as clear-felling of trees for agriculture and infrastructure development (Borman, 2005; Lampila *et al.,* 2005; Tabarelli & Gascon, 2005). Intensive treatments can significantly reduce the abundance or productivity of certain species associated with closed canopy stands. In this study, 36% of the plots were old regrowth woodland while 32 % of the plots were degraded old growth miombo (Figure 3.8). These woodland types had high vegetation structural diversity in that they were not dominated by either canopy trees or understorey trees (Table 3.5). Their high vegetation structural diversity means that they can support species associated with canopy trees as well as those associated with understorey trees. Overall one would not expect significant differences in avian abundance, avian species richness and avian guild richness among the two miombo woodland types and that of old growth miombo or young regrowth miombo. The common woodland types in the study area have some aspects of the vegetation structure of both old growth miombo and young regrowth miombo and can therefore support avifauna associated with such woodland types.

4.6 Conclusions

Sixty - seven species of birds belonging to 16 dietary and foraging guilds were identified in the study area. The most common bird species were Shelley's Sunbird, Common Bulbul, Tawny-flanked Prinia, Miombo Double-collared Sunbird and Fork-tailed Drongo. Canopy specialized omnivores, understorey and canopy insectivores and canopy specialized insectivores were the major guilds in the study area. Principal Component Analysis and cluster analysis identified six groups of bird species as being closely associated. Black-collared Eremomela, Trilling Cisticola, Southern Black Tit, Cape Turtle Dove, Böhm's Flycatcher and Bleating Bush Warbler are similar to each other in terms of their occurrence and abundance in the study area. Yellow-breasted Apalis and Jameson Firefinch are closely associated with each other as are African Grey Cuckoo and Yellow-fronted Tinkerbird. Red-capped Crombec and Miombo Pied Barbet are similar to each other as are Black-collared Barbet and Greater Honeyguide. Miombo Grey Tit and Long-tailed Paradise Widow are also closely related. Clustering of sample plots using vegetation characteristics and that using bird abundance by species data yielded different results indicating that vegetation might not be the only influence in habitat selection among birds.

The study set out to test three hypotheses and these were:

(i) Avian species richness decreases with increased woodland degradation,

(ii) The number of avian guilds decreases with increased woodland degradation and,

(iii) Avian abundance decreases with increased woodland degradation.

The results from the study indicate that avian abundance, avian species richness and guild richness do not significantly vary among the different habitat types. This is an indication that degraded woodland is not totally inhabitable to some species of birds.

CHAPTER 5 MODELING AVIFAUNA RESPONSES TO MIOMBO WOODLAND DEGRADATION

5.1 Introduction

Biologists have long used the knowledge of animal life history attributes to model animal ecology. A common approach is to model animal habitat by linking known habitat use patterns with maps of existing vegetation, thereby identifying the spatial extent of important habitat features for use in conservation and management (Edwards *et al.,* 1996). Species – habitat associations are usually analyzed in terms of ecological and behavioural habitat selection of birds. The basis of the classification is usually provided by the structural forms of the vegetation (Kikkawa, 1968). The study of the bird - habitat associations is important for two primary aims associated with prediction. The first is the prediction of species distributions in poorly documented areas and secondly, prediction of the areas into which a re-introduced species maybe expected to spread (Fielding & Haworth, 1995). Models are also used to predict how a species will respond to habitat modification. This is important because models can help in the design of management and conservation plans. The general predictive success of bird-habitat models depends partially on the data selected to develop the model. If a model is to have predictive generality it must be possible to extrapolate beyond the geographical range of the model data and the current habitat structure (Fielding & Haworth, 1995). Statistical models can be used to relate observed variation in abundance or demographic rates of birds to variation in the presence or extent of habitat variables. The key to the predictive ability of many species-distribution models is the incorporation of habitat variables that reflect directly the mechanism of habitat selection.

There are several ways in which vegetation structure can influence habitat selection for bird species. Vegetation influences possible foraging strategies for many types of animals in addition to birds (Vale *et al.,* 1982). It provides the physical substrate on which food may be found and it affects the timing and abundance of food sources, either directly through seasonality of leaf flush, flowering, fruiting and seed production or indirectly through support of prey populations (Figure 5.1a & b). Vegetation structure may also impede movement of foraging birds both physically and behaviourally and may influence foraging efficiency through its effects on detectability and accessibility of food items (Bradbury *et al.,* 2005). Other requirements of animals such as shelter, cover and breeding sites may be influenced by vegetation or other habitat conditions (Vale *et al.,* 1982; Figure 5.1c & d). The risk of nest predation may provide selection for diversification of nest sites thus creating a direct link between vegetation structure and avian diversity. Modified and degraded habitats now form an increasingly large proportion of the tropical landscape (Gray *et al.,* 2007), therefore there is urgent need to investigate whether any general patterns are evident in terms of how avian community structure respond to degradation.

Figure 5.1 (a) Caterpillars on a *Julbernardia paniculata* tree, (b) Flowering *Protea angolensis* tree in the foreground, a source of nectar, (c) Bird nest in open vegetation and (d) Bird nest in dense vegetation in Serenje District.

This chapter presents regression analysis and correspondence analysis studies that were done in order to determine the relationship between miombo woodland degradation and avian community structure. The results answer to the overall objective stated in 1.5.1: to analyze the impact of woodland degradation on the avian community structure. The specific objectives of the study were:

(i) To identify habitat factors that significantly influence avian community structure,

(ii) To develop models to predict how the avian community structure responds to habitat factors and,

(iii) To predict avian responses to woodland degradation.

The study tested the following hypotheses:

(i) Vegetation characteristics are correlated with avian species richness, avian guild richness and avian abundance,

(ii) Avian species composition changes along the woodland degradation gradient with species from disturbed woodland gradually replacing those of intact woodland and,

(iii) Different bird guilds respond differently to woodland degradation.

5.2 Methods

5.2.1 Modeling the responses of the avian community structure to habitat factors

In order to evaluate how avian species richness, avian guild richness and avian abundance are influenced by habitat factors, linear regression analysis was used. Regression analysis is usually performed (i) to explore possible cause-effect relations, (ii) to develop some predictive relationship or (iii) some combination of these. Cause-effect modeling focuses on determining the important independent variables while predictive modeling focuses more on the development of a good predictor of the dependent variable than on the contribution due to any particular independent variable (Analytical Software, 2003). Linear regression analysis estimates the coefficients of the linear equation involving one or more independent variables that best predict the value of the dependent variable (SPSS, 2005).

In order to determine which habitat factors influenced avian community structure, 3 avian variables were correlated with 15 vegetation variables discussed in chapter 3. The 3 avian variables are (1) avian species richness, (2) avian guild richness and (3) avian abundance. The 15 vegetation variables discussed in chapter 3 are (1) stand basal area cover, (2) tree basal area cover, (3) tree size (DBH), (4) tree height, (5) stem density, (6) canopy cover, (7) total plant species richness, (8) total plant species diversity, (9) tree species richness, (10) tree species diversity, (11) tree species evenness, (12) sapling density, (13) sapling species richness, (14) sapling species diversity, and (15) sapling evenness. The vegetation variables that best predict the value of the avian variable in a linear equation are the significant habitat factors. Avian factors used in the study were based on the pooled data from the nine bird censuses as outlined in section 4.3.3 and 4.3.4 while habitat factors were measured once in March, 2006.

There are several assumptions associated with linear regression analysis and these are that:

(i) The dependent and independent variables should be quantitative,

(ii) The distribution of the dependent variable must be normal,

(iii) The relationship between the dependent and independent variable should be linear and,

(iv) All observations should be independent.

All the variables used in the regression analysis were quantitative and spatial autocorrelation analysis of avian data and the subsequent detrending of the autocorrelated data ensured that the avian observations also met the requirements of the second and fourth assumptions.

5.2.2 Predicting avifaunal responses to miombo woodland structure and degradation

Multivariate statistical analyses were used to predict how different bird species and guilds respond to miombo woodland structure and degradation. Multivariate statistics weight variables by their relative contribution to the total community pattern and reduce a large number of correlated variables into a small number of identifiable factors that determine similarities or differences among species or samples (Holmes *et al.,* 1979). Multivariate statistics used to predict how the avifauna community responds to miombo woodland structure and degradation was Correspondence Analysis. Correspondence Analysis is used to position a species in an n-dimensional community space so that similarities or differences among species can be visualized. The goal of correspondence analysis is to describe the relationship between two variables in a correspondence table in a low dimensional space while simultaneously describing the relationship between the categories for each variable. The analysis identifies as few dimensions (axes) as possible needed to explain the most variation or correlation between two variables. Species and sample/plot scores are correlated with each other using an eigenvalue. The eigenvalue is a measure of how species scores correspond with the sample/plot scores. The eigenvalue of a dimension is equal to the correlation coefficient between species scores and sample/plot scores. The analysis results in dimension scores for species and sample/plot scores ordinated along the same axis. Second and higher dimensions are also calculated ensuring that the different dimensions are uncorrelated to each other until all the correlation between the species and sample/plot scores is explained. Then both species and sample/plot scores are graphed simultaneously as a biplot with species and sample/plot scores represented as circles. A species is located in a space where it is most abundant. Species and sample/plot scores close to one another are highly correlated. Correspondence analysis uses categorical data and can be used as a form of indirect gradient analysis (SPSS, 2005).

Vegetation characteristics that are easily associated with woodland degradation are those that describe vegetation structure (Grainger, 1999). Tree height, tree size (DBH), basal area cover, canopy cover and stem density are good indicators of woodland degradation. Habitat factors that describe vegetation structure were therefore used in the correspondence analysis between vegetation characteristics and avian community structure because they are easier to relate to woodland degradation. The response of the avian community structure to miombo woodland structure was analyzed in detail by examining the relationship between avian community structure and indicators of woodland degradation. Correspondence analysis was performed on indicators of woodland degradation and (i) bird species occurrence and (ii) avian guild type. Since correspondence analysis uses categorical variables, only tree height, tree size and canopy cover were used in the analysis because these variables can be easily put in categories that can be related to woodland degradation. The vegetation height in the plots was classified as shrubs and small trees, understorey trees and canopy trees using the height classification of Trapnell (1959). Using this classification, small trees and shrubs range in height from 0 – 5 metres, understorey trees range from 5 – 10 metres while canopy trees are over 10 metres. Tree sizes were also classified in categories with small stemmed trees having a DBH of 0 – 20 cm, medium-sized stemmed trees with 21 – 40 cm and large stemmed trees having a DBH of over 40 cm. For canopy cover, three categories were created with an open canopy woodland being one with canopy cover ranging from 0 – 40 %, a lightly closed canopy being one with canopy cover ranging from 41 -70 % while a woodland with over 70 % canopy cover was classified as a closed canopy woodland. The vegetation structure in each plot was described in terms of the above categories and a correspondence analysis performed with the avian community structure variables. Avian community data was obtained using methods described in chapter 4 while the vegetation structure data was obtained by methods described in chapter 3.

Correspondence analysis was also used to determine the relationship between the avian community structure and the status of woodland at each plot. The woodland status categories in different plots were those identified in chapter 3 as old growth miombo, degraded old growth miombo, old regrowth miombo and young regrowth miombo (Figure 3.8). The correlation between the avian community structure variables and the status of the woodland in the study plots was used to predict how the avian community responds to woodland degradation. The avian community structure variables used in the correspondence analysis were (i) bird species occurrence and (ii) avian guild type.

5.3 Data analysis

5.3.1 Linear regression analysis

SPSS© analytical software (SPSS, 2005) was used to perform linear regression analysis. The dependent variables used in the linear regression analysis were the avian factors while the vegetation characteristics were used as independent variables. The regression method used was the backward method with a stepping method criteria which used the probability of the F-value. The entry probability was 0.05 while the removal probability was 0.1. This regression method produces several models using different combinations of independent variables. The regression analysis output has an ANOVA table which shows the probability of the significance test of different models in predicting the value of the dependent variable. The output also gives a summary of the strength of the relationship between the independent variables and dependent variables by providing (i) multiple correlation coefficient (R) (ii) coefficient of determination (R^2) and (iii) adjusted R^2. The problem of collinearity among the independent variables is diagnosed by collinearity statistics such as tolerance and variance inflation factor (VIF) values that are given as an output in the table of coefficients. Collinearity statistics indicate which independent variables are intercorrelated. A critical assumption in linear regression analysis is that the observations should be independent, therefore collinearity violates that assumption. Tolerance indicates the % of the variance in a given predictor that cannot be explained by other predictors. Tolerance values close to zero indicate high collinearity. The linear regression analysis also produces standardized coefficients of the independent variables in order to determine which variables significantly influence the model. Since backward linear regression analysis produces several models, there is need to select the best model among the models produced. The best model was selected by taking into account the following considerations: (i) whether it was a significant predictor using the F- value and its probability, (ii) how much of the variation in the dependent variable was explained by the model using the adjusted coefficient of determination, and (iii) whether there was collinearity among the independent variables using the tolerance value. The model that had (a) an ANOVA significance probability that was less than 0.05, (b) a relative high adjusted R^2, and (c) relative high tolerance values among the independent variables was selected as the best model. The vegetation variables in the best model were identified as significant habitat factors that influenced avian community structure.

5.3.2 Correspondence analysis

SPSS© analytical software (SPSS, 2005) was used to carry out correspondence analysis between the avian community structure and vegetation structure characteristics as well as the status of the woodland at each plot. The rows in the correspondence analysis consisted of the avian community structure variables (bird species and avian guild type) in the plots while the columns consisted of the status of the woodland in the plot as well as the categorical data on tree size, tree height and % canopy cover. Since no significance statistics are attached to the results of correspondence analysis, a positive or negative correlation coefficient of 50 % and above was considered as significant correspondence in this study.

5.4 Results

5.4 1 Modeling the responses of the avian community structure to habitat factors

5.4.1.1 Modeling the response of avian species richness to habitat factors

Twelve models were produced by linear regression analysis of vegetation variables on avian species richness (Appendix 5.1). Models 5 -12 were all statistically significant in predicting avian species richness from vegetation characteristics. Model 12 was selected among the significant models as the best linear model to predict avian species richness. The vegetation variables in this model are total species richness, sapling density, tree size and tree height. These habitat factors are therefore significant in influencing avian species richness. Summary statistics on coefficients and collinearity statistics are given in Apendix 5.2. The linear regression equation for determining avian species richness (y) is:

$y = 2.190\ HEIGHT + 0.242\ SAPDEN - 2.060\ DBH - 0.322\ TOTRICH + 5.210$

From the standardized coefficients, tree height and tree size have the greatest influence on the model. Avian species richness is expected to increase in a woodland with tall trees that have small stems.

5.4.1.2 Modeling the response of avian guild richness to habitat factors

Thirteen models were produced by linear regression analysis for predicting avian guild richness from vegetation characteristics (Appendix 5.3). Models 2 – 13 were statistically significant and out of these, the 13th model was selected as the best predictor of avian guild richness. The habitat factors in the selected model are tree species evenness, tree species diversity and tree size. Therefore these vegetation variables are significant habitat factors in influencing avian guild richness. Summary statistics on coefficients and collinearity statistics are given in Appendix 5.4. The linear equation for predicting avian guild richness (y) is:

$$y = 6.959 + 0.788\ TREEVEN - 0.952\ TREEDIV - 0.223\ DBH$$

From the standardized coefficients, tree species evenness and tree species diversity have the greatest influence on avian guild richness. Avian guild richness is expected to increase in a woodland with low tree species diversity and high tree species evenness.

5.4.1.3 Modeling the response of avian abundance to habitat factors

Twelve models were produced by linear regression analysis of vegetation variables on avian abundance (Appendix 5.5). Models 9 - 12 were statistically significant in predicting avian abundance from vegetation variables. The 12th model was selected as the best among the significant models. The vegetation variables in the best model were tree species diversity, total species richness, sapling density and tree species richness. These are the significant habitat factors influencing avian abundance. Summary statistics on coefficients and collinearity statistics are given in Appendix 5.6. The linear equation for predicting avian abundance (y) is:

$$y = 46.854 + 0.400\ TREEDIV + 0.239\ SAPDEN - 0.425\ TRERICH - 0.293\ TOTRICH$$

From the standardized coefficients, tree species richness and tree species diversity have the greatest influence on avian abundance. Avian abundance is expected to increase in a woodland with low tree species richness and high tree species diversity.

5.4.2 Response of avian species to miombo woodland vegetation structure

5.4.2.1 Correlation between avian species occurrence and tree height

Eleven dimensions were identified in the correspondence analysis between bird species occurrence and tree height. The first and second dimensions accounted for 18.1 % and 16.2 % of the correlation, respectively. Small trees and shrubs were correlated with the first dimension by 27.7% whereas with the second dimension, the correlation was less than 10%. Understorey and canopy trees' correlation with either the first or second dimension was less than 10%. The first dimension divided bird species into those that were correlated with canopy trees and were positively correlated with the first dimension from those that were negatively correlated with the first dimension and correlated with understorey trees, canopy trees and small trees and shrubs (Figure 5.2). Bird species correlated either positively or negatively with the second dimension were also correlated with canopy trees, understorey trees and small trees and shrubs. When the first and second dimensions were graphed as a biplot, bird species and tree height were correlated as shown in Figure 5.2. Twenty bird species were correlated with canopy trees while 13 species and 3 species were correlated with understorey trees and small trees and shrubs, respectively. The detailed bird species correlation with tree height data is given in Table 5.1.

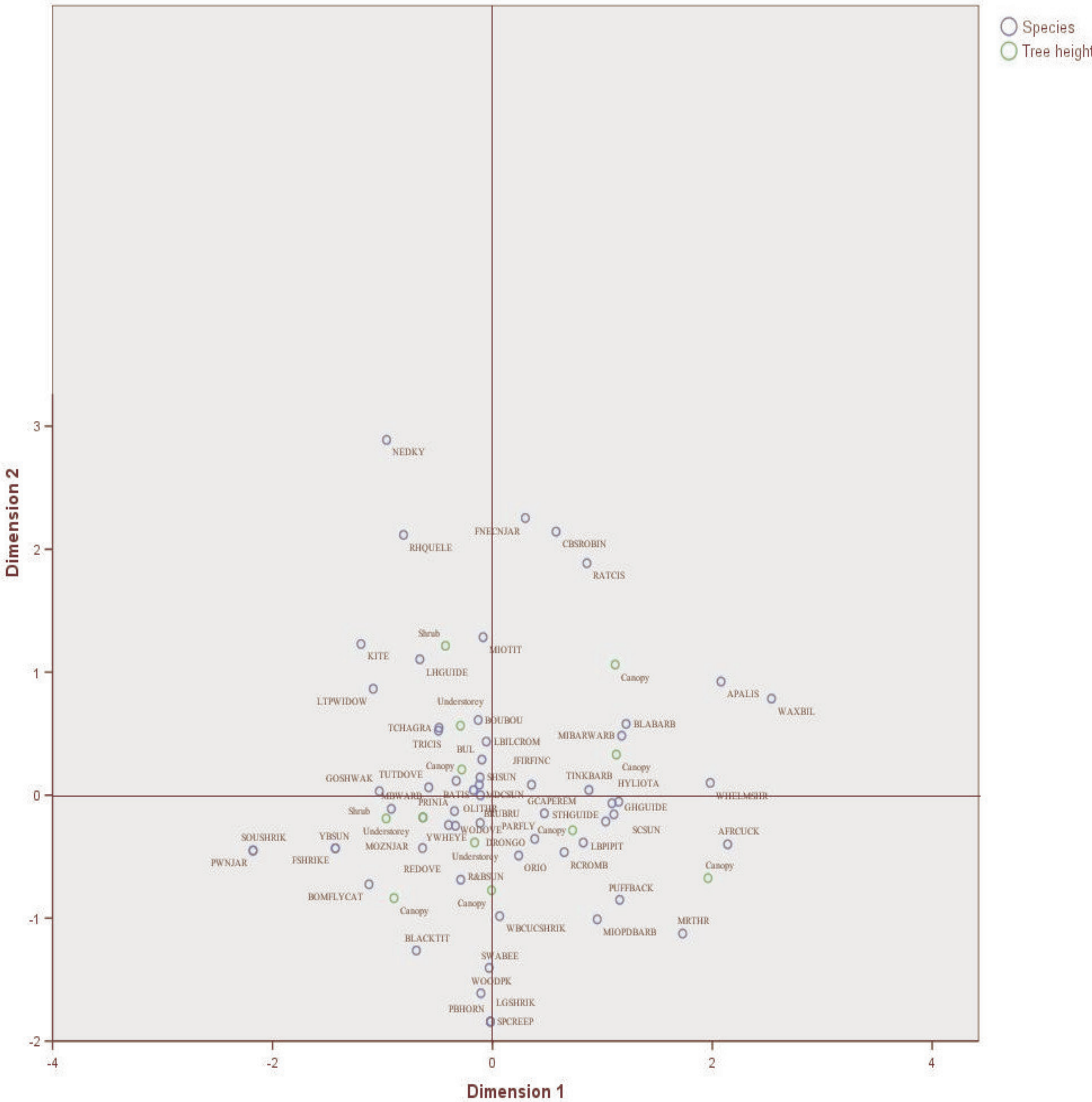


Figure 5.2 Correspondence map of avian species occurrence and tree height. Bird species abbreviations are given below

BUL – Common Bulbul, SHSUN – Shelley's Sunbird, ORIO – Eastern Black-headed Oriole, MBWARB – Bleating Bush Warbler, OLITHR – Olive Thrush, PARFLY – Paradise Flycatcher, RATCIS – Rattling Cisticola, TRICIS – Trilling Cisticola, NEDKY – Neddicky, APALIS – Yellow-breasted Apalis, PRINIA – Tawny-flanked Prinia, REDOVE – Red-eyed Dove, SWABEE – Swallow-tailed Bee-eater, KITE – Black (Yellow-billed) Kite, DRONGO – Fork-tailed Drongo, WOODPK – Bennett's Woodpecker, BLACKTIT – Southern Black Tit, TINKBARB – Yellow-fronted Tinkerbird, MRTHR – Miombo Rock Thrush, MDCSUN – Miombo Double-collared Sunbird, RCROMB – Red-capped Crombec, WHELMSHR – White Helmetshrike, LHGUIDE – Lesser Honeyguide, GHGUIDE – Greater Honeyguide, STHGUIDE – Scaly-throated Honeyguide, MIOTIT – Miombo Grey Tit, BATIS – Chinspot Batis, TCHAGRA – Black-crowned Tchagra, GOSHAWK – Dark Chanting Goshawk, FSHRIKE – Fiscal Shrike, TUTDOVE – Cape Turtle Dove, LBILCROM – Long-billed Crombec, MIBARBWARB – Miombo Barred Warbler, GCAPERE – Green-capped Eremomela, BLABARB – Black Collared Barbet, R&BSUN – Red – and – Blue Sunbird, SCSUN – Scarlet-chested Sunbird, BOUBOU – Tropical Boubou, MOZNJAR – Mozambique Nightjar, FNECNJAR – Fiery-necked Nightjar, PWNJAR – Pennant-winged Nightjar, CBSROBIN – Central Bearded Scrub Robin, AFRCUCK – African Grey Cuckoo, BOMFLYCAT – Böhm 's Flycatcher, MIOPDBARB – Miombo Pied Barbet, PBHORN – Pale-billed Hornbill, SOUSHRIK – Souza's Shrike, LTPWIDOW – Long-tailed Paradise Widow, RHQUELE – Red-headed Quelea, WBCUCSHRIK – White-breasted Cuckoo-shrike, PUFFBACK – Southern Puffback, JFIRFINC – Jameson Firefinch, LBPIPIT – Long-billed Pipit, YWHEYE – Yellow White-eye, SPCREEP – Spotted Creeper, YBSUN – Yellow-bellied Sunbird, LGSHRIK – Lesser Grey Shrike, HYLIOTA – Yellow-bellied Hyliota, BRUBRU – Brubru, BCCEREM – Black –capped Eremomela

Table 5.1 Bird species correlated with different woody vegetation heights

	Canopy trees	Understorey trees	Shrubs and small trees
1	African Grey Cuckoo	Black-crowned Tchagra	Bleating Bush Warbler
2	Black-collared Barbet	Brubru	Lesser Honeyguide
3	Böhm's Flycatcher	Emerald-spotted Wood Dove	Miombo Grey Tit
4	Chinspot Batis	Fork-tailed Drongo	
5	Common Bulbul	Long-billed Crombec	
6	Eastern Black-headed Oriole	Mozambique Nightjar	
7	Greater Honeyguide	Olive Thrush	
8	Long-billed Pipit	Paradise Flycatcher	
9	Miombo Barred Warbler	Red-eyed Dove	
10	Miombo Double-collared Sunbird	Tawny-flanked Prinia	
11	Miombo Rock Thrush	Trilling Cisticola	
12	Red - and - Blue Sunbird	Tropical Boubou	
13	Red-capped Crombec	Yellow White-eye	
14	Scaly-throated Honeyguide		
15	Scarlet-chested Sunbird		
16	Shelley's Sunbird		
17	Southern Black Tit		
18	White-breasted Cuckoo-shrike		
19	Yellow-bellied Hyliota		
20	Yellow-fronted Tinkerbird		

5.4.2.2 Correlation between avian species occurrence and tree size

Twenty-two dimensions accounted for the correlation between bird species occurrence and tree size. The first and second dimension accounted for 11.1 % and 9.5 % of the correlation respectively. The first dimension's correlation with trees of different sizes was less than 10% whereas the second dimension was correlated with medium-size stemmed trees by 33.5%. The other tree sizes' correlation with the second dimension was less than 10%. The first dimension did not separate bird species correlated with trees of different sizes neither did the second dimension. When the first and second dimensions were graphed as a biplot, the bird species were correlated with tree size as shown in Figure 5.3. Fourteen species were correlated with large stemmed trees while 15 species each were correlated with medium-size stemmed trees and small stemmed trees. The detailed correlation between bird species and tree size is given in Table 5.2.

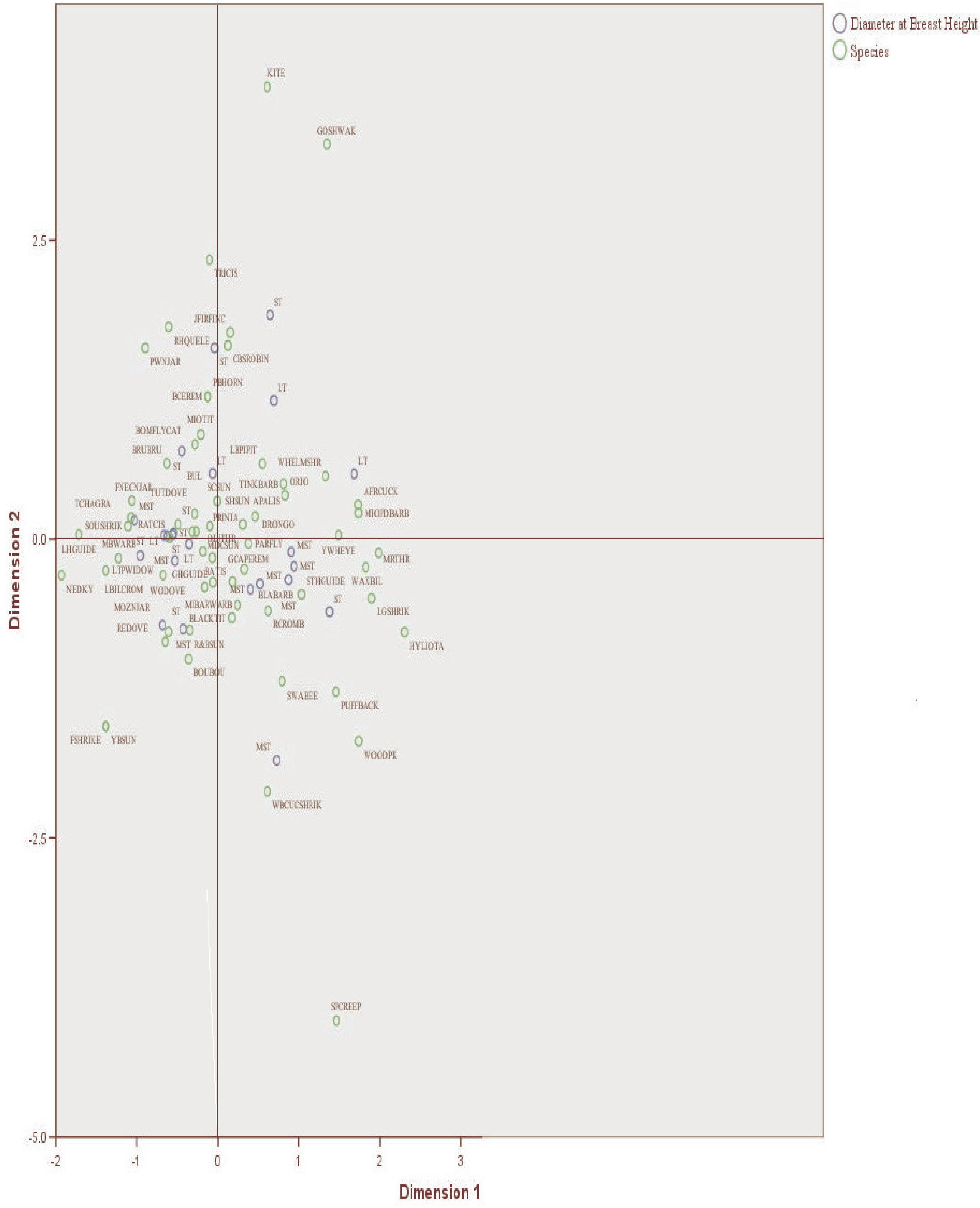


Figure 5.3 Correspondence map of avian species occurrence and tree size. For bird abbreviations see Figure 5.1 above. Tree size abbreviations are as follows: LT – Large stemmed trees, MST – Medium size stemmed trees, ST – Small stemmed trees

Table 5.2 Bird species correlation with trees of different sizes (DBH)

	Large stemmed trees	Medium size stemmed trees	Small stemmed trees
1	African Grey Cuckoo	Black-collared Barbet	Black-capped Eremomela
2	Chinspot Batis	Black-crowned Tchagra	Böhm's Flycatcher
3	Common Bulbul	Bleating Bush Warbler	Brubru
4	Eastern Black-headed Oriole	Cape Turtle Dove	Central Bearded Scrub Robin
5	Greater Honeyguide	Fiery-necked Nightjar	Jameson Firefinch
6	Long-billed Pipit	Fork-tailed Drongo	Long-tailed Paradise Widow
7	Miombo Double-collared Sunbird	Miombo Barred Warbler	Miombo Bleating Warbler
8	Miombo Pied Barbet	Paradise Flycatcher	Miombo Grey Tit
9	Olive Thrush	Rattling Cisticola	Mozambique Nightjar
10	Scarlet-chested Sunbird	Red - and - Blue Sunbird	Pale-billed Hornbill
11	Shelley's Sunbird	Red-capped Crombec	Pennant-winged Nightjar
12	White Helmet Shrike	Scaly-throated Honeyguide	Red-eyed Dove
13	Yellow-breasted Apalis	Souza's Shrike	Red-headed Quelea
14	Yellow-fronted Tinkerbird	Tropical Boubou	Tawny-flanked Prinia
15		Yellow White-eye	Trilling Cisticola

5.4.2.3 Correlation between avian species occurrence and canopy cover

Eleven dimensions were identified in the correspondence analysis between bird species occurrence and canopy cover. The first and second dimensions accounted for 17.0 % and 15.4 % of the correlation, respectively. The different canopy covers were correlated with the first dimension by less than 10% while lightly closed canopy woodland was correlated with the second dimension by 32.4%. The other canopy cover types were correlated with the second dimension by less than 10%. The first dimension divided bird species into those that were positively correlated with the first dimension and correlated with a lightly closed canopy cover woodland from those that were negatively correlated with the first dimension and correlated with both open canopy cover woodland and lightly closed canopy cover woodland. The second dimension did not separate bird species according to their correlation with different woodland canopy cover. When the first and second dimensions were graphed as a biplot, avian species occurrence and canopy cover were correlated as shown in Figure 5.4. Fourteen bird species were correlated with open canopy woodland while lightly closed canopy woodland was correlated with 13 species. The detailed correlation between avian species occurrence and canopy cover is summarized in Table 5.3.

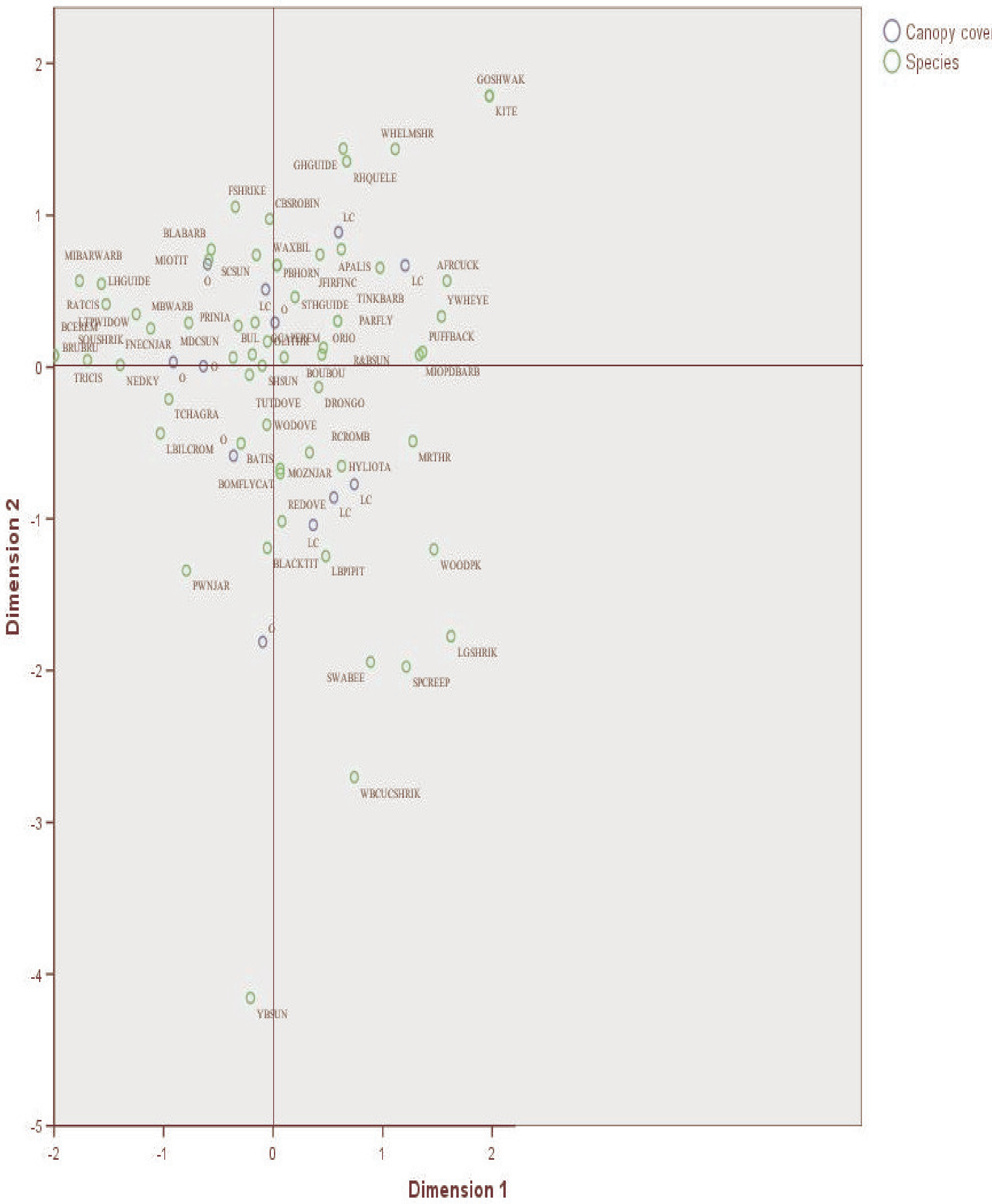


Figure 5.4 Correspondence map of avian species occurrence and woodland canopy cover. For the bird abbreviations, see Figure 5.1. The abbreviations for % canopy cover are as follows: O – Open canopy woodland and LC – Lightly closed canopy woodland.

Table 5.3 Bird species correlated with woodland with different canopy cover

	Open canopy woodland	Lightly closed canopy woodland
1	Black-collared Barbet	African Grey Cuckoo
2	Black-crowned Tchagra	Böhm's Flycatcher
3	Bleating Bush Warbler	Green-capped Eremomela
4	Chinspot Batis	Long-billed Pipit
5	Common Bulbul	Mozambique Nightjar
6	Emerald-spotted Wood Dove	Pale-billed Hornbill
7	Fiery-necked Nightjar	Red-capped Crombec
8	Long-billed Crombec	Red-eyed Dove
9	Long-tailed Paradise Widow	Scarlet-chested Sunbird
10	Miombo Double-collared Sunbird	Southern Black Tit
11	Miombo Grey Tit	Yellow-bellied Hyliota
12	Neddicky	Yellow-breasted Apalis
13	Shelley's Sunbird	Yellow-fronted Tinkerbird
14	Tawny-flanked Prinia	

5.4.2.4 Overall correlation between bird species occurrence and vegetation structure

Out of the 20 bird species that were correlated with tall canopy trees (Table 5.1), 11 species were also correlated with trees that had large stems while five species were correlated with canopy trees with medium-sized stems (Table 5.2). Böhm’s Flycatcher was the only species correlated with tall canopy trees that had small stems. In relation to canopy cover (Table 5.3), of the 20 bird species correlated with tall canopy trees, Chinspot Batis, Common Bulbul, Miombo Double-collared Sunbird, Shelley’s Sunbird and Black-collared Barbet were correlated with an open canopy woodland. Bird species correlated with canopy trees with a lightly closed canopy were African Grey Cuckoo, Long-billed Pipit, Scarlet-chested Sunbird, Yellow-fronted Tinkerbird, Red-capped Crombec and Böhm’s Flycatcher.

Table 5.4 Bird species correlated with trees of different heights and sizes. The letters in parentheses indicate the guild type. For guild abbreviations see Appendix 4.2

	Tall canopy trees with large stems	Tall canopy trees with medium sized stems	Understorey trees with medium sized stems	Understorey trees with small stems
1	African Grey Cuckoo (UCI)	Black-collared Barbet (CSO)	Black-crowned Tchagra (USI)	Brubru (CSI)
2	Chinspot Batis (UCI)	Miombo Barred Warbler (GI)	Fork-tailed Drongo (VGI)	Mozambique Nightjar (AI)
3	Common Bulbul (VGO)	Scaly-throated Honeyguide (CSI)	Paradise Flycatcher (UCI)	Red-eyed Dove (VGV)
4	Eastern Black-headed Oriole (CSO)	Red- and -Blue Sunbird (CSO)	Tropical Boubou (USI)	Tawny-flanked Prinia (USI)
5	Greater Honeyguide (CSI)	Red-capped Crombec (CSI)	Yellow White-eye (CSO)	Trilling Cisticola (USI)
6	Long-billed Pipit (GO)			
7	Miombo Double collared Sunbird (CSO)			
8	Scarlet-chested Sunbird (CSO)			
9	Shelley's Sunbird (CSO)			
10	White Helmet Shrike (UCI)			
11	Yellow-fronted Tinkerbird (CSO)			

Thirteen bird species were correlated with understorey trees (Table 5.1). Out of these 13 species, eleven were also correlated with tree size (Table 5.2). The Olive Thrush was correlated with understorey trees with large stems while five species were correlated with understorey trees with medium-sized stems (Table 5.4). Five bird species were also correlated with understorey trees with small stems (Table 5.4). Of the bird species correlated with understorey trees, the Black-crowned Tchagra and Tawny-flanked Prinia were correlated with open canopy woodland while Mozambique Nightjar and Red-eyed Dove were correlated with lightly closed canopy woodland. Three bird species were correlated with shrubs and small trees (Table 5.1). There was no bird species correlated with shrubs and small trees with large stems while the Bleating Bush Warbler was correlated with short trees with medium-sized stems. The Miombo Grey Tit was correlated with short trees with small stems. Both Miombo Grey Tit and Bleating Bush Warbler were correlated with open canopy woodland.

5.4.3 Response of avian guilds to miombo woodland vegetation structure

5.4.3.1 Correlation between avian guild type and tree height

Eleven dimensions were identified by correspondence analysis as explaining the total correlation between avian guild type and tree height. The first dimension accounted for 31.2 % of the correlation while the second dimension accounted for 24.1 %. Understorey trees were correlated with the first dimension by 57.7% while small trees and shrubs were correlated with the second dimension by 30.9%. Canopy trees' correlation with either dimension was less than 10%. When the first and second dimensions were graphed as a biplot, the correlation between avian guild type and tree height is as shown in Figure 5.5. Canopy trees were correlated with canopy specialised insectivores, canopy specialised omnivores, understorey and canopy insectivores, understorey specialised insectivores, understorey and ground insectivores and generalist vegetarians. Understorey trees were correlated with generalist vegetarians, generalist insectivores, ground insectivores and ground omnivores while shrubs and small trees were correlated with understorey and ground insectivores, generalist vegetarians, generalist omnivores and aerial insectivores.

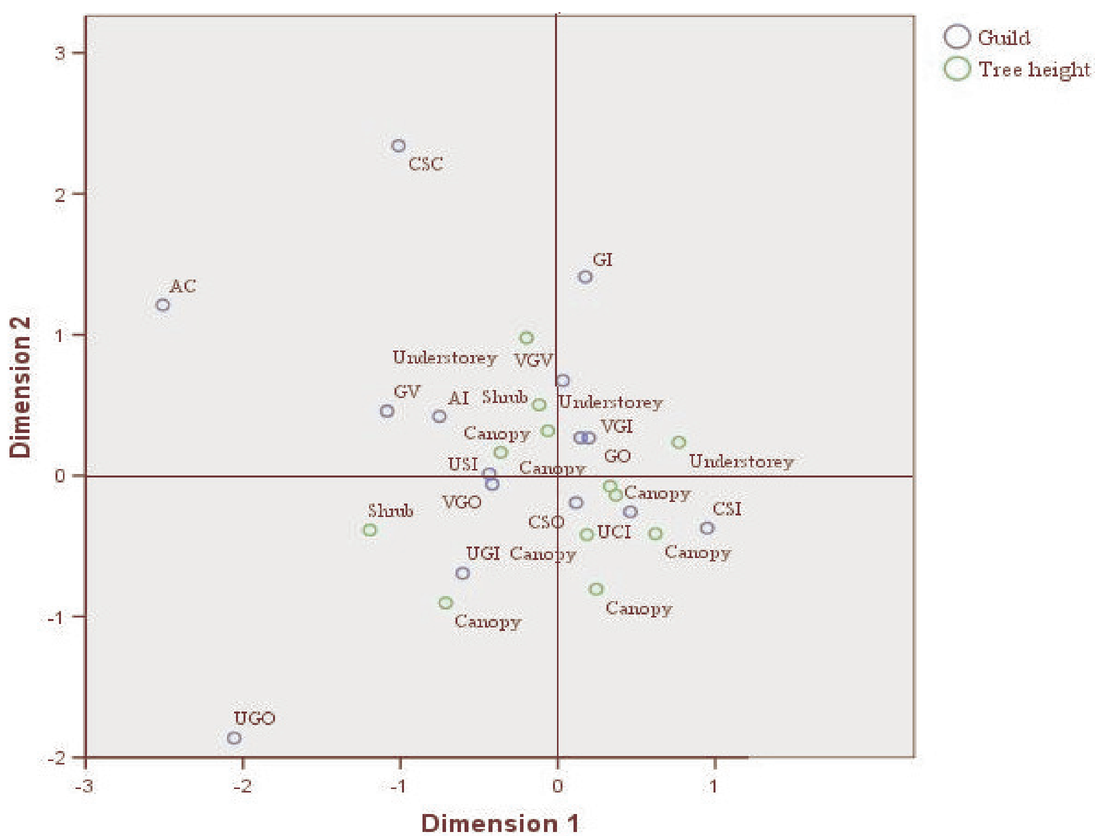


Figure 5.5 Correspondence map of avian guild type and tree height. Avian guild abbreviations are given as follows: AC – Aerial carnivore, CSC – Canopy specialised carnivore, CSI – Canopy specialised insectivore, CSO – Canopy specialised omnivore, USI – Understory specialised insectivore, AI – Aerial insectivore, GI – Ground insectivore, GO – Ground omnivore, GV – Ground vegetarian, UCI – Understory and canopy insectivore, UGI – Understory and ground insectivore, UGO – Understory and ground omnivore, VGI – Generalist insectivore, VGO – Generalist omnivore, VGV – Generalist vegetarian

5.4.3.2 Correlation between avian guild type and tree size

Fourteen dimensions accounted for all the correlation between avian guild type and tree size. The first dimension contributed 25.8 % to the correlation while the second dimension accounted for 17.2 %. The first dimension was correlated with trees of various stem sizes by less than 10% while the second dimension was correlated with medium-sized stems by 25.6%. The correlation of the second dimension with the other stem sizes was less than 10%. When the first and second dimensions were graphed as a biplot, small stemmed trees were correlated with ground insectivores, understorey and ground insectivores, understorey specialiazed insectivores, understorey and ground omnivores and generalist vegetarians. Medium-stemmed trees were correlated with canopy specialized insectivores, understorey and canopy insectivores and aerial insectivores while large stemmed trees were correlated with canopy specialised omnivores, generalist omnivores and ground omnivores (Figure 5.6).

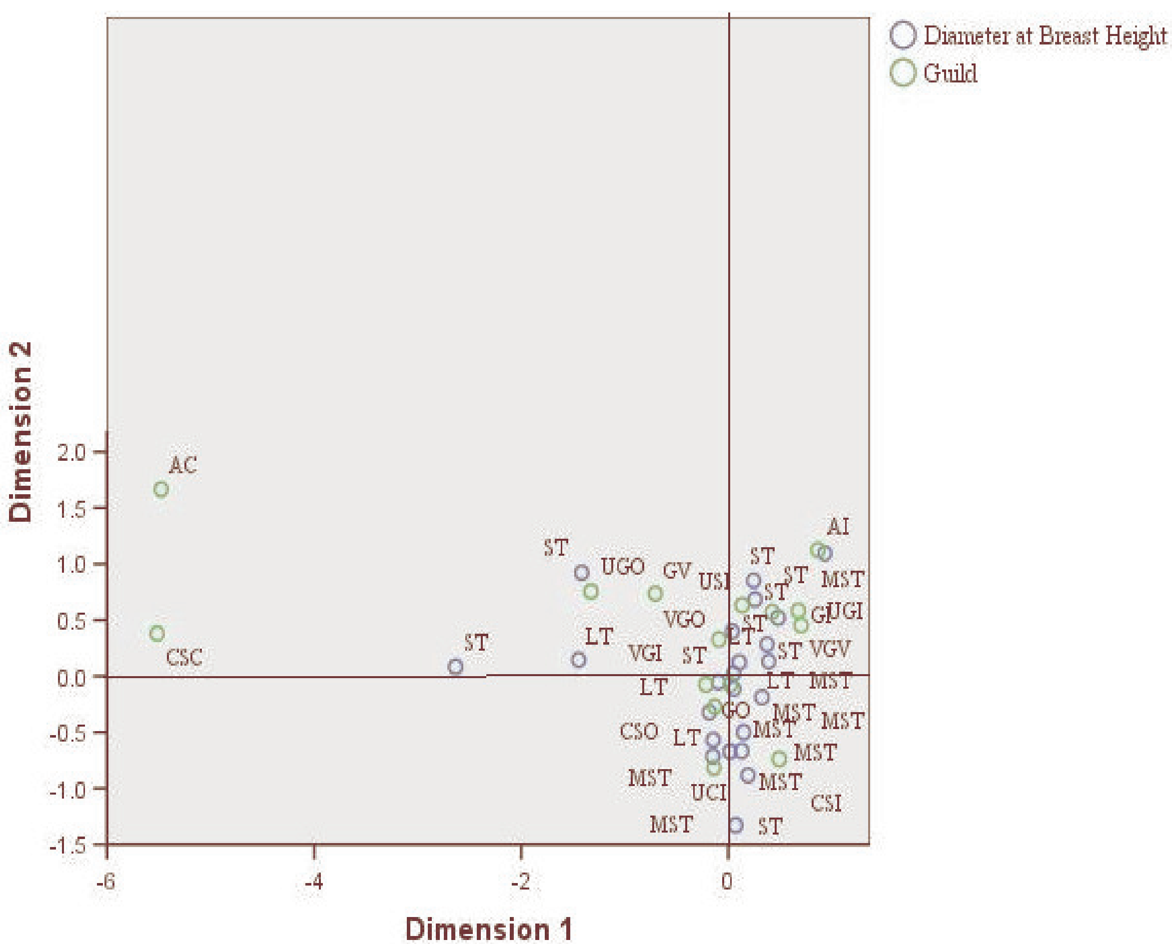


Figure 5.6 Correspondence map of avian guild type and tree size. For bird guild abbreviations see Figure 5.5. Tree size abbreviations are as follows: LT – Large stemmed trees, MST – Medium sized stemmed trees, ST – Small stemmed trees

5.4.3.3 *Correlation between avian guild type and canopy cover*

Eleven dimensions accounted for the total correlation between woodland canopy cover and avian guild type. The first dimension accounted for 25.9% of the correlation while second dimension accounted for 20.9%. The first dimension was correlated with an open canopy by 10.8% whereas the other canopy cover types were correlated with the first dimension by less than 10%. The second dimension was correlated with a lightly closed canopy by 28% while the other canopy cover types were correlated with the second dimension by less than 10%. The first dimension divided bird guilds correlated with an open canopy woodland from those correlated with a lightly closed canopy woodland.When the first and second dimensions were graphed as a biplot, a lightly closed canopy woodland was correlated with canopy specialised insectivores, canopy specialised omnivores, understorey and canopy insectivores and generalist insectivores. An open canopy woodland was correlated with aerial insectivores, ground insectivores, ground omnivores, understorey specialised insectivores, understorey and ground insectivores, generalist omnivores and generalist vegetarians (Figure 5.7).

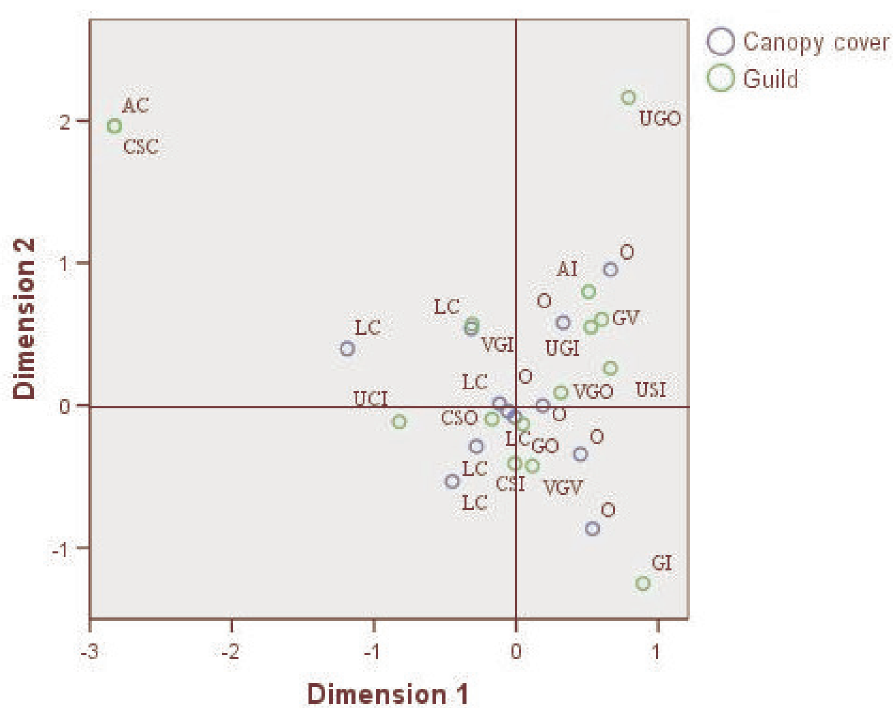


Figure 5.7 Correspondence map of avian guild type and woodland canopy cover. The abbreviations for % canopy cover are as follows: O – Open canopy woodland and LC – Lightly closed canopy woodland. For guild abbreviations see Figure 5.5

5.4.3.4 Overall correlation between avian guilds and vegetation structure

Canopy specialized omnivores were correlated with tall canopy trees that have large stems and form a lightly closed canopy while canopy specialized insectivores and understorey and canopy insectivores, were correlated with tall canopy trees that have medium-sized stems and form a lightly closed canopy. Understorey specialized insectivores and understorey and ground insectivores, were correlated with canopy trees that have small stems and form an open canopy. Ground insectivores were correlated with understorey trees that have small stems and form an open canopy while ground omnivores were correlated with understorey trees that have large stems and form an open canopy.

5.4.4 Response of avian species and guilds to miombo woodland degradation

5.4.4.1 Avian species composition along the woodland degradation gradient

Three dimensions were identified in the correspondence analysis between bird species occurrence and woodland status. The first dimension accounted for 40.3 % of the correlation between bird species occurrence and woodland degradation while the second and third dimensions accounted for 33.0 % and 26.7 % respectively. Of the three dimensions identified, degraded old growth miombo and old regrowth miombo were highly correlated with the first dimension while old growth miombo was correlated with the second dimension. Young regrowth miombo was highly correlated with the third dimension (Table 5.5). Fifty-six bird species out of the 67 species recorded in the study area were found to be correlated with the three dimensions (Appendix 5.7). Twenty bird species were correlated with the first dimension while nineteen bird species were correlated with the second dimension. Seventeen bird species were correlated with the third dimension.

Table 5.5 Correlation between woodland status and correspondence analysis dimensions of bird species occurrence. The values indicate Pearson's correlation coefficients.

Woodland status	Dimension 1	Dimension 2	Dimension 3	Total
Old growth Miombo	0.000	0.868	0.132	1.00
Degraded old growth Miombo	0.906	0.078	0.016	1.00
Old regrowth Miombo	0.632	0.006	0.362	1.00
Young regrowth Miombo	0.127	0.296	0.576	1.00

When the first and second dimensions were graphed as a biplot (Figure 5.8), bird species were correlated with woodland type as shown in Table 5.6. The first dimension separated bird species correlated with old growth miombo and degraded old growth miombo from those that were correlated with old regrowth miombo and young regrowth miombo. The second dimension separated bird species correlated with old growth miombo from those that were correlated with degraded old growth miombo, old regrowth miombo and young regrowth miombo. Nine bird species were correlated with old growth miombo while degraded old growth miombo was correlated with six species. Old regrowth miombo and young regrowth miombo were correlated with 9 species and 5 species respectively.

Table 5.6 Bird species correlation with different miombo woodland types. Letters in parentheses indicate habitat range distribution of the species: E – Miombo woodland endemics, R – Habitat restricted species and G – Habitat generalist species.

	Old growth Miombo	**Degraded old growth Miombo**	**Old regrowth Miombo**	**Young regrowth Miombo**
1	African Grey Cuckoo (G)	Eastern Black-headed Oriole (G)	Bleating Bush Warbler (G)	Black-collared Barbet (G)
2	Böhm's Flycatcher (E)	Emerald-spotted Wood Dove (G)	Chinspot Batis (G)	Cape Turtle Dove (G)
3	Miombo Barred Warbler (E)	Paradise Flycatcher (G)	Miombo Double-collared Sunbird (R)	Fiery-necked Nightjar (G)
4	Miombo Rock Thrush (E)	Red-capped Crombec (E)	Common Bulbul (G)	Green-capped Eremomela (R)
5	Red - and - Blue Sunbird (E)	Tawny-flanked Prinia (G)	Long-billed Crombec (G)	Mozambique Nightjar (G)
6	Red-eyed Dove (G)	Central Bearded Scrub-Robin (E)	Shelley's Sunbird (E)	
7	White Helmet Shrike (G)		Olive Thrush (G)	
8	White-breasted Cuckoo-shrike (G)		Scarlet-chested Sunbird (G)	
9	Yellow-fronted Tinkerbird (G)		Souza's Shrike (R)	

Forty-four percent of the species correlated with old growth miombo were miombo endemics while 55.6 % were habitat generalists. In degraded old growth miombo, 40 % of the bird species were miombo endemics while 60 % were habitat generalists. In old regrowth miombo, bird species correlated with this type of woodland consisted of 11.1 % miombo endemics, 22.2 % habitat-restricted birds and 66.7 % habitat generalists. In young regrowth miombo, the bird species correlated with it consisted of 20 % habitat-restricted birds while 80 % were habitat generalists.

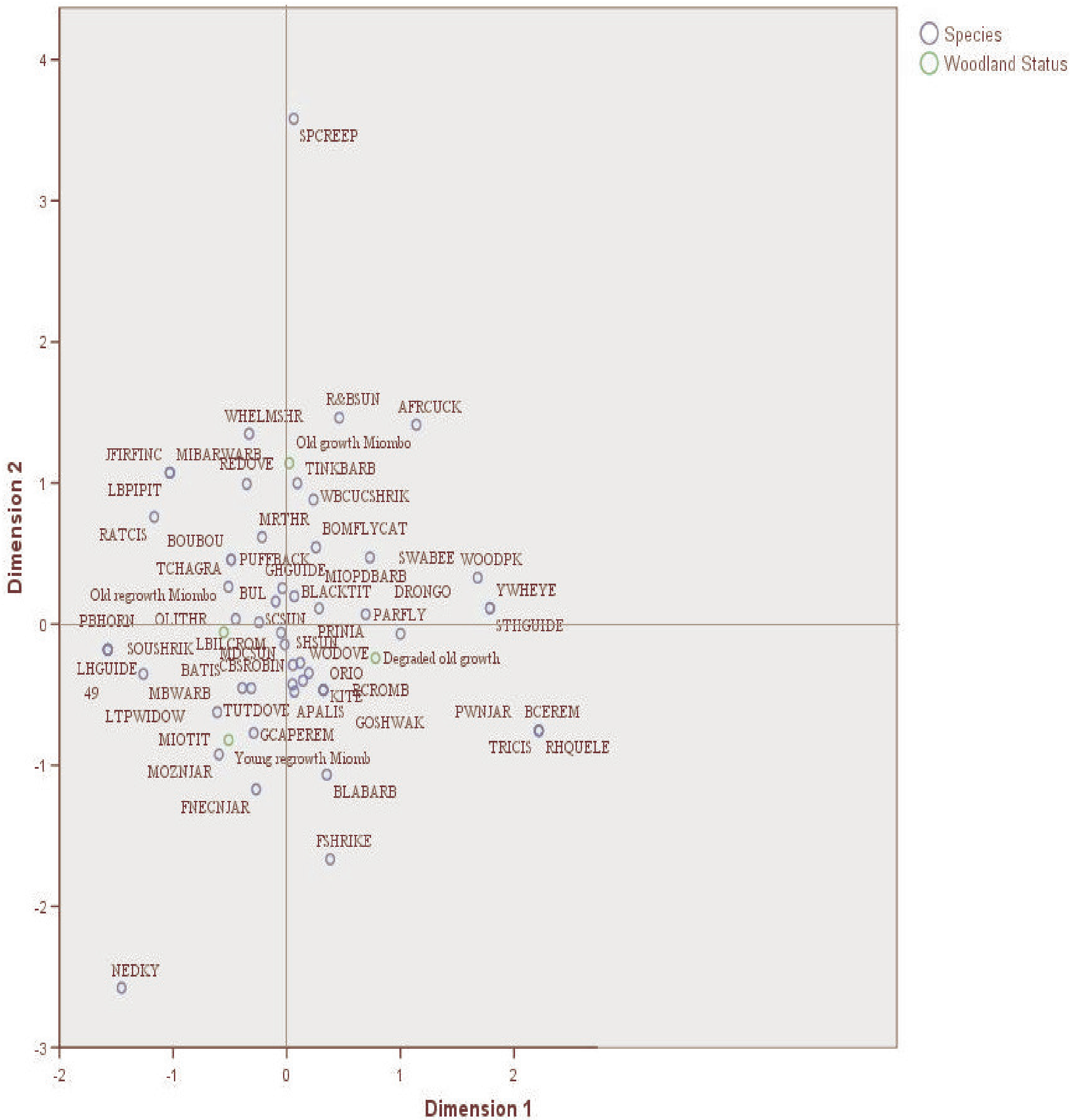


Figure 5.8 Correspondence map of avian species occurrence and woodland status. For bird species abbreviations see Figure 5.2.

5.4.4.2 Avian guild composition along the woodland degradation gradient

Three dimensions were identified in the correspondence analysis between guild type and woodland status. The first dimension accounted for 56.1 % of the correlation between guild type and woodland status while the second and third dimensions accounted for 29.0 % and

14.9 % respectively. Degraded old growth miombo and young regrowth miombo were highly correlated with the first dimension while old growth miombo and old regrowth miombo were highly correlated with the second dimension. The third dimension was not highly correlated with any woodland type (Table 5.7).

Table 5.7 Correlation between woodland status and correspondence analysis dimensions of avian guild type. The values indicate Pearson's correlation coefficients.

Woodland status	Dimension 1	Dimension 2	Dimension 3	Total
Old growth miombo	0.005	0.903	0.093	1.000
Degraded old growth miombo	0.879	0.002	0.119	1.000
Old regrowth miombo	0.152	0.579	0.269	1.000
Young regrowth miombo	0.841	0.004	0.156	1.000

Twelve out of the 16 identified avian guilds were correlated with the three dimensions (Table 5.8). Canopy specialized insectivores, understorey specialized insectivores, ground insectivores, ground vegetarians, generalist insectivores and generalist omnivores were correlated with the first dimension while aerial carnivores, canopy specialized carnivores, canopy specialized omnivores and understorey and ground omnivores were correlated with the second dimension. Understorey and ground insectivores and ground omnivores were correlated with the third dimension.

Table 5.8. Correlation between avian guild type and correspondence analysis dimensions of woodland status. The values indicate Pearson's correlation coefficients.

Avian guild type	Dimension 1	Dimension 2	Dimension 3	Total
1. Aerial carnivore	0.408	0.591	0.001	1.000
2. Canopy specialized carnivore	0.408	0.591	0.001	1.000
3. Canopy specialized insectivore	0.765	0.232	0.003	1.000
4. Canopy specialized omnivore	0.025	0.836	0.14	1.000
5. Understorey specialized insectivore	0.98	0.014	0.005	1.000
6. Ground insectivore	0.896	0.104	0.000	1.000
7. Ground omnivore	0.444	0.028	0.528	1.000
8. Ground vegetarian	0.814	0.057	0.129	1.000
9. Understorey and ground insectivore	0.077	0.066	0.857	1.000
10. Understorey and ground omnivore	0.109	0.775	0.116	1.000
11. Generalist insectivore	0.874	0.04	0.086	1.000
12. Generalist omnivore	0.809	0.165	0.026	1.000

When the first and second dimensions were graphed as a biplot (Figure 5.9), the first dimension separated old growth miombo, old regrowth miombo and young regrowth miombo from degraded old growth miombo while the second dimension separated old growth miombo and young regrowth miombo from old regrowth miombo and degraded old growth miombo. Old growth miombo was correlated with canopy specialized omnivores, understorey and canopy insectivores and generalist omnivores. Degraded old growth miombo was correlated with canopy specialized insectivores, canopy specialized omnivores, understorey and canopy insectivores and generalist insectivores. Old regrowth miombo was correlated with understorey specialized insectivores, understorey and ground insectivores, ground omnivores and generalist vegetarians while young regrowth miombo was correlated with ground vegetarians, ground insectivores, ground omnivores and generalist omnivores.

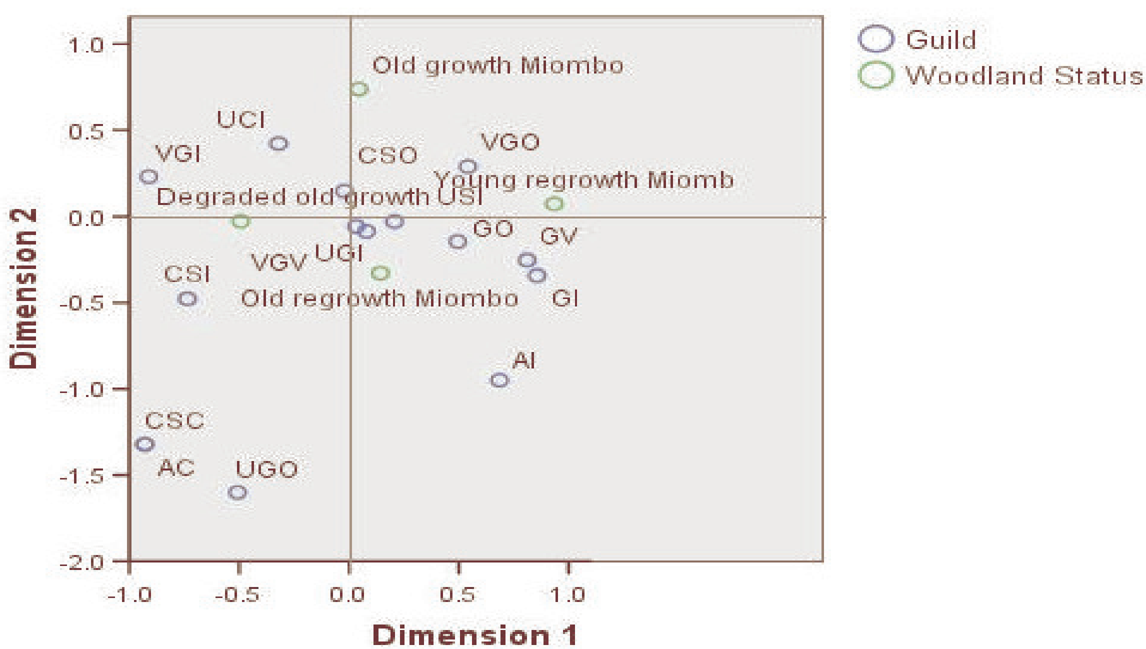


Figure 5.9 Correspondence map of avian guild type and woodland status. For avian guild abbreviations see Figure 5.5.

5.5 Discussion

5.5.1 Vegetation characteristics that influence avian community structure

Tree height and tree size are significant factors influencing avian species richness in the study area according to the linear model developed for predicting avian species richness from vegetation variables. Avian species richness is expected to increase in a woodland which has tall trees with small stems. Foliage height and the size of trees are important determinant of avian diversity because they influence the type of foraging behaviour in birds (Holmes *et al*., 1979; Vale *et al.,* 1982). The addition of shrubs and then trees along a vegetation gradient from grassland to forest increases foliage layering and complexity by providing supporting structures such as stems and branches which act as foraging regions. The proportion of foliage at different heights is also a function of the branching structure of trees. As trees become taller, they develop more branches. This branching results in increased foraging opportunities for birds leading to increased diversity. Apart from that, the size of the tree will determine the type of guilds that can forage there. The bark of trees become an important foraging substrate when trees are large and well developed because their bark is thick enough to provide adequate shelter for different insects. Bark probers are therefore likely to be found in mature woodland. Morphological complexity of plants provides different types and qualities of hiding places for insects. The foraging efficiency of birds is affected by the detectability and accessibility of food items on the plant (Bradbury *et al.,* 2005). For birds that glean branches and leaves for their food, smaller branches reduce the surface area from which they have to search for food, thereby increasing their feeding efficiency. Tall trees that have small stems therefore mean that the branching provides lots of foraging opportunities for different birds to utilize while the small size of the stem implies that the size of branches is also reduced making searching for food easier for birds. The combination of tall trees with small stems is likely to increase avian richness particularly that of gleaners. This type of vegetation structure which is likely to lead to increased avian richness can be found in both degraded old growth miombo and old regrowth miombo. The disjointed structure of degraded old growth miombo means that one is likely to find trees of various heights and sizes while old regrowth miombo is a regenerating woodland that also has trees of variable heights and sizes. These two woodland types have high vegetation structural diversity (Table 3.5) and are expected to have increased avian richness because the physiognomy of their foliage can support different guilds. Mature woodland is expected to support more bark probers while young regrowth woodland is expected to support more gleaners, therefore old growth miombo and young regrowth miombo are likely to support specialized guilds while old regrowth miombo and degraded old growth miombo can support a variety of guilds leading to increased avian richness. Apart from tree height and tree sizes influencing avian diversity, the abundance and quality of food resources also influence avian diversity (Holmes & Recher, 1986; Powell, 1989). Different plant species provide different food resources to bird species (Figure 5.1a & b). In miombo woodland, the dominant plant species such as *Brachystegia* spp, *Julbernardia* spp and *Pericopsis angolensis* support abundant insect populations (Mbata *et al.,* 2002). Caterpillar outbreaks are a common occurrence particularly in regrowth woodland. A woodland with plant species that offer abundant food resources is likely to have increased avian richness if this is coupled with vegetation structure characteristics which encourage increased avian richness compared to a woodland with the right vegetation structure whose plant species composition does not provide food resources utilized by birds. In this study, the quality and quantity of food resources provided by different plant species was not included in the development of the model. Studies done elsewhere have shown that the availability and abundance of food resources influences the occurrence of bird species. This aspect of habitat selection by birds should be incorporated in the development of future models for predicting avian species richness in miombo woodland. Overall, the model for predicting avian species richness developed in this study is supported by findings of other researchers.

Avian guild richness is significantly influenced by tree species diversity and tree species evenness according to the linear model for predicting avian guild richness from vegetation characteristics. The factors described above as influencing avian species richness also influence avian guild richness. However, the model for predicting avian guild richness emphasizes plant species composition as the most important influence on avian guild richness compared to vegetation structure characteristics. Different guilds feed on different food resources provided by different species of plants. One therefore expects a woodland with high plant species diversity to provide different plant resources leading to increased avian guild richness. For miombo woodland, increased nectar production by plants is found in mature woodland because plant normally produce flowers when they have reached maturity while regrowth woodland has been found to support high populations of insects compared to mature woodland (Clauss, 1992; Mbata *et al.,* 2002). Grasses thrive in woodland with an open canopy compared to a woodland with a closed canopy (Gray *et al.,* 2007). Seed production by grasses is therefore expected to be high in regrowth woodland compared to mature woodland. Increased avian guild richness is expected in a woodland with high tree evenness and low tree species diversity according to the model. Results from section 3.4.3 indicate that there were no significant differences in tree species evenness among the four miombo woodland types. However, there were differences in tree species diversity. Old growth miombo and young regrowth miombo were not significantly different from each other in terms of tree species diversity while degraded old growth miombo and old regrowth miombo were also not significantly different from each other. The highest tree species diversity was in young regrowth miombo (Figure 3.11b). This means that young regrowth miombo and old growth miombo are expected to have low avian guild richness because of their higher tree species diversity while degraded old growth miombo and old regrowth miombo are expected to have higher avian guild richness. The prediction of the model are supported by the fact that in degraded old growth miombo and old regrowth miombo, one expects to find flowering tree plants because both woodland types have mature trees. The presence of a high proportion of understorey trees also supports high insect populations. The open canopy of regrowth woodland allows grasses to thrive while the spatial heterogeneity of degraded old growth miombo means that grasses are able to thrive in patches where there is regrowth woodland. This allows the two woodland types to have a variety of food resources to support different guilds. However, old growth miombo does not support high abundances of insect populations nor does it produce large amounts of grasses. Young regrowth miombo can support high abundances of insect populations and grasses, however, the amount of nectar produced in young regrowth miombo is low. Old growth miombo and young regrowth miombo therefore support specialized guilds whereas degraded old growth miombo and old regrowth miombo can support a variety of guilds.

Avian species richness is closely linked with avian guild richness. High avian richness is expected to lead to high avian guild richness. Although the models of the two avian variables had different significant vegetation variables, they led to the same prediction regarding the type of woodland where one expects to find increased avian species richness and avian guild richness. The model for avian species richness identified degraded old growth miombo and old regrowth miombo as woodland types where one expects increased avian species richness while the model for avian guild richness also identified the same woodland types as the ones where one expects to find increased avian guild richness.

For avian abundance, the interpretation of the results was not straight forward. Tree species richness and tree species diversity were the significant habitat factors in determining avian abundance. From the model, avian abundance is expected to increase in a woodland with low tree species richness and high tree species diversity. High tree species diversity and high tree species richness were both found in young regrowth woodland (Figure 3.11), this means that high avian abundance is expected in young regrowth woodland based on the high tree species diversity. However, high avian abundance is also expected in the other woodland types based on their low tree species richness compared to young regrowth woodland. Therefore high avian abundance can be found in any woodland type. Comparison of avian abundances among different miombo woodland types yielded insignificant differences (Table 4.2 & Table 4.3). As mentioned above, different woodland types provide different food resources, therefore different woodland types are expected to support different types of bird species such that overall avian abundance is not expected to be different among woodland types. One also expect a situation where old growth woodland should have more nectarivores compared to regrowth woodland while regrowth woodland is expected to have more insectivores and granivores compared to old growth woodland. However, results from chapter 4 indicate that there were no significant differences in avian abundance according to dietary guild although the abundance of nectarivores showed a decreasing trend from old growth miombo to young regrowth miombo while the abundance of granivores showed an increasing trend from old growth miombo to young regrowth miombo (Appendix 4.5). The abundance of insectivores did not show any trend along the woodland degradation gradient. Apart from the availability of food resources, avian abundance is also influenced by the availability of nest cover and breeding sites (Vale *et al.,* 1982). The risk of nest predation can force bird species to select habitats that are marginal in terms of quality and quantity of food. Factors that influence the selection of breeding sites among birds should be incorporated in future models for predicting avian richness and abundance in miombo woodlands

Biotic interactions such as competition, predation and parasitism have been found to influence avian community structure apart from vegetation stratification (MacArthur & MacArthur, 1961; MacArthur *et al.,* 1962; Landres & MacMahon, 1980). Habitat characteristics largely determine the number of bird species and individuals that may exploit available resources and survive in a particular habitat while biotic interactions may alter individual foraging characteristics and contribute to partitioning of exploitable resources.

This study was limited to the correlation between vegetation characteristics and avian community structure only. Factors that influence habitat selection in birds such as food availability, nest site availability and intra and interspecific interactions were not included in the analysis. In order for bird - habitat models to have greater predictive power, such information should also be included in the development of models. Future research will focus on the inclusion of such factors in the development of models for miombo woodlands. Studies of the responses of miombo avifauna to woodland degradation are few, infact literature review showed that many studies on birds' responses to habitat degradation and modification have been restricted to bird species found in tropical forested areas particularly those in South America as well as forested areas in western countries. This study was therefore a preliminary study to determine how miombo bird community structure respond to changes in vegetation characteristics, future work will focus on the influence of other factors that were not included in this study.

5.5.2 Correlation between avian species and guilds and miombo woodland structure and degradation

Correspondence analysis results in which avian species and avian guilds were correlated with individual vegetation structure characteristics did not yield as highly correlated results as those in which avian species and avian guilds were correlated with woodland status. In the analyses involving vegetation structure characteristics, about 11 to 22 dimensions were identified by correspondence analysis as explaining all the correlation between vegetation variables and avian variables. This is an indication that the avian species and guilds and individual vegetation variables were not highly correlated. However, when the avian species and guilds were correlated with woodland status, only three dimensions were extracted and these explained all the correlation between the variables. The difference in the correspondence analysis results between the two could be that bird species rarely select only one habitat factor but instead select a combination of different habitat factors which provide them with food, shelter and cover. Correspondence analysis involving woodland status takes into account a combination of different habitat factors. For example, old growth miombo is expected to mainly have tall trees with large to medium-sized stems while young regrowth woodland is expected to have short trees with small stems. Hence the correlation between avian variables and woodland status can be explained by very few dimensions compared to that between avian variables and individual vegetation structure characteristics.

Although correspondence analysis with individual vegetation structure characteristics did not yield highly correlated results, the analysis yielded more details about habitat selection in birds than those of the more highly correlated woodland status. Instead of just correlating bird species with a particular woodland type, the correspondence analysis with vegetation structure characteristics went further by identifying individual habitat factors bird species were selecting in a particular woodland type. The correlation between avian species and trees of different height and sizes (Table 5.4) agrees with the guild type the birds were assigned to. During data collection, some bird species were not observed directly foraging or feeding. Therefore their assignment to different guilds was based on the findings of others (Sigel *et al.,* 2006; Fry *et al.,* 1982-2004; Mackworth –Praed & Grant, 1962-63; Benson *et al.,* 1971). Despite this, species identified by correspondence analysis as being correlated with tall canopy trees were classified as either canopy specialized guilds or understorey and canopy guilds. The Long-billed Pipit and Miombo Barred Warbler were the only species correlated with tall trees that were ground foragers whereas the Common Bulbul was identified as a generalist forager. Species identified as being correlated with understorey trees ranged from canopy specialized guilds, understorey and canopy guilds, understorey specialized guilds, generalist guilds to aerial guilds (Table 5.4). Overall the results of avian species correlation with vegetation structure are supported by findings from literature.

Correspondence analysis results between avian guilds and vegetation structure characteristics revealed that understorey trees are correlated with mainly generalist guilds and ground based guilds while short trees are correlated with generalist guilds, understorey and ground guilds and aerial guilds. Canopy trees are correlated with a variety of guilds from those that specialize in the canopy and understorey to those that are ground based including generalist guilds. The fact that canopy trees are correlated with more guilds stems from the fact that tall trees and their extensive branching provide more foraging opportunities particularly for insectivorous birds because they provide a variety of hiding places for different insects ((Holmes *et al*., 1979; Vale *et al.,* 1982; Bradbury *et al.,* 2005).

5.5.3 Correlation between avian species and guilds with miombo woodland degradation

Avian species that are correlated with different miombo woodland types are given in Table 5.6. When the avian species composition of species correlated with different woodland types was analyzed in terms of the habitat range distribution of species (Table 5.6), old growth woodland had a slightly higher percentage of miombo endemics compared with regrowth woodland while regrowth woodland had a higher percentage of habitat generalists compared to old growth woodland. In Australian savanna woodland, Hannah *et al*., (2007) found that as woodland regrowth develops, its avifaunal assemblages increasingly resemble that of intact woodland. Generalist species tend to increase in disturbed habitats because of the influx of opportunistic species that come in to exploit the new resources availed by changes in the habitat structure (Marsden & Pilgrim, 2003; Alo & Turner, 2005). Lampila *et al.*, (2005) found that specialist forest-interior species and non-migratory species are more likely to be behaviorally inhibited from crossing barriers such as matrix habitat created by human activities compared to generalist and migratory species and are therefore likely to have higher abundances in intact habitats than disturbed ones. Birds with smaller geographical ranges have also been found to show the greatest declines in abundance following disturbance (Gray *et al*., 2007). In addition, the range of habitats utilized by tropical bird species varies with food availability. Species dependent on food resources that are scattered in several habitats and occurring in low abundances tend to show greater overlap in habitat specialization than species whose food resources are concentrated in a few habitats (Karr & Roth, 1971). Avian species composition changed along the degradation gradient with endemic species having a higher percentage in old growth miombo and degraded old growth miombo while the percentage of habitat generalists was higher in old regrowth miombo and young regrowth miombo.

Correspondence analysis results between avian guilds and miombo woodland status revealed that all miombo woodland types in the study area were correlated with generalist bird guilds, however old growth miombo and degraded old growth miombo were the only woodland types correlated with canopy specialized guilds and, understorey and canopy guilds while old regrowth miombo and young regrowth miombo were correlated with understorey specialized guilds and ground-based guilds (Figure 5.9). Old growth miombo had more than 70 % of its trees in the canopy height category while degraded old growth miombo had 44 % of its trees in the canopy height category (Figure 3.15b), therefore, it is likely that there should be a correlation between these two woodland types with canopy specialized guilds. Ground-based guilds were highly correlated with regrowth woodland because they thrive in an open canopy woodland. An intercontinental comparison of determinants of guild structure in forest bird communities by Holmes & Recher, (1986) found that the initial separation of guilds was related to differential use of the vertical strata particularly ground versus above ground foraging. Forest stratification seems to be the major factor segregating species suggesting that foraging opportunities for birds in these forests differ with height. The second major factor segregating guilds was related to differences in foraging methods especially how birds obtained their food (foraging method) and the substrates from which the prey was taken. Vegetation structural diversity allows the co-existence of many guilds without competitive exclusion. In this study, only the primary food habit and the foraging height were used to assign birds to different guilds. The foraging method used by birds was not used. It is expected that degraded old growth miombo and old regrowth miombo that have high vegetation structural diversity (Table 3.5) should have a high diversity of avian guilds and while old growth miombo and young regrowth miombo are expected to have specialist guilds as a result of their low vegetation structural diversity. Results on the correlation between guild type and tree height indicated that canopy trees support more guilds than understorey trees or short trees. However, canopy trees in degraded old growth miombo are expected to support more guilds than those in old growth miombo. This disparity might be the result of the influence of foraging method on guild diversity. The large stems and branches associated with tall canopy trees in old growth miombo affect the detectability and accessibility of food for birds that forage by gleaning. The surface area to search for food increases with large stems and branches and accessing the food might prove difficult because birds cannot grip the large stems and branches.

5.6 Conclusions

Modeling the distribution and abundance of organisms enables the identification of key areas for management and the prediction of changes in the abundance and distribution of organisms resulting from habitat change. From a conservation perspective, predicting the effects of land-use change on biodiversity is essential to inform the decision-making process of strategic planning.

The study set out to test the following hypotheses:

(i) Vegetation characteristics are correlated with avian species richness, avian guild richness and avian abundance,

(ii) Avian species composition changes along the woodland degradation gradient with species from disturbed woodland gradually replacing those of intact woodland and,

(iii) Different bird guilds respond differently to woodland degradation.

The first hypothesis that vegetation characteristics are correlated with avian community structure characteristics was supported by results from this study. Avian species richness is greatly influenced by tree height and tree size while avian guild richness is influenced by tree species diversity and tree species evenness. Avian abundance is greatly influenced by tree species richness and tree species diversity. The models developed to predict avian species richness and avian guild richness are supported by findings from other studies while the model for predicting avian abundance does not seem to be an effective predictor.

The second hypothesis that avian species composition changes along the woodland degradation gradient was supported by results from this study. Old growth miombo and degraded old growth miombo were similar to each other in terms of percentages of miombo endemic species and habitat generalists while old regrowth miombo and young regrowth miombo were similar to each other in terms of percentage of miombo endemics, habitat restricted species and habitat generalists.

The third hypothesis that different bird guilds respond differently to woodland degradation is supported by results from this study. Canopy specialized guilds were correlated with old growth woodland while understorey guilds and ground-based guilds were correlated with regrowth woodland.

CHAPTER 6 CONCLUSIONS

The findings from the whole study can be summarized into two broad conclusions that:

(i) Woodland degradation leads to changes in the vegetation structure and composition of miombo woodland.

(ii) Woodland degradation causes changes in the avian species composition and avian guild composition. Small-scale or low intensity woodland degradation such as single tree selection for timber or charcoal production produces changes in woodland structure that are expected to lead to increased avian species richness and increased avian guild richness. High vegetation structural diversity produced by low intensity silvicultural treatments is beneficial to the avian community structure.

6.1 Challenges facing avifauna conservation in miombo woodland

There are three broad sets of issues that must be addressed in order to conserve Africa's avifauna (Brooks & Thompson, 2001). These are data, planning and implementation issues. For data issues, the most urgent requirement for bird conservation is availability of distributional information because birds cannot be protected if one does not know where they are found, as well as species-specific data regarding bird behaviour and their habitat requirements because this is critical for management purposes. With respect to planning issues, the critical issues are integrating avifauna data into conservation planning at the local level as well as integrating avifauna data with socioeconomic data in order to determine conservation priorities in relation to other social priorities. For implementation issues, the challenge is translating conservation strategy into action on the ground. Strict protection of biodiversity is the fundamental core of conservation implementation but for this to work, the needs of people around protected areas or those that have to be relocated to give way to the creation of protected areas must be addressed. Strict protection is implemented when the biodiversity in the protected area is irreplaceable, however when irreplaceability of species and their habitats is relatively low, there is need to encourage sustainability in natural resource harvest.

BirdLife International has come up with criteria for identifying important bird areas (IBAs) for the conservation of birds. Some of the factors considered when designating an area as an IBA are (i) endemicity in the avifauna (ii) presence of habitat restricted bird species and (iii) species that are in the CITES appendices and IUCN red data lists (BirdLife International, 2000; Leonard, 2005). Miombo woodland is known for its endemic avifauna (Benson & Irwin, 1966). However, miombo woodland is one of the region in Africa lacking any significant prioritization in terms of avifauna conservation.

Avifauna conservation priorities in miombo woodland should focus on conserving the endemic avifauna and its habitat as well as species that are mainly restricted to miombo woodland. Results from this study indicate that miombo endemics were present in all woodland types in the study area although the percentage of endemic species correlated with old growth miombo was slightly higher than in the other woodland types. Results from this study also indicate that low intensity silvicultural treatments are critical for the maintenance of increased species diversity in miombo woodland. Therefore to conserve the avifauna that is endemic and restricted to miombo woodland, there is need to protect old growth miombo as well as reducing woodland degradation in regrowth woodland so that the woodland is allowed to regenerate. In the endemic miombo avifauna as well as species that are restricted to miombo woodland, there are different guild structures. Some species belong to the canopy, understorey and ground guilds. Specific guild requirements should be taken into consideration when designing conservation and management plans for birds. Within old growth miombo, there is need to introduce managed silvicultural treatments that will enhance spatial heterogeneity in the vegetation in order to cater for species that require regrowth woodland for foraging or nesting. Miombo avifauna conservation can only be achieved if there is a multi-sectoral cooperation between organizations involved in avifauna conservation. This cooperation will enable aspects of avifauna conservation and management that are critical for birds to be incorporated into management practices of protected areas. Legislature exist for the protection of woodland in Zambia, similar legislation to allow for increased spatial heterogeneity as a management tool for the promotion of avian species diversity should also be enacted for PFAs.

The models developed in the present study do demonstrate that some level of degradation is actually beneficial to avian diversity. Although little is known about the impact of miombo woodland degradation on birds, the models developed in this study to predict avian species richness and avian guild richness are strong enough to aid in the management of miombo avifauna.

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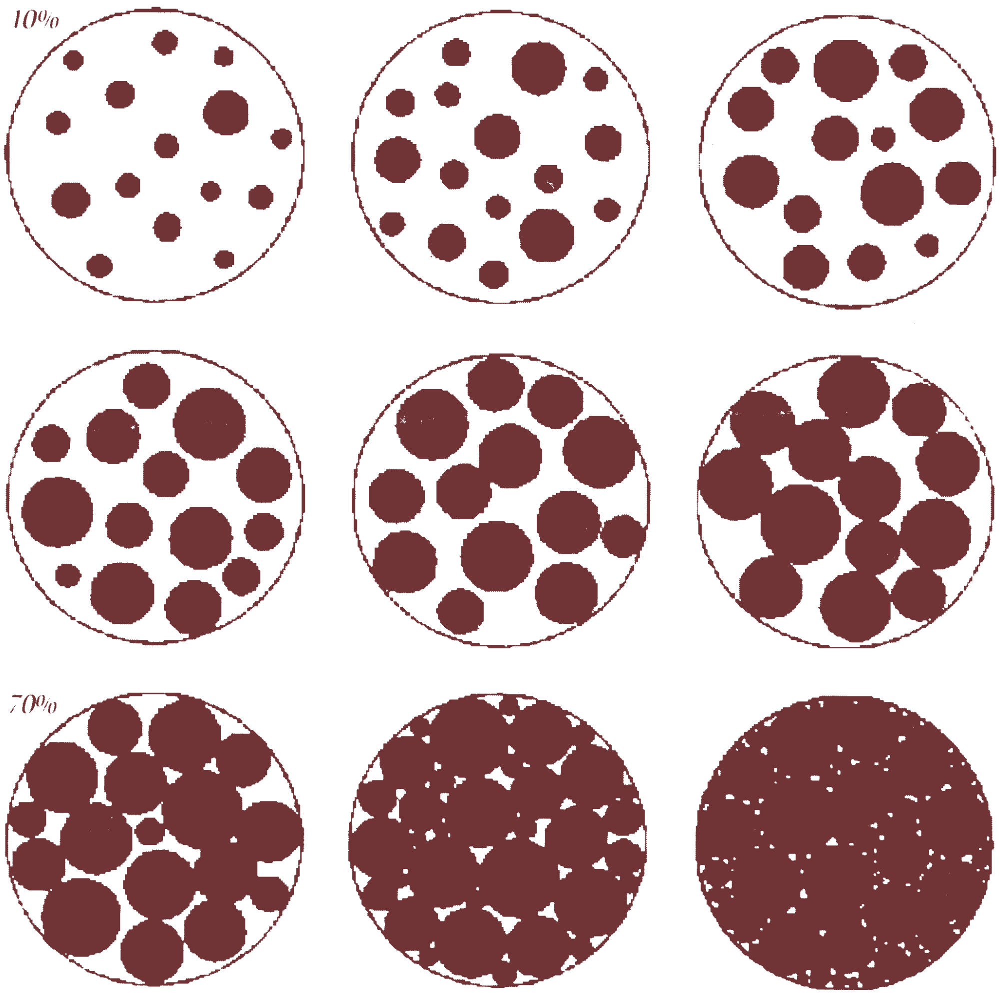
APPENDICES

Appendix 3.1 Diagrams used for visually estimating percentage canopy cover. Adapted from the Birds in Forested Landscapes project (BFL), Cornell University, USA.



Appendix 3.2 Plant species recorded in plant census plots in Serenje District, Zambia. Nomenclature follows White, (1962) and Fanshawe, (1971).

	Name	**Family**
1	*Blepharis buchneri* Lindau	Acanthaceae
2	*Lannea discolor* (Sond.) Engl.	Anacardiaceae
3	*Lannea schweinfurthii* (Engl.) Engl.	Anacardiaceae
4	*Ozoroa reticulata* (Baker f.) R. Fern & A. Fern	Anacardiaceae
5	*Anisophyllea boehmii* Engl.	Anisophylleaceae
6	*Hexalobus monopetalus* (A. Rich) Engl. & Diels	Annonaceae
7	*Xylopia odoratissima* Welw. ex Oliv.	Annonaceae
8	*Steganotaenia araliacea* Hochst.	Apiaceae
9	*Cussonia arborea* Hochst ex A. Rich	Araliaceae
10	*Asparagus africanus* Lam.	Asparagaceae
11	*Aloe mzimbana* I. Verdc. & Christian	Asphodelaceae
12	*Bidens pilosa* L.	Asteraceae
13	*Bidens schimperi* Sch. Bip. ex Walp.	Asteraceae
14	*Erythrocephalum zambesianum* Oliv. & Hiern	Asteraceae
15	*Helichrysum kirkii* Oliv. & Hiern	Asteraceae
16	*Vernonia petersii* Oliv. & Hiern ex Oliv.	Asteraceae
17	*Distephanus divaricatus* (Streetz) H. Rob. & B. Kahn	Asteraceae
18	*Tecomaria capensis* (Thunb.) Spach.	Bignoniaceae
19	*Myrianthus holstii* Engl.	Cecropiaceae
20	*Parinari curatellifolia* Planch. ex Benth	Chrysobalanaceae
21	*Garcinia livingstonei* T. Anderson	Clusiaceae
22	*Gloriosa superba* L.	Colchicaceae
23	*Combretum molle* R. Br.	Combretaceae
24	*Aneilema hockii* De Wild.	Commelinaceae
25	*Commelina africana* L	Commelinaceae
26	*Byrsocarpus orientalis* (Baill.) Baker	Connaraceae
27	*Cyperus rotundus* L.	Cyperaceae
28	*Fimbristylis dichotoma* (L.) Vahl	Cyperaceae
29	*Pteridium aquilinum* (L.) Kuhn	Dennstaedtiaceae
30	*Cephalaria pugens* Szabó	Dipsacaceae
31	*Monotes africanus* A. DC.	Dipterocarpaceae
32	*Monotes discolor* R. E. Fr.	Dipterocarpaceae
33	*Diospyros batocana* Hiern	Ebenaceae
34	*Maprounea africana* Müll.Arg.	Euphorbiaceae
35	*Pseudolachnostylis maprouneifolia* Radcl.-Sm.	Euphorbiaceae

36	*Uapaca kirkiana* Müll.Arg.	Euphorbiaceae
37	*Uapaca nitida* Müll.Arg.	Euphorbiaceae
38	*Uapaca sansibarica* Pax	Euphorbiaceae
39	*Abrus precatorius* L.	Fabaceae
40	*Aeschynomene abyssinica* (A. Rich.) Vatke	Fabaceae
41	*Aeschynomene bracteosa* Welw. ex Baker	Fabaceae
42	*Albizia antunesiana* Harms	Fabaceae
43	*Brachystegia boehmii* Taub.	Fabaceae
44	*Brachystegia floribunda* Benth.	Fabaceae
45	*Brachystegia longifolia* Benth.	Fabaceae
46	*Brachystegia microphylla* Harms.	Fabaceae
47	*Brachystegia spiciformis* Benth.	Fabaceae
48	*Brachystegia taxifolia* Harms.	Fabaceae
49	*Chamaecrista mimosoides* (L.) Greene	Fabaceae
50	*Crotalaria lanceolata* E. Mey.	Fabaceae
51	*Crotalaria natalitia* Meisn.	Fabaceae
52	*Dalbergia nitidula* Baker	Fabaceae
53	*Desmodium dregeanum* Benth	Fabaceae
54	*Dolichos kilimandscharicus* Taub	Fabaceae
55	*Eriosema buchananii* Baker f.	Fabaceae
56	*Erythrophleum africanum* (Welw. ex Benth) Harms	Fabaceae
57	*Indigofera schimperi* Jaub. & Spach.	Fabaceae
58	*Isoberlinia angolensis* (Welw. ex Benth) Hoyle & Brennan	Fabaceae
59	*Julbernardia paniculata* (Benth) Troupin	Fabaceae
60	*Pericopsis angolensis* (Baker) Meeuwen	Fabaceae
61	*Pterocarpus angolensis* DC.	Fabaceae
62	*Swartzia madagascariensis* Desv.	Fabaceae
63	*Vigna frutescens* A. Rich.	Fabaceae
64	*Chironia palustris* Burch.	Gentianaceae
65	*Hypoxis goetzei* Harms	Hypoxidaceae
66	*Gladiolus laxiflorus* Baker	Iridaceae
67	*Vitex doniana* Sweet	Lamiaceae
68	*Grewia bicolor* Juss.	Malvaceae
69	*Corchorus tridens* L.	Malvaceae
70	*Memycylon flavovirens* Baker	Melastomataceae
71	*Ficus wakefieldii* Hutch.	Moraceae
72	*Syzygium guineense guineense* (Willd.) DC.	Myrtaceae
73	*Syzgium guineense macrocarpum* (Willd.) DC.	Myrtaceae
74	*Nephrolepis cordifolia* (L.) C. Presl	Nephrolepidaceae
75	*Ochna pulchra* Hook. f.	Ochnaceae

76	*Biophytum crassipes* Engl.	Oxalidaceae
77	*Sesamum angolense* Welw.	Passifloraceae
78	*Brachiaria serrata* (Thunb.) Stapf	Poaceae
79	*Eleusine coracana* (L.) Gaertn.	Poaceae
80	*Chloris pycnothrix* Trin.	Poaceae
81	*Digitaria eriantha* Steud.	Poaceae
82	*Diheteropogon amplectens* (Nees) Clayton	Poaceae
83	*Eragrostis aspera* (Jacq.) Nees	Poaceae
84	*Eragrostis racemosa* (Thunb.) Steud.	Poaceae
85	*Heteropogon contortus* (L.) Roem. & Schult.	Poaceae
86	*Hyparrhenia rufa* (Nees) Stapf	Poaceae
87	*Loudetia simplex* (Nees) C. E. Hubb.	Poaceae
88	*Panicum pectinellum* Stapf	Poaceae
89	*Rottboellia cochinchinensis* (Lour.) Clayton	Poaceae
90	*Setaria pumila* (Poir) Roem & Schult.	Poaceae
91	*Sporobolus fibrosus* Cope	Poaceae
92	*Sporobulus pyramidalis* P. Beauv.	Poaceae
93	*Urochloa mosambicensis* (Hack.) Dandy	Poaceae
94	*Securidaca longipedunculata* Fresen.	Polygalaceae
95	*Protea angolensis* Welw.	Proteaceae
96	*Clematis welwitschii* Hiern ex Kuntze	Ranunculaceae
97	*Fadogia triphylla* Baker	Rubiaceae
98	*Gardenia imperialis* K. Schum.	Rubiaceae
99	*Rothmannia engleriana* (K. Schum.) Keay	Rubiaceae
100	*Vangueriopsis lanciflora* (Hiern) Robyns ex R. D. Good	Rubiaceae
101	*Mimusops zeyheri* Sond.	Sapotaceae
102	*Striga asiatica* (L.) Kuntze	Sapotaceae
103	*Strychnos cocculoides* Baker	Strychnaceae
104	*Strychnos pugens* Soler.	Strychnaceae
105	*Strychnos spinosa* Lam.	Strychnaceae
106	*Xerophyta equisetoides* Baker	Velloziaceae
107	*Cyphostemma cirrhosum* (Thunb.) Desc. ex Wild & R. B. Drumm.	Vitaceae

Appendix 3.3 Correlation matrix of the principal components of vegetation structure and composition in Serenje District, Zambia and Measures of Sampling Adequacy (MSA) values of each vegetation variable.

	TREEDIV	TRERICH	TREDEN	TOTRICH	TOTDIV	CCOVER	TOTBA	TREEBA	DBH	HEIGHT
TREEDIV	1	0.744	0.463	0.305	0.348	0.168	0.205	-0.168	-0.071	-0.036
TRERICH	0.744	1	0.661	0.448	0.452	-0.049	0.228	-0.24	-0.271	-0.278
TREDEN	0.463	0.661	1	0.207	0.153	-0.387	-0.006	-0.531	-0.584	-0.586
TOTRICH	0.305	0.448	0.207	1	0.978	0.082	0.039	0.009	-0.011	-0.021
TOTDIV	0.348	0.452	0.153	0.978	1	0.138	0.087	0.068	0.063	0.057
CCOVER	0.168	-0.049	-0.387	0.082	0.138	1	0.412	0.454	0.57	0.595
TOTBA	0.205	0.228	-0.006	0.039	0.087	0.412	1	0.686	0.674	0.655
TREEBA	-0.168	-0.24	-0.531	0.009	0.068	0.454	0.686	1	0.948	0.909
DBH	-0.071	-0.271	-0.584	-0.011	0.063	0.57	0.674	0.948	1	0.994
HEIGHT	-0.036	-0.278	-0.586	-0.021	0.057	0.595	0.655	0.909	0.994	1
MSA	***0.641***	***0.689***	***0.779***	***0.54***	***0.55***	***0.9***	***0.79***	***0.59***	***0.601***	***0.596***

TREEDIV - Tree species diversity, TRERICH - Tree species richness, TREDEN - Stem density, TOTRICH - Total plant species richness, TOTDIV- Total plant diversity, CCOVER - % Canopy cover, TOTBA - Stand basal area cover, TREEBA - Mean tree basal area cover, DBH - Diameter at breast height and HEIGHT - Tree height

Appendix 3.4 Distribution of plant census plots in different miombo woodland types in Serenje District, Zambia. The first number after the name of the study site represents the transect number while the second number represents the plot number along the transect.

Old growth plots	Degraded old growth plots	Old regrowth plots	Young regrowth plots
Serenje 11	Serenje 13	Serenje 14	Kanona 12
Serenje 12	Serenje22	Serenje 15	Kanona 32
Serenje 21	Serenje 23	Serenje 24	Kanona 34
Serenje 33	Serenje 31	Serenje 25	Kafunda 32
Serenje 35	Serenje 34	Serenje 32	Kafunda 34
Kanona 21	Kanona 11	Kanona 13	Kafunda 41
Kanona 25	Kanona 24	Kanona 14	Kafunda 44
Kanona 35	Kafunda 12	Kanona 15	
Kafunda 14	Kafunda 15	Kanona 22	
	Kafunda 22	Kanona 23	
	Kafunda 23	Kanona 31	
	Kafunda 25	Kanona 33	
	Kafunda 31	Kafunda 11	
	Kafunda 33	Kafunda 13	
	Kafunda 35	Kafunda 21	
	Kafunda 42	Kafunda 24	
		Kafunda 43	
		Kafunda 45	

Appendix 3.5 Structural and floristic characteristics of four miombo types in Serenje District, Zambia. Values are mean ± SE per plot.

Vegetation variable/0.01ha plot	Old growth miombo (n = 9)	Degraded old growth miombo (n = 16)	Old regrowth miombo (n = 18)	Young regrowth miombo (n = 7)
Canopy cover (%)	51.11 ± 4.984	36.88 ± 4.607	26.11 ± 4.601	6.429 ± 0.922
Tree basal area cover (dm²)	13.86 ± 1.527	6.19 ± 1.350	5.08 ± 0.743	1.78 ± 0.303
Tree DBH (cm)	35.19 ± 2.014	22.08 ± 2.227	20.77 ± 1.691	12.68 ± 1.113
Tree height (m)	14.97 ± 0.633	10.84 ± 0.734	10.51 ± 0.588	7.63 ± 0.459
Sapling density	28.78 ± 4.881	46.50 ± 7.373	26.44 ± 3.796	25.43 ± 3.747
Sapling species diversity	1.20 ± 0.088	1.19 ± 0.077	0.92 ± 0.124	1.12 ± 0.191
Sapling species evenness	0.75 ± 0.040	0.78 ± 0.035	0.71 ± 0.071	0.75 ± 0.062
Sapling species richness	5.11 ± 0.423	4.88 ± 0.364	3.39 ± 0.405	4.57 ± 0.649
Stem density	17.22 ± 1.588	19.50 ± 2.255	18.17 ± 2.371	48.00 ± 3.786
Stand basal area (dm²)	226.11 ± 18.947	86.87 ± 8.331	79.68 ± 11.441	104.13 ± 21.236
Total species diversity	3.48 ± 0.033	3.54 ± 0.028	3.26 ± 0.057	3.55 ± 0.080
Total species richness	32.56 ± 1.069	34.75 ± 1.006	26.78 ± 1.220	35.43 ± 2.543
Tree species diversity	1.43 ± 0.145	1.38 ± 0.105	1.21 ± 0.130	1.85 ± 0.146
Tree species evenness	0.70 ± 0.063	0.70 ± 0.040	0.64 ± 0.054	0.74 ± 0.049
Tree species richness	7.78 ± 0.434	7.50 ± 0.645	6.28 ± 0.604	12.57 ± 1.251

Appendix 4.1 Bird species recorded in bird census plots in Serenje District, Zambia. Nomenclature follows Benson *et al.*, (1971) and that used by Dowsett & Forbes-Watson, (1993). Letters in parentheses indicate the habitat range distribution of the species. E – Miombo endemics, R – Habitat- restricted species and G – Habitat generalists. For avian guild abbreviations see Appendix 4.2

	Common name	Scientific name	Frequency of detection	Diet and foraging height guild
1	Red-and-blue Sunbird (E)	*Anthreptes anchietae* Bocage	0.032	CSO
2	Long-billed Pipit (R)	*Anthus similis* Jerdon	0.012	GO
3	Yellow-breasted Apalis (G)	*Apalis flavida* Strickland	0.008	UCI
4	Chinspot Batis (G)	*Batis molitor* Hahn and Küster	0.092	UCI
5	Bleating Bush Warbler (G)	*Camaroptera brachyura* Vieillot	0.028	GI
6	Miombo Barred Warbler (E)	*Camaroptera undosa* Reichenow	0.02	GI
7	Bennett's Woodpecker (G)	*Campethera bennettii* Smith	0.02	UCI
8	Mozambique Nightjar (G)	*Caprimulgus fossi* Hartlaub	0.032	AI
9	Fiery-necked Nightjar (G)	*Caprimulgus pectoralis* Cuvier	0.012	AI
10	Rattling Cisticola (G)	*Cisticola chiniana* Smith	0.008	USI
11	Neddicky (R)	*Cisticola fulvicapilla* Vieillot	0.016	UGI
12	Trilling Cisticola (R)	*Cisticola woosnami* Olgilvie - Grant	0.004	USI
13	Striped Crested Cuckoo (G)	*Clamator levaillantii* Swainson	0.002	UCI
14	White-breasted Cuckoo-shrike (G)	*Coracina pectoralis* Jardine and Selby	0.012	UCI
15	African Grey Cuckoo (G)	*Cuculus gularis* Stephens	0.02	UCI
16	Fork-tailed Drongo (G)	*Dicrurus adsimilis* Bechstein	0.168	VGI
17	Southern Puffback (R)	*Dryoscopus cubla* Shaw	0.02	UCI
18	Cabanis's Bunting (R)	*Emberiza cabanisi* Reichenow	0.002	GO
19	Black-collared Eremomela (E)	*Eremomela atricollis* Bocage	0.004	CSI
20	Yellow-bellied Eremomela (G)	*Eremomela icteropygialis* Lafresnaye	0.002	CSI
21	Green-capped Eremomela (R)	*Eremomela scotops* Sundevall	0.028	CSI
22	Central Bearded Scrub Robin (E)	*Erythropygia barbata* Finsch and Hartlaub	0.028	UGO
23	Fawn-breasted Waxbill (G)	*Estrilda paludicola* Heuglin	0.012	GV
24	Yellow-bellied Hyliota (R)	*Hyliota flavigaster* Swainson	0.008	CSI
25	Greater Honeyguide (G)	*Indicator indicator* Sparrman	0.024	CSI

26	Lesser Honeyguide (G)	*Indicator minor* Stephens	0.008	CSI
27	Scaly-throated Honeyguide (R)	*Indicator variegatus* Lesson	0.024	CSI
28	Jameson Firefinch (G)	*Lagonosticta rhodopareia* Heuglin	0.004	GV
29	Tropical Boubou (G)	*Laniarius aethiopicus* Gmelin	0.02	USI
30	Fiscal Shrike (G)	*Lanius collaris* Linnaeus	0.008	GI
31	Lesser Grey Shrike (G)	*Lanius minor* Gmelin	0.004	GI
32	Souza's Shrike (R)	*Lanius souzae* Bocage	0.004	GI
33	Black-collared Barbet (G)	*Lybius torquatus* Dumont	0.016	CSO
34	Pennant-winged Nightjar (R)	*Macrodipteryx vexillarius* Gould	0.004	AI
35	Dark Chanting Goshawk (G)	*Melierax metabates* Heuglin	0.008	CSC
36	Swallow-tailed Bee-eater (G)	*Merops hirundineus* Lichtenstein	0.032	CSI
37	Black (Yellow-billed) Kite (G)	*Milvus migrans* Boddært	0.008	AC
38	Miombo Rock Thrush (E)	*Monticola angolensis* Souza	0.016	UGI
39	Böhm's Flycatcher (E)	*Muscicapa boehmi* Reichenow	0.036	UCI
40	Miombo Double-collared Sunbird (R)	*Nectarinia manoensis* Reichenow	0.176	CSO
41	Scarlet-chested Sunbird (G)	*Nectarinia senegalensis* Linnaeus	0.044	CSO
42	Shelley's Sunbird (E)	*Nectarinia shelleyi* Alexander	0.324	CSO
43	Yellow-bellied Sunbird (G)	*Nectarinia venusta* Shaw and Nodder	0.004	CSO
44	Brubru (G)	*Nilaus afer* Latham	0.008	CSI
45	Eastern Black-headed Oriole (G)	*Oriolus larvatus* Lichtenstein	0.088	CSO
46	Miombo Grey Tit (E)	*Parus griseiventris* Reichenow	0.036	CSO
47	Southern Black Tit (G)	*Parus niger* Vieillot	0.036	CSO
48	Yellow-fronted Tinkerbird (G)	*Pogoniulus chrysoconus* Temminck	0.068	CSO
49	Tawny-flanked Prinia (G)	*Prinia subflava* Gmelin	0.176	USI
50	White Helmet Shrike (G)	*Prionops plumatus* Shaw	0.028	UCI
51	Common Bulbul (G)	*Pycnonotus barbatus* Desfontaines	0.276	VGO
52	Red-headed Quelea (G)	*Quelea erythrops* Hartlaub	0.008	GV
53	Spotted Creeper (R)	*Salponis spilonotus* Franklin	0.004	UCI
54	Cape Turtle Dove (G)	*Streptopelia capicola* Sundevall	0.08	VGV
55	Red-eyed Dove (G)	*Streptopelia semitorquata* Rüppell	0.044	VGV
56	Long-billed Crombec (G)	*Sylvietta rufescens* Vieillot	0.044	UGI

57	Red-capped Crombec (E)	*Sylvietta ruficapilla* Bocage	0.016	CSI
58	Black-crowned Tchagra (G)	*Tchagra senegalus* Linnaeus	0.052	USI
59	Paradise Flycatcher (G)	*Terpsiphone viridis* Müller	0.032	UCI
60	Pale-billed Hornbill (E)	*Tockus pallidirostris* Finsch and Hartlaub	0.004	CSO
61	Miombo Pied Barbet (R)	*Tricholaema frontata* Cabanis	0.032	CSO
62	Arrow-marked Babbler (G)	*Turdoides jardineii* Smith	0.002	USO
63	Olive Thrush (G)	*Turdus olivaceus* Linnaeus	0.112	GO
64	Emerald-spotted Wood Dove (G)	*Turtur chalcospilos* Wagler	0.108	VGV
65	Long-tailed Shrike (G)	*Urolestes melanoleucus* Jardine	0.002	UCI
66	Long-tailed Paradise Widow (G)	*Vidua paradisaea* Linnaeus	0.024	GV
67	Yellow White-eye (G)	*Zosterops senegalensis* Bonaparte	0.02	CSO

Appendix 4.2 Bird guilds recorded in bird census plots in Serenje, District, Zambia including their abbreviations and proportions.

	Guild	**Abbreviation**	**Number of species (% of total number of species)**
1	Aerial carnivore	AC	1(1%)
2	Canopy specialized carnivore	CSC	1(1%)
3	Canopy specialized insectivore	CSI	10 (15%)
4	Canopy specialized omnivore	CSO	13 (19%)
5	Understorey specialized insectivore	USI	5 (7%)
6	Understory specialized omnivore	USO	1 (1%)
7	Aerial insectivore	AI	3 (4%)
8	Ground insectivore	GI	5 (7%)
9	Ground omnivore	GO	3 (4%)
10	Ground vegetarian	GV	4 (6%)
11	Understory and canopy insectivore	UCI	12 (18%)
12	Understory and ground insectivore	UGI	3 (4%)
13	Understory and ground omnivore	UGO	1 (1%)
14	Generalist insectivore	VGI	1 (1%)
15	Generalist omnivore	VGO	1 (1%)
16	Generalist vegetarian	VGV	3(4%)

Appendix 4.3 Distribution of plant census plots in different clusters based on bird abundance by species data in Serenje District, Zambia. The first number after the name of the study site represents the transect number while the second number represents the plot number along the transect.

	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Cluster 5
1	Serenje 12	Kanona 14	Serenje 13	Serenje 11	Kanona 11
2	Serenje 15	Kanona 15	Kafunda 14	Serenje 24	Kanona 13
3	Serenje 21	Kanona 24	Kafunda 22	Serenje 25	
4	Serenje 22	Kanona 35	Kafunda 25	Serenje 31	
5	Serenje 23	Kafunda 21		Serenje 33	
6	Serenje 34	Kafunda 41		Serenje 35	
7	Kanona 22			Kanona 31	
8	Kanona 23			Kanona 33	
9	Kanona 25			Kafunda 12	
10	Kanona 34			Kafunda 15	
11	Kafunda 11			Kafunda 23	
12	Kafunda 13			Kafunda 24	
13	Kafunda 31				
14	Kafunda 32				
15	Kafunda 33				
16	Kafunda 34				
17	Kafunda 35				
18	Kafunda 42				
19	Kafunda 43				
20	Kafunda 44				
21	Kafunda 45				

Appendix 4.4 Spatial autocorrelation results for the avian community transect data in Serenje District, Zambia. R^2 is the adjusted coefficient of determination from the linear regression analysis; range is the distance from the beginning of a transect at which spatial autocorrelation in the data ends and NS means the linear regression model of the transect data was not significant.

Transect	Avian species richness	Avian guild richness	Pooled bird abundance	Abundance of endemics
Serenje 1	NS	$R^2 = 0.44$; Range = 881.6m	NS	NS
Serenje 2	NS	NS	NS	$R^2 = 0.29$; Range = 478.1m
Serenje 3	NS	NS	$R^2 = 0.59$; Range = 600.0m	$R^2 = 0.41$; Range = 833.1m
Kanona 1	$R^2 = 0.30$; Range = 829.7m	NS	$R^2 = 0.50$; Range = 798.5m	NS
Kanona 2	$R^2 = 0.41$; Range = 1169.1m	$R^2 = 0.33$; Range = 848.7m	NS	NS
Kanona 3	NS	NS	NS	NS
Kafunda 1	NS	NS	NS	NS
Kafunda 2	$R^2 = 0.76$; Range = 600m	$R^2 = 0.53$; Range = 600.0m	$R^2 = 0.69$; Range = 600.0m	$R^2 = 0.78$; Range = 600m
Kafunda 3	NS	NS	NS	NS
Kafunda 4	$R^2 = 0.39$; Range = 801.9m	$R^2 = 0.40$; Range = 753.4m	$R^2 = 0.31$; Range = 722.3m	$R^2 = 0.83$; Range = 1467.0m

Transect	Abundance of habitat generalist birds	Abundance of habitat restricted birds	Abundance of omnivores	Abundance of nectarivores	Abundance of insectivores	Abundance of vegetarians
Serenje 1	NS	$R^2 = 0.47$; Range = 940.0m	$R^2 = 0.55$; Range = 249.0m	NS	$R^2 = 0.33$; Range = 140.3m	NS
Serenje 2	NS	NS	$R^2 = 0.51$; Range = 3153.0m	$R^2 = 0.51$; Range = 3242.4m	NS	NS
Serenje 3	$R^2 = 0.63$; Range = 600.0m	$R^2 = 0.62$; Range = 600.0m	NS	NS	NS	NS
Kanona 1	NS	NS	NS	NS	$R^2 = 0.59$; Range = 1186.5m	NS
Kanona 2	$R^2 = 0.85$; Range = 600.0m	NS	$R^2 = 0.44$; Range =	$R^2 = 0.25$; Range =	NS	NS

			600.0m	600.0m		
Kanona 3	NS	NS	NS	R^2 = 0.38; Range = 600.0m	NS	R^2 = 0.26; Range = 600.0m
Kafunda 1	NS	NS	NS	R^2 = 0.56; Range = 600.0m	R^2 = 0.60; Range = 1051.4m	R^2 = 0.44; Range = 600.0m
Kafunda 2	NS	R^2 = 0.67; Range = 3065.0m	NS	R^2 = 0.67; Range = 600.0m	NS	NS
Kafunda 3	NS	NS	R^2 = 0.40; Range = 1231.5m	NS	NS	NS
Kafunda 4	NS	NS	R^2 = 0.53; Range = 600.0m	NS	NS	NS

Appendix 4.5 Table of pooled avian variables in different habitats and in different seasons in Serenje District, Zambia. Values are means and standard errors per plot.

Avian variable	**Old growth miombo (n = 9)**	**Degraded old growth miombo (n = 16)**	**Old regrowth miombo(n = 18)**	**Young regrowth miombo (n = 7)**
Avian species richness	3.00 ± 0.332	2.61 ± 0.259	2.86 ± 0.277	2.67 ± 0.371
Avian guild richness	2.75 ± 0.350	2.29 ± 0.158	2.45 ± 0.218	2.51 ± 0.273
Overall avian abundance	6.40 ± 0.819	6.00 ± 0.809	5.78 ± 0.848	5.12 ± 1.195
Abundance of endemics	1.62 ± 0.299	1.10 ± 0.214	1.45 ± 0.187	1.33 ± 0.303
Abundance of habitat restricted birds	1.41 ± 0.407	1.18 ± 0.317	1.05 ± 0.298	0.69 ± 0.334
Abundance of habitat generalists	3.32 ± 0.419	3.76 ± 0.463	3.43 ± 0.534	3.46 ± 0.866
Abundance of omnivores	1.06 ± 0.262	1.04 ± 0.278	1.54 ± 0.298	0.93 ± 0.246
Abundance of nectarivores	2.06 ± 0.360	1.73 ± 0.324	1.26 ± 0.230	1.21 ± 0.439
Abundance of vegetarians	0.28 ± 0.073	0.46 ± 0.141	0.42 ± 0.104	0.69 ± 0.389
Abundance of	2.24 ± 0.490	3.27 ± 0.478	2.85 ± 0.617	1.98 ± 0.489

insectivores				
Cool and dry season	**Old growth miombo (n = 9)**	**Degraded old growth miombo (n = 16)**	**Old regrowth miombo(n = 18)**	**Young regrowth miombo (n = 7)**
Avian species richness	3.48 ± 0.631	2.22 ± 0.448	2.48 ± 0.272	2.24 ± 0.499
Avian guild richness	2.63 ± 0.422	1.92 ± 0.311	1.97 ± 0.218	1.96 ± 0.377
Overall avian abundance	8.59 ± 2.056	5.52 ± 1.428	4.71 ± 0.704	4.68 ± 1.536
Abundance of endemics	2.18 ± 0.632	0.93 ± 0.299	1.27 ± 0.287	1.26 ± 0.346
Abundance of habitat restricted birds	2.75 ± 1.178	1.67 ± 0.654	1.06 ± 0.317	0.36 ± 0.179
Abundance of habitat generalists	3.33 ± 0.678	3.06 ± 0.943	2.46 ± 0.461	3.43 ± 1.390
Abundance of omnivores	1.00 ± 0.322	1.25 ± 0.382	1.86 ± 0.632	1.00 ± 0.345
Abundance of nectarivores	2.56 ± 0.621	2.22 ± 0.572	1.75 ± 0.344	0.64 ± 0.322
Abundance of vegetarians	0.22 ± 0.121	0.69 ± 0.400	0.36 ± 0.113	0.29 ± 0.149
Abundance of insectivores	1.17 ± 0.799	2.34 ± 0.743	2.14 ± 0.610	0.36 ± 0.179
Hot and dry season	**Old growth miombo (n = 9)**	**Degraded old growth miombo (n = 16)**	**Old regrowth miombo(n = 18)**	**Young regrowth miombo (n = 7)**
Avian species richness	3.48 ± 0.724	3.65 ± 0.565	3.78 ± 0.521	3.11 ± 0.518
Avian guild richness	3.75 ± 0.748	3.16 ± 0.440	3.49 ± 0.498	3.25 ± 0.447
Overall avian abundance	5.91 ± 1.697	7.76 ± 1.596	7.02 ± 1.495	4.68 ± 1.527
Abundance of endemics	1.11 ± 0.564	1.31 ± 0.631	1.81 ± 0.497	1.30 ± 0.332
Abundance of habitat restricted birds	0.78 ± 0.222	1.31 ± 0.575	0.94 ± 0.424	0.71 ± 0.565
Abundance of habitat generalists	4.16 ± 1.257	5.02 ± 0.926	4.79 ± 1.070	2.95 ± 1.064
Abundance of	1.00 ± 0.333	0.63 ± 0.155	2.00 ± 0.464	0.57 ± 0.297

omnivores				
Abundance of nectarivores	1.33 ± 0.645	1.69 ± 0.888	0.83 ± 0.316	1.57 ± 0.948
Abundance of vegetarians	0.44 ± 0.242	0.25 ± 0.144	0.61 ± 0.282	1.00 ± 0.845
Abundance of insectivores	4.22 ± 1.516	5.63 ± 1.268	3.94 ± 1.068	2.71 ± 0.680
Hot and wet season	**Old growth miombo (n = 9)**	**Degraded old growth miombo (n = 16)**	**Old regrowth miombo(n = 18)**	**Young regrowth miombo (n = 7)**
Avian species richness	2.05 ± 0.307	1.96 ± 0.287	2.31 ± 0.312	2.64 ± 0.730
Avian guild richness	1.89 ± 0.309	1.78 ± 0.234	1.89 ± 0.251	2.34 ± 0.510
Overall avian abundance	4.71 ± 1.060	4.73 ± 1.296	5.61 ± 0.886	5.99 ± 2.458
Abundance of endemics	1.58 ± 0.428	1.05 ± 0.284	1.26 ± 0.313	1.42 ± 0.751
Abundance of habitat restricted birds	0.70 ± 0.434	0.56 ± 0.199	1.13 ± 0.330	1.00 ± 0.478
Abundance of habitat generalists	2.47 ± 0.608	3.18 ± 1.018	3.03 ± 0.503	4.00 ± 1.729
Abundance of omnivores	1.17 ± 0.408	1.25 ± 0.614	0.75 ± 0.199	1.21 ± 0.324
Abundance of nectarivores	2.28 ± 0.672	1.28 ± 0.368	1.19 ± 0. 432	1.43 ± 0.659
Abundance of insectivores	1.33 ± 0.527	1.84 ± 0.554	2.47 ± 0.597	2.86 ± 1.045
Abundance of vegetarians	0.17 ± 0.083	0.44 ± 0.176	0.28 ± 0.092	0.79 ± 0.625

Appendix 5.1 Regression ANOVA results of various linear models for predicting avian species richness from vegetation variables. Vegetation variable abbreviations are:

CCOVER – Canopy cover; DBH – Tree diameter at breast height HEIGHT – Tree height; TREEBA – Mean tree basal area cover; SAPDEN – Sapling density; SAPDIV – Sapling species diversity; SAPEVEN – Sapling species evenness; SAPRICH – Sapling species richness; TREDEN – Stem density; TREEDIV – Tree species diversity; TREEVEN – Tree species evenness; TOTBA – Stand basal area cover; TOTDIV - Total plant species diversity; TOTRICH – Total species plant richness and TRERICH – Tree species richness

Model	Source of variation	Sum of Squares	df	Mean Square	F- value	P	Adjusted R^2
1	Regression	247.443	15	16.496	1.484	0.166(a)	0.129
	Residual	377.937	34	11.116			
	Total	625.380	49				
2	Regression	247.344	14	17.667	1.636	0.118(b)	0.154
	Residual	378.036	35	10.801			
	Total	625.380	49				
3	Regression	246.871	13	18.990	1.806	0.080(c)	0.176
	Residual	378.509	36	10.514			
	Total	625.380	49				
4	Regression	245.530	12	20.461	1.993	0.054(d)	0.196
	Residual	379.850	37	10.266			
	Total	625.380	49				
5	Regression	244.016	11	22.183	2.210	0.035(e)	0.214
	Residual	381.364	38	10.036			
	Total	625.380	49				
6	Regression	240.607	10	24.061	2.439	0.023(f)	0.227
	Residual	384.773	39	9.866			
	Total	625.380	49				
7	Regression	240.109	9	26.679	2.770	0.013(g)	0.245
	Residual	385.271	40	9.632			
	Total	625.380	49				
8	Regression	239.133	8	29.892	3.173	0.007(h)	0.262
	Residual	386.247	41	9.421			
	Total	625.380	49				
9	Regression	222.464	7	31.781	3.313	0.007(i)	0.248
	Residual	402.916	42	9.593			
	Total	625.380	49				
10	Regression	200.226	6	33.371	3.375	0.008(j)	0.225
	Residual	425.154	43	9.887			
	Total	625.380	49				
11	Regression	178.633	5	35.727	3.519	0.009(k)	0.204
	Residual	446.747	44	10.153			
	Total	625.380	49				
12	Regression	152.440	4	38.110	3.626	0.012(l)	0.177
	Residual	472.940	45	10.510			
	Total	625.380	49				

a Predictors: (Constant), HEIGHT, TOTRICH, SAPDEN, TREEVEN, SAPDIV, TRERICH, CCOVER, TREDEN, SAPEVEN, TOTBA , TREEBA, SAPRICH, TREEDIV, TOTDIV, DBH

b Predictors: (Constant), HEIGHT, TOTRICH, SAPDEN, SAPDIV, TRERICH, CCOVER, TREDEN, SAPEVEN, TOTBA , TREEBA, SAPRICH, TREEDIV, TOTDIV, DBH

c Predictors: (Constant), HEIGHT, TOTRICH, SAPDEN, SAPDIV, TRERICH, CCOVER, TREDEN, SAPEVEN, TOTBA , TREEBA, SAPRICH, TREEDIV, DBH

d Predictors: (Constant), HEIGHT, TOTRICH, SAPDEN, SAPDIV, CCOVER, TREDEN, SAPEVEN, TOTBA , TREEBA, SAPRICH, TREEDIV, DBH
e Predictors: (Constant), HEIGHT, TOTRICH, SAPDEN, SAPDIV, CCOVER, SAPEVEN, TOTBA , TREEBA, SAPRICH, TREEDIV, DBH
f Predictors: (Constant), HEIGHT, TOTRICH, SAPDEN, SAPDIV, CCOVER, TOTBA , TREEBA, SAPRICH, TREEDIV, DBH
g Predictors: (Constant), HEIGHT, TOTRICH, SAPDEN, CCOVER, TOTBA , TREEBA, SAPRICH, TREEDIV, DBH
h Predictors: (Constant), HEIGHT, TOTRICH, SAPDEN, CCOVER, TOTBA , TREEBA, TREEDIV, DBH
i Predictors: (Constant), HEIGHT, TOTRICH, SAPDEN, CCOVER, TOTBA , TREEBA, DBH
j Predictors: (Constant), HEIGHT, TOTRICH, SAPDEN, CCOVER, TREEBA, DBH
k Predictors: (Constant), HEIGHT, TOTRICH, SAPDEN, TREEBA, DBH
l Predictors: (Constant), HEIGHT, TOTRICH, SAPDEN, DBH

Appendix 5.2 Table of coefficients and collinearity statistics for linear models predicting avian species richness from vegetation variables.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		B	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-17.29	34.24		-0.51	0.62		
	TREEDIV	2.46	5.17	0.34	0.47	0.64	0.03	29.55
	TREEVEN	-0.91	9.63	-0.05	-0.09	0.93	0.07	14.08
	TOTRICH	-0.30	0.50	-0.50	-0.60	0.55	0.03	38.40
	TOTDIV	2.83	14.30	0.17	0.20	0.84	0.02	42.92
	SAPRICH	-0.67	1.09	-0.32	-0.62	0.54	0.07	14.79
	SAPEVEN	-3.05	6.35	-0.18	-0.48	0.63	0.13	7.87
	SAPDIV	3.00	5.39	0.36	0.56	0.58	0.04	23.25
	SAPDEN	0.06	0.04	0.39	1.79	0.08	0.37	2.68
	TOTBA	-0.02	0.01	-0.37	-1.28	0.21	0.22	4.63
	TRERICH	-0.17	0.50	-0.15	-0.33	0.74	0.09	11.03
	TREDEN	0.03	0.07	0.12	0.44	0.66	0.23	4.43
	CCOVER	0.05	0.03	0.30	1.46	0.15	0.42	2.38
	TREEBA	1.90	1.17	2.90	1.62	0.11	0.01	180.41
	DBH	-4.01	2.56	-10.87	-1.57	0.13	0.00	2695.07
	HEIGHT	9.42	5.95	8.42	1.58	0.12	0.00	1590.42
2	(Constant)	-17.87	33.20		-0.54	0.59		
	TREEDIV	2.00	1.93	0.28	1.04	0.31	0.24	4.22
	TOTRICH	-0.30	0.49	-0.50	-0.62	0.54	0.03	38.14
	TOTDIV	2.94	14.04	0.18	0.21	0.84	0.02	42.61
	SAPRICH	-0.65	1.04	-0.31	-0.62	0.54	0.07	14.00
	SAPEVEN	-3.05	6.26	-0.18	-0.49	0.63	0.13	7.87
	SAPDIV	2.93	5.26	0.35	0.56	0.58	0.04	22.78
	SAPDEN	0.06	0.03	0.38	1.89	0.07	0.42	2.39
	TOTBA	-0.02	0.01	-0.36	-1.31	0.20	0.23	4.44
	TRERICH	-0.13	0.34	-0.12	-0.39	0.70	0.19	5.40
	TREDEN	0.03	0.07	0.12	0.44	0.67	0.24	4.13
	CCOVER	0.05	0.03	0.30	1.48	0.15	0.42	2.37
	TREEBA	1.91	1.15	2.92	1.66	0.11	0.01	178.23
	DBH	-4.04	2.50	-10.95	-1.62	0.11	0.00	2652.29
	HEIGHT	9.48	5.83	8.47	1.63	0.11	0.00	1570.62
3	(Constant)	-11.70	15.03		-0.78	0.44		

	TREEDIV	2.00	1.90	0.28	1.05	0.30	0.24	4.22
	TOTRICH	-0.20	0.11	-0.34	-1.92	0.06	0.54	1.84
	SAPRICH	-0.57	0.95	-0.27	-0.60	0.55	0.08	11.88
	SAPEVEN	-2.45	5.48	-0.14	-0.45	0.66	0.16	6.19
	SAPDIV	2.46	4.71	0.29	0.52	0.60	0.05	18.77
	SAPDEN	0.06	0.03	0.37	1.93	0.06	0.45	2.24
	TOTBA	-0.02	0.01	-0.37	-1.36	0.18	0.23	4.37
	TRERICH	-0.12	0.33	-0.11	-0.36	0.72	0.19	5.21
	TREDEN	0.03	0.07	0.11	0.42	0.68	0.25	4.07
	CCOVER	0.05	0.03	0.30	1.49	0.14	0.42	2.37
	TREEBA	1.93	1.13	2.95	1.71	0.10	0.01	177.20
	DBH	-4.09	2.46	-11.08	-1.67	0.10	0.00	2631.42
	HEIGHT	9.61	5.72	8.59	1.68	0.10	0.00	1552.54
4	(Constant)	-12.95	14.44		-0.90	0.38		
	TREEDIV	1.54	1.40	0.22	1.10	0.28	0.43	2.35
	TOTRICH	-0.22	0.10	-0.36	-2.20	0.03	0.61	1.63
	SAPRICH	-0.56	0.94	-0.26	-0.60	0.55	0.08	11.87
	SAPEVEN	-2.38	5.41	-0.14	-0.44	0.66	0.16	6.19
	SAPDIV	2.41	4.65	0.29	0.52	0.61	0.05	18.75
	SAPDEN	0.06	0.03	0.37	1.94	0.06	0.45	2.24
	TOTBA	-0.02	0.01	-0.41	-1.64	0.11	0.27	3.75
	TREDEN	0.03	0.07	0.10	0.38	0.70	0.25	4.01
	CCOVER	0.05	0.03	0.30	1.50	0.14	0.42	2.37
	TREEBA	1.97	1.11	3.01	1.78	0.08	0.01	175.22
	DBH	-4.23	2.39	-11.47	-1.77	0.09	0.00	2560.06
	HEIGHT	10.03	5.53	8.96	1.81	0.08	0.00	1487.28
5	(Constant)	-12.99	14.28		-0.91	0.37		
	TREEDIV	1.77	1.26	0.25	1.41	0.17	0.52	1.93
	TOTRICH	-0.21	0.09	-0.35	-2.19	0.03	0.64	1.55
	SAPRICH	-0.58	0.92	-0.28	-0.63	0.53	0.08	11.82
	SAPEVEN	-2.98	5.12	-0.18	-0.58	0.56	0.18	5.67
	SAPDIV	2.74	4.52	0.33	0.61	0.55	0.06	18.12
	SAPDEN	0.06	0.03	0.37	1.94	0.06	0.45	2.22
	TOTBA	-0.02	0.01	-0.35	-1.72	0.09	0.38	2.63
	CCOVER	0.05	0.03	0.27	1.48	0.15	0.48	2.09
	TREEBA	2.03	1.09	3.11	1.87	0.07	0.01	171.41
	DBH	-4.39	2.33	-11.90	-1.89	0.07	0.00	2482.45
	HEIGHT	10.34	5.41	9.23	1.91	0.06	0.00	1457.09
6	(Constant)	-12.64	14.14		-0.89	0.38		
	TREEDIV	1.62	1.22	0.23	1.33	0.19	0.54	1.85
	TOTRICH	-0.22	0.09	-0.37	-2.43	0.02	0.69	1.46
	SAPRICH	-0.26	0.73	-0.12	-0.35	0.73	0.13	7.42
	SAPDIV	0.58	2.57	0.07	0.22	0.82	0.17	5.94
	SAPDEN	0.06	0.03	0.35	1.90	0.06	0.46	2.19
	TOTBA	-0.02	0.01	-0.35	-1.72	0.09	0.38	2.63
	CCOVER	0.05	0.03	0.28	1.56	0.13	0.48	2.07

	TREEBA	1.97	1.07	3.01	1.84	0.07	0.01	169.60
	DBH	-4.26	2.30	-11.53	-1.85	0.07	0.00	2456.35
	HEIGHT	10.00	5.33	8.93	1.87	0.07	0.00	1440.18
7	(Constant)	-13.48	13.48		-1.00	0.32		
	TREEDIV	1.61	1.20	0.23	1.34	0.19	0.54	1.85
	TOTRICH	-0.22	0.09	-0.36	-2.45	0.02	0.70	1.44
	SAPRICH	-0.12	0.36	-0.05	-0.32	0.75	0.53	1.90
	SAPDEN	0.05	0.03	0.34	2.04	0.05	0.57	1.75
	TOTBA	-0.02	0.01	-0.36	-1.88	0.07	0.41	2.43
	CCOVER	0.05	0.03	0.28	1.56	0.13	0.49	2.05
	TREEBA	2.03	1.02	3.10	1.98	0.05	0.01	159.13
	DBH	-4.39	2.19	-11.90	-2.01	0.05	0.00	2281.97
	HEIGHT	10.33	5.06	9.23	2.04	0.05	0.00	1327.60
8	(Constant)	-13.32	13.33		-1.00	0.32		
	TREEDIV	1.58	1.18	0.22	1.33	0.19	0.55	1.83
	TOTRICH	-0.23	0.08	-0.38	-2.82	0.01	0.82	1.22
	SAPDEN	0.05	0.02	0.31	2.23	0.03	0.79	1.27
	TOTBA	-0.02	0.01	-0.37	-1.93	0.06	0.41	2.41
	CCOVER	0.04	0.03	0.26	1.58	0.12	0.57	1.75
	TREEBA	2.04	1.01	3.11	2.01	0.05	0.01	159.05
	DBH	-4.39	2.16	-11.89	-2.03	0.05	0.00	2281.86
	HEIGHT	10.32	5.01	9.22	2.06	0.05	0.00	1327.54
9	(Constant)	-13.57	13.45		-1.01	0.32		
	TOTRICH	-0.19	0.08	-0.31	-2.48	0.02	0.96	1.05
	SAPDEN	0.04	0.02	0.24	1.86	0.07	0.90	1.11
	TOTBA	-0.01	0.01	-0.27	-1.52	0.14	0.49	2.05
	CCOVER	0.04	0.03	0.26	1.61	0.11	0.57	1.75
	TREEBA	1.91	1.02	2.92	1.88	0.07	0.01	157.72
	DBH	-4.43	2.18	-12.00	-2.03	0.05	0.00	2281.35
	HEIGHT	10.56	5.05	9.44	2.09	0.04	0.00	1325.75
10	(Constant)	-13.76	13.65		-1.01	0.32		
	TOTRICH	-0.19	0.08	-0.32	-2.51	0.02	0.96	1.04
	SAPDEN	0.05	0.02	0.29	2.25	0.03	0.95	1.05
	CCOVER	0.04	0.03	0.25	1.48	0.15	0.57	1.74
	TREEBA	1.79	1.03	2.73	1.74	0.09	0.01	156.70
	DBH	-4.38	2.22	-11.87	-1.98	0.05	0.00	2280.86
	HEIGHT	10.42	5.12	9.31	2.03	0.05	0.00	1325.29
11	(Constant)	-15.00	13.81		-1.09	0.28		
	TOTRICH	-0.18	0.08	-0.30	-2.30	0.03	0.98	1.02
	SAPDEN	0.04	0.02	0.26	2.00	0.05	0.98	1.02
	TREEBA	1.67	1.04	2.55	1.61	0.12	0.01	155.78
	DBH	-4.30	2.25	-11.65	-1.91	0.06	0.00	2279.40
	HEIGHT	10.52	5.19	9.40	2.03	0.05	0.00	1325.06
12	(Constant)	5.21	5.78		0.90	0.37		
	TOTRICH	-0.19	0.08	-0.32	-2.47	0.02	0.99	1.01
	SAPDEN	0.04	0.02	0.24	1.85	0.07	0.98	1.02

DBH	-0.76	0.44	-2.06	-1.73	0.09	0.01	84.69
HEIGHT	2.45	1.33	2.19	1.84	0.07	0.01	84.56

Appendix 5.3 Regression ANOVA results of various linear models for predicting avian guild richness from vegetation variables. For vegetation variable abbreviation see Appendix 5.1 above

Model	Source of variation	Sum of Squares	df	Mean Square	F- value	P	Adjusted R^2
1	Regression	78.877	15	5.258	1.958	0.052(a)	0.227
	Residual	91.303	34	2.685			
	Total	170.180	49				
2	Regression	78.877	14	5.634	2.160	0.033(b)	0.249
	Residual	91.303	35	2.609			
	Total	170.180	49				
3	Regression	78.843	13	6.065	2.390	0.020(c)	0.269
	Residual	91.337	36	2.537			
	Total	170.180	49				
4	Regression	78.824	12	6.569	2.660	0.011(d)	0.289
	Residual	91.356	37	2.469			
	Total	170.180	49				
5	Regression	77.353	11	7.032	2.879	0.008(e)	0.297
	Residual	92.827	38	2.443			
	Total	170.180	49				
6	Regression	75.783	10	7.578	3.131	0.005(f)	0.303
	Residual	94.397	39	2.420			
	Total	170.180	49				
7	Regression	71.913	9	7.990	3.253	0.005(g)	0.293
	Residual	98.267	40	2.457			
	Total	170.180	49				
8	Regression	67.461	8	8.433	3.366	0.005(h)	0.279
	Residual	102.719	41	2.505			
	Total	170.180	49				
9	Regression	60.836	7	8.691	3.338	0.006(i)	0.250
	Residual	109.344	42	2.603			
	Total	170.180	49				
10	Regression	57.923	6	9.654	3.698	0.005(j)	0.248
	Residual	112.257	43	2.611			
	Total	170.180	49				
11	Regression	53.015	5	10.603	3.982	0.005(k)	0.233
	Residual	117.165	44	2.663			
	Total	170.180	49				
12	Regression	47.854	4	11.963	4.401	0.004(l)	0.217
	Residual	122.326	45	2.718			
	Total	170.180	49				
13	Regression	41.987	3	13.996	5.022	0.004(m)	0.198

	Residual	128.193	46	2.787			
	Total	170.180	49				

a **Predictors**: (Constant), HEIGHT, TOTRICH, SAPDEN, TREEVEN, SAPDIV, TRERICH, CCOVER, TREDEN, SAPEVEN, TOTBA , TREEBA, SAPRICH, TREEDIV, TOTDIV, DBH
b **Predictors**: (Constant), HEIGHT, TOTRICH, SAPDEN, TREEVEN, SAPDIV, TRERICH, CCOVER, TREDEN, SAPEVEN, TREEBA, SAPRICH, TREEDIV, TOTDIV, DBH
c **Predictors:** (Constant), HEIGHT, TOTRICH, SAPDEN, TREEVEN, SAPDIV, TRERICH, CCOVER, SAPEVEN, TREEBA, SAPRICH, TREEDIV, TOTDIV, DBH
d **Predictors**: (Constant), HEIGHT, TOTRICH, SAPDEN, TREEVEN, SAPDIV, CCOVER, SAPEVEN, TREEBA, SAPRICH, TREEDIV, TOTDIV, DBH
e **Predictors**: (Constant), HEIGHT, TOTRICH, SAPDEN, TREEVEN, SAPDIV, CCOVER, SAPEVEN, TREEBA, TREEDIV, TOTDIV, DBH
f **Predictors**: (Constant), HEIGHT, TOTRICH, TREEVEN, SAPDIV, CCOVER, SAPEVEN, TREEBA, TREEDIV, TOTDIV, DBH
g **Predictors**: (Constant), TOTRICH, TREEVEN, SAPDIV, CCOVER, SAPEVEN, TREEBA, TREEDIV, TOTDIV, DBH
h **Predictors**: (Constant), TOTRICH, TREEVEN, SAPDIV, SAPEVEN, TREEBA, TREEDIV, TOTDIV, DBH
i **Predictors**: (Constant), TOTRICH, TREEVEN, SAPDIV, SAPEVEN, TREEBA, TREEDIV, DBH
j **Predictors**: (Constant), TOTRICH, TREEVEN, SAPDIV, TREEBA, TREEDIV, DBH
k **Predictors**: (Constant), TOTRICH, TREEVEN, SAPDIV, TREEDIV, DBH
l **Predictors:** (Constant), TOTRICH, TREEVEN, TREEDIV, DBH
m **Predictors**: (Constant), TREEVEN, TREEDIV, DBH

Appendix 5.4 Table of coefficients and collinearity statistics for linear models predicting avian guild richness from vegetation variables.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		Beta	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-22.98	16.83		-1.37	0.18		
	TREEDIV	-3.42	2.54	-0.92	-1.35	0.19	0.03	29.55
	TREEVEN	8.84	4.73	0.88	1.87	0.07	0.07	14.08
	TOTRICH	-0.46	0.24	-1.48	-1.90	0.07	0.03	38.40
	TOTDIV	11.11	7.03	1.30	1.58	0.12	0.02	42.92
	SAPRICH	-0.36	0.53	-0.33	-0.68	0.50	0.07	14.79
	SAPEVEN	-4.22	3.12	-0.48	-1.35	0.18	0.13	7.87
	SAPDIV	3.15	2.65	0.72	1.19	0.24	0.04	23.25
	SAPDEN	0.02	0.02	0.20	0.95	0.35	0.37	2.68
	TOTBA	0.00	0.01	0.00	0.00	1.00	0.22	4.63
	TRERICH	0.03	0.25	0.05	0.12	0.90	0.09	11.03
	TREDEN	0.00	0.04	-0.03	-0.10	0.92	0.23	4.43
	CCOVER	0.02	0.02	0.26	1.36	0.18	0.42	2.38
	TREEBA	0.94	0.58	2.75	1.63	0.11	0.01	180.41
	DBH	-1.68	1.26	-8.71	-1.34	0.19	0.00	2695.07
	HEIGHT	3.30	2.92	5.65	1.13	0.27	0.00	1590.42
2	(Constant)	-22.99	16.52		-1.39	0.17		
	TREEDIV	-3.42	2.49	-0.92	-1.37	0.18	0.03	29.25
	TREEVEN	8.85	4.57	0.88	1.94	0.06	0.07	13.52
	TOTRICH	-0.46	0.24	-1.48	-1.93	0.06	0.03	38.19
	TOTDIV	11.11	6.86	1.30	1.62	0.11	0.02	42.10
	SAPRICH	-0.36	0.52	-0.33	-0.70	0.49	0.07	14.35
	SAPEVEN	-4.23	3.03	-0.48	-1.40	0.17	0.13	7.62
	SAPDIV	3.15	2.56	0.72	1.23	0.23	0.04	22.27
	SAPDEN	0.02	0.02	0.20	0.97	0.34	0.38	2.66

	TRERICH	0.03	0.24	0.05	0.12	0.90	0.09	10.86
	TREDEN	0.00	0.03	-0.03	-0.11	0.91	0.29	3.47
	CCOVER	0.02	0.02	0.26	1.40	0.17	0.43	2.32
	TREEBA	0.94	0.57	2.75	1.66	0.11	0.01	179.22
	DBH	-1.68	1.24	-8.71	-1.36	0.18	0.00	2693.90
	HEIGHT	3.30	2.88	5.65	1.15	0.26	0.00	1585.48
3	(Constant)	-23.15	16.23		-1.43	0.16		
	TREEDIV	-3.39	2.44	-0.91	-1.39	0.17	0.03	28.78
	TREEVEN	8.75	4.42	0.87	1.98	0.06	0.08	13.01
	TOTRICH	-0.47	0.23	-1.49	-2.01	0.05	0.03	36.98
	TOTDIV	11.25	6.66	1.32	1.69	0.10	0.02	40.79
	SAPRICH	-0.37	0.51	-0.34	-0.74	0.47	0.07	14.04
	SAPEVEN	-4.19	2.96	-0.47	-1.41	0.17	0.13	7.50
	SAPDIV	3.16	2.52	0.72	1.25	0.22	0.04	22.25
	SAPDEN	0.02	0.02	0.20	1.05	0.30	0.40	2.50
	TRERICH	0.02	0.22	0.03	0.09	0.93	0.11	9.24
	CCOVER	0.02	0.02	0.27	1.52	0.14	0.47	2.11
	TREEBA	0.92	0.54	2.70	1.71	0.10	0.01	167.52
	DBH	-1.64	1.18	-8.52	-1.39	0.17	0.00	2507.24
	HEIGHT	3.21	2.75	5.51	1.17	0.25	0.00	1485.66
4	(Constant)	-22.95	15.85		-1.45	0.16		
	TREEDIV	-3.20	1.12	-0.86	-2.86	0.01	0.16	6.22
	TREEVEN	8.45	2.85	0.84	2.97	0.01	0.18	5.54
	TOTRICH	-0.47	0.23	-1.49	-2.04	0.05	0.03	36.82
	TOTDIV	11.24	6.57	1.32	1.71	0.10	0.02	40.78
	SAPRICH	-0.38	0.49	-0.34	-0.77	0.45	0.07	13.65
	SAPEVEN	-4.22	2.90	-0.48	-1.45	0.15	0.14	7.40
	SAPDIV	3.19	2.46	0.73	1.30	0.20	0.05	21.73
	SAPDEN	0.02	0.02	0.21	1.10	0.28	0.42	2.40
	CCOVER	0.02	0.02	0.27	1.54	0.13	0.48	2.10
	TREEBA	0.92	0.53	2.70	1.73	0.09	0.01	166.92
	DBH	-1.63	1.15	-8.46	-1.41	0.17	0.00	2468.41
	HEIGHT	3.18	2.68	5.45	1.19	0.24	0.00	1453.63
5	(Constant)	-19.98	15.29		-1.31	0.20		
	TREEDIV	-3.44	1.07	-0.92	-3.23	0.00	0.17	5.71
	TREEVEN	8.88	2.78	0.88	3.20	0.00	0.19	5.33
	TOTRICH	-0.41	0.22	-1.32	-1.90	0.06	0.03	33.57
	TOTDIV	9.55	6.16	1.12	1.55	0.13	0.03	36.27
	SAPEVEN	-2.72	2.15	-0.31	-1.26	0.21	0.24	4.12
	SAPDIV	1.48	1.04	0.34	1.42	0.16	0.25	3.95
	SAPDEN	0.01	0.01	0.12	0.80	0.43	0.64	1.56
	CCOVER	0.02	0.02	0.25	1.46	0.15	0.49	2.06
	TREEBA	0.96	0.53	2.81	1.82	0.08	0.01	165.44
	DBH	-1.72	1.14	-8.92	-1.51	0.14	0.00	2443.01
	HEIGHT	3.40	2.65	5.82	1.28	0.21	0.00	1437.64
6	(Constant)	-19.86	15.22		-1.30	0.20		

	TREEDIV	-3.74	1.00	-1.00	-3.75	0.00	0.20	5.04
	TREEVEN	9.29	2.72	0.93	3.42	0.00	0.19	5.15
	TOTRICH	-0.41	0.22	-1.32	-1.91	0.06	0.03	33.57
	TOTDIV	9.71	6.13	1.14	1.58	0.12	0.03	36.23
	SAPEVEN	-3.32	2.01	-0.37	-1.65	0.11	0.28	3.63
	SAPDIV	1.82	0.95	0.42	1.92	0.06	0.30	3.29
	CCOVER	0.02	0.01	0.22	1.31	0.20	0.52	1.94
	TREEBA	0.94	0.52	2.76	1.80	0.08	0.01	165.18
	DBH	-1.69	1.13	-8.76	-1.49	0.15	0.00	2439.97
	HEIGHT	3.34	2.64	5.72	1.26	0.21	0.00	1436.52
7	(Constant)	-11.64	13.87		-0.84	0.41		
	TREEDIV	-3.79	1.00	-1.02	-3.78	0.00	0.20	5.03
	TREEVEN	9.52	2.73	0.95	3.49	0.00	0.20	5.12
	TOTRICH	-0.43	0.22	-1.37	-1.98	0.06	0.03	33.46
	TOTDIV	9.84	6.17	1.15	1.59	0.12	0.03	36.22
	SAPEVEN	-2.78	1.98	-0.31	-1.40	0.17	0.29	3.47
	SAPDIV	1.72	0.95	0.39	1.81	0.08	0.31	3.27
	CCOVER	0.02	0.01	0.23	1.35	0.19	0.52	1.94
	TREEBA	0.31	0.16	0.91	1.97	0.06	0.07	14.87
	DBH	-0.26	0.10	-1.34	-2.61	0.01	0.06	18.16
8	(Constant)	-12.64	13.99		-0.90	0.37		
	TREEDIV	-3.56	1.00	-0.96	-3.56	0.00	0.20	4.89
	TREEVEN	9.14	2.74	0.91	3.33	0.00	0.20	5.07
	TOTRICH	-0.44	0.22	-1.41	-2.02	0.05	0.03	33.39
	TOTDIV	10.13	6.23	1.19	1.63	0.11	0.03	36.17
	SAPEVEN	-3.23	1.97	-0.36	-1.64	0.11	0.30	3.37
	SAPDIV	2.10	0.92	0.48	2.29	0.03	0.34	2.98
	TREEBA	0.26	0.16	0.76	1.68	0.10	0.07	14.00
	DBH	-0.20	0.09	-1.06	-2.24	0.03	0.07	15.27
9	(Constant)	9.94	1.69		5.88	0.00		
	TREEDIV	-3.11	0.98	-0.83	-3.18	0.00	0.22	4.50
	TREEVEN	8.19	2.73	0.82	3.00	0.00	0.21	4.84
	TOTRICH	-0.09	0.05	-0.30	-2.00	0.05	0.68	1.47
	SAPEVEN	-1.95	1.84	-0.22	-1.06	0.30	0.35	2.84
	SAPDIV	1.74	0.91	0.40	1.92	0.06	0.36	2.80
	TREEBA	0.23	0.16	0.66	1.44	0.16	0.07	13.73
	DBH	-0.17	0.09	-0.86	-1.85	0.07	0.07	14.27
10	(Constant)	9.66	1.67		5.77	0.00		
	TREEDIV	-3.07	0.98	-0.82	-3.14	0.00	0.22	4.50
	TREEVEN	7.71	2.70	0.77	2.86	0.01	0.21	4.71
	TOTRICH	-0.10	0.05	-0.32	-2.13	0.04	0.69	1.45
	SAPDIV	1.04	0.62	0.24	1.68	0.10	0.76	1.31
	TREEBA	0.21	0.16	0.63	1.37	0.18	0.07	13.67
	DBH	-0.16	0.09	-0.84	-1.79	0.08	0.07	14.22
11	(Constant)	8.90	1.59		5.58	0.00		
	TREEDIV	-2.92	0.98	-0.78	-2.97	0.00	0.23	4.44

	TREEVEN	6.46	2.57	0.64	2.52	0.02	0.24	4.17
	TOTRICH	-0.09	0.05	-0.28	-1.91	0.06	0.71	1.41
	SAPDIV	0.85	0.61	0.19	1.39	0.17	0.80	1.25
	DBH	-0.04	0.03	-0.22	-1.66	0.10	0.89	1.12
12	(Constant)	8.80	1.61		5.47	0.00		
	TREEDIV	-3.00	0.99	-0.80	-3.03	0.00	0.23	4.42
	TREEVEN	6.90	2.57	0.69	2.68	0.01	0.24	4.11
	TOTRICH	-0.06	0.04	-0.20	-1.47	0.15	0.84	1.19
	DBH	-0.04	0.03	-0.21	-1.60	0.12	0.89	1.12
13	(Constant)	6.96	1.02		6.80	0.00		
	TREEDIV	-3.55	0.93	-0.95	-3.82	0.00	0.26	3.79
	TREEVEN	7.91	2.51	0.79	3.15	0.00	0.26	3.82
	DBH	-0.04	0.03	-0.23	-1.73	0.09	0.90	1.11

Appendix 5.5 Regression ANOVA results of various linear models for predicting avian abundance from vegetation variables. For vegetation abbreviations see Appendix 5.1 above.

Model	Source of variation	Sum of Squares	df	Mean Square	F-value	P	Adjusted R^2
1	Regression	4054.647	15	270.310	1.034	0.447(a)	0.01
	Residual	8889.833	34	261.466			
	Total	12944.480	49				
2	Regression	4054.483	14	289.606	1.140	0.361(b)	0.039
	Residual	8889.997	35	254.000			
	Total	12944.480	49				
3	Regression	4022.716	13	309.440	1.249	0.288(c)	0.062
	Residual	8921.764	36	247.827			
	Total	12944.480	49				
4	Regression	3981.211	12	331.768	1.370	0.224(d)	0.083
	Residual	8963.269	37	242.251			
	Total	12944.480	49				
5	Regression	3926.708	11	356.973	1.504	0.170(e)	0.102
	Residual	9017.772	38	237.310			
	Total	12944.480	49				
6	Regression	3866.942	10	386.694	1.661	0.125(f)	0.119
	Residual	9077.538	39	232.757			
	Total	12944.480	49				
7	Regression	3717.569	9	413.063	1.791	0.100(g)	0.127
	Residual	9226.911	40	230.673			
	Total	12944.480	49				

8	Regression	3651.388	8	456.424	2.014	0.069(h)	0.142
	Residual	9293.092	41	226.661			
	Total	12944.480	49				
9	Regression	3640.271	7	520.039	2.347	0.041(i)	0.161
	Residual	9304.209	42	221.529			
	Total	12944.480	49				
10	Regression	3400.412	6	566.735	2.553	0.033(j)	0.160
	Residual	9544.068	43	221.955			
	Total	12944.480	49				
11	Regression	3331.334	5	666.267	3.050	0.019(k)	0.173
	Residual	9613.146	44	218.481			
	Total	12944.480	49				
12	Regression	3318.732	4	829.683	3.879	0.009(l)	0.190
	Residual	9625.748	45	213.906			
	Total	12944.480	49				

a **Predictors**: (Constant), HEIGHT, TOTRICH, SAPDEN, TREEVEN, SAPDIV, TRERICH, CCOVER, TREDEN, SAPEVEN, TOTBA , TREEBA, SAPRICH, TREEDIV, TOTDIV, DBH

b **Predictors**: (Constant), HEIGHT, TOTRICH, SAPDEN, TREEVEN, SAPDIV, TRERICH, TREDEN, SAPEVEN, TOTBA , TREEBA, SAPRICH, TREEDIV, TOTDIV, DBH

c **Predictors**: (Constant), HEIGHT, TOTRICH, SAPDEN, TREEVEN, SAPDIV, TRERICH, SAPEVEN, TOTBA , TREEBA, SAPRICH, TREEDIV, TOTDIV, DBH

d **Predictors**: (Constant), HEIGHT, TOTRICH, SAPDEN, TREEVEN, SAPDIV, TRERICH, SAPEVEN, TOTBA , TREEBA, SAPRICH, TREEDIV, DBH

e **Predictors**: (Constant), HEIGHT, TOTRICH, SAPDEN, SAPDIV, TRERICH, SAPEVEN, TOTBA , TREEBA, SAPRICH, TREEDIV, DBH

f **Predictors**: (Constant), HEIGHT, TOTRICH, SAPDEN, SAPDIV, TRERICH, SAPEVEN, TREEBA, SAPRICH, TREEDIV, DBH

g **Predictors**: (Constant), HEIGHT, TOTRICH, SAPDEN, SAPDIV, TRERICH, TREEBA, SAPRICH, TREEDIV, DBH

h **Predictors**: (Constant), HEIGHT, TOTRICH, SAPDEN, TRERICH, TREEBA, SAPRICH, TREEDIV, DBH

i **Predictors**: (Constant), HEIGHT, TOTRICH, SAPDEN, TRERICH, TREEBA, TREEDIV, DBH

j **Predictors**: (Constant), TOTRICH, SAPDEN, TRERICH, TREEBA, TREEDIV, DBH

k **Predictors:** (Constant), TOTRICH, SAPDEN, TRERICH, TREEBA, TREEDIV

l **Predictors**: (Constant), TOTRICH, SAPDEN, TRERICH, TREEDIV

Appendix 5.6 Table of coefficients and collinearity statistics for linear models predicting avian abundance from vegetation variables.

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.	Collinearity Statistics	
		Beta	Std. Error	Beta			Tolerance	VIF
1	(Constant)	-69.34	166.05		-0.42	0.68		
	TREEDIV	25.99	25.10	0.80	1.04	0.31	0.03	29.55
	TREEVEN	-22.82	46.70	-0.26	-0.49	0.63	0.07	14.08
	TOTRICH	-1.76	2.40	-0.65	-0.73	0.47	0.03	38.40
	TOTDIV	29.58	69.34	0.40	0.43	0.67	0.02	42.92
	SAPRICH	-5.13	5.27	-0.53	-0.97	0.34	0.07	14.79
	SAPEVEN	-25.07	30.79	-0.32	-0.81	0.42	0.13	7.87
	SAPDIV	25.43	26.14	0.67	0.97	0.34	0.04	23.25
	SAPDEN	0.28	0.17	0.38	1.64	0.11	0.37	2.68
	TOTBA	-0.04	0.07	-0.16	-0.53	0.60	0.22	4.63
	TRERICH	-2.85	2.42	-0.56	-1.18	0.25	0.09	11.03
	TREDEN	0.12	0.36	0.10	0.34	0.74	0.23	4.43
	CCOVER	0.00	0.17	0.01	0.03	0.98	0.42	2.38
	TREEBA	5.37	5.69	1.80	0.95	0.35	0.01	180.41
	DBH	-10.06	12.39	-5.99	-0.81	0.42	0.00	2695.07
	HEIGHT	22.83	28.86	4.48	0.79	0.43	0.00	1590.42
2	(Constant)	-69.34	163.66		-0.42	0.67		
	TREEDIV	26.00	24.73	0.80	1.05	0.30	0.03	29.54
	TREEVEN	-22.80	46.02	-0.26	-0.50	0.62	0.07	14.08
	TOTRICH	-1.76	2.36	-0.64	-0.74	0.46	0.03	38.31
	TOTDIV	29.52	68.29	0.40	0.43	0.67	0.02	42.86
	SAPRICH	-5.11	5.15	-0.53	-0.99	0.33	0.07	14.55
	SAPEVEN	-25.18	30.00	-0.33	-0.84	0.41	0.13	7.69
	SAPDIV	25.47	25.72	0.67	0.99	0.33	0.04	23.15
	SAPDEN	0.28	0.16	0.38	1.74	0.09	0.41	2.45
	TOTBA	-0.04	0.07	-0.16	-0.54	0.60	0.22	4.51
	TRERICH	-2.85	2.38	-0.56	-1.20	0.24	0.09	11.02
	TREDEN	0.12	0.33	0.10	0.35	0.73	0.25	3.93
	TREEBA	5.38	5.60	1.81	0.96	0.34	0.01	180.24
	DBH	-10.09	12.18	-6.01	-0.83	0.41	0.00	2680.37
	HEIGHT	22.90	28.32	4.50	0.81	0.42	0.00	1576.17
3	(Constant)	-67.05	161.54		-0.42	0.68		
	TREEDIV	24.46	24.04	0.75	1.02	0.32	0.03	28.62
	TREEVEN	-18.38	43.76	-0.21	-0.42	0.68	0.08	13.04
	TOTRICH	-1.66	2.32	-0.61	-0.72	0.48	0.03	37.82
	TOTDIV	27.51	67.23	0.37	0.41	0.68	0.02	42.57
	SAPRICH	-5.10	5.09	-0.53	-1.00	0.32	0.07	14.55
	SAPEVEN	-26.76	29.30	-0.35	-0.91	0.37	0.13	7.52
	SAPDIV	25.93	25.37	0.68	1.02	0.31	0.04	23.09
	SAPDEN	0.27	0.16	0.37	1.73	0.09	0.41	2.43

	TOTBA	-0.03	0.06	-0.11	-0.43	0.67	0.28	3.62
	TRERICH	-2.61	2.25	-0.51	-1.16	0.25	0.10	10.11
	TREEBA	5.75	5.43	1.93	1.06	0.30	0.01	173.84
	DBH	-11.00	11.76	-6.55	-0.94	0.36	0.00	2560.83
	HEIGHT	24.65	27.54	4.84	0.90	0.38	0.00	1527.98
4	(Constant)	-8.40	73.68		-0.11	0.91		
	TREEDIV	25.30	23.68	0.78	1.07	0.29	0.04	28.40
	TREEVEN	-20.39	42.99	-0.23	-0.47	0.64	0.08	12.87
	TOTRICH	-0.73	0.50	-0.27	-1.47	0.15	0.56	1.80
	SAPRICH	-4.35	4.70	-0.45	-0.93	0.36	0.08	12.70
	SAPEVEN	-20.88	25.24	-0.27	-0.83	0.41	0.18	5.71
	SAPDIV	21.66	22.86	0.57	0.95	0.35	0.05	19.18
	SAPDEN	0.26	0.15	0.35	1.70	0.10	0.43	2.33
	TOTBA	-0.03	0.06	-0.13	-0.53	0.60	0.29	3.47
	TRERICH	-2.56	2.23	-0.50	-1.15	0.26	0.10	10.08
	TREEBA	5.86	5.37	1.97	1.09	0.28	0.01	173.41
	DBH	-11.28	11.61	-6.71	-0.97	0.34	0.00	2552.04
	HEIGHT	25.56	27.14	5.02	0.94	0.35	0.00	1518.00
5	(Constant)	-15.89	71.23		-0.22	0.82		
	TREEDIV	14.89	8.78	0.46	1.70	0.10	0.25	3.99
	TOTRICH	-0.75	0.49	-0.27	-1.51	0.14	0.56	1.79
	SAPRICH	-3.69	4.44	-0.38	-0.83	0.41	0.09	11.56
	SAPEVEN	-19.53	24.82	-0.25	-0.79	0.44	0.18	5.63
	SAPDIV	19.15	22.01	0.50	0.87	0.39	0.06	18.15
	SAPDEN	0.23	0.14	0.32	1.66	0.11	0.49	2.03
	TOTBA	-0.03	0.06	-0.13	-0.50	0.62	0.29	3.45
	TRERICH	-1.82	1.57	-0.36	-1.16	0.25	0.19	5.13
	TREEBA	6.04	5.30	2.03	1.14	0.26	0.01	172.61
	DBH	-11.71	11.45	-6.97	-1.02	0.31	0.00	2536.08
	HEIGHT	26.54	26.78	5.21	0.99	0.33	0.00	1509.21
6	(Constant)	-10.07	69.60		-0.14	0.89		
	TREEDIV	15.49	8.62	0.48	1.80	0.08	0.26	3.92
	TOTRICH	-0.69	0.47	-0.25	-1.44	0.16	0.59	1.69
	SAPRICH	-4.11	4.31	-0.43	-0.95	0.35	0.09	11.13
	SAPEVEN	-19.69	24.58	-0.25	-0.80	0.43	0.18	5.63
	SAPDIV	20.75	21.57	0.54	0.96	0.34	0.06	17.77
	SAPDEN	0.25	0.14	0.34	1.80	0.08	0.51	1.96
	TRERICH	-2.21	1.36	-0.43	-1.63	0.11	0.26	3.91
	TREEBA	5.52	5.15	1.85	1.07	0.29	0.01	166.15
	DBH	-10.90	11.23	-6.49	-0.97	0.34	0.00	2484.87
	HEIGHT	24.35	26.17	4.78	0.93	0.36	0.00	1469.17
7	(Constant)	-8.96	69.28		-0.13	0.90		
	TREEDIV	14.14	8.41	0.44	1.68	0.10	0.27	3.77
	TOTRICH	-0.78	0.46	-0.29	-1.72	0.09	0.64	1.57
	SAPRICH	-1.88	3.28	-0.20	-0.57	0.57	0.15	6.49
	SAPDIV	6.43	12.01	0.17	0.54	0.60	0.18	5.56

	SAPDEN	0.23	0.14	0.32	1.71	0.10	0.52	1.92
	TRERICH	-2.13	1.35	-0.42	-1.58	0.12	0.26	3.89
	TREEBA	5.09	5.10	1.71	1.00	0.32	0.01	164.36
	DBH	-10.06	11.13	-5.99	-0.90	0.37	0.00	2463.18
	HEIGHT	22.43	25.94	4.40	0.86	0.39	0.00	1456.79
8	(Constant)	-17.12	66.99		-0.26	0.80		
	TREEDIV	14.29	8.34	0.44	1.71	0.09	0.27	3.76
	TOTRICH	-0.74	0.44	-0.27	-1.66	0.11	0.66	1.51
	SAPRICH	-0.36	1.62	-0.04	-0.22	0.83	0.62	1.61
	SAPDEN	0.20	0.12	0.27	1.65	0.11	0.63	1.58
	TRERICH	-2.24	1.32	-0.44	-1.69	0.10	0.26	3.80
	TREEBA	5.68	4.93	1.91	1.15	0.26	0.01	156.76
	DBH	-11.48	10.71	-6.83	-1.07	0.29	0.00	2323.27
	HEIGHT	25.79	24.96	5.06	1.03	0.31	0.00	1371.63
9	(Constant)	-16.10	66.07		-0.24	0.81		
	TREEDIV	14.19	8.23	0.44	1.72	0.09	0.27	3.75
	TOTRICH	-0.77	0.41	-0.28	-1.88	0.07	0.76	1.32
	SAPDEN	0.19	0.11	0.26	1.76	0.08	0.81	1.24
	TRERICH	-2.25	1.30	-0.44	-1.73	0.09	0.26	3.78
	TREEBA	5.72	4.87	1.92	1.17	0.25	0.01	156.51
	DBH	-11.46	10.59	-6.83	-1.08	0.29	0.00	2323.20
	HEIGHT	25.67	24.67	5.04	1.04	0.30	0.00	1370.96
10	(Constant)	50.79	15.32		3.31	0.00		
	TREEDIV	15.59	8.13	0.48	1.92	0.06	0.27	3.65
	TOTRICH	-0.81	0.41	-0.30	-1.97	0.06	0.76	1.31
	SAPDEN	0.18	0.11	0.25	1.69	0.10	0.81	1.24
	TRERICH	-2.50	1.28	-0.49	-1.94	0.06	0.27	3.66
	TREEBA	0.89	1.48	0.30	0.60	0.55	0.07	14.40
	DBH	-0.48	0.86	-0.29	-0.56	0.58	0.07	15.35
11	(Constant)	46.28	12.92		3.58	0.00		
	TREEDIV	12.94	6.55	0.40	1.98	0.05	0.41	2.41
	TOTRICH	-0.81	0.41	-0.30	-2.00	0.05	0.76	1.31
	SAPDEN	0.17	0.11	0.24	1.66	0.10	0.82	1.22
	TRERICH	-2.12	1.09	-0.41	-1.95	0.06	0.37	2.68
	TREEBA	0.10	0.40	0.03	0.24	0.81	0.92	1.08
12	(Constant)	46.85	12.56		3.73	0.00		
	TREEDIV	12.99	6.48	0.40	2.00	0.05	0.42	2.41
	TOTRICH	-0.80	0.40	-0.29	-2.01	0.05	0.78	1.29
	SAPDEN	0.18	0.10	0.24	1.68	0.10	0.82	1.22
	TRERICH	-2.18	1.05	-0.43	-2.07	0.04	0.39	2.56

Appendix 5.7 Correlation between avian species occurrence and correspondence analysis dimensions of woodland status. The values indicate Pearson's correlation coefficients.

	Species	Dimension 1	Dimension 2	Dimension 3	Total
1	Scaly-throated Honeyguide	0.996	0.004	0.000	1.000
2	Yellow White-eye	0.996	0.004	0.000	1.000
3	Olive thrush	0.991	0.006	0.004	1.000
4	Bennett's Woodpecker	0.963	0.034	0.003	1.000
5	Fork-tailed Drongo	0.947	0.009	0.044	1.000
6	Trilling Cisticola	0.884	0.092	0.024	1.000
7	Pennant-winged Nightjar	0.884	0.092	0.024	1.000
8	Red-headed Quelea	0.884	0.092	0.024	1.000
9	Black-collared Eremomela	0.884	0.092	0.024	1.000
10	Paradise Flycatcher	0.854	0.004	0.142	1.000
11	Swallow-tailed Bee-eater	0.695	0.263	0.041	1.000
12	Long-tailed Paradise	0.689	0.049	0.263	1.000
13	Black-crowned Tchagra	0.604	0.145	0.251	1.000
14	Rattling Cisticola	0.564	0.216	0.220	1.000
15	Lesser Honeyguide	0.534	0.006	0.460	1.000
16	Pale-billed Hornbill	0.534	0.006	0.460	1.000
17	Souza's Shrike	0.534	0.006	0.460	1.000
18	Fawn-breasted Waxbill	0.534	0.006	0.460	1.000
19	Yellow-bellied Sunbird	0.534	0.006	0.460	1.000
20	Lesser Grey Shrike	0.534	0.006	0.460	1.000
21	African Grey Cuckoo	0.38	0.529	0.091	1.000
22	Mozambique Nightjar	0.311	0.675	0.014	1.000
23	Common Bulbul	0.309	0.001	0.69	1.000
24	Scarlet-chested Sunbird	0.289	0.7	0.011	1.000
25	Tropical Boubou	0.279	0.22	0.501	1.000
26	Southern Puffback	0.279	0.22	0.501	1.000
27	Miombo Pied Barbet	0.193	0.027	0.780	1.000
28	Böhm's Flycatcher	0.152	0.618	0.230	1.000
29	Green-capped Eremomela	0.126	0.802	0.072	1.000
30	Emerald-spotted Wood Dove	0.121	0.874	0.005	1.000
31	Red-eyed Dove	0.116	0.83	0.054	1.000
32	Long-billed Crombec	0.113	0.551	0.335	1.000
33	Black-headed Oriole	0.103	0.296	0.601	1.000
34	Neddicky	0.094	0.267	0.640	1.000
35	Black-collared Barbet	0.094	0.783	0.123	1.000

36	Yellow-breasted Apalis	0.091	0.174	0.734	1.000
37	Black (Yellow-billed) Kite	0.091	0.174	0.734	1.000
38	Red-capped Crombec	0.091	0.174	0.734	1.000
39	Dark Chanting Goshawk	0.091	0.174	0.734	1.000
40	Yellow-breasted Hyliota	0.091	0.174	0.734	1.000
41	Brubru	0.091	0.174	0.734	1.000
42	Miombo Rock Thrush	0.079	0.576	0.345	1.000
43	Southern Black Tit	0.074	0.592	0.333	1.000
44	White-breasted Cuckoo-shrike	0.071	0.911	0.018	1.000
45	White Helmet Shrike	0.063	0.936	0.001	1.000
46	Red and Blue Sunbird	0.056	0.511	0.433	1.000
47	Fiery-necked Nightjar	0.042	0.711	0.247	1.000
48	Shelley's Sunbird	0.036	0.046	0.918	1.000
49	Fiscal Shrike	0.026	0.448	0.526	1.000
50	Tawny-flanked Prinia	0.024	0.619	0.357	1.000
51	Cape Turtle Dove	0.02	0.911	0.069	1.000
52	Yellow-fronted Tinkerbird	0.009	0.98	0.011	1.000
53	Miombo Double-collared Sunbird	0.003	0.205	0.792	1.000
54	Greater Honeyguide	0.003	0.137	0.859	1.000
55	Central Bearded Scrub Robin	0.002	0.143	0.855	1.000
56	Spotted Creeper	0.000	0.842	0.158	1.000

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