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AN ECOLOGICAL STUDY OF BENOUE NATIONAL PARK, CAMEROON

by

© Malcolm A. Stark

A THESIS

SUBMITTED TO THE FACULTY OF GRADUATE STUDIES AND RESEARCH

IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE

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Kenneth O. Higginbotham

Date ....

To my mom, dad and Sammy,

ABSTRACT

An ecological study was conducted from April 1974 to July 1975 in Benoue National Park, Cameroon, West Africa. The major objectives of the study were to delineate the major plant communities, examine some of the effects of annual burning, evaluate the numbers and distribution patterns of the large herbivores, and describe habitat-use relationships within an insular large herbivore community.

Vegetation was classified into five major communities based on dominant species and structure: namely, *Isoberlinia* woodland, *Anogeissus* riparian forest, *Terminalia laxiflora* open savanna, *T. macroptera* open savanna and *Burkea-Detarium* open savanna. Tufted perennials of *Andropogon* spp., *Hyparrhenia* spp. and *Loudetia* spp. dominated the grass layer.

Benoue National Park is burned annually during the early dry season. This is a critical time of the year, for although fire plays an important role for grazers in encouraging new, nutritious growth of perennial grasses, there are detrimental effects on the woody species, *Afzelia africana*. *Afzelia africana* is a common, somewhat fire-tolerant species, but under annual burning, *Afzelia* woodland is dying and being invaded by *Monotes kerstingii*. Basal scarring is severe and chronic on the majority of *Afzelia africana*. Four hundred and eighty-nine *Afzelia* trees in 5 different stands were randomly selected and measured. Twenty-two *Afzelia* trees were aged. Direction of basal scars revealed historic and present-day annual fire spread in Benoue National Park and aging revealed 2 distinct fire histories. Annual burning appears to be the cause of the decline of Afzelia woodland due to repeated scorching of cambial cells which do not allow time for basal scars to heal.

The most common large herbivores in the park are Buffon's kob (Kobus kobus), defassa waterbuck (Kobus defassa), western hartebeest (Alcelaphus buselaphus), roan antelope (Hippotragus equinus) and savanna buffalo (Syncerus caffer brachyceros). Standardized roadside counts and foot transects were established to determine the numbers and biomass of the five large herbivores, to determine their geographical distributions within Benoue National Park and to determine use of the five major plant communities and habitat overlap during the dry and wet seasons. Benoue National Park appears to be below its estimated carrying capacity, probably because of poaching. Distributions of large herbivores lay on an east-west gradient in relation to the perennially flowing Benoue River. Highest animal concentrations throughout the year were found within 10 km of Benoue River. Habitat overlap among all five large herbivores occurred more during the dry season than wet season.

Results of the study are focused in a preliminary management plan. The three most important and immediate concerns for Benoue National Park are fire control, especially in Afzelia africana woodland, poaching and

hunting pressure. Tourism and park extension are of less immediate concern but are also addressed.

ACKNOWLEDGEMENTS

Appreciation is extended to many people since initiation of the study in Benoue National Park. I thank Monsieur P. Lima, head of "Les Eaux et Forests" and especially Dr. J. Esser who not only aided in data collection during 1977 but who along with his wife, extended sincere friendship during my stay in Cameroon from 1973-1975.

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Table of Contents

LIST OF TABLES

LIST OF FIGURES

Figure Page

CHAPTER I

INTRODUCTION

Benoue National Park, Cameroon, is one of several little-known protected areas in savanna West Africa. The park is an island of protected habitat encircled by hunting zones. It's area of 180,000 ha is small in relation to the total of 2,000,000 ha under protection in Cameroon, and in comparison with many protected areas in Africa. With only 11 large mammalian species, faunal diversity is correspondingly low (Table 1.1) (also lower than one would expect on the basis of area).

From April 1974 to July 1975, I conducted an ecological study in Benoue National Park. The study, jointly sponsored by the United Nations Development Program (UNDP) and the Food and Agriculture Organization (FAO), provided a unique and challenging opportunity to examine habitat and wildlife in a representative savanna ecosystem in West Africa.

The term "savanna" was probably first used in Central America where it denoted scrublands, marshes or any other areas not covered with forests but consisting mainly of grassy plains (Richards 1952). However, its interpretation has been broad. Beard (1953) defined savanna as "communities comprising a virtually continuous, ecologically dominant stratum of more or less xeromorphic herbaceous plants, of which grasses and sedges are the principal components and with scattered shrubs, trees and

Table 1.1 Size and faunal richness of some protected areas in East Africa compared with Benoue National Park (Soule et al. 1979).

Protected Area	Area (km^2)	Number of large mammal species
Tsavo NP, Kenya	20808	63
Serengeti NP, Tanzania	14504	70
Ruaha NP, Tanzania	12950	49
Ngorongoro CA, Tanzania	6475	40
Murchison Falls NP, Uganda	4040	42
Amboseli GR, Kenya	3261	56
Marsabit NP, Kenya	2072	46
Queen Elizabeth NP, Uganda	1986	48
Masai Mara GR, Kenya	1813	66
Kidepo Valley NP, Uganda	1259	44
Mikumi NP, Tanzania	1165	34
Meru GR, Kenya	1021	58
Aberdares NP, Kenya	590	43
Mt. Kenya NP, Kenya	588	31
Lake Manyara NP, Tanzania	319	42
Samburu-Isiolo GR, Kenya	298	56
Nairobi NP, Kenya	114	56
Ngurdoto Crater NP, Tanzania	54	38
Benoue NP, Cameroon	1800	11

palms sometimes present". Kimble (1960) described savanna as a vegetation type comprised of grasses, shrubs and trees adapted to conditions of alternating wetness and dryness. Hill (1965) added that vegetation formations such as gallery (riparian) forest and forest mosaics are likely to be present.

Savanna in West Africa, first described by Chevalier (1900, 1934), encompasses approximately 4,950,000 km^2 (Pugh and Perry 1960), including parts of Senegal, Mali, Mauritania, Upper Volta, Ivory Coast, Togo, Ghana, Niger, Benin (Dahomey), Nigeria, Chad and the United Republic of Cameroon. Despite this magnitude, ecological studies of savanna ecosystems in West Africa have been largely overlooked in preference for studies in East Africa.

The ecological study in Benoue National Park was the first of its kind. Identifying, classifying, recording and cataloguing the park's resources, flora and fauna were therefore necessary. For reasons beyond anyone's control, research was usually carried out alone and much of the work had to be opportunist and part-time; funds for research were very limited. For this reason there are gaps in the pattern that emerges and the quality of the data collected is variable. Inferences have been made about the management of Benoue National Park from the results of short-term studies. Clearly, a continuous monitoring system for Benoue National Park is desirable and it is hoped that others will build on this study's findings.

Over the 16 month study, data were collected on the history, climate, topography and geology, soils, drainage and water resources, vegetation, fire and wildlife. This thesis synthesizes that data.

Specifically, the objectives of the study were:

1. to delineate the major plant communities;
2. to examine some of the effects of annual burning;
3. to evaluate the numbers and distribution patterns of the large herbivores;
4. to describe habitat-use relationships within an insular, large herbivore community.

This thesis has the following organization: Chapter II presents a brief description of the study area, its history, climate, topography and geology, drainage and water resources, soils, vegetation and wildlife. Chapter III provides an objective phytosociological delineation of the major plant communities. Chapter IV reviews the fire history of Benoue National Park and effects of annual burning on ground cover and *Afzelia africana* woodland. The numbers, distribution patterns and habitat preferences of the larger herbivores are presented in Chapter V. Chapter VI examines the role of Benoue National Park as a protected area in Africa and concludes the thesis with a preliminary management plan.

CHAPTER II

STUDY AREA

Benoue National Park (lat. 7°55' - 8°40'N; long. 13°4' - 14°1'E) attained national park status in 1964. It was first established on November 19, 1932 as a forest reserve. Buffle Noir hunting camp had been established 5 years earlier. Situated on the Benoue plains at the foot of the Adamaoua Plateau in north-central Cameroon, the park lies completely within the Northern Guinea Savanna Zone. The eastern boundary of the park follows the Benoue River while a tarmac road delineates the greatest part of the western park boundary. The northern and southern boundaries are demarcated by the Laindeaol and Sala Rivers, respectively (Fig. 2.1).

2.1 History

It is likely that man occupied what is now Benoue National Park for a considerable length of time. From Letouzey's account (1948), it is apparent that what is vacant today, was "fairly heavily populated" during the late 1800's and early 1900's. Archeological and ecological evidences uncovered during the study supported this view. Old village sites and grinding stones were often discovered. The distribution of Adansonia digitata and Piliostigma thonningii trees, both of which have edible pods, confirm human habitation. A few old village sites are demarcated by the sausage tree (Kigelia

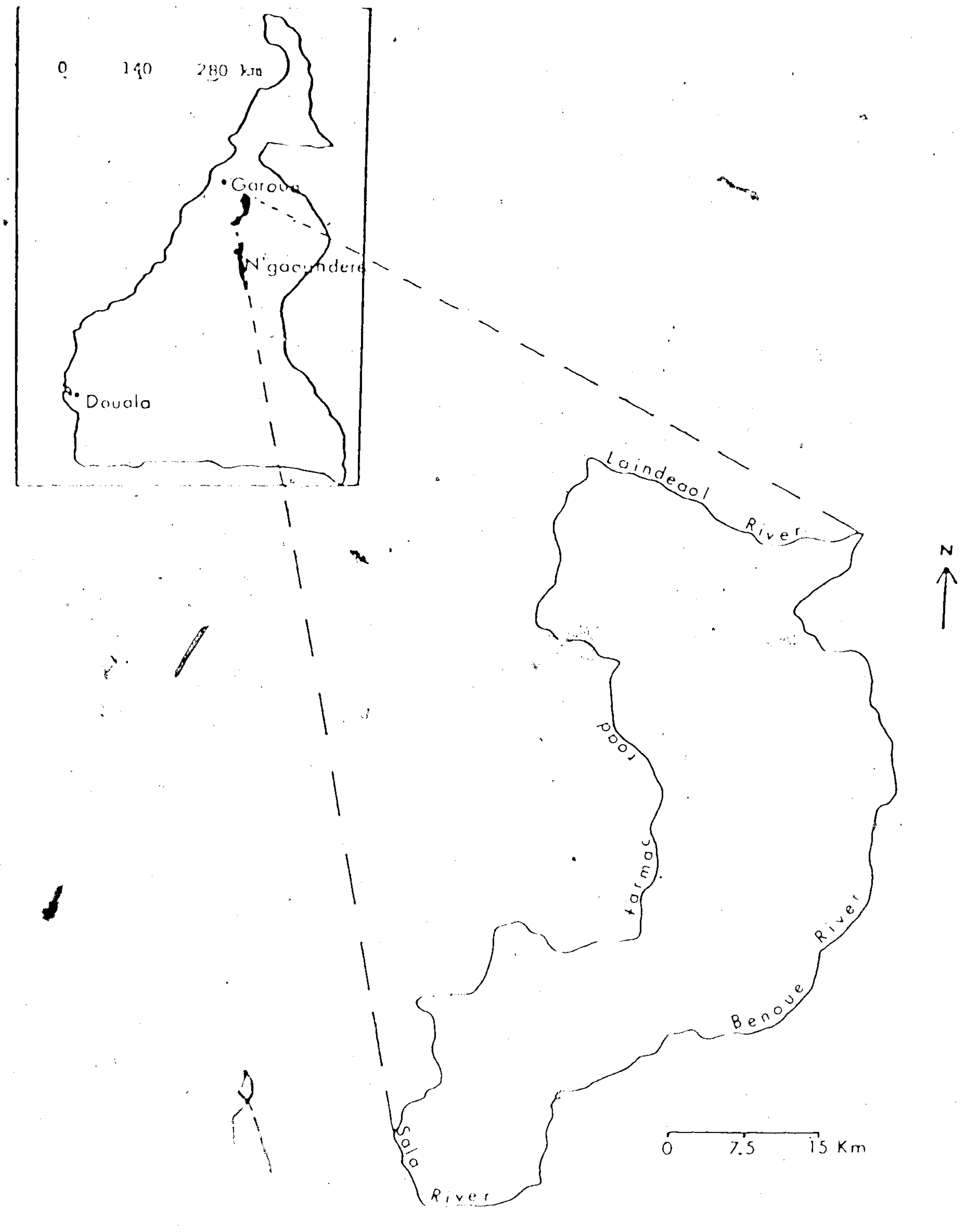


Fig. 2.1 Benoue National Park - Its position and size in relation to the United Republic of Cameroon.

aethiopica) whose fruit is also edible. Numerous pottery shards are common at such sites and portions of old boukaroo (mud hut) walls still stand.

2.2 Climate

Climate is of considerable ecological importance. Benoue National Park has two seasons characteristic of a tropical climate: a long, well-marked dry season from late November/early December to mid-May, and a wet season from late May to mid-November. The peak dry (April) and wet (August) months coincide with the passage of the tropical air masses. During May the first storms appear. Rains are light and intermittent but winds are violent and atmospheric electricity is high. The majority of thunderstorms, averaging 100 per year, commonly occurs during August and September (L'Institut de Recherches Scientifiques du Cameroun 1971).

Unfortunately, there are no meteorological stations in the park, largely because there is little surrounding human settlement. Therefore, temperature, humidity and rainfall were extrapolated from stations outside the park, namely N'gaoundere and Garoua. At N'gaoundere, 160 km south of Benoue National Park, the annual mean (averaged over a 12 year period) maximum temperature is 28.6°C and at Garoua, 200 km north, the mean maximum (averaged over a 15 year period) is 34.7°C (Letouzey 1968). Mean minimum temperatures are 15.7°C and 21.3°C for N'gaoundere and Garoua respectively (Letouzey 1968). The mean minimum and maximum temperatures for Benoue National Park should be similar to the values recorded in the two cities.

Humidity is generally low. For N'gaoundere, the monthly mean relative humidity is 67% (range 60-73%) and for Garoua the mean is 58% (range 49-67%). Accordingly, humidity for Benoue National Park should be similar to the values recorded in the two cities.

Rainfall is of most interest, largely through its effect on the length of the growing season. Average rainfall (averaged over a 31 year period) at N'gaoundere is 1,582 mm and is 985 mm at Garoua (Letouzey 1968).

2.3 Topography and Geology

Benoue National Park ranges from 300-1000 m in altitude. The land rises gently south-east from the southern regions of the park and then falls fairly steeply to the lower flood-plain around Laindeaol River in the north and from there to the Niger-Gulf of Guinea watershed.

Three-quarters of the park is underlain by a Basement Complex of late Pre-Cambian metamorphic rock, most of which is granitic and forms the central massif of northern Cameroon. Gneiss overlays most of the park, except the north-west region which is covered by grey and red sandstone laid down during the Cretaceous period (Brabant and Humbel 1974). Early intrusions of porphyritic granite (Gazel 1956) exist in the north-central region of the park. Here, mountains attain heights up to 1000 m. These highlands have withstood the levelling influences of weathering and erosion and represent small, relatively elevated relics of ancient landforms. They do not form part of a mountain chain and therefore do not form a barrier-like feature. More recent intrusions (some mere surface exposures, others heaps of boulders up to 40 m high) are found scattered in the southern part of the park. These are composed mainly of basalt (Brabant and Humbel 1974). The entire park is dotted with isolated steep-sided hills.

2.4 Soils

Soils of Benoue National Park are classified as ferruginous tropical (Bridges 1970, Brabant and Humbel 1974). These soils are found where there is a pronounced dry season and in previous classifications, these soils were called red earths or red latosols. In Benoue National Park, these soils can be broken down into soil subtypes based on underlying parent rock (Fig. 2.2). For the most part, the soils are derived from granite, gneiss and acid schist. The pH is generally slightly acidic but becomes more basic with depth (Nye and Bartheux 1957). The clay fraction is predominantly kaolinitic, often with small amounts of illite (Kowal and Kassam 1978). Surface horizon clay content is variable (0-25%) depending on parent material. Cation exchange capacities are low (1-10 ME/100 gm soil) (Kowal and Kassam 1978).

Free drainage occurs in the upper horizons and as a

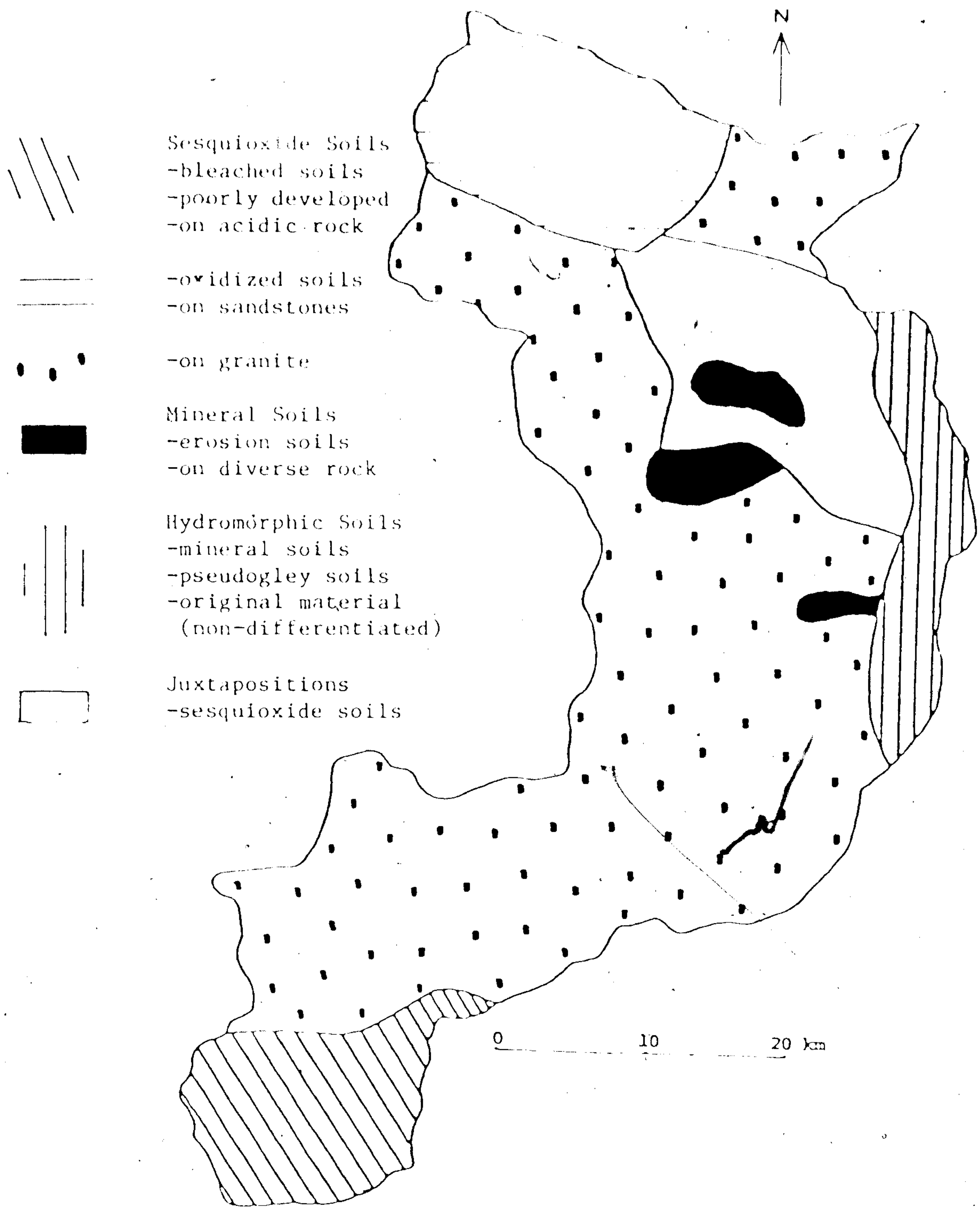


Fig. 2.2 Soils of Benoue National Park (adapted from Brabant and Humbel, 1974).

result of leaching of iron compounds, an eluvial horizon of free iron oxides occurs in the form of concretions, mottles or ferruginous hardpans approximately 3 meters below the soil surface (Nye and Greenland 1960, Kowal and Kassam 1978). These soils are more yellow in colour where moisture conditions prevail for longer periods. A typical profile of a ferruginous tropical soil is found below:

0-5 cm	Very dark brown to dark grey-brown clayey sand to sandy clay, generally structureless; few ferruginous concretions.
5-20 cm	Transition.
20-120 cm	Dark brown or brown-yellow clay or sandy clay, structureless; moderately compact; normally with a few ferruginous concretions.
120 cm+	Parent rock.

(adapted from Bridges 1970)

2.5 Drainage and Water Resources

Benoue River, the greatest of the Niger tributaries, drains almost the entire park. Descending from its source on the Adamaoua Plateau, Benoue River winds its way northward interrupted by falls and rapids through granitic bedrock. It gradually widens onto an alluvial plain after the confluence with the Laindeaol River in the extreme north-east corner of the park. The Sala River drains the southern region of the park.

A number of small tributaries join the Benoue River inside the park. These are usually quite short and have a highly seasonal discharge, only a trickle between February and March, with dry beds in smaller channels, rising to a peak in September-October.

It is not until late June after the first heavy rainfalls that Benoue River begins to rise noticeably. The level rises rapidly during July and reaches its maximum in August. High water continues after the rains have ceased but the level drops rapidly during November and December to the base-flow of February/March. Pelleway (1971) quoted that the average volume of flowing water past a given point in November was 1/5 the volume flowing in the previous month.

Water supply is not a problem in Benoue National Park. In addition to the perennially flowing Benoue and Sala Rivers, all major watercourses have permanent shaded pools of water along their lengths throughout the dry season. In the northern interior of the park, a large waterhole exists which is important to wildlife towards the end of the dry season. Heavy clay-lined depressions (pans) scattered among open *Terminalia* woodland fill with water during the wet season and retain water until mid-February.

2.6 Vegetation

Vegetation consists of open savanna woodland (Chapter III), typified by *Isoberlinia* spp., *Afzelia africana* and

Terminalia spp. These trees are usually short-boled, broad-leaved and reach heights up to 9-12 m. At best, these trees form closed woodland but wherever the tree canopy is open, perennial grasses of *Andropogon* spp. and *Hyparrhenia* spp. dominate the ground layer. Woody climbers are present locally. Over 142 species of trees and shrubs and 85 species of grasses occur within the park (Appendix I).

2.7 Wildlife

Information on wildlife in Benoue National Park prior to this study was almost non-existent. Apart from Letouzey (1948) who stated that game meat was "readily available", no information on wildlife species or populations was found. Jeannin (1951) gave population estimates of various wildlife species but these represented national totals and not populations for specific parks and reserves. Although the list is not exhaustive, there are over 45 species of mammals (Appendix II), 12 species of reptiles (Appendix III), and 200 species of birds (Appendix IV).

CHAPTER III

Classification of Major Plant Communities

Knowledge of plant communities, their present status and ecological significance to wildlife are essential for sound park management. Delineation of plant communities in Benoue National Park, therefore, was awarded high priority in this study.

Differentiation among plant communities has been determined using physiognomic (structural) and floristic (taxonomic) characteristics (Beard 1944, Kuchler 1960, Hopkins 1974, Moll, Campbell and Probyn 1976). In terms of individual plant characteristics, features such as herbaceous and woody, tall and short, plant densities and spacing, leaf-size and phenology can be used. For example, Aubreville (1949) differentiated vegetation types taxonomically but placed more emphasis on the physiognomic-structural approach. Richards, Tansley and Watts (1939a,b), Kuchler (1947), Hopkins (1957) and Keay (1953) identified West African savanna vegetation by the dominance of certain species.

3.1 Methods

Field work was carried out in two stages. During the first stage, a general reconaissance of the park was made. Floristically distinct plant communities were confirmed using randomly selected line transects approximately 2 km in length throughout the park. A total of 78 line transects were run. Arboreal vegetation was identified, photographed and marked on aerial photographs (scale 1:50,000). Grasses and forbs were recorded using paced-line transects primarily during the wet season when positive identifications were possible. Plant species which could not be identified were collected, mounted and sent to Wageningen, Holland for positive identification.

During the second stage, physiognomic-structural aracteristics of each stand were recorded using a standardized field data sheet (Appendix V). The collection of environmental data was standarized and limited to factors thought to be of major importance in determining community structure and composition. Thirty stands were randomly selected to represent the diversity of vegetation in the park.

3.1.1 Stand Measurement

Procedures followed Moll et al. (1976) with modifications: in addition to noting biotic influences, the following site factors were recorded at every second step along each transect:

1. Topography: aspect and percent slope.
2. Mean diameter (cm) of surface rock and percent (%) total rock cover: 0 representing 0 % rock cover, 1 representing 1-5%; 2 representing 5-25%; 3 representing 25-50%; 4 representing 50-75%; 5 representing 75-100%.

3. Soils: soil texture; color.

4. Moisture regime in general terms: dry; seasonally moist; seasonally wet; permanently wet.

Floristic data were used to group plant communities into similar physiognomic-structural classes. Classification of different plant communities was compiled using 30, 80-point line transects. Every second step was held stationary in the direction of march. If the toe landed on a grass tuft a "hit" was recorded. The following were also determined at every second step:

1. Percent tree canopy cover, a subjective estimate: (0-25%; 26-50%; 51-75%; 76-100%).
2. Distance and tree species (>1 metre in height) closest to the vertex of the right angle formed by the right and left foot and within the boundary formed by the imaginary projections from both feet (Fig. 3.1).
3. Height of the tree closest to the vertex.

3.1.2 Statistical Analysis

Principal Component Analysis (procedure HIERARCHY and procedure RELOCATE) was applied using the CLUSTAN IC cluster analysis package (Wishart 1975).

Principal Component (Factor) Analysis (PCA) transforms a given set of variables into a reduced set of composite variables or principal components (Austin and Orloci 1966, Clifford and Stephenson 1975, Nie et al.

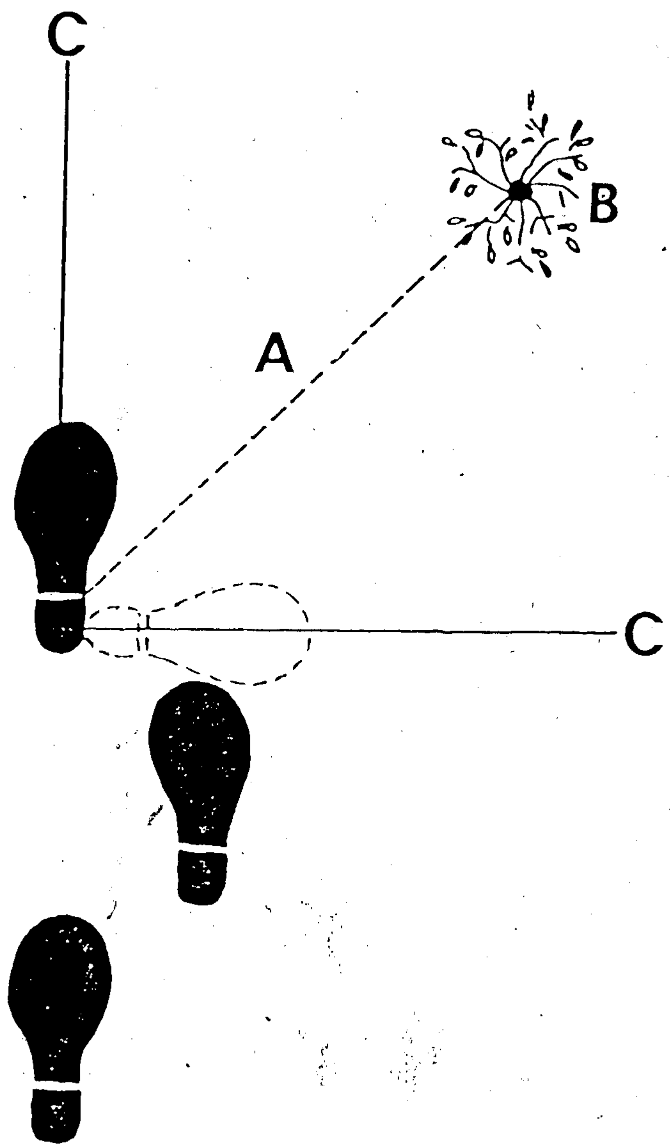


Fig. 3.1 Vertex formed by the right and left foot, every second step, 80-point line transects, Benoue National Park, 1977.

A = Distance (m) to the closest tree >1 m high
B = Tree species >1 m high
C = Imaginary lines from the left and right foot with the vertex formed as origin

1975, Wishart 1975). The analysis displays clearly and conveniently many of the relationships among the distribution of stands. It provides axes which are extracted in a descending order of importance (Austin and Orloci 1966) which are orthogonal (uncorrelated) and which are oriented in the direction of maximal vegetation variation among plant communities. PCA enables variations to be treated as a continuum rather than as discrete associations. Eigenvector values indicate the relative importance of each axis and therefore, the degree to which the original variables are associated with each component (factor). PCA is multidimensional and can provide as many axes as desired. In this study, the first three dimensions were used.

Hierarchical cluster analysis (procedure HIERARCHY, Ward 1963) based on the least increase in the error sum of squares starts with N clusters which are numbered according to the input order of the individuals. It produces a fusion hierarchy from which an associated dendrogram is drawn. The dendrogram indicates the level where the groups (plant communities in this case) make the best split on an intuitive basis.

Classifications derived by procedure HIERARCHY were optimized using an iterative relocation procedure. Procedure RELOCATE starts with a classification of the population of N individuals into K clusters. During one relocation scan, each individual is considered in turn and its similarities with all K clusters are computed. If the similarity with another cluster is greater than the similarity with the parent cluster, the individual will be relocated to the new cluster. If the same resulting classifications are obtained from several different starting groupings, then the probability that the global solution has been achieved is high (Wishart 1975).

3.2 Results and Discussion

3.2.1 Levels of Vegetation

Three more-or-less distinct overall strata of vegetation based on height were distinguished in Benoue National Park (Fig. 3.2). The upper tree level (level III) consisted of relatively tall trees over 7 metres, often reaching 11-18 metres in height. Afzelia africana, Isoberlinia doka, I. tomentosa and Anogeissus leiocarpus were the most common tree species in this level. Their boles were relatively short but they had full spreading crowns. Other common trees in this level were Burkea africana and Lophira lanceolata. The latter two had tall straight boles. Other less common species were Borassus aethiopium, Ficus spp., Butyrospermum paradoxum and Uapaca togoensis.

The intermediate tree level (level II) consisted of trees up to approximately 7 metres in height. Terminalia macroptera and T. laxiflora were the most common trees, although Combretum spp., Piliostigma thonningii, Monotes kerstingii and Crossopteryx febrifuga were very common.

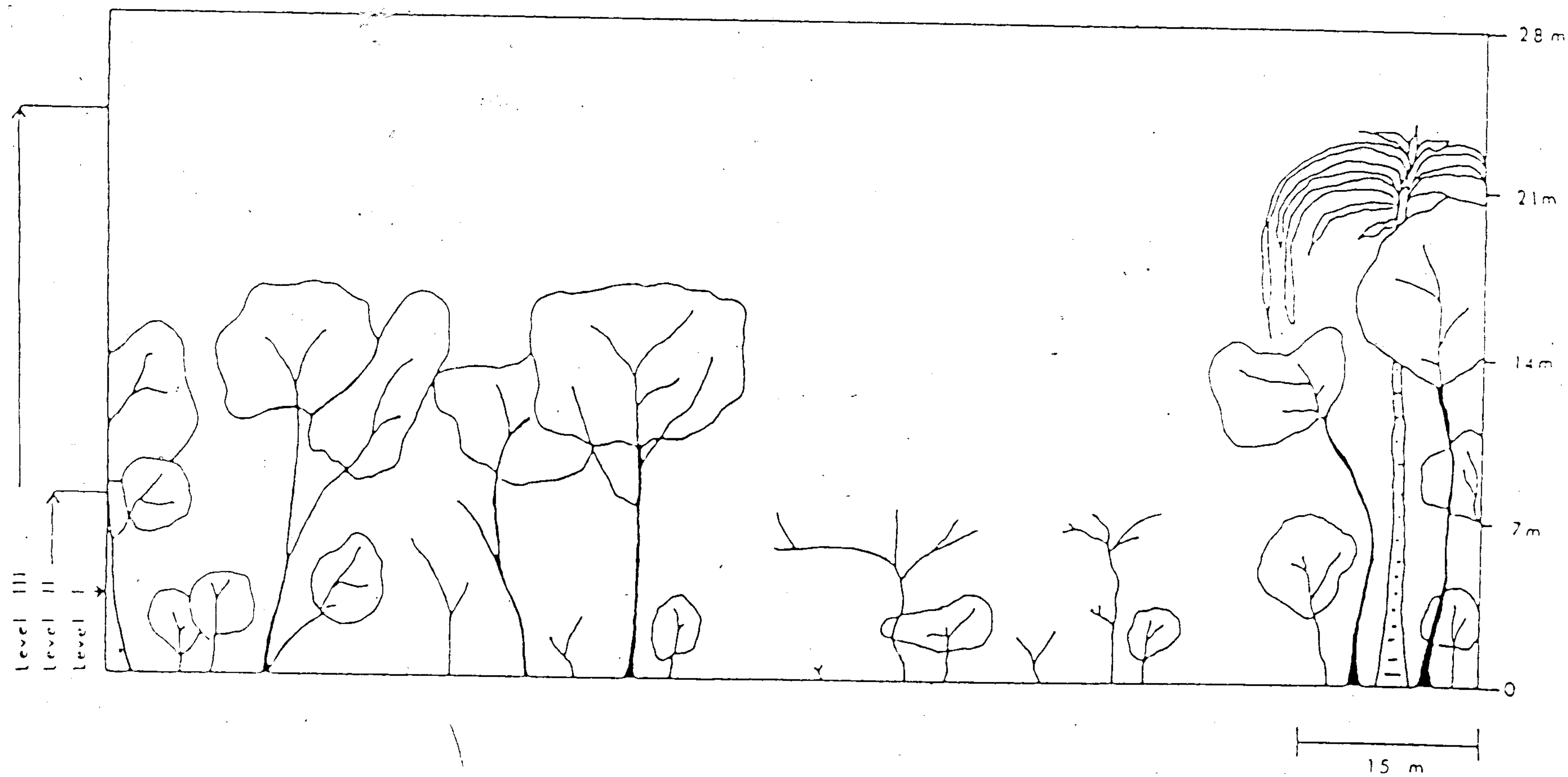


Fig. 3.2 Structural profiles of three vegetation levels in Benoue National Park.

Annona senegalensis, Lannea spp., Detarium microcarpum and Maytenus senegalensis occurred less frequently. Within this level, young trees of the upper level were represented in different stages of growth. In riparian forest, regeneration in this tree level was restricted to shade-tolerant trees such as Prosopsis africana, Combretum spp. and Acacia spp.

The shrub level (level I) included erect and climbing shrubs as well as tree seedlings and suckers. Annual fires prevented this level from establishing except along watercourses and in heavily shaded valleys and depressions. The most common erect shrubs were Protea angolensis, Ziziphus mucronata, Nauclea latifolia and Gardenia erubescens, the latter often reaching 4 metres in height. Opilia celtidifolia was only present locally. In open, flat regions of Benoue National Park the heights of Piliostigma thonningii, Combretum spp. and Terminalia spp. were often held in check as a result of fires and made up a good part of the shrub level. The shrub level was never continuous apart from areas on rocky hills and along watercourses.

The ground level was dominated by perennial grasses from the genera Andropogon and Hyparrhenia; they reached up to 2 metres by the end of the wet season. The ground between tussocks was more or less bare and tussocks seldom formed a complete grass cover. Andropogon gayanus is the most widely distributed and abundant grass in Benoue National Park. It is a large perennial, forming dense, hemispherical tussocks up to 1 metre in diameter. It appears to favor sandy and sandy-clay soils which predominate throughout Benoue National Park. It is drought-resistant (Hopkins 1965) and forms the principal fuel for annual fires in the park. Burning not only removed dead and mature leaves but most of the young green flush as well. The ground becomes bare and blackened and trees in the lower level become charred and usually leafless. The leaves are either burned off or fall naturally. Although areas of the park rested in this burned state for two or three weeks, those areas previously overlain with good grass cover, especially where Andropogon gayanus prevailed, sent up new shoots very quickly after the last fires. Rhizomes are probably responsible for the early regrowth and fire drought resistance of this grass. Tussocks of Andropogon gayanus grow radially. Large tussocks encircle a central portion of dead tillers. These central portions were declining in vigour and did not send up new growth even during the wet season. After burning, these central portions were completely consumed by fire and did not resprout.

The annuals, Brachiaria bizantha, Setaria sphacelata, Loudetia spp., Imperata cylindrica, Sporobolus pyramidalis, S. festuvius, Panicum spp. and Pennisetum spp. have shallow, fibrous roots and are the first grasses to flush at the commencement of the rainy season after the first light showers. Prior to the peak of the rainy season (July/August), these grasses form the bulk of the grass cover. However, annuals make up only a small component of the ground layer: from paced-line transects, annuals made up less than 3% of the total ground cover. Gradually, as the rains lessen, Andropogon gayanus and Hyparrhenia spp. overtake these species in height.

In general, grasses were shorter on hilltops and mountains than on slopes and lowlands. This was due to the soil catenas (Bell 1970, Laws, Parker and Johnstone 1975). On hilltops and mountains, wind and rain had severely eroded soils leaving bare, exposed rock interlaced with cracks which trap enough soil to support grass growth. This soil was heavy clay and during the dry season, became hard and dry.

On slopes and lowlands, soil depth and soil moisture retention increased. Tree cover, absent on hilltops and mountains, augmented soil moisture retention and productivity as a result of leaf fall. Lowlands supported good grass production averaging 1.5 metres in height during the wet season. Grass cover on slopes was high but intermittent and averaged slightly less than 1 metre in height during the wet season. Clay loam soils and lowlands showed higher productivity than sandy clay soils of slopes and clay soils of hilltops and mountains.

3.2.2 Habitat Classification

Relationships among stands were classified by orthogonal principal components (factors) (Figs. 3.3, 3.4, 3.5). Factor I (% slope) and Factor II (soil

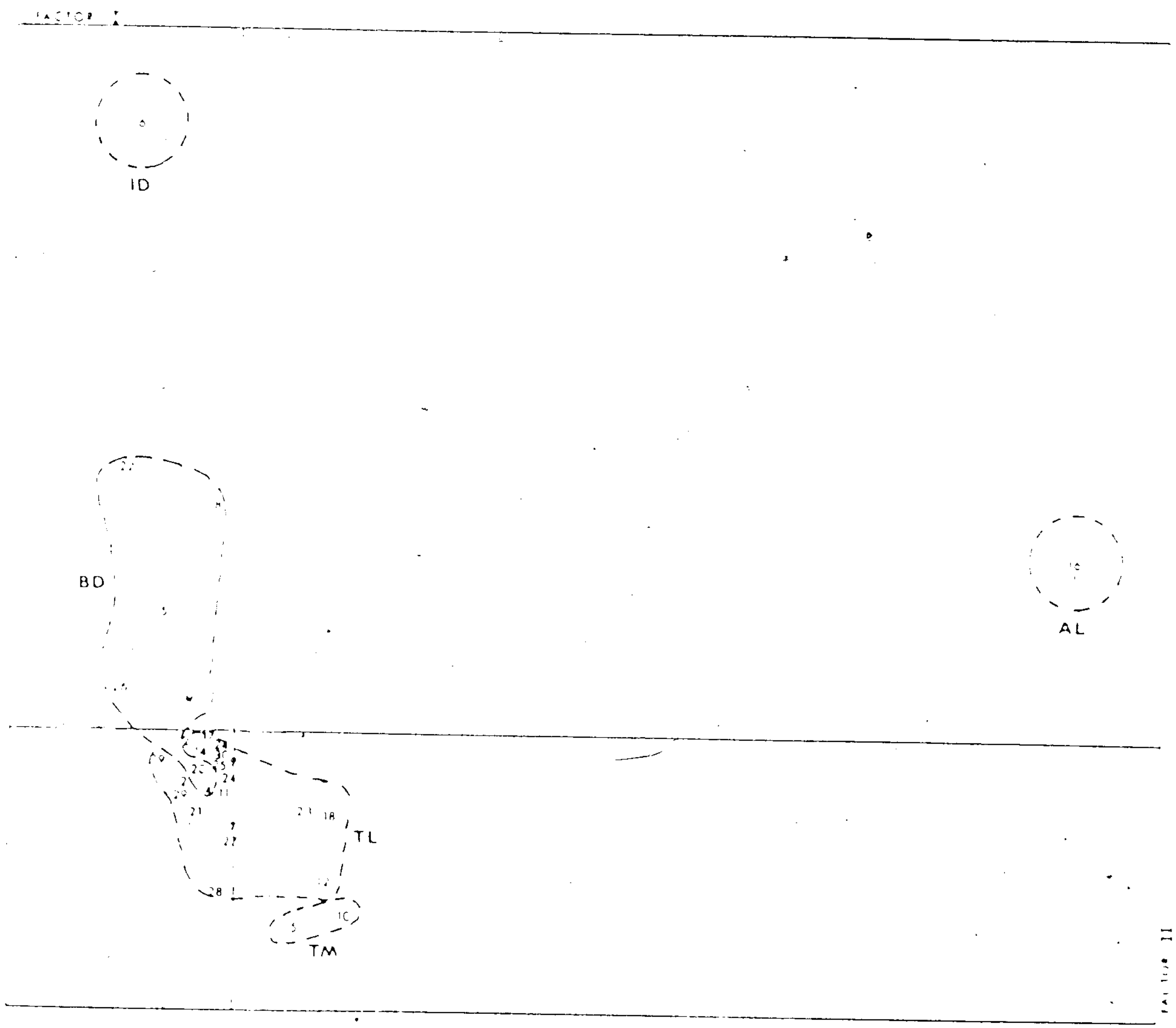


Fig. 3.3 Distribution of 30 stands in relation to the first two principal components. AL = Anogeissus leiocarpus; BD = Burkea-Detarium; ID = Isoberlinia doka; TL = Terminalia laxiflora; TM = Terminalia macroptera.

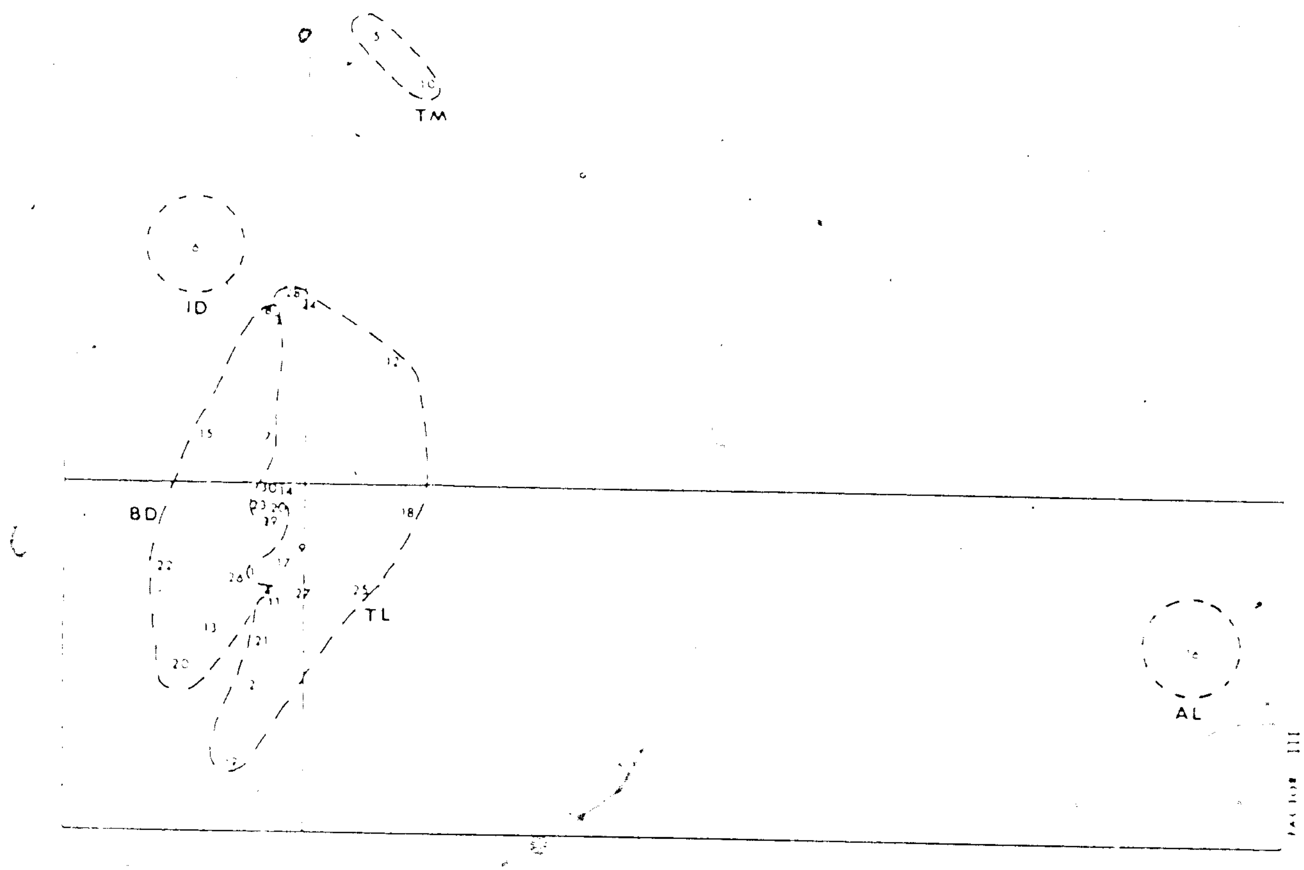


Fig. 3.4 Distribution of 30 stands in relation to the first and third principal components. Symbols as in Fig. 3.3.

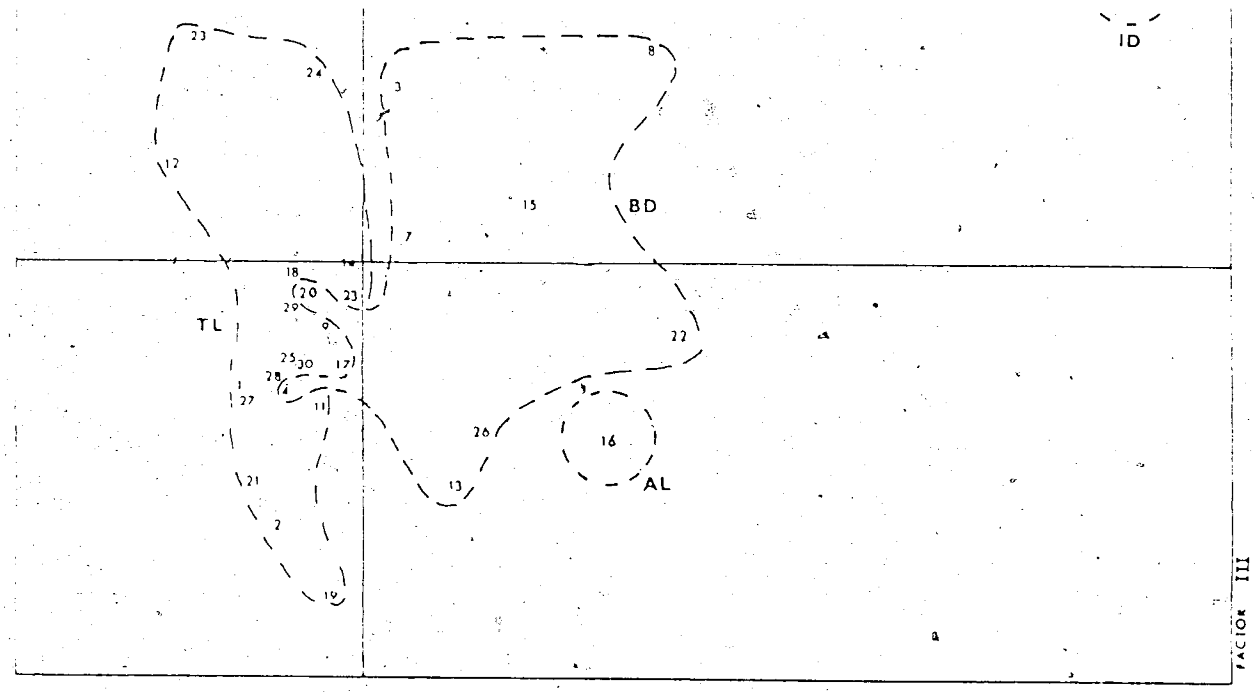


Fig. 3.5 Distribution of 30 stands in relation to the second and third principal components. Symbols in Fig. 3.3.

texture) accounted for 17% and 13% respectively, of the variance in the data as a whole and appeared to represent the catenary gradient. Only two (original) stands (4 and 20) were not classified. Anogeissus riparian forest and soil moisture were positively associated with Factor I while open Terminalia laxiflora, T. macroptera savanna and grass cover were inversely related. Factor II was (highly) positively associated with Isoberlinia woodland and soil moisture while negatively associated with open T. laxiflora, T. macroptera and grass cover. On the basis of these two factors, a separation between forest and open woodland and between moist soils (good grass cover) and dry soils (poor grass cover) repectively took place. There was a definite gradient from open savanna; good grass cover and moist, clay soils to dense forest and woodland, low grass cover and dry, sandy loam soils.

Factor III (% total surface rock cover) did not contribute greatly to plant community classifications. However, the distinctiveness of Terminalia laxiflora and T. macroptera was highlighted. The discrepency caused by the predominance of Monotes kerstingii in stand 4 and Protea spp. in stand 20, did not affect the vegetation classification as a whole or the characteristics of each cluster.

Fig. 3.6 displays th[illegible]ndrogram produced with procedure HIERARCHY. Examining photographs taken of stands in the field and considering physiognomic-structural characteristics of each stand,

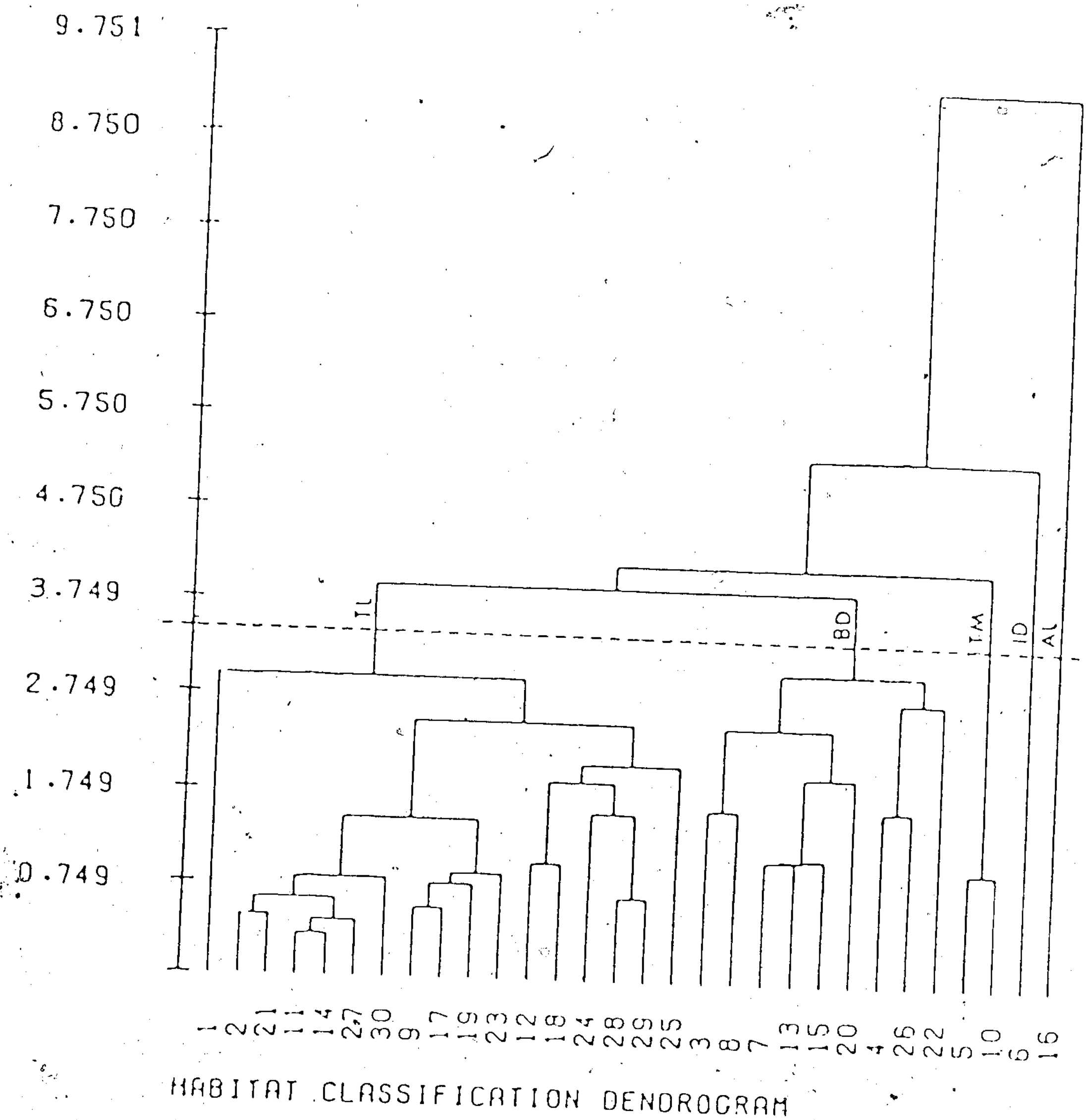


Fig. 3.6 Dendrogram produced by procedure HIERARCHY showing classifications of 30 stands. The vertical axis represents a measure of homogeneity of each cluster using the least increase error sum of squares. The dotted horizontal line represents the "best" level where plant communities are defined. Symbols as in Fig. 3.3.

horizontal line was drawn subjectively, designating five recognizable plant communities. Fig. 3.7 represents the cluster circles drawn by procedure HIERARCHY. They were drawn almost exactly the same as by PCA.

Procedure RELOCATE produced five cluster circles the same as PCA and procedure HIERARCHY further establishing the robustness of classification. Therefore, from PCA, procedure HIERARCHY and procedure RELOCATE, five major plant communities were defined. Physiognomic and structural characteristics of each stand are listed in Table 3.1 and are described below. Photographs of representative stands are provided in Fig. 3.8.

1. *Isoberlinia* Woodland

Isoberlinia doka is a broad-leaved deciduous species reaching heights of 18 metres. It was found predominantly on incline areas and upper slopes where drainage and erosion left accumulations of pebble-sized ironstone. Often found in pure stands, the foliage of *Isoberlinia doka* (up to 14 metres in diameter) frequently formed a closed canopy.

Woody species associated with *Isoberlinia* woodland included *Protea* spp., *Burkea africana*, *Crossopteryx febrifuga*, and *Gardenia erubescens*. In some sections of the park, notably the south-east, *Isoberlinia tomentosa* more-or-less completely replaced *Isoberlinia doka*. The major grasses were the perennials *Andropogon* spp., *Hyparrhenia* spp. and *Sporobolus* spp. Their total basal

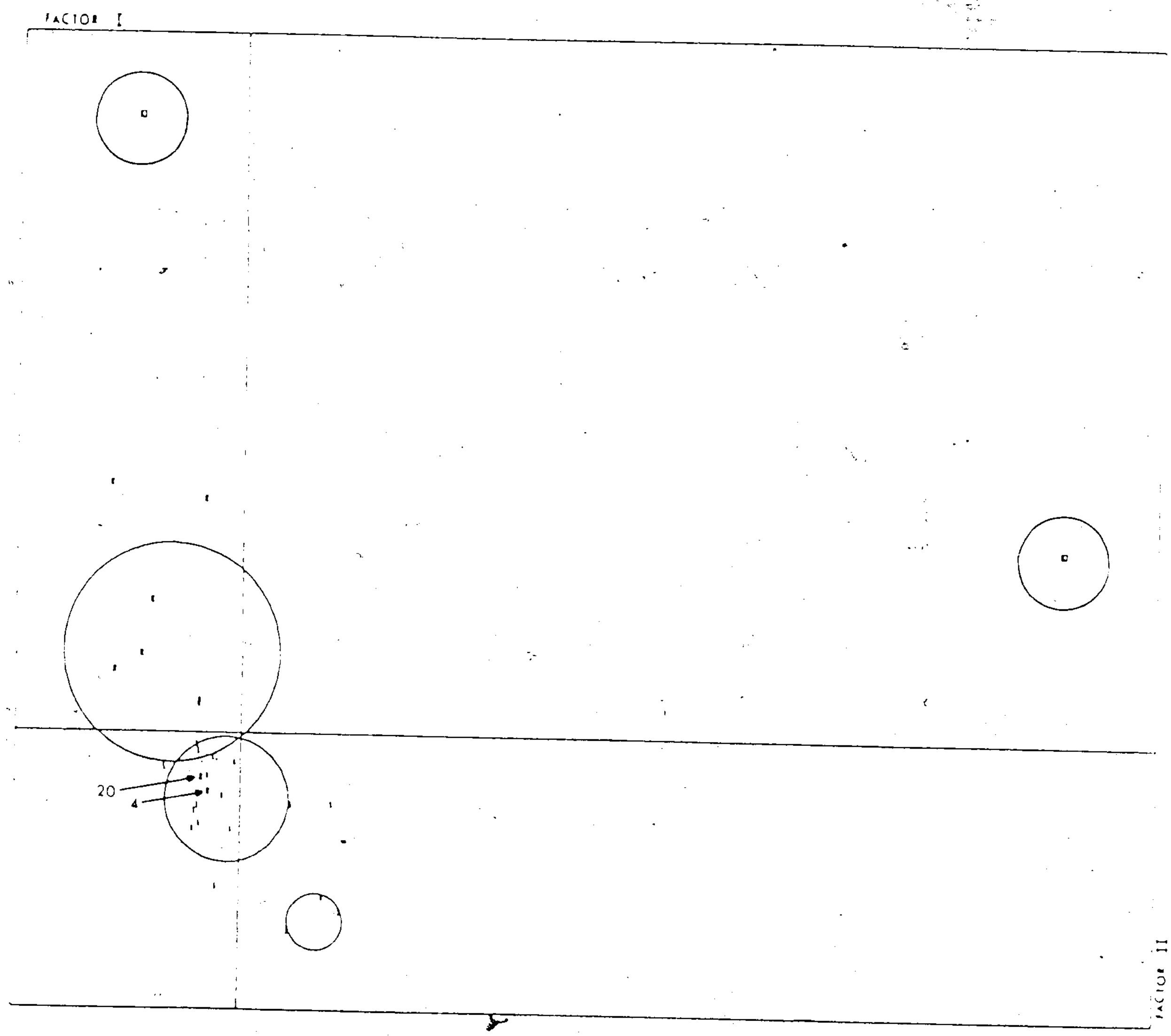


Fig. 3.7 Cluster circles drawn by procedure HIERARCHY.

Table 3.1 Physiognomic and structural characteristics by stand (n=30), Benoue National Park, 1977. (The numbering of the stands along the top of the table corresponds to the hierarchy in Fig. 3.6).

	1	2	21	11	14	27	30	9	17	19	23	12	18	24	28	29	25	3	8	7	13	15	20	4	26	22	5	10	6	16
Grass cover (%)	10-12																	4-6									13-15		1	1
Soil type (cSaLm=1; fSa=2; fSaLm=3; ClLm=4; SaClLm=5; SaCl=6)	1	2	5	5	1	3	1	1	3	1	2	6	5	1	4	1	1	3	3	1	6	5	5	3	1	5	4	4	1	[illegible]
Rock cover (%)	0	0	2	2	1	[illegible]	0	1	1	2	[illegible]	[illegible]	[illegible]	[illegible]	0	[illegible]	[illegible]	[illegible]	[illegible]	2	3	0	2	0	0	0	3	1	4	[illegible]
Aspect	W	W	E	W	N	SW	SW	S	SE	S	SW	W	S	SW	N	SW	E	[illegible]	E	SW	SE	E	S	SE	NE	NE	N	N	N	SE
Canopy cover (%) of major tree species																														
Crossopteryx febrifuga	4			3			2	1	2										6	4		1		1						
Lophira lanceolata		3	20	2								1											14							
Isoberlinia tomentosa																		24	9	9	31			1				[illegible]	5	
Monotes kerstingii																								22	6					
Terminalia laxiflora	3	4			1	1	4	2			4			1		4	3						2	3				6		
Isoberlinia doka			1								15		10	1	3		5	10	16	5	11		2	3	1	42			25	
Afzelia africana					58			10					4	1	3			5	11	16		9			24			6	7	[illegible]
Terminalia macroptera				1								13		3	4			4						2			30	23		
Anogeissus leiocarpus												5	52				51													35
Protea spp.		1	1			[illegible]				3							2									1			3	
Maytenus senegalensis						4																				1				
Burkea africana	2	2	2	1	1		1	2		1	9						6			5				7	1				3	
Gardenia erubescens															2								1						1	
Combretum spp.	1	1		1				2	2				9				2		1						2			2		3
Detarium microcarpum	1	1		2											1			1	3	2										
Piliostigma thonningii	1					2					1		2			1	2													
Bridelia scleroneura					1	1							1	1													4		1	
Ficus spp.							6																							
Ximenia americana							1																							
Prosopis spp.									3													8								1
Hymenocardia acida									1									1												
Lannea spp.										1											1	1	1							1
Annona senegalensis													1														1			5
Uapaca togoensis																								3						
Butyrospermum paradoxum																													4	

area averaged 10%.

2. Anogeissus Riparian Forest

Tree and shrub forests occurring along streams, valley bottoms and riverbanks are often referred to as riparian or "gallery forests". Vegetation was usually thick and often impenetrable, particularly during the wet season. The dominant tree was Anogeissus leiocarpus. Other large trees consisted of Borassus aethiopium, Prosopsis africana and Combretum spp. Pterocarpus erinaceus was a much less common tree located in the lower tree level.

Acacia ataxacantha, Ficus spp., Syzygium macrocarpum, Ximenia americana and Ziziphus mucronata made up the majority of the lower tree and thicket-forming layers. Basal area of the perennials Andropogon spp., Hyparrhenia spp. and Eragrostis spp. averaged 3%.

3. Terminalia laxiflora Open Savanna

This open savanna woodland supports primarily Terminalia laxiflora, although frequently in association with Combretum spp., Piliostigma thonningii, Protea spp., Lophira lanceolata, Bridelia scleroneura and Crossopteryx febrifuga. T. laxiflora trees were usually widely spaced and had small boles which were roughly barked, spongy and permanently charred.

Surface horizon soil was heavy (clay)) and gray in color. During the wet season, drainage was impeded and as a result, flooding was frequent. Over the year, this plant community was subject to wide variations in moisture conditions. Basal area, predominantly Hyparrhenia spp., was dense (15%), and they averaged 2 meters in height.

4. Terminalia macroptera Open Savanna

Although widespread in occurrence, Terminalia macroptera open savanna never occurred in areas larger than 1.5 km^2. Gardenia erubescens, Combretum spp., Pseudocedrela kotschyi, Annona senegalensis, Detarium microcarpum and Piliostigma thonningii were frequently associated with this vegetation type but never occurred in great numbers.

Soils were heavy (clay) and seasonally inundated. Basal area of predominantly Andropogon gayanus, averaged 18%.

5. Burkea-Detarium Open Savanna

This open savanna woodland is characterized by Burkea africana and Detarium microcarpum, and common around the bases of large hills. Other species included Lophira lanceolata, Ximenia americana, Protea spp., Crossopteryx febrifuga, Hymenocardia acida, Gardenia erubescens, Terminalia laxiflora, T. macroptera, Piliostigma thonningii and Combretum spp. The ability of the latter four species to produce vigorous coppice shoots after burning (Keay 1959), gave them a defin[illegible]e growth advantage. Afzelia africana woodland often interspersed this savanna type close to Benoue River.

Soils of Burkea-Detarium savanna woodland were heavy clay and rather coarse on the surface. Flooding was common during the wet season and grass production of Andropogon gayanus, the dominant perennial, averaged 11% basal area.

Terminalia laxiflora open savanna. Soils are heavy clay.

Large-leaved Isoberlinia woodland on shallow soil. Pebble-sized ironstone concretions are common.

Fig. 3.8 Five major plant communities defined in Benoue National Park, Cameroon, West Africa.

Dense Anogeissus riparian forest with thick understorey.

Terminalia macroptera open savanna. Note crookedness of boles and good grass cover.

Light barked Hymenocardia acida (foreground) among Burkea-Detarium open savanna.

CHAPTER IV

Fire History and *Afzelia africana*

Annual grassland burning has been practised by African peoples for centuries. In the African Guinea savanna zone, annual fires occurred as much as 2,500 years ago (Muller 1855). According to Schnell (1950) and Richards (1952), fire was recorded in West Africa at the time of Hanno's voyage before 480 B.C.

Effects of annual burning may be short or long-term. Short-term effects center around the destruction of most vegetative cover and the sudden release of mineral elements. These are soon utilized by the plants or gradually leached by rain (Egunjobe 1971). Probably the most obvious long-term effect is on floristic composition. Generally, savanna areas protected from fire become more wooded with increases in fire-susceptible species, while areas subjected to constant burning have fewer trees and retain a much denser grass cover (Ramsay and Rose Innes 1963, Hopkins 1965). Prolonged burning most often results in the development of fire-tolerant plant species which become dependent upon periodic burning for their existence (Glöver 1968).

If habitat is to be maintained and yet burned (it is very difficult to dissuade native people from burning annually), the most "appropriate" time is during the early dry season when much grass is still green and plant moisture content is high. Fire intensity is then correspondingly low. With the lengthening of the dry season, more and more fuel is made available as grasses mature, resulting in progressively "hotter" burns. These burns completely remove aerial parts of plants except for woody growth large enough or resistant enough to withstand them.

In Benoue National Park today, burning occurs on a wide scale. Annually, with the onset of the dry season in December/January, grasses are burned commencing in the vicinity of greatest human activity, Buffle Noir Tourist Camp, and progressively radiate from it. Although the primary and immediate effect of burning in Benoue National Park is to restrict dry season food supplies of herbivores, important long-term effects on the composition and structure of the park vegetation are occurring.

Fire-tolerant trees such as *Terminalia macroptera*, *T. laxiflora* and lately, *Monotes kerstingii* (Keay 1949, Hopkins 1974) are common and adapted to regular burning. *Terminalia* spp. have deeply fissured, thick spongy bark which aids in the protection from fire. Charring is common on the bark and may in fact aid in the preservation and increase of these species. Charring of fence posts was a method, now mostly forgotten, used by North American pioneers to preserve wood (Jeffrey 1925, Komarek 1972). *Monotes kerstingii* has a fine orange powder covering its thin bark which acts as a fire retardant (Hopkins 1965). *Afzelia africana* is also common and somewhat fire-tolerant (Keay 1949, Hopkins 1974), but under repeated burning, Afzelia woodland is dying and is being invaded by Monotes kerstingii. Also, severe basal scarring occurs on the majority of Afzelia trees.

This study investigated the historical nature of burning of Benoue National Park and set out to provide evidence that fire has been the main reason for the decline of Afzelia africana.

4.1 Materials and Methods

4.1.1 Basal Scars

Fire can leave evidence of its presence on woody vegetation as bark or wood scars. Backfires can be particularly damaging (Fahnestock and Hare 1964, Tunstall et al. 1976). Fire is drawn into a vortex at the base of a tree creating a hotter fire - particularly for large trees (Fig. 4.1). Flames and heat caught in this vortex cause bark to scorch. Before the dead bark is shed, fires in the following dry season are again drawn in by a wind vortex and heat subsequently ignites dead bark and kills more cambium. Exposed scars do not have time to heal between annual fires and are scorched repeatedly. On the edges of these scars, one often finds folds of healing tissue forming over the open scar or "catface" (an open scar which has resulted from more than one fire) (Lutz 1930). Although a catface can occur anywhere on a tree depending on flame heights, it usually develops near the base, hence the more common terminology, basal scar.

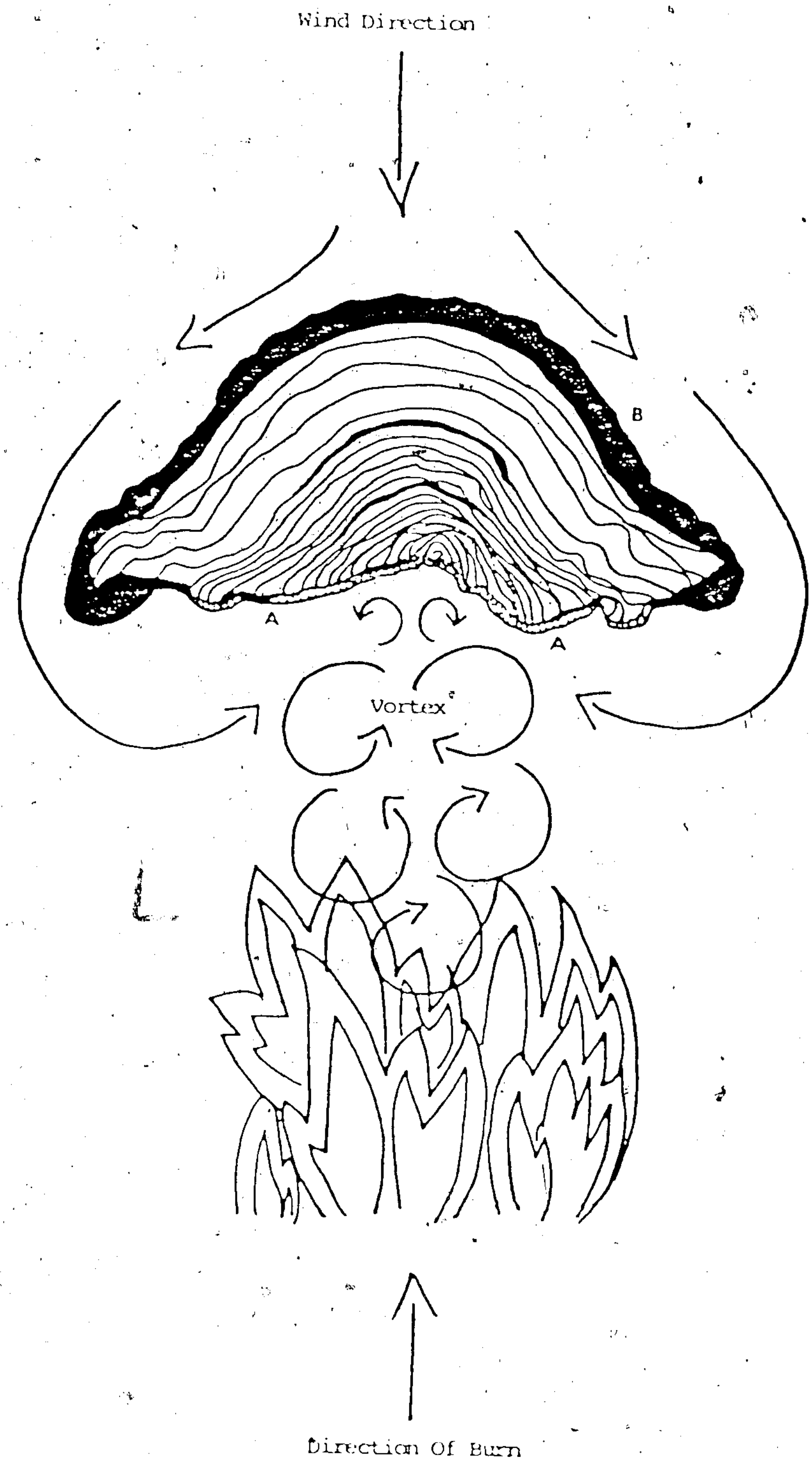


Fig. 4.1 An example of the creation of a wind vortex resulting from an opposite moving fire and wind direction.
A = catface; B = bark

In 1974, 5 different stands (labelled A,B,C,D,E) of *Afzelia africana* woodland were selected within Benoue National Park with the aid of aerial photographs (scale 1:50,000) (Fig. 4.2). In total, 489 *Afzelia* trees were randomly selected and measured. Measurements included tree height and bole circumference, basal scar height, width and depth and basal scar direction. Tree height was measured using a Suunto clinometer. Basal scar direction was determined using a Silva compass. Bole circumference (taken 1 m above ground surface) and basal scar height, width and depth were measured using a metric measuring tape.

Scar classes were assigned using the following criteria:

1 - no damage

2 - damage to 0° to 45° of the bole circumference extending from ground surface to 0.5 m above the ground

3 - damage to 45° to 90° of the bole circumference extending 0.5 metres to 1.5 m above the ground

4 - damage to 90° to 180° of the bole circumference and extending 1.5 m to 3 m above the ground

In 1977, 22 randomly selected *Afzelia* trees among the 5 stands were aged, including one *Afzelia* tree per stand which had no basal scar. Aging was carried out by core and wedge sampling. Using a 40 cm Swedish increment borer (0.8 cm in diameter), a core sample was taken 1 m above

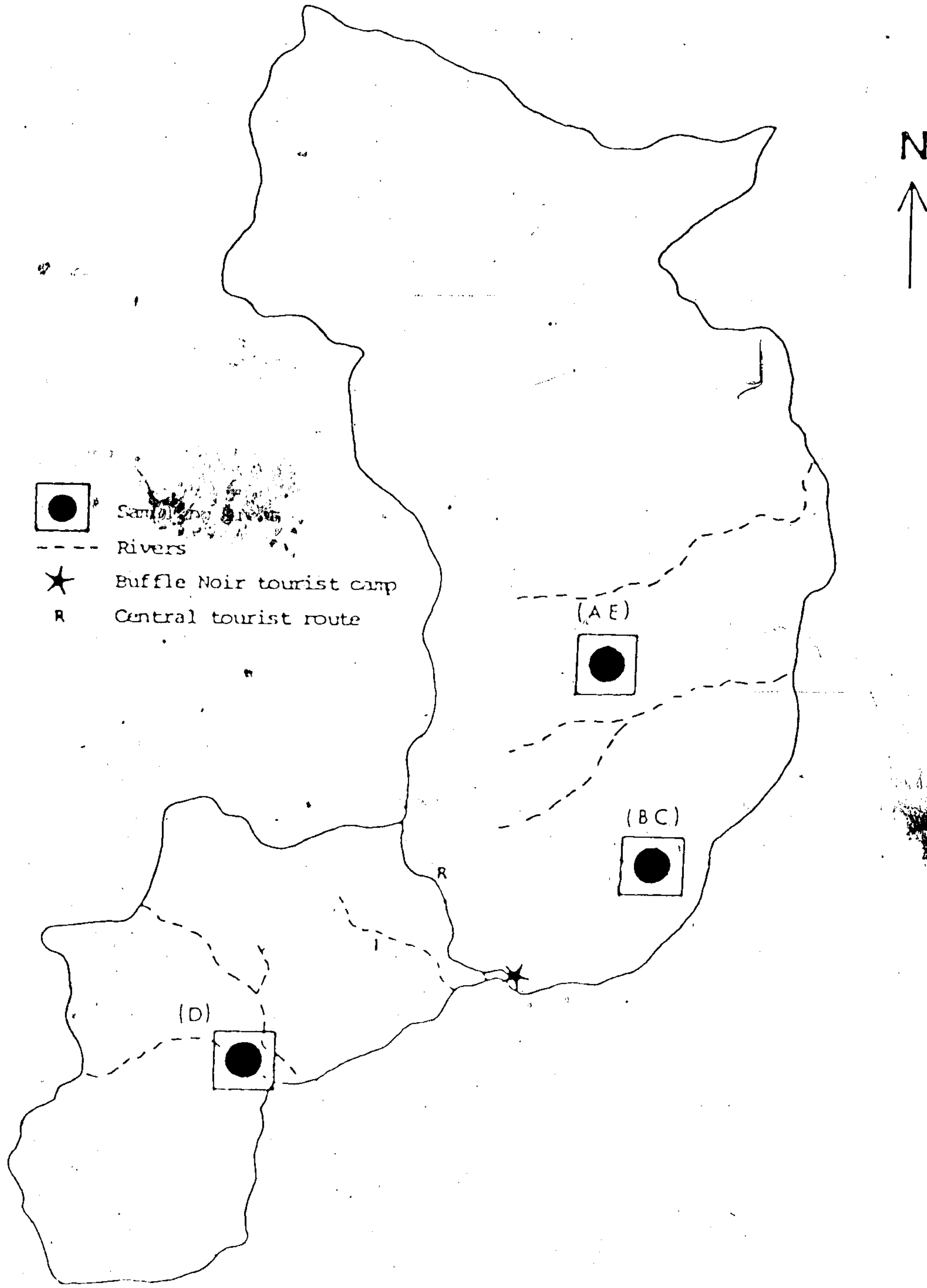


Fig. 4.2 Location of Afzelia africana stands sampled in Benoue National Park, 1977.

ground surface on the side of a bole opposite (180°) a basal scar (in no instance was fire damage evident on the side of a bole opposite a basal scar). A narrow wedge was obtained by sawing two converging cuts (one taken at a right angle to the bole) midway on the basal scar to a distance deep enough to include the pith (Fig. 4.3).

4.1.2 Annual Ring Counts

Cores were glued on mounting boards with the vertical grain oriented in a horizontal position. To facilitate counting of annual rings, core samples were lightly sanded using fine sandpaper and a solution of phenol red dissolved in methyl alcohol was used to wet and accentuate indistinct rings. The first and successive annual rings showing burned wood were marked and the number of rings laid down from the pith were recorded.

4.1.3 Correlating Fire Chronologies

An annual ring includes wood formed by cambium from the time growth starts in the wet season until it ceases because of the approach of the height of the dry season. Wet season (spring) wood is composed of cells which are large, thin-walled and light-coloured, whereas dry season (summer) wood is composed of cells which are small, thick-walled and dark-coloured. A constant and abundant supply of available moisture causes the formation of consistently thick rings (Stevens 1924). In contrast, a constant but restricted supply of available moisture

Fig. 4.3 A wedge removed from an Afzelia africana basal scar, Bènoue National Park, 1977.

causes the formation of consistently thin rings. As a rule, the spring wood merges gradually into the summer wood and the latter terminates abruptly in a sharp outer face.

To establish the chronological identity of annual rings from different trees of the same site, line diagrams were constructed (Appendix VI). Cross-dating was used to overcome minor errors which could result from missing rings, rot or false rings.

4.2 Results

Table 4.1 gives the circumference, height, age and dimensions of basal scars of Afzelia sampled in 1977. Fire damage to Afzelia africana was extensive: in total, 73.9% of Afzelia trees sampled had basal scars, the majority of which fell in scar class 4 (Fig. 4.4). Basal scars were oval in shape and in most cases, extended from ground surface to 3.5 m (Fig. 4.5). Scarring has been so severe on some Afzelia that the trees have died (Fig. 4.6). Afzelia trees without basal scars were all young trees averaging 37 cm (range 31-42 cm) in circumference and ranging from 28-31 years old.

Ground cover is burned annually from Buffle Noir Tourist Camp and along both sides of the central park road (R1, Fig. 4.7). This burning practice was evident from the directions of the basal scar[illegible]. The majority of basal scars faced south and south-west [illegible] 4.2). Afzelia trees in the south of the park (s[illegible] [illegible]ad west-facing

Table 4.1 Tree dimensions and basal scar direction (magnetic) of Afzelia africana sampled in Benoue National Park, 1977.

	TREE			SCAR			
Site	Circ. (cm)[1]	Height (m)	Age[2]	Height (cm)	Width (cm)	Depth (cm)	Direction
A 1)	160.0	11.5	70	104.0	30.0	12.0	S
2)	99.0	10.0	85	83.0	30.0	35.0	SW
3)	171.5	12.0	130	0.0	0.0	0.0	-
4)	71.0	9.5	35	101.0	25.0	3.5	SW
5)	148.0	10.0	130	0.0	0.0	0.0	-
6)	66.0	8.0	65	54.0	19.0	1.0	SW
B 1)	146.5	11.5	155	35.0	15.0	2.5	S
2)	104.0	10.0	70	49.0	17.0	3.0	S
3)	96.5	10.0	65	178.0	44.0	6.0	S
4)	174.0	12.7	105	255.0	78.0	16.0	SW
C 1)	76.0	7.5	87	165.0	29.0	8.0	SW
2)	79.0	8.5	90	77.0	17.0	4.0	SW
3)	88.5	10.5	83	0.0	0.0	0.0	-
D 1)	139.5	9.7	110	138.0	4.0	5.0	W
2)	114.0	11.3	80	34.0	21.0	3.0	SW
3)	219.0	13.5	120	0.0	0.0	0.0	W
4)	220.0	14.0	115	108.0	40.0	5.0	W
E 1)	105.0	10.0	[illegible]	52.0	50.0	4.0	SW
2)	179.0	11.7	107	141.0	60.0	12.0	S
3)	69.0	[illegible]	45	40.0	28.0	1.0	S
4)	72.5	9.3	50	132.0	44.0	5.5	SW
5)	99.0	7.5	45	107.0	36.0	4.0	SW

[1] Circumference at base height (1 meter above the ground)

[2] Best estimate (±5 years)

Note: The 5 young trees without basal scars from sites A, B, C, D, E were 25, 28, 26, 26 and 28 years old respectively.

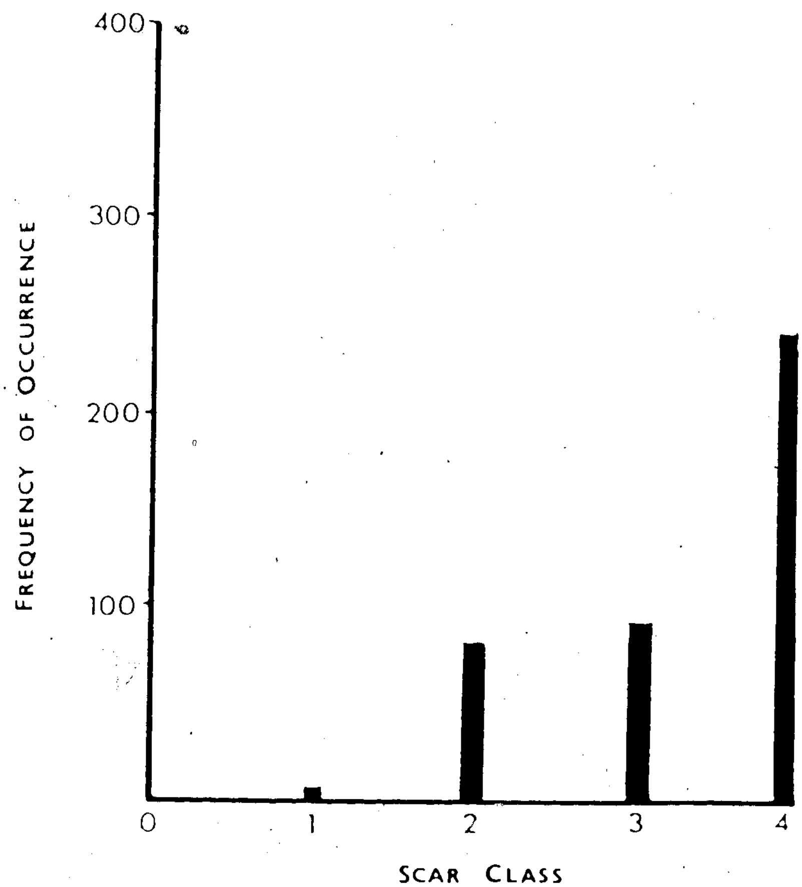


Fig. 4.4 Frequency of occurrence of the four basal scar classes on Afzelia africana, Benoue National Park, 1977.

Fig. 4.5 An *Afzelia africana* basal scar showing the pronounced oval shape and severity of damage, Benoue National Park, 1977.

Fig. 4.6 An *Afzelia africana* tree with only one-half of its bole remaining due to fire damage (left). Eventually the tree dies (right).

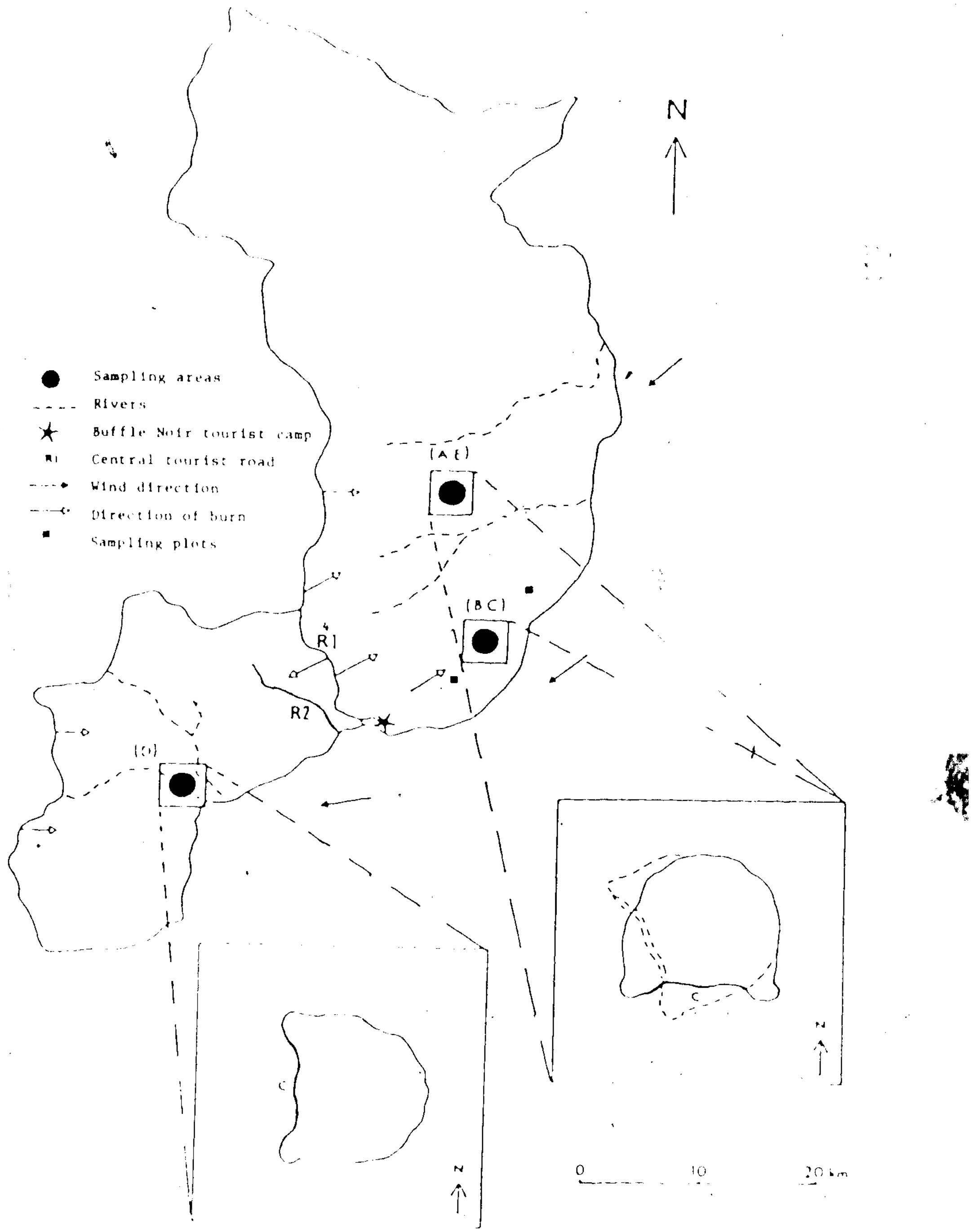


Fig. 4.7 Direction of annual fire spread through Benoue National Park and direction (magnetic) of the majority of basal scars in respective Afzelia stands.
C = catface

Table 4.2 Percent occurrence of basal scar direction on *Afzelia africana*, Benoue National Park, 1977.

DIRECTION	NUMBER OF TREES	PERCENT
South	152	42.1
South-west	105	29.1
South-south-west	55	15.2
West	19	5.3
South-east	18	5.0
South-south-east	6	1.6
North	3	0.8
North-north-west	1	0.3
East	1	0.3
West-north-west	1	0.3

scars, and those in the mid-central (sites B, C) and north (sites A, C) had south and south west-facing basal scars (see Fig. 4.7). In addition to different scar directions, *Afzelia* stands had two distinct fire histories: stands A, E and D had the first evidence of burned wood in the 1930-1933 annual rings; stands B and C had burned wood first evident in the 1944-1946 annual rings (Fig. 4.8). Eight percent (8%) of the *Afzelia* trees examined were dead.

During the study, no *Afzelia* seedlings were found. However, seedlings of *Monotes kerstingii* were common and found invading (by suckering) sites previously held by *Afzelia* trees (Fig. 4.9). Because *Afzelia* woodland does not characteristically form closed canopies, *Andropogon* spp. grass cover was good (18%), whereas grass cover in *Monotes* stands, composed primarily of *Hyparrhenia* spp., was low (< 4%).

4.3 Discussion

Direction of basal scars on *Afzelia africana* revealed historic and present-day annual fire spread in Benoue National Park. Fires burn north-east and south-west as roads and topography dictate. Fires burning north-east have no natural or man-made barriers to stop their spread, and therefore retain a north-east heading attacking trees from the south and south-west. However, fires spreading south-west are interrupted by a road (R2) which acts as a fire break (see Fig. 4.7). To counteract this, park

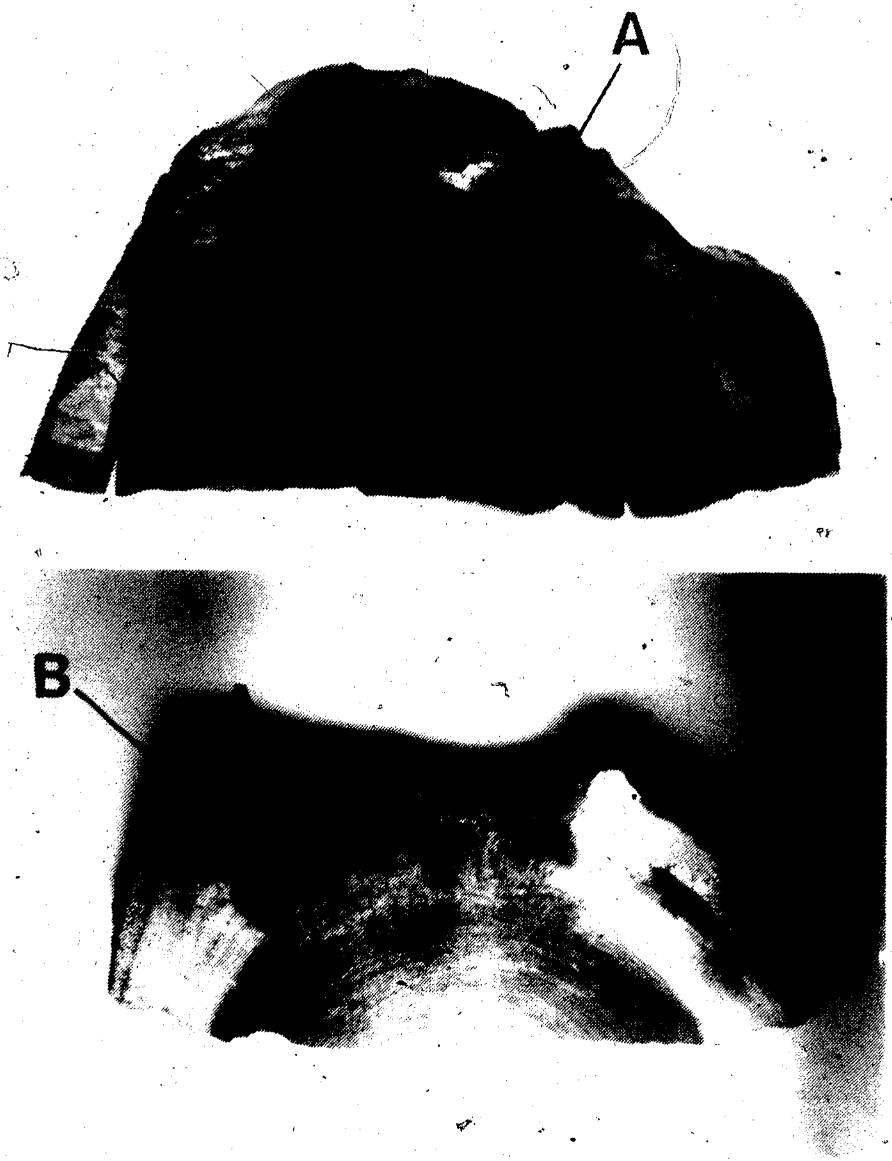


Fig. 4.8 Top: Wedge of an Afzelia africana taken from the mid-east central region of Benoue National Park showing first fire damage (A) around the 1944-1946 annual rings. Bottom: Wedge from the north-central region showing first fire damage around the 1930-1933 annual rings (A). B is a subsequent 1945 annual ring showing severe fire damage. From the 1930-1933 annual rings, no healing-over of the basal scar has occurred.

Fig. 4.9 The invasion of Monotes kerstingii on a mature stand of Afzelia africana, Benoue National Park, 1977.

personnel torch ground cover along the western park boundary. Fires, therefore, spread in an easterly direction damaging trees from the west. However, harmattan winds blow from the north-east during the early dry season, thereby opposing the heading fires, creating vortices on the west, south and south-west sides of boles. As a result, Afzelia trees north of Buffle Noir have basal scars on the south and south-west of their boles and Afzelia trees south of Buffle Noir have the majority of basal scars on the west side of their boles.

Letouzey (1948) stated that the first recorded (severe late dry season) total burn of Benoue National Park (excluding 2,000 ha in the "mid-central region" of the park) occurred just before 1932, but in 1945, a hot, late, dry season fire burned the entire park including the remaining 2,000 ha. The results of Afzelia annual ring analysis confirmed this fire history: late, severe, dry season fires (around 1930 and 1945) created initial basal scars on Afzelia africana. Hopkins (1965) showed that late, dry season fires produced temperatures in excess of 538°C from the soil surface up to heights of 3 m on Nigerian savannas. It is likely that similar temperatures, possibly hotter, induced the initial damage on Afzelia africana in the early 1930's and mid 1940's in Benoue National Park. Basal scars have not had time to heal because of annual fires and are scorched repeatedly, killing more cambial cells. Afzelia trees without basal scars were established after 1945 and therefore were not subjected to the same late, hot, dry season fires. In 1946, legislation was passed making the lighting of fires in Benoue National Park "obligatory" at the beginning of the dry season (Letouzey 1948). This burning policy is still in effect and as a result, Afzelia trees established after 1945 show no fire damage.

Fire is an ecological factor of great significance in Benoue National Park. The present burning policy is to burn ground cover annually, as early as possible in the dry season to prevent hotter fires later in the season. However, even early dry season burning continues to have long-term effects on the composition and structure of vegetation. The most obvious change is the die-off of Afzelia trees greater than 45 years old (initially damaged by fires during 1930-1933) due to severe and chronic basal scarring resulting from successive annual fires, and the invasion of Monotes kerstingii into Afzelia woodland where Afzelia trees are dying or dead. Annual fires are damaging Afzelia whereas they are stimulating the growth of Monotes, a much smaller tree which provides little shade. The abrupt transition from Andropogon spp. grass cover in Afzelia woodland, to a ground cover of Hyparrhenia spp. among invading Monotes stands occurs because shade is removed. Clayton (1958) noted an opposite effect in Nigerian savanna, where Andropogon spp. replaced Hyparrhenia spp. grasses wherever a savanna tree grew large enough to cast an appreciable amount of shade. Grasses in Monotes stands still burn but fire intensity is not intense enough to damage Monotes. Grasses in Afzelia stands on the other hand, provide a good supply of fuel and therefore enhance fire spread into the stands, suppressing any seedling growth.

There appears to be little doubt that without annual burning (lightning strikes are rare in Bénoue National Park), tree density would increase in Benoue National Park, especially since this savanna type was originally derived from high forest (Chevalier 1934, Jones 1950, Richards et al. 1939a,b, Glover 1968). For this reason, it is recommended that there be no policy change for burning except in Afzelia woodland. Afzelia woodland must have a reprieve from burning or it will continue to die out and Monotes kerstingii will continue to proliferate. In Chapter VI suggestions are made to prevent the further decline of Afzelia africana.

CHAPTER V

Habitat Relationships of Larger Herbivores

The fauna of Benoue National Park is typical of the Guinea Savanna Zone of West Africa. The park includes species associated with open-wooded savanna, good perennial water supplies and riparian vegetation. As elsewhere in Africa, poaching has left certain species almost extirpated.

Prior to this study, no recorded information existed on the numbers and distributions of animals in Benoue National Park. At the request of "Les Eaux et Forets", Garoua, my specific objectives were: a) to determine the numbers and biomass of the more common large herbivores: Buffon's kob (Kobus kobus), western hartebeest (Alcelaphus buselaphus), defassa waterbuck (Kobus defassa), roan antelope (Hippotragus equinus) and savanna buffalo (Syncerus caffer brachyceros); b) to determine their geographical distributions within Benoue National Park; and c) to determine use of 5 major plant communities and habitat overlap during the dry and wet seasons by the 5 large herbivores.

5.1 Methods

5.1.1 Numbers and Distributions of Animals

Both road counts and foot transects were used to determine the spatial abundance of animals (Fig. 5.1).

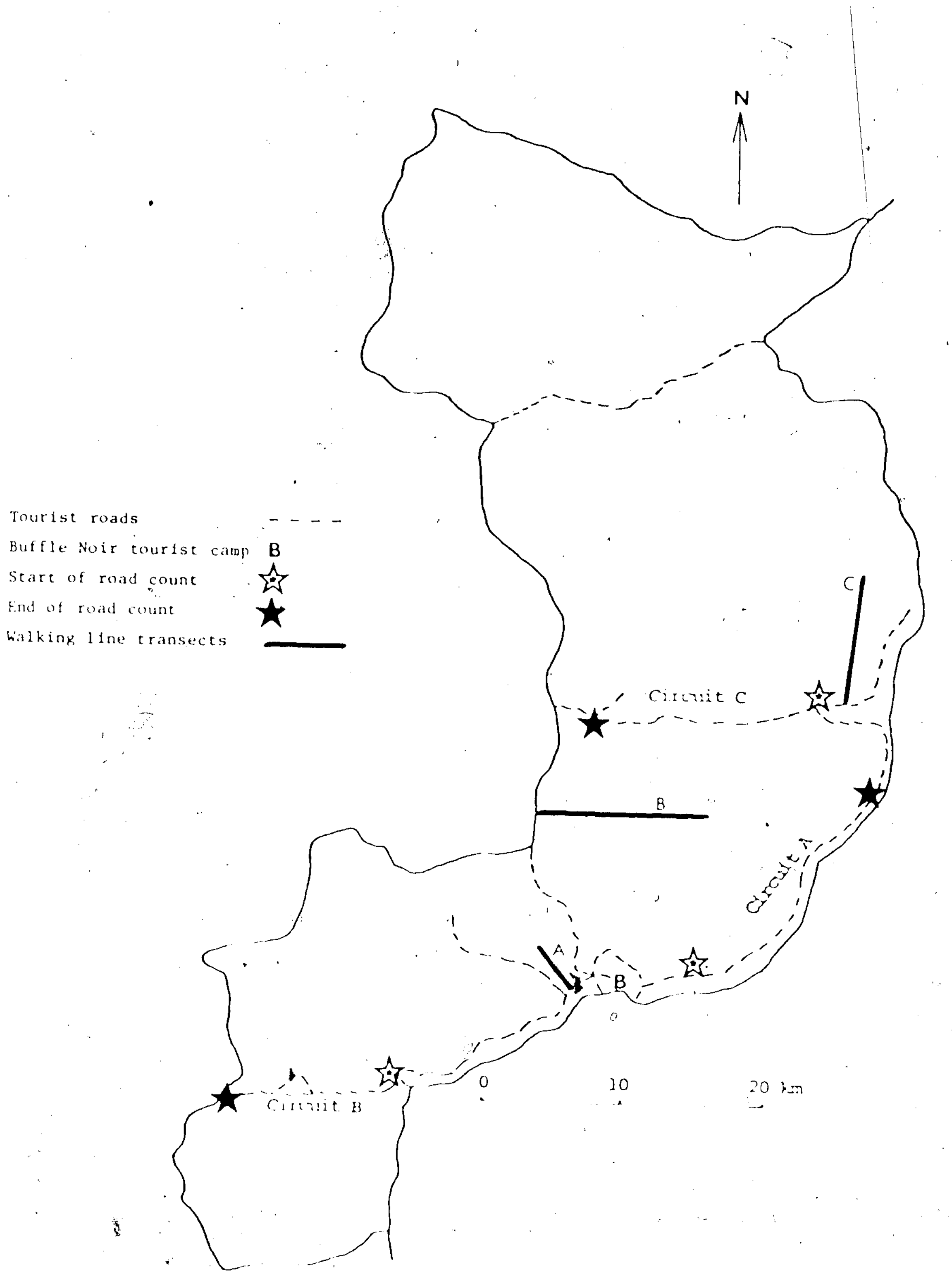


Fig. 5.1 Distribution of the three roads and three foot transects in Benoue National Park, 1974-1975.

Unfortunately only one observer-driver was present during the road counts. Neither of these techniques was suitable for secretive species such as duikers (*Cephalophus rufilatus* and *Sylvicapra grimmia*), bushbuck (*Tragelaphus scriptus*), oribi, (*Ourebi ourebi*), and bohor reedbuck (*Redunca redunca*).

Road counts were carried out along the 3 longest roads in the park, a combined distance of 54 km. Road "A" (22 km) passed through savanna and riparian woodland of varying density and composition. During the wet season, this road was impassable by Land-Rover and was accessed using a motorcycle. Although it was evident that the motorcycle reduced counting efficiency due to the noise disturbance, observations were possible during the wet season and counts were therefore continued throughout the season. Road "B" (14 km) passed through riparian forest and herbaceous floodplains. Road "C" (18 km) passed through open savanna and woodland types. Both roads "B" and "C" were passable year-round.

Mean visibility was determined by placing life-sized painted plywood figures of the five large herbivores at varying distances (by someone other than myself) along the transects. I then drove the transects, noted the figures seen and estimated their distances. Placement of the figures was repeated at 25 m distances until the figures were no longer seen. Average sighting distances (mean visibility) on either side of roads "B" and "C" (for their total lengths) was 150 m and 100 m on either side of Road

"A" (for its total length). The area counted covered 0.8% of the park's 1800 km².

Counts were run at two different times during census days (starting 1/2 hr. before sunrise and 4 hr. before sunset) and were run at least 13 days per month. However, 3 months (2 during the dry season) were missed because of other research commitments. Information was collected on species, number of animals, sex and distance observed. During the wet season, vegetation restricted visibility and greatly reduced areas counted.

Foot transects varied in length from 4-12 km (25 km total) and were located in mountainous regions, open savanna woodland and riparian forest. The area counted (total of all 3 transects), covered 2.7% of the park's 1800 km². Each transect was walked noting the species sighted, sighting distance, numbers of animals and sex. Estimated population densities were calculated:

$$D = N/2(TD)$$

D = estimated population density

N = total number of each species observed

T = total distance walked

D = average distance from the observer to the animal(s) when sighted

Three general assumptions were made: 1) animals vary with regard to sighting distance from the observer; 2) assuming that animals vary with respect to sighting distance, then they are randomly scattered relative to the path of the observer; and 3) the average sighting distance is a true average of all animals in the population.

Observations from road counts and foot transects, and miscellaneous observations made throughout the park, including 4, 3-day foot safaris to the interior of the park were used to produce general distribution maps for the five large herbivores.

5.1.2 Data Analysis

Numbers of animals for each species per km were calculated for each road count and foot transect, and totalled monthly.

Live-weight biomass for all large herbivores in Benoue National Park was estimated using the mean mass of an individual animal (based on the mean mass of an adult female of each species) derived from weights provided by Blancou (1935), Talbot and Talbot (1964), Sachs (1967), Ledger (1968), Child (1974), Bindernagel (1975) and Leuthold and Leuthold (1976).

Distributions were plotted for each species on maps of Benoue National Park produced by SYMAP (Synagraphic Mapping System, Dougenik and Sheehan 1976) on an electrostatic plotter (Appendix VII).

In recognition of the importance of distance to water, data were stratified into three regions in relation to distance from Benoue River: savanna adjacent to riparian habitat (0-3 km from Benoue River); savanna middle distance (3-10 km from Benoue River); and savanna interior (10-15 km from Benoue River). In recognition of the importance of habitat, plant communities' use was summarized for each large herbivore species.

To test overlap in terms of "common" habitat, a custom program involving number (frequency) of observations, circle radii and distance between circle centers was used (Appendix VIII). The program solves for D, the distance between circle centers using a series of iterations with a modified bisection method. Radius 1 produces a circle whose area is proportional to frequency 1, and radius 2 produces a circle whose area is proportional to frequency 2. The distance (D) between circle centers causes an area of overlap (if one exists) that is proportional to frequency (1+2) overlap. Circle radii lengths are left to the discretion of the researcher. For ease of drawing, a radius of 5 cm, representing 200 observations was used in determining habitat overlap. Using "Fisher's Exact Method" (Keeping 1962), probabilities of habitat overlap were calculated by 2 x 2 tables using the same set of marginal frequencies (observations).

5.2 Results

5.2.1 Numbers and Biomass

From road counts and foot transects, group size and adult sex ratio for the five large herbivores were averaged and totalled (Table 5.1). Population estimates and 95% confidence limits, density and live-weight biomass estimates of 15 of the larger herbivores for Benoue National Park are shown in Table 5.2. Table 5.3 compares biomass densities of large herbivores from various parks in East and West Africa with Benoue National Park.

5.2.2 General Distributions

Kob ranged almost exclusively within 1.5 km of Benoue River throughout the year, although the very northern and southern stretches supported very few kob (Fig. 5.2). Hartebeest were the most widely distributed of the larger herbivores. They were found in all plant communities and it was not unusual to find them in the interior of the park during the late dry season (Fig. 5.3). Waterbuck usually ranged within 3 km from Benoue River although sightings were made along smaller tributaries towards the interior of the park (Fig. 5.4). They narrowed their range during the wet season to approximately 1.5 km, greatly overlapping the range of kob. Both roan antelope and buffalo ranged throughout Benoue National Park Figs. 5.5, ~~5.6~~). However, antelope frequented more the interior of the park and buffalo frequented regions closer to Benoue River.

5.2.3 Distribution by Habitat Preférence

Animal distributions were seasonal in Benoue National

Table 5.1 Mean group size and adult sex ratio in Buffon's kob, defassa waterbuck, western hartebeest, roan antelope and savanna buffalo, Benoue National Park, 1974-1975.

Species	Sex Ratio (M:100F)	Group Size Mean	Range	S.D.	n
Buffon's kob	71:100	4.5	1-12	2.7	745
western hartebeest	53:100	5.8	1-24	2.2	446
defassa waterbuck	63:100	3.1	1-7	1.6	464
roan antelope	100:100	3.6	1-11	0.5	142
savanna buffalo	31:100	36.4	1-125	3.7	328

Table 5.2 Population estimates (PE) and 95% confidence limits (CL), densities, and live-weight biomass for 15 large herbivores, Benoue National Park, 1974-1975.

Species	PE	CL	Density (km^2)	Biomass (kg/ha)
Elephant	33	26	0.02	0.30
Rhinoceros	8	5	0.004	0.04
Hippopotamus	235	212	0.13	0.60
Buffalo	2060	1865	1.16	5.96
Buffon's kob	2850	1772	1.58	0.95
Western hartebeest	3000	2501	1.66	2.42
Bushbuck	650	443	0.36	0.12
Defassa waterbuck	1350	1014	0.75	0.54
Roan antelope	325	196	0.18	0.42
Oribi	73	54	0.04	0.005
Warthog	1200	986	0.66	0.35
Giant eland	375	214	0.20	0.98
Red-flanked duiker	1000	580	0.55	0.04
Grimm's duiker	1650	962	0.91	0.06
Giraffe	17	7	0.001	0.09

Table 5.3 Comparison of biomass densities (kg/ha) of large herbivores from various parks in East and West Africa with Benoue National Park.

Locality	Biomass (kg/ha)
Sahara, Rio del Oro	0.01
Tano Nimri Forest Reserve, Ghana	0.05
West of Oum-Cha-Coaba, Chad	0.80
Aberdare Mountains, Kenya	4.20
Borgu Game Reserve, Nigeria	7.03
Baragoi Plains, Kenya	8.95
Tarangire Game Reserve, Tanzania	10.50
Mkomazi Game Reserve, Tanzania	12.00
Benoue National Park, Cameroon	10.40-13.80
Akagera National Park, Rwanda	21.40
Shinyanga, Tanzania	28.10
Tsavo East National Park, Kenya	41.15
Nairobi National Park, Kenya	56.90
Serengeti National Park, Tanzania	63.00
Queen Elizabeth National Park, Uganda	122.50
Albert National Park, Zaire	140.40

1 Cloudsley-Thompson (1969)
2 Child (1974)
3 Harris (1970)
4 Spinage (1969)
5 Leuthold (1976)
6 Present study

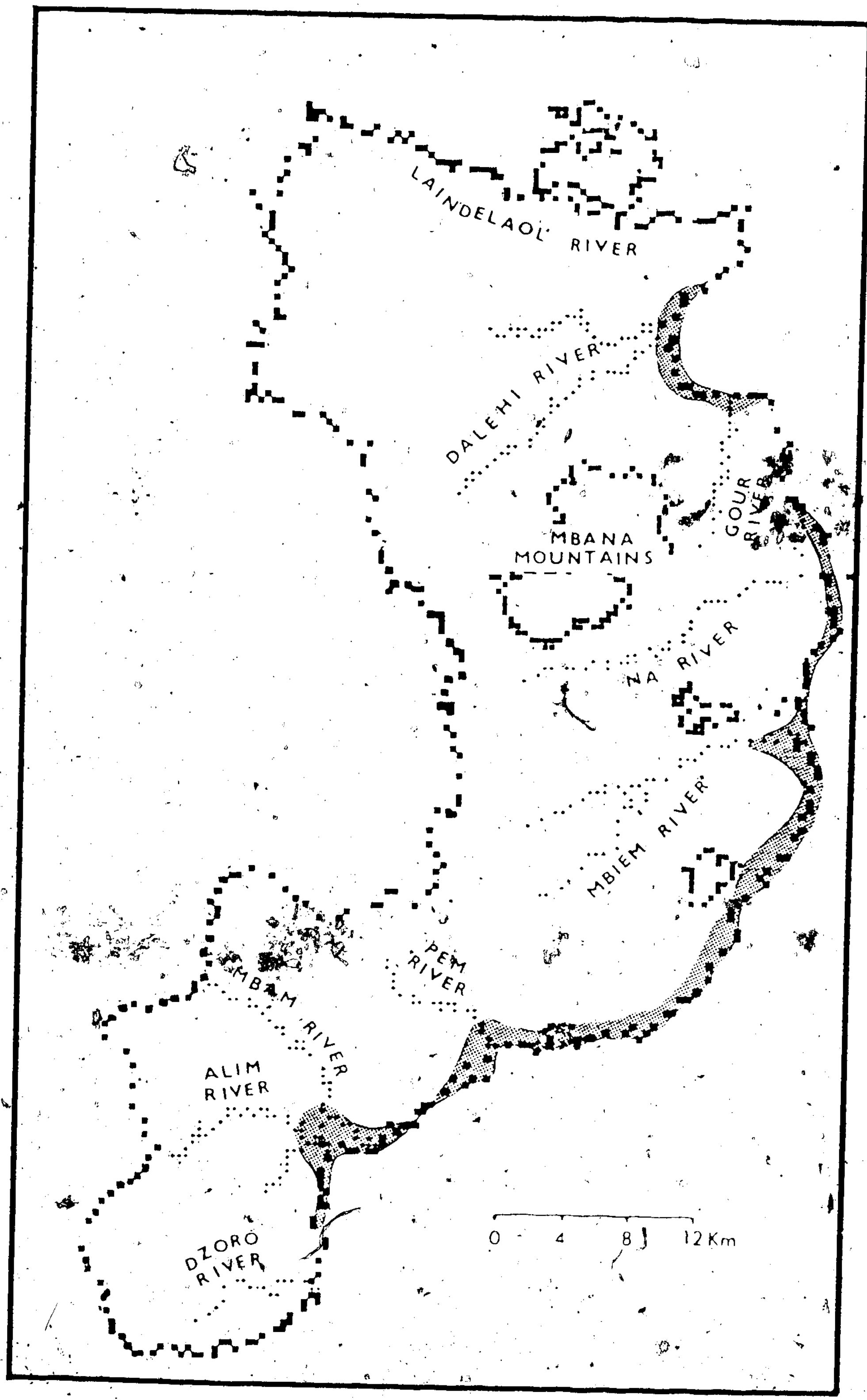


Fig. 5.2 Distribution of Buffon's kob (gray hatches), Benoue National Park, 1974-1975.

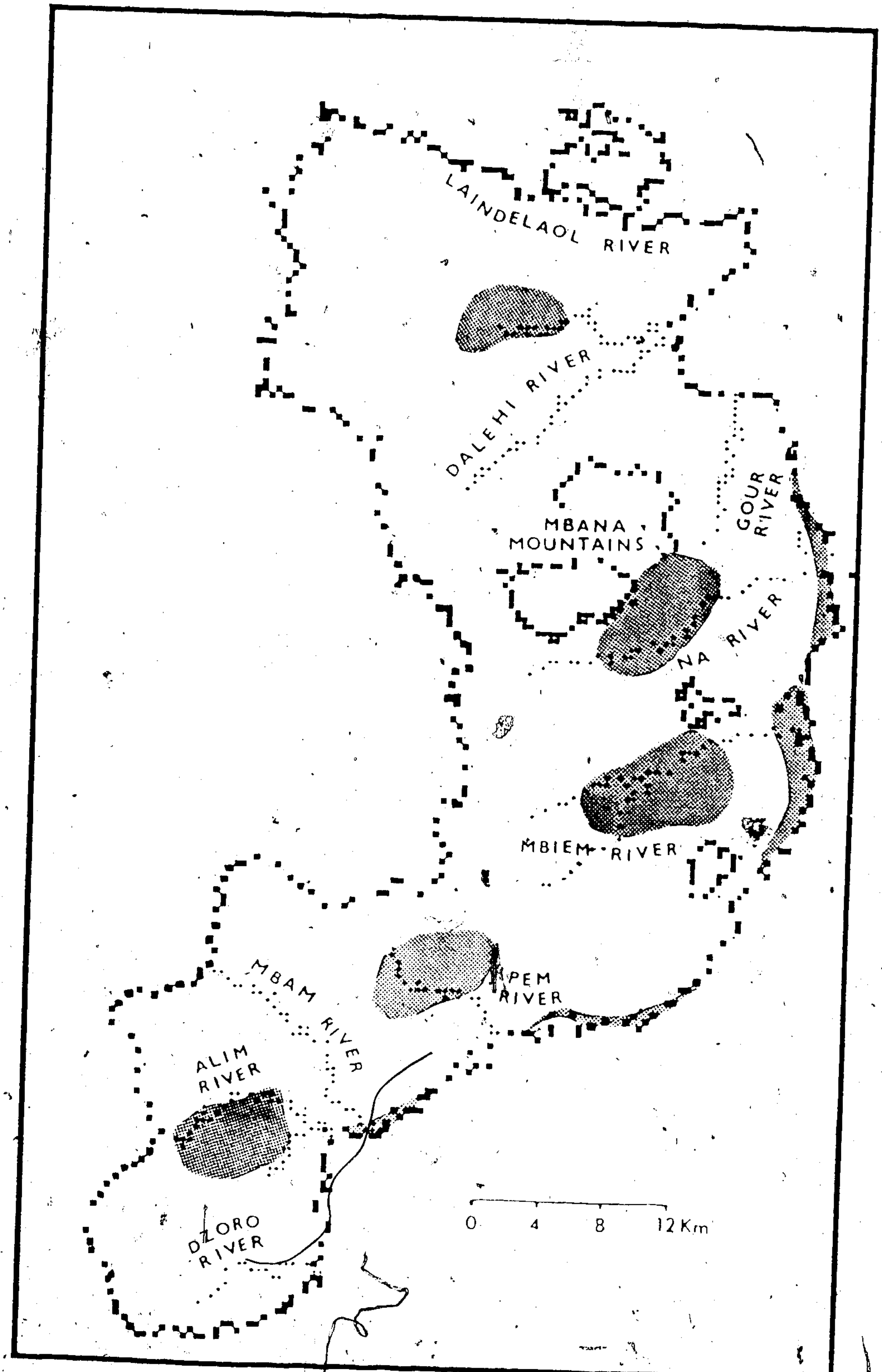


Fig. 5.3 Distribution of western hartebeest (gray hatches), Benoue National Park, 1974-1975.

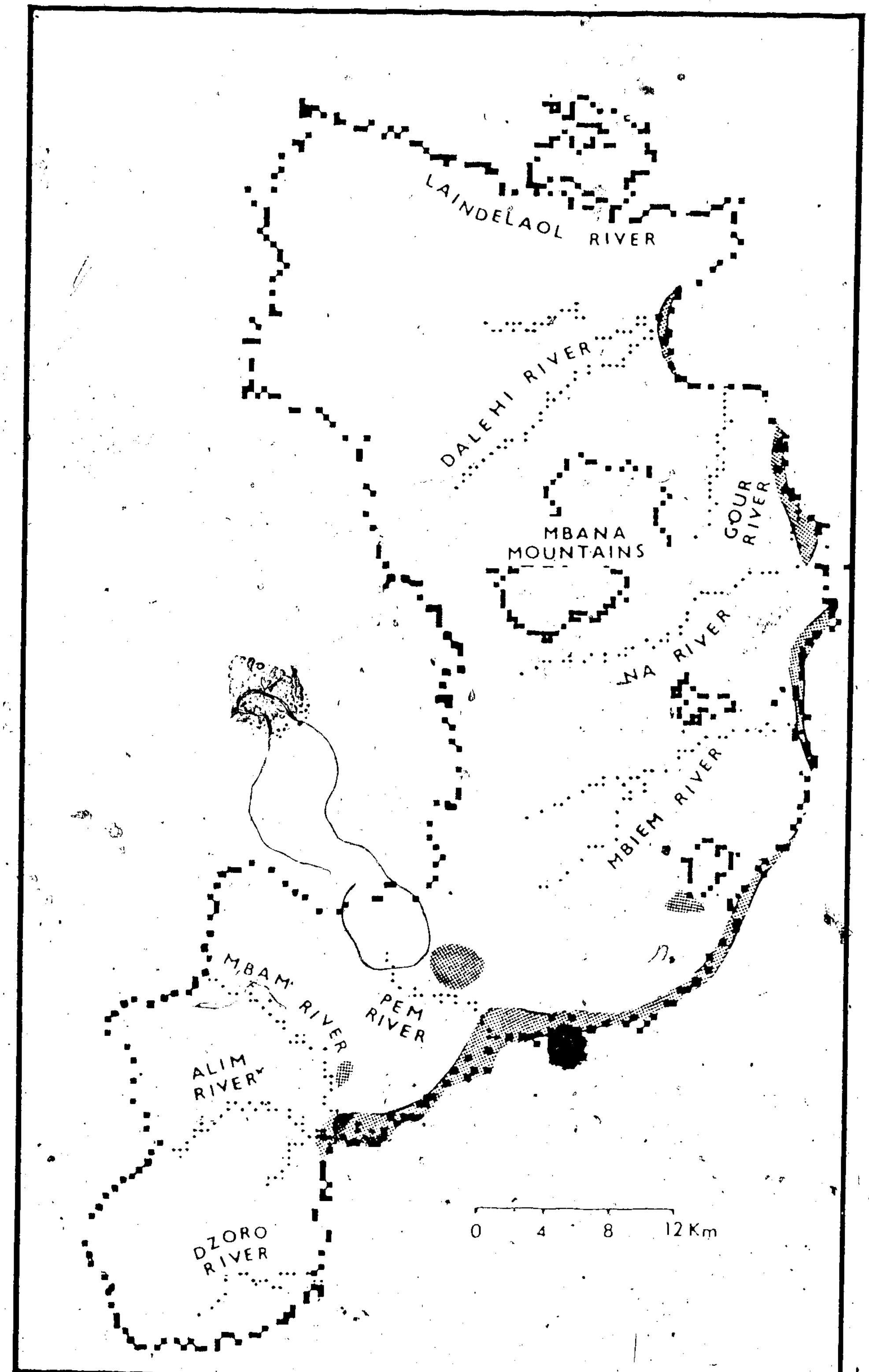


Fig. 5.4 Distribution of defassa waterbuck (gray hatches), Benoue National Park, 1974-1975.

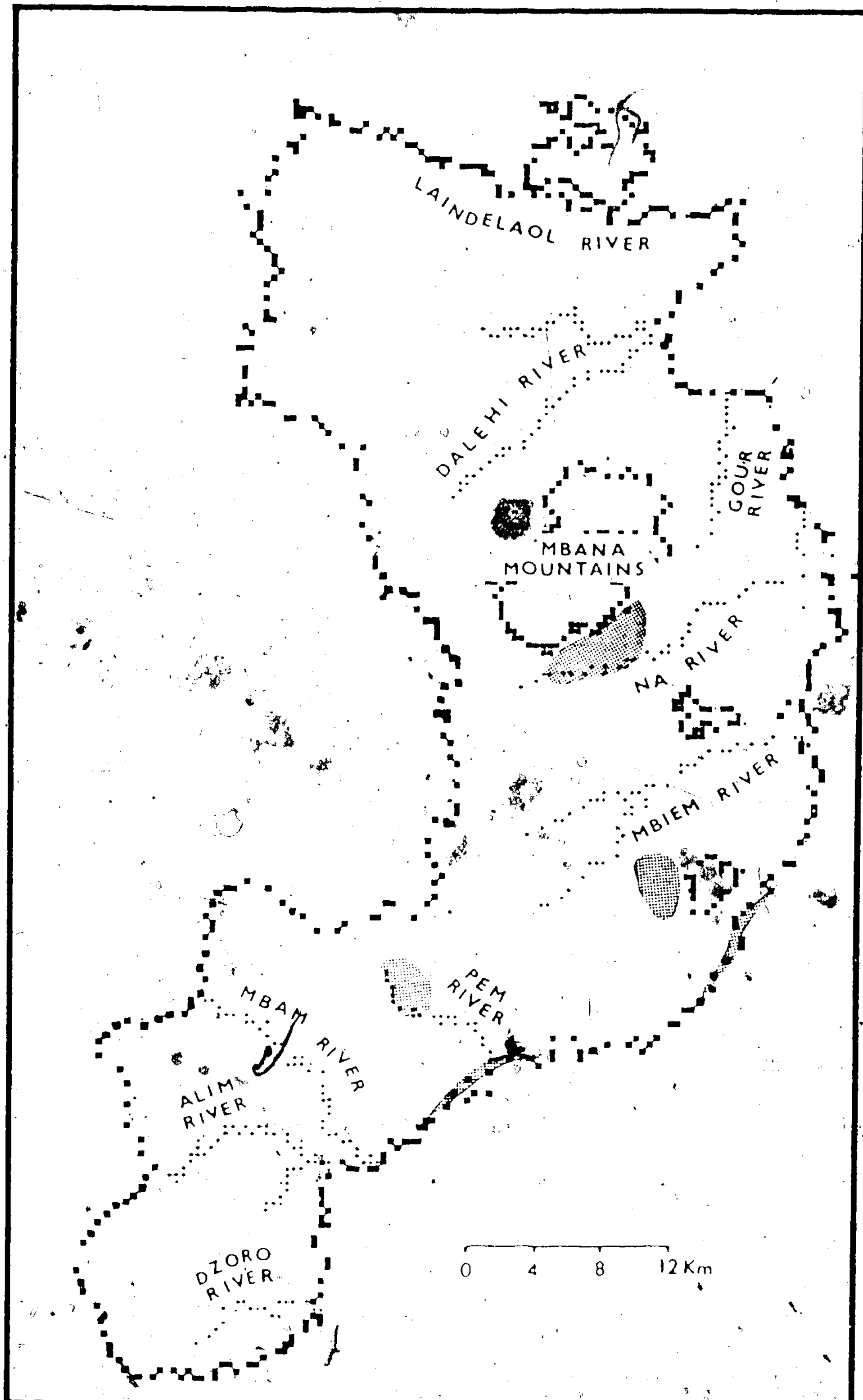


Fig. 5.5 Distribution of roan antelope (gray hatches), Benoue National Park, 1974-1975.

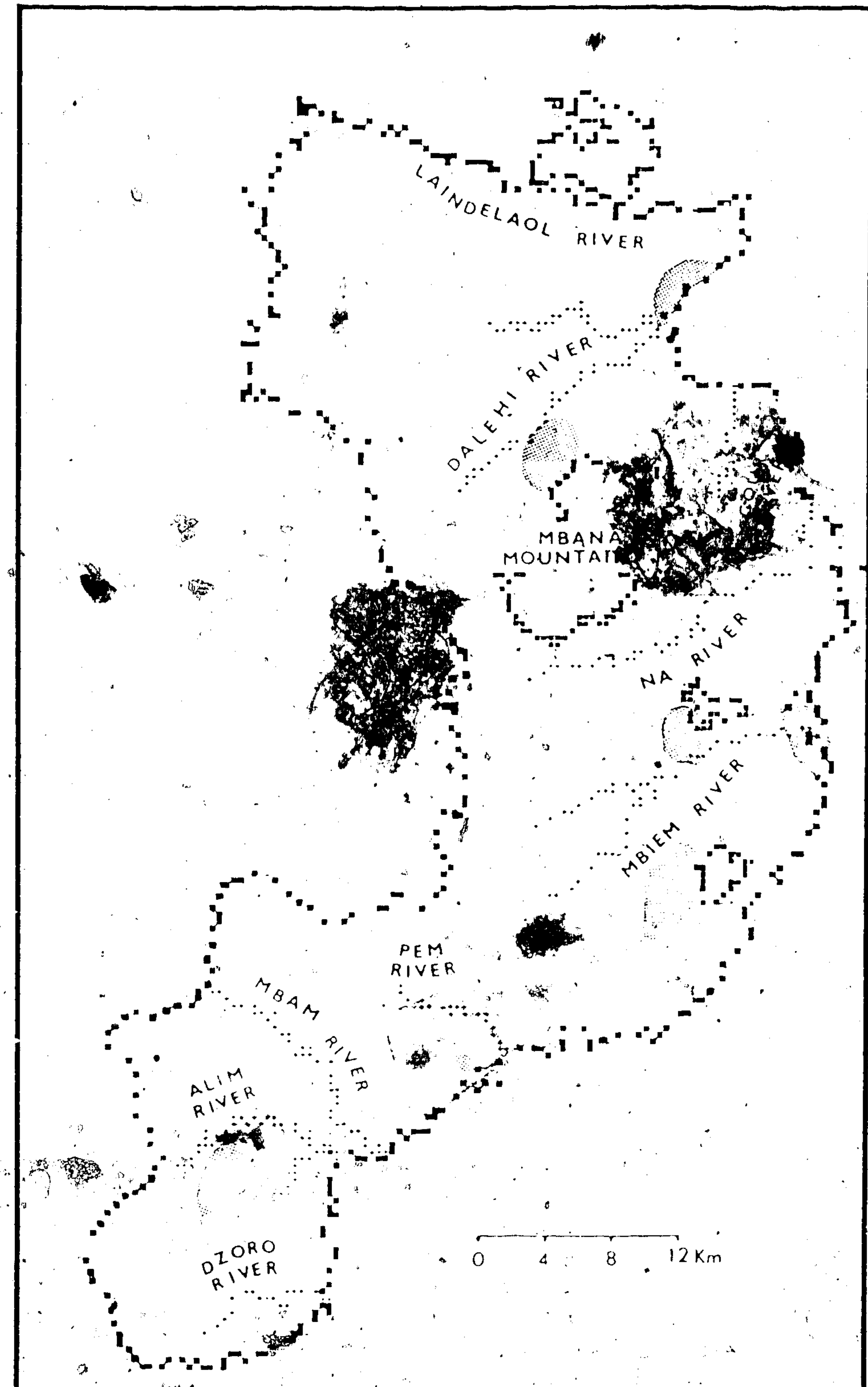


Fig. 5.6 Distribution of savanna buffalo (gray hatches), Benoue National Park, 1974-1975.

shifting closer to Benoue River during the dry season. During the dry season the mean number of combined sightings per month was 87±4.36 sightings 0-3 km distance from Benoue River; 55±4.36 sightings 3-10 km distance from Benoue River; and 15±4.36 sightings greater than 10 km distance from Benoue River. During the wet season the mean number of sightings per month was: 58±2.32 sightings 0-3 km distance from Benoue River; 64±2.32 sightings 3-10 km distance from Benoue River; and 23±2.32 sightings greater than 10 km distance from Benoue River.

Fig. 5.7 presents habitat preference during the dry and wet seasons based on number of sightings in relation to distance from Benoue River. Use of riparian habitat was greatly influenced by the time of year, location and extent of annual grass burning in open savanna woodland. Although each of the five large herbivores favored drier adjacent savanna woodland for feeding, there was a regular movement in and out of this habitat to drink or wallow in shaded pools and riverbeds. Grazing and browsing frequently occurred during this movement and many visits to riparian habitat were in search of natural licks. Mimosa spp. scrub vegetation at confluences of the Benoue River and its tributaries were favorite feeding grounds for kob and waterbuck at mid-day and early evenings during the dry season.

Savanna adjacent to riparian habitat (0-3 km from Benoue River) was utilized by all large herbivores and in some instances, particularly on the short grass swards of

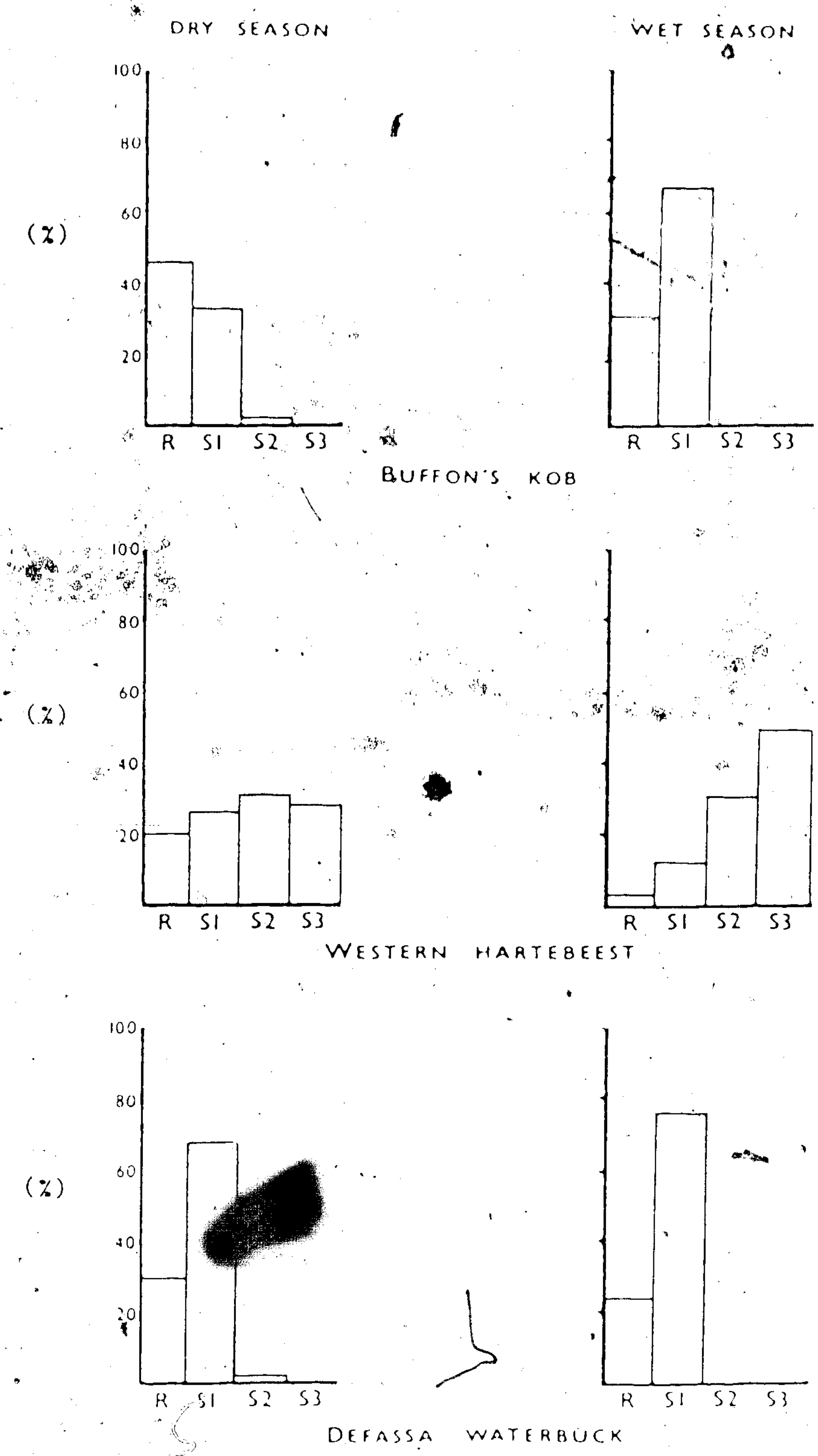
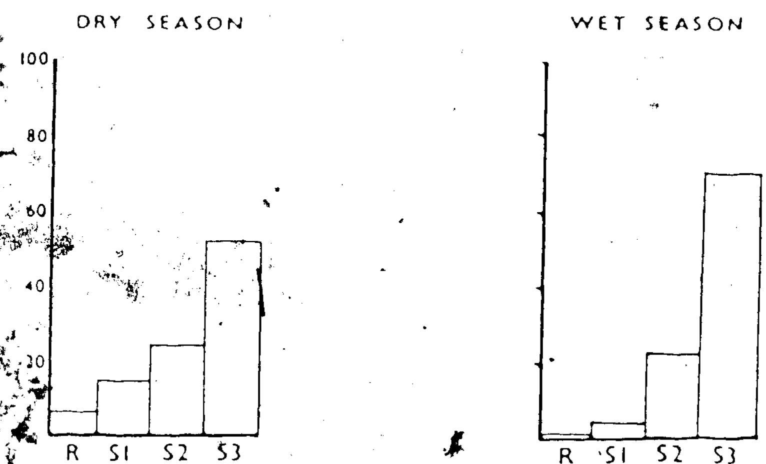
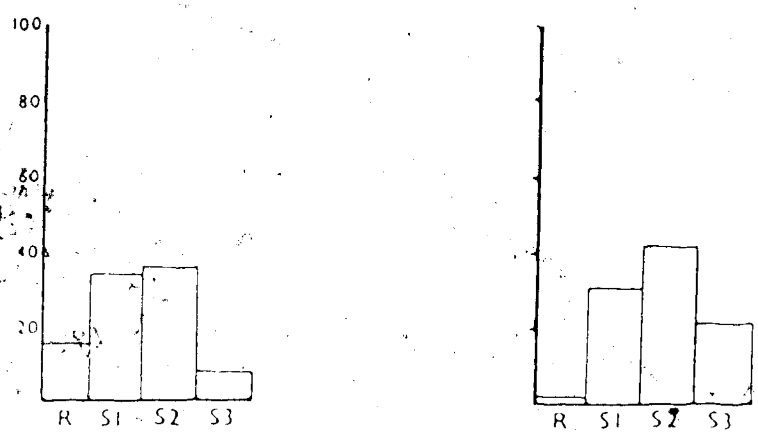


Fig. 5.7 Habitat preferences (%) of the five large herbivores in relation to distance from Benoue River during the dry and wet seasons Benoue National Park, 1974-1975. (R = riparian; S1 = savanna adjacent, 0-3 km; S2 = savanna middle distance, 3-10 km; S3 = savanna interior, 10-15 km).



ROAN ANTELOPE



SAVANNA BUFFALO

old village sites where animals congregated during both the dry and wet seasons, there were signs of deterioration of grass cover. Flushes of perennial grasses after annual fires attracted hartebeest, buffalo and antelope, and supported resident populations of territorial kob, Grimm's duiker (Sylvicapra grimmia) and waterbuck.

Hartebeest and buffalo were found primarily in savanna middle distance (3-10 km from Benoue River). Roan antelope increasingly occupied this savanna during the late dry season. Kob were never observed in this savanna and only rarely were waterbuck observed.

Very low levels of vegetation utilization occurred in savanna interior (10-15 km from Benoue River). In many instances, perennial grass tussocks were left untouched. Widely spaced distributions of hartebeest and buffalo occurred in this region. This savanna was preferred by antelope throughout the year until late in the dry season when water sources became scarce, forcing them to move closer to Benoue River.

The percent use of the five major plant communities during the dry and wet seasons is illustrated in Fig. 5.8. Kob had a narrow plant community preference in Terminalia laxiflora open savanna, particularly during the dry season. During the wet season, utilization of Anogeissus riparian forest along smaller tributaries and Isoberlinia woodland increased with movement away from Benoue River.

Hartebeest did not show a preference for one

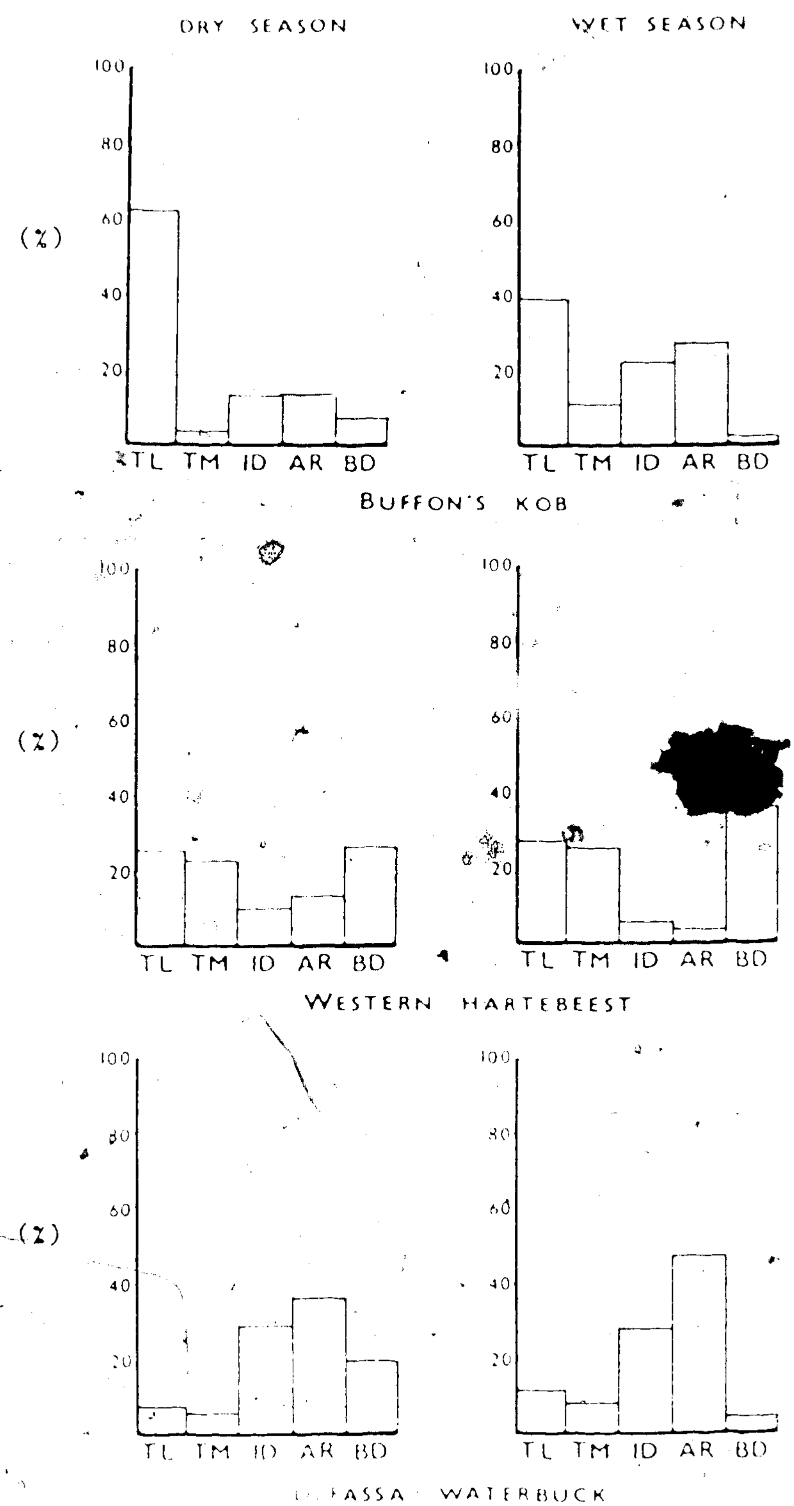
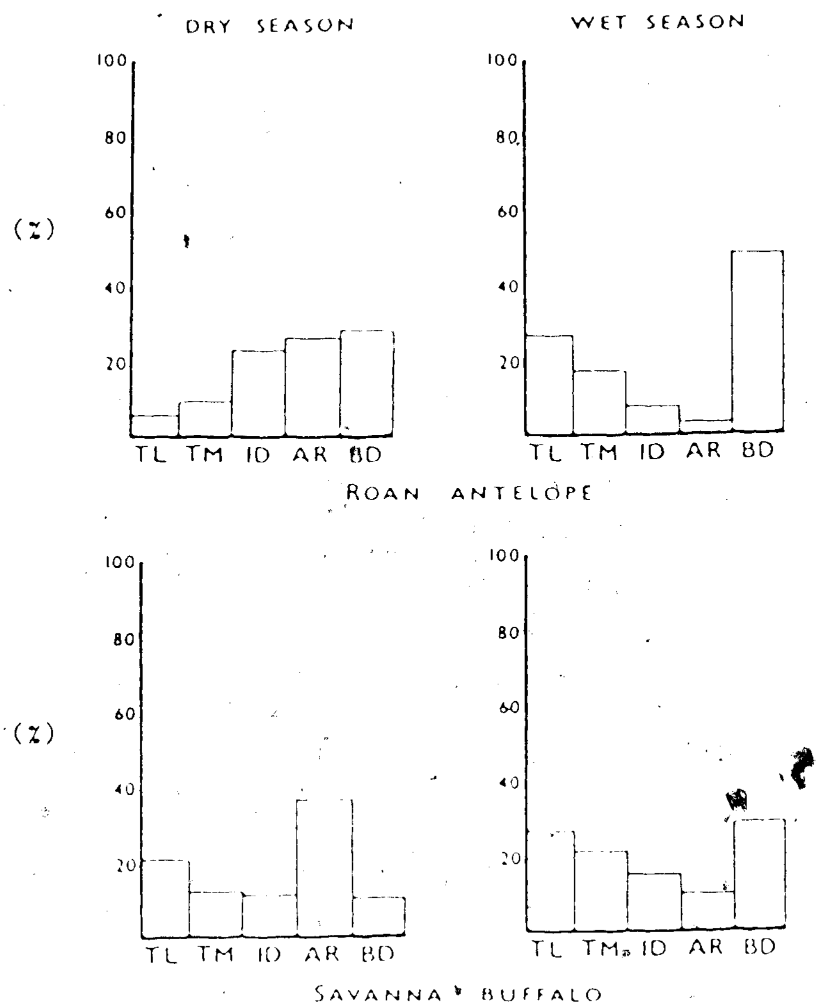


Fig. 5.8 Percent use of the five major plant communities by the five large herbivores, Benoue National Park, 1974-1975. (TL = *Terminalia laxiflora*; TM = *T. macroptera*; ID = *Isoberlinia doka*; AR = *Anogeissus riparian*; BD = *Burkea-Detarium*).


DRY SEASON
WET SEASON
(%)
100
80
60
40
20
TL TM ID AR BD
ROAN ANTELOPE
SAVANNA BUFFALO

particular plant community during the dry season: *Burkea-Detarium*, *T. laxiflora* and *T. macroptera* open savanna were all used in almost the same proportion as were *Isoberlinia* woodland and *Anogeissus* riparian forest combined. During the wet season, use of *Burkea-Detarium* open savanna increased as hartebeest moved more to the interior of the park, beyond *Anogeissus* riparian forest and *Isoberlinia* woodland, common close to the Benoue River.

Waterbuck spent more than one-half the dry season in either *Anogeissus* riparian forest or *Isoberlinia* woodland. During the wet season, use of *Isoberlinia* woodland decreased slightly but there was a significant shift to *Anogeissus* riparian forest as animals moved further into the park but remained along smaller tributaries.

Roan antelope showed a significant shift into *Burkea-Detarium* and *T. laxiflora* open savanna during the wet season whereas use of *Anogeissus* riparian forest decreased. Their shift towards the interior of the park, away from Benoue River accounted for these changes.

As with the other four large herbivores, there was a significant shift in use of habitat by buffalo close to Benoue River and its tributaries, to the interior of the park as temporary water sources increased during the wet season. Buffalo utilized *Anogeissus* riparian forest heavily during the dry season whereas *Burkea-Detarium* open savanna use increased during the wet season.

5.2.4 Habitat Overlap

The spatial overlap is depicted in Fig. 5.9 in terms of "common" habitat used by the five larger herbivores during the dry and wet seasons. There was overlap among all five large herbivores during the dry season, whereas during the wet season, there was no overlap between kob, waterbuck or roan, or between kob and buffalo. The overlap during the dry season resulted from an apparent shift of animals closer to the permanent water source, Benoue River. Antelope moved far into the park's interior accounting for no overlap with kob and waterbuck which remained close to Benoue River. Frequent movements of hartebeest into the interior of the park accounted for the significant overlap with antelope and buffalo. Although there was no overlap between kob and buffalo during the wet season, there was some overlap between waterbuck and buffalo resulting from a slight shift by waterbuck towards the park's interior. Hartebeest and antelope which were found more towards the interior of the park during the wet season only overlapped buffalo range slightly due to buffaloes' preference of savanna middle distance.

5.3 Discussion

The low biomass for Benoue National Park is the result of low numbers of very large herbivores - giant eland (Taurotragus derbianus), elephant (Loxodonta africana), giraffe (Giraffa camelopardalis), buffalo and

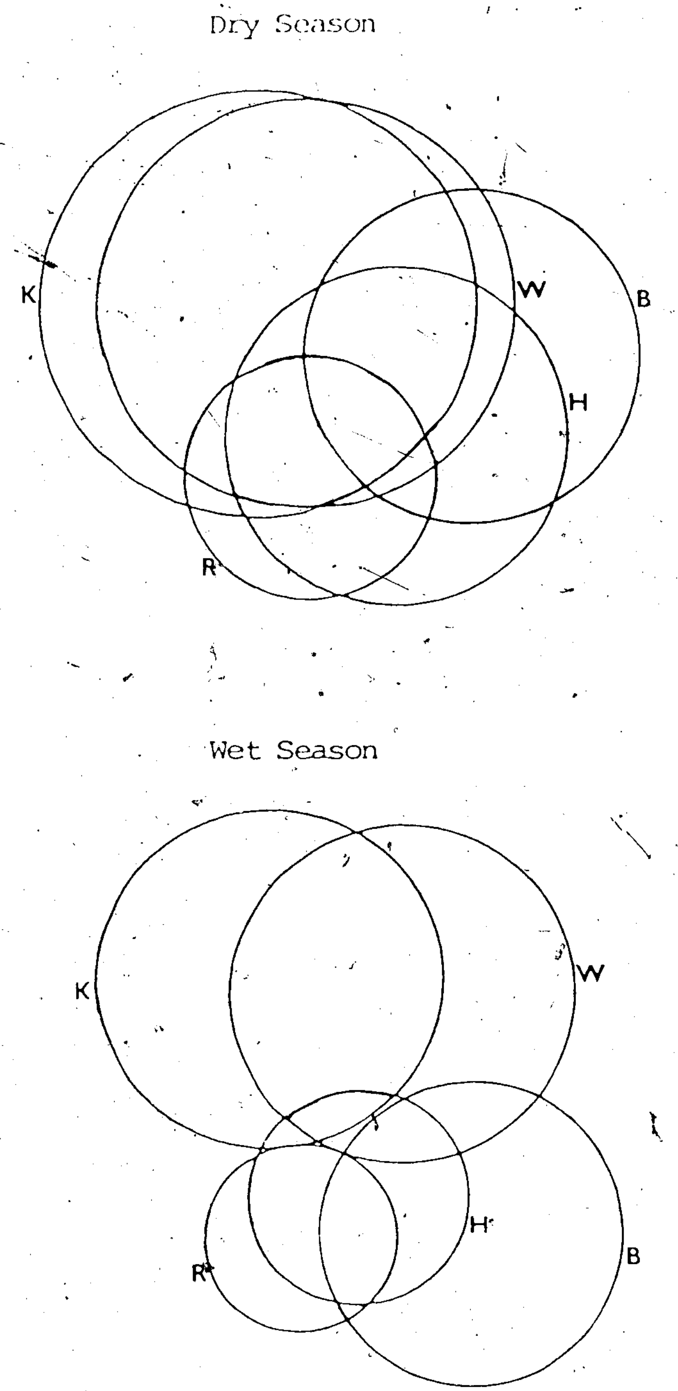


Fig. 5.9 Spatial overlap of Buffon's kob (K), western hartebeest (H), defassa waterbuck (W), roan antelope (R), and savanna buffalo (B) during the dry and wet seasons, Benoue National Park, 1974-1975. (Circle diameters represent habitat preference - the smaller the diameter, the more narrow the habitat preference).

rhino (*Diceros bicornis*). Using the logarithmic curve of large herbivore biomass in relation to annual precipitation (Coe, Cumming and Phillipson, 1976), Benoue National Park should support 125-158 kg/ha. Presently, the park is supporting 10% of the expected biomass. Although herbivore biomass of habitat (vegetation) types in East and South Africa are not directly applicable to West Africa (*Acacia* woodland in East and South Africa has high primary productivity, Laws et al. 1975), the ratio 1:10 herbivore biomass does reveal that Benoue National Park is below its carrying capacity. The main reason for the low biomass is poaching. During the study, poachers blatantly entered the park at any time of the year and during daylight hours, shooting animals with modern rifles. Although no deaths of game guards occurred, the guards were frequently challenged by poachers. The guards' obsolete 303 rifles were no match for the poachers, often civil servants and equipped with modern rifles. As a result, guards usually turned a blind eye to poaching.

The ecosystem of Benoue National Park is highly seasonal and this has an important bearing on the dispersal of large herbivores. The availability of water varied seasonally and habitat preference varied during the dry and wet seasons as a result. This was illustrated by stratifying Benoue National Park into three general savanna regions and comparing the relative abundance of the five large herbivores in each during the dry and wet seasons. The two savanna regions (adjacent to riparian habitat and middle savanna) have the Benoue River, a constant water source throughout the dry season. The savanna region greater than 10 km from Benoue River, has intermittent standing water sources, the majority of which dry up by the end of the dry season.

Seasonal movements of animals in Benoue National Park are not as impressive nor as vast as seasonal movements of animals in parks of East Africa. However, there is a distinct seasonal movement of animals, with the exception of roan antelope and giant eland which reside primarily in the interior regions of the park. These movements are largely in relation to availability of water. In Benoue National Park, greatest concentrations of large herbivores during both the dry and wet seasons were found within an average distance of 7 km from Benoue River. Lamprey (1963), noting the confined distribution of herbivores in Tarangire National Park during the dry season, commented that the extent and distribution of permanent water in the dry season throughout the Masai area of Tanganyika (now Tanzania) was probably the most important limiting factor in the number and distribution of game animals in the savanna of East Africa.

According to Harris (1972) and Sale (1974), the relative proportion of times a species is observed in various habitats is a suitable index of habitat preference. A positive relationship has usually been assumed between habitat overlap and competition and measures of overlap have been used as estimates of competition coefficients (Culver 1970, 1974, Pianka 1974, Davidson 1980, Porter and Dueser 1982). Colwell and Futuyma (1971) and Hurlbert (1978) have commented that overlap need not result in competition, if resources are not in short supply. In Benoue National Park, the greatest overlap occurred during the dry season among all 5 large herbivores. During the wet season, a shift away from Benoue River decreased the overlap of all species as their distributions became more scattered.

The herbivore study had its limitations with the techniques used, in particular there was only one observer-driver on the road counts. Nevertheless, the study provided some indication of the numbers and distributions of the five large herbivores and their habitat preferences. These will hopefully be useful for comparison with follow-up studies in Benoue National Park and possibly elsewhere in Africa. A possible extension to the boundary of Benoue National Park has been proposed and it is hoped that the knowledge gained during the study on habitats of general importance for the five large ungulates may be relevant to decisions on the extension.

Chapter VI

Synthesis and Management Proposals

Protected areas in Africa can encompass thousands of square kilometers: in Kenya, Tsavo National Park is more than 20,720 km^2, the Serengeti in Tanzania is more than 15,540 km^2 and the Luangwa Valley in Zambia is over 12,950 km^2. Parks in Kenya, Tanzania, Uganda and Zambia total 98,420 km^2, whereas in other countries including Malawi, Botswana, Rwanda, Ethiopia, Mozambique, Zimbabwe and South Africa, protected areas total almost 103,600 km^2 (Myers 1972). Most of these areas are found in savanna and because of their extreme diversity in biota, are usually complex. Virtually all protected areas are, or soon will be, ecologically incomplete, insular islands of "natural" habitat surrounded by supporting territory which is becoming less and less supportive, and in most cases, lost. Many, if not most, are poorly managed. Some are essentially unmanaged. Policies, if any were set up to fulfill management objectives, may once have been dynamic but most are now unable to adjust to new pressures and opportunities.

A protected area must have a perceived purpose and researchers and governments must realize that natural succession in its biota is no longer possible. In short, protected areas cannot continue to be vigorously defended enclaves (as most areas are today) excluded from local land-use planning. They must be integrated into a multiple-use concept. Myers (1972) stated that future protected areas in Africa will reflect the extent to which ecological needs are balanced with socio-economic needs. Any new protected area must cope with encroaching pressures of the environs and must be able to adjust to new pressures and to establish a specific policy from which to derive management objectives. According to Soule et al. (1979), the best one can hope for protected areas in Africa today is "benign neglect".

6.1 Benoue National Park

Benoue National Park is not a complete ecological unit as evidenced during the study which showed some species extended their ranges beyond the park boundaries. Although a prohibited hunting zone extends 1 km from the park boundary, it does little in providing a buffer zone between hunting zones which completely encircle the park (Fig. 6.1). The park has no clearly enunciated or written policy on wildlife or habitat management. In principle, the park provides for multiple-use: it protects ancient Africa, promotes tourism, serves as a sanctuary for wildlife (the prevalence of the tsetse fly excludes livestock), preserves vegetation, and permits fishing in Benoue River (this includes fishing by line, and poison). However, in practice, the park assumes two roles, a small degree of tourism and a reservoir to maintain wildlife for sport hunting.

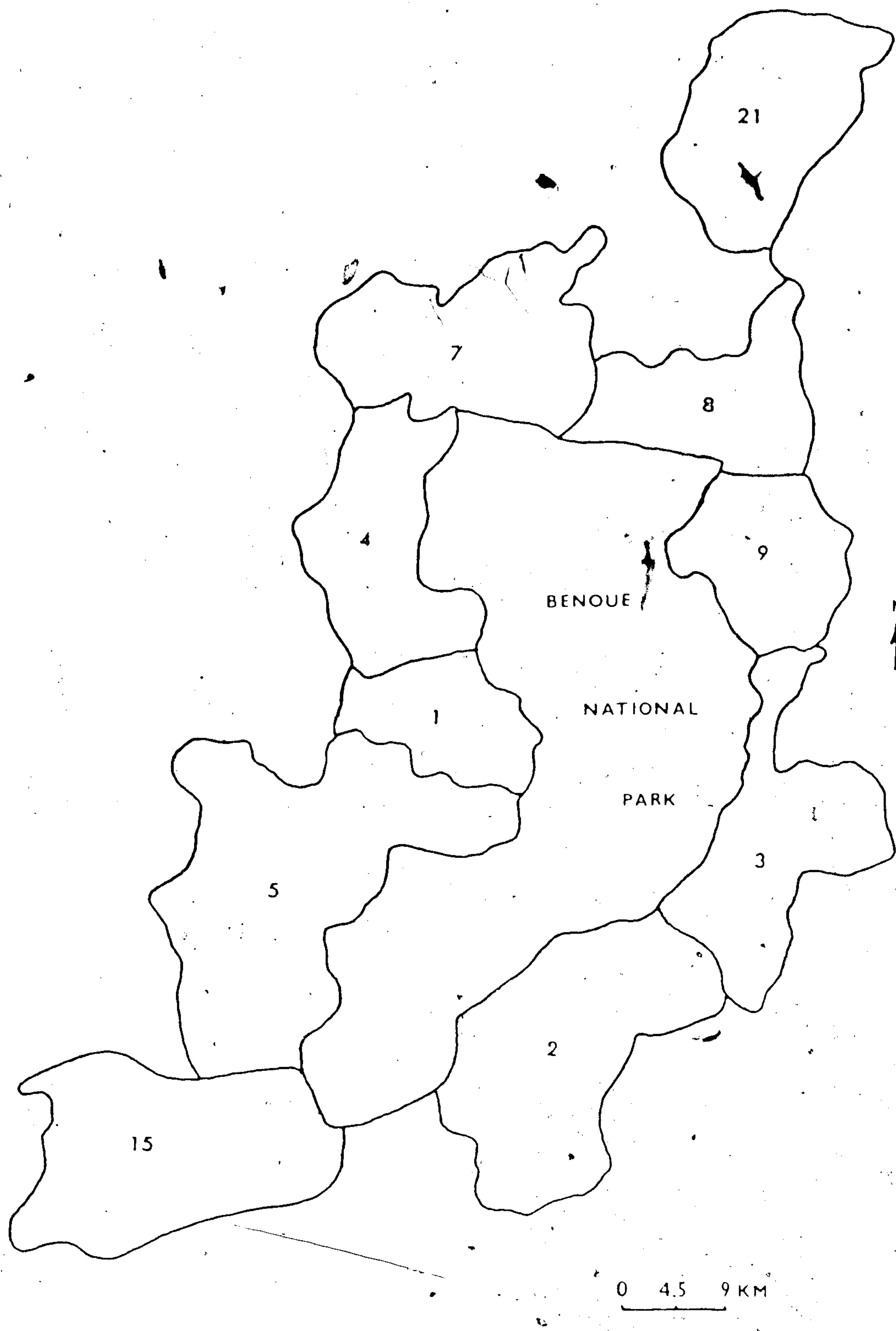


Fig. 6.1 Benoue National Park and surrounding hunting zones, 1974-1975.

From the study, there are 3 areas of immediate concern for Benoue National Park: fire control, poaching and hunting pressure. Tourism and park extension which are of less immediate concern but still very important, are directly related to these concerns and therefore are also addressed in the management proposals. The management proposals for all five concerns are presented below.

6.2 Management Proposals

The current stage of habitat in Benoue National Park is suited to the needs of grass-eating and shade-seeking herbivores and the habitat must be maintained to discourage the establishment of a denser woodland. An immediate objective of managing Benoue National Park is to maintain the present burning policy except in certain areas where fire must be eliminated or controlled. Because animal densities are highest within 7 km from Benoue River along most of its length, particularly during the dry season, annual burning is not recommended within 7 km of Benoue River. The construction of a second tourist road running parallel to the present river road, but at a distance of 7 km from Benoue River is proposed (the existing road running along Benoue River would still be maintained). A system would be set up in the 7 km wide band whereby "blocks" (these blocks would be delineated by water courses which flow east to west from the interior of the park) would be alternately burned every 1-3 years, depending on the amount of fuel and condition of the ground cover (Fig. 6.2). The blocks would vary in size and burning would be carried out early in the dry seasons. The water courses would act as natural fire breaks (water still flows during the early dry season). Alternate burning of blocks would create a mosaic of rested, unburned vegetation, and yet maintain open areas for viewing wildlife.

To prevent further decline of Afzelia africana woodland, it is proposed that burning be completely eliminated from all Afzelia woodland for 5 years. Every 3-5 years thereafter, burning would be carried out very early in the dry season when fuels are damp and partially green, and in the same direction (not opposite) as the prevailing harmattan winds. Burning as such would eliminate the potential of very hot fires resulting from a fuel load built up over a 3-5 year period. Afzelia stands are not so large that an encircling fire break could not be cleared to prevent the spread of fire into the stands. Exclusion of fire would allow establishment of seedlings and give more time for basal scars to heal.

Effective protection of wildlife in Benoue National Park is essential. This includes not only manipulating or removing annual fires, but more importantly, controlling poaching. Poaching is heavy, both inside and outside the park, especially along Benoue River. If stopped, or at least controlled, it would allow a build-up of all animal numbers, resulting in increased live-weight biomass. More

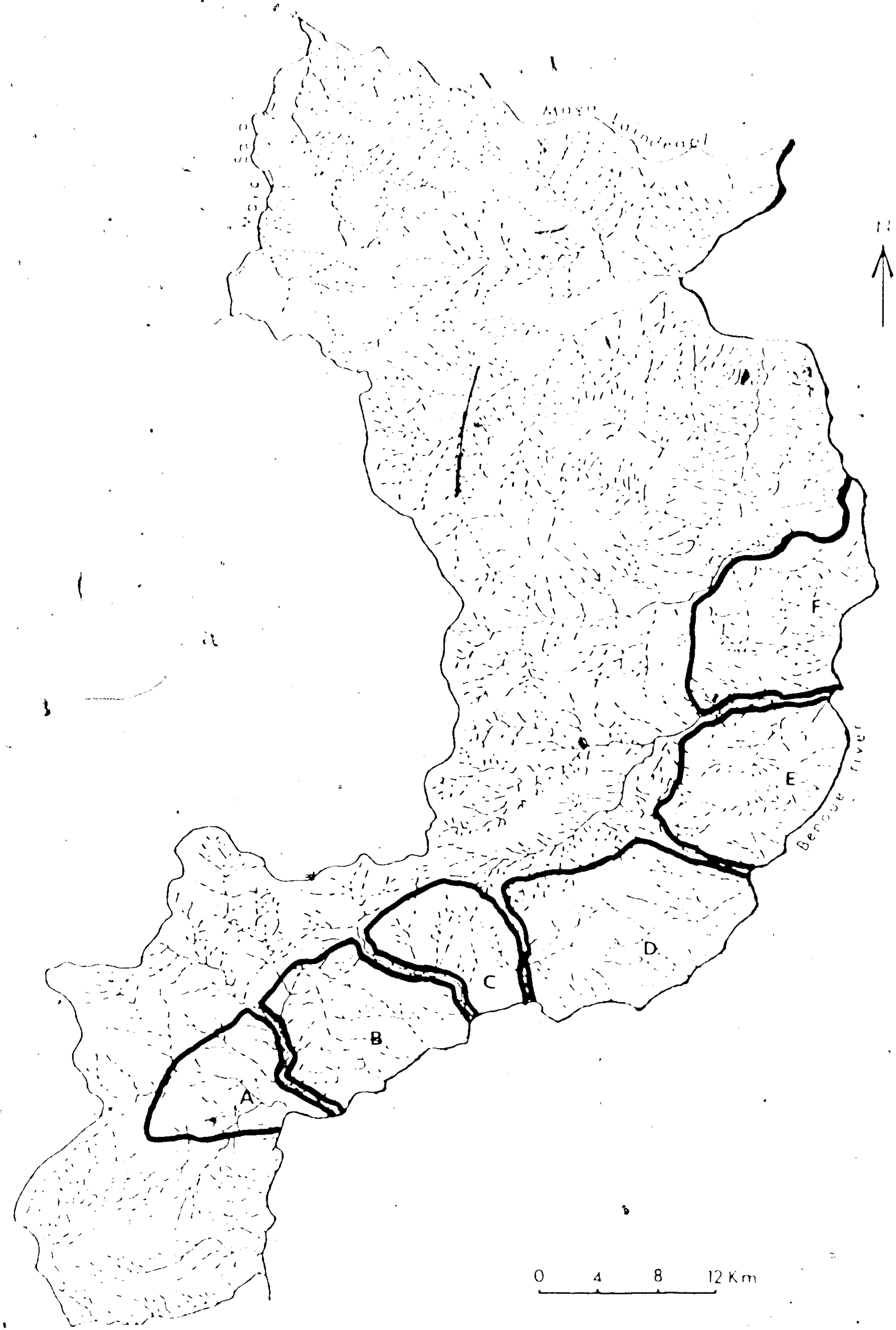


Fig. 6.2 Benoue National Park showing blocks of vegetation (A-F) for proposed alternating burning program.

field staff, transportation and field offices are desperately needed for proper surveillance of the park. Field staff must be trained in communications, use of firearms and the biology and ecology of the park. Foot and vehicle patrols must be stepped up, including night patrols, and monthly census flights could also be used to help check on poaching camps. It is proposed that all field staff eventually attend the Garoua Wildlife Specialist's School.

Hunting pressure in hunting zones encircling the park must decrease or cease. Quotas are often exceeded and wounded animals are a serious problem. Enforced supervision of hunters is essentially non-existent, even though guides (who are actually park rangers) are required with each hunter. Bribery is common. With movements of wildlife common outside the park, hunting is severly depleting the park's wildlife. With the combination of both poaching and hunting pressures, wildlife of Benoue National Park can only continue to decrease, seriously affecting any potential for tourism.

Little time, energy, finances or resources has been spent in establishing an infrastructure for the pleasure and enjoyment of tourists in Benoue National Park. Tourism is far below the actual potential of the park: in 1976, 2,200 tourists visited the park, and in 1982 there were 2,438 visitors. Eighty-eight percent of these tourists were expatriates working in Cameroon or native Cameroonians. Although there are daily flights from

Europe to Cameroon, there is at least a 4-5 hour drive to the park from either N'gaoundere or Garoua. There are no 'package' tours from either of these points to the park and therefore car hires are necessary.

No major development of the land around Benoue National Park appears likely in the foreseeable future and so the clientele will continue to be only persons whose interest in the wildlife and facilities override the problems of accessibility. The game viewing situation and its problems are entirely different from those of savanna areas of East Africa. Consequently, special methods must be adopted to provide tourists with adequate opportunities to encounter and photograph wildlife. Riparian and open savanna vegetation provide adequate opportunities to encounter good numbers and a wide diversity of animals in a relatively short time, but the system can be improved. Game guards who accompany tourists are generally unfamiliar with interesting areas of the park, and aspects of the behaviour and movements of wildlife. Consequently, tourists leave the park without having had the opportunity to see most wildlife or understand different aspects of the park. Walking safaris in the company of a game guard should be developed for tourists. This might also provide another means of detering poaching.

Plans are still underway to extend Benoue National Park northward to include approximately 40,000 ha which would increase the park to 220,000 ha (Fig. 6.3). This would include the Mbay River and almost 40 more km of

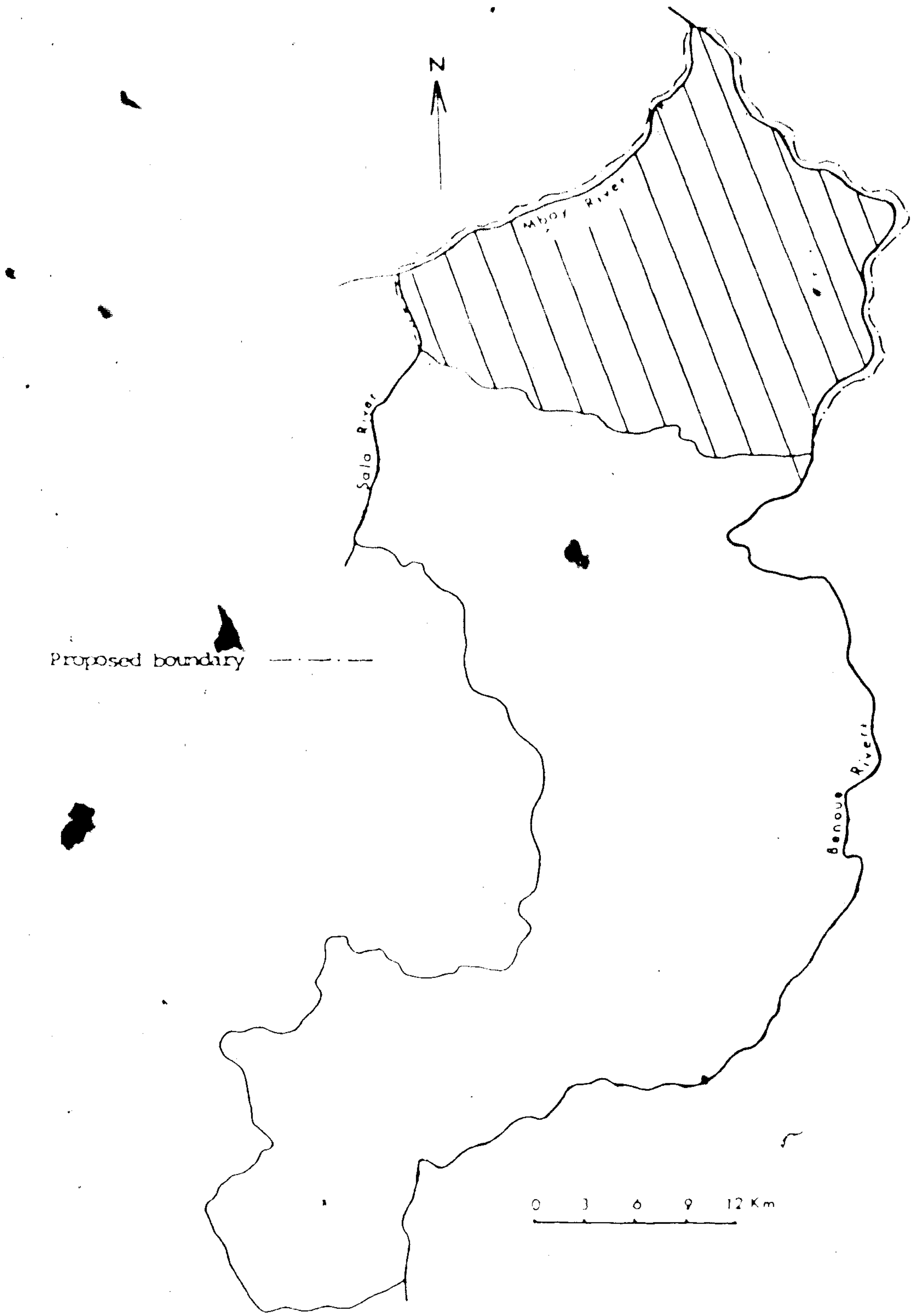


Fig. 6.3 Proposed extension of Benoue National Park (hatched area).

Benoue River, which becomes very wide and spreads out over an alluvial flood plain. Hunting zones 7, 8 and 21 would be permanently closed. It is hoped that any proposed road system for the extension will be examined from the point-of-view of advantages and disadvantages of accessibility, wildlife viewing and poaching (proper patrolling is a necessity). In addition, west of the proposed extension (the proposed 40,000 ha lie just on the edge of the tsetse fly range) there is a high cattle population. It may prove difficult to control movements of cattle entering the proposed extension and a problem of illegal grazing could result.

The results of this study have provided baseline information, and identified and suggested management proposals for the major problem areas in Benoue National Park. The key to any successful multiple-use plan for a park lies in co-ordinating land-use management and co-operation between governments and local peoples. An integrated resource management plan which will be flexible, and which can be reviewed at any time for necessary changes is needed for Benoue National Park. Further research will be necessary to evaluate these changes. There is little doubt that demands placed upon Benoue National Park will increase as population and cultivation demands increase. It is hoped that these findings will assist future co-ordinated resource management planning.

LITERATURE CITED

Aubreville, A. 1949. Climats, Forets et Desertification de l'Afrique Tropicale. Societe d'editions Geographiques Maritimes et Coloniales, Paris. 234 pp.

Austin, M. P. and L. Orloci. 1966. Geometric models in ecology. An evaluation of some ordination techniques. J. Ecol. 54:217-227.

Beard, J. S. 1944. Climax vegetation in tropical America. Ecology 25:127-158.

Beard, J. S. 1953. The savanna vegetation of northern tropical America. Ecol. Monogr. 23:149-215.

Bell, R. H. V. 1970. The use of the herb layer by grazing ungulates in the Serengeti. In animal populations in relation to their food resources. ed. A. Watson. Oxford: Blackwell. pp. 111-123.

Bindernagel, J. A. 1975. Wildlife utilization in Tanzania: The ecology of three wildlife areas in Tanzania with special reference to wildlife utilization. Project Working Document No. 1. URT: 72/011. FAO, Rome. 121 pp.

Blancou, L. 1935. Buffles de L'Oubangui-Chari-Tchad. Service des Eaux et Forets. La Terre et la Vie 5:202-223.

Brabant, P. et F. Humbel. 1974. Carte pedologique du Cameroun, Poli. Section de pedologie. O.R.S.T.O.M., Centre de Yaounde, Cameroun. No. 51.

Bridges, E. M. 1970. World Soils. Cambridge University Press. 87 pp.

Chevalier, A. 1900. Les zones et les provinces botaniques de l'A.O.F. Comptes Rendus de l'Acadamie Science. 130 pp.

Chevalier, A. 1934. Etude sur les prairies de l'Ouest African. Rev. Bot. Appl. Agric. Trop. 14:17-48.

Child, G. S. 1974. An ecological survey of the Borgu Game Reserve, Kainji Lake Res. Project Rep. Nigeria. FI:SF/NIR 24, Tech. Report 4, Rome. 123 pp.

Clayton, W. D. 1958. Secondary vegetation and the transition to savanna near Ibadan, Nigeria. J. Ecol. 46:217-238.

Clifford, H. T. and W. Stephenson. 1975. An Introduction to Numerical Classification. Academic Press, New York. 229 pp.

Coe, M. J., D. H. Cumming and J. Phillipson. 1976. Biomass and production of large African herbivores in relation to rainfall and primary production. Oecologia 22:341-354.

Colwell, R. K. and D. J. Futuyma. 1971. On the measurement of niche breadth and overlap. Ecology 52:567-576.

Culver, D. C. 1970. Analysis of simple cave communities: niche separation and species packing. Ecology 51:949-958.

Culver, D. C. 1974. Species packing in Caribbean and north temperate ant communities. Ecology 55:974-988.

Davidson, D. W. 1980. Some consequences of diffuse competition in a desert ant community. Am. Nat. 116:92-105.

Dougenik, J. A. and D. E. Sheehan. 1976. SYMAP users reference manual. Laboratory for computer graphics and spatial analysis. Harvard University. 131 pp.

Egunjobi, J. K. 1971. Savanna burning, soil fertility and herbage productivity in the derived savanna zone of Nigeria. Proc. Symp. Wildlife Conservation in West Africa. IUCN. Publ. 22:52-58.

Fahnestock, G. R. and R. C. Hare. 1964. Heating of tree trunks in surface fires. J. For. 62:799-805.

Gazel, F. D. 1956. Les Sols du Cameroun. O.R.S.T.O.M. Paris. 112 pp.

Glover, P. E. 1968. The role of fire and other influences on the savannah habitat, with suggestions for further research. E. Afr. Wildl. J. 6:131-137.

Harris, L. D. 1972. An ecological description of a semi-arid east African ecosystem. Colorado State University. Range Science Dept. Sci. Series No. 11. 79 pp.

Hill, T. L. 1965. "Savannas: a review of a major research problem in Tropical Geography". Can. Geogr. 9:216-227.

Hopkins, B. 1957. Pattern in the plant community. J. Ecol. 45:451-463.

Hopkins, B. 1965. Observations on savanna burning in the Olokemeji Forest Reserve, Nigeria. J. Appl. Ecol. 2:367-381.

Hopkins, B. 1974. Forest and Savanna. Heinemann, Ibadan. 154 pp.

Hurlbert, S. H. 1978. The measurement of niche overlap and some relatives. Ecology 59:67-77.

Jeannin, A. 1951. La Faune Africaine. Payot, Paris. 242 pp.

Jeffrey, E. C. 1925. Coal and Civilization. MacMillan Co., N.Y. 178 pp.

Jones, E. W. 1950. Some aspects of natural regeneration in the Benin rain forest. Emp. For. J. 29:212-235

Keay, R. W. J. 1949. An example of Sudan zone vegetation in Nigeria. J. Ecol. 37:335-364.

Keay, R. W. J. 1953. Vegetation of Nigeria. Map. Government Printer. Lagos, Nigeria.

Keeping, E. S. 1962. Introduction to Statistical Inference. D. Van Nostrad Co. Inc., Princeton, New Jersey. pp 319-321.

Kimble, G. H. T. 1960. Tropical Africa. 2 Volumes. The Twentieth Century Fund, N.Y.

Komarek, E. V. 1972. Ancient fires. Tall Timbers Conference on Ecological Fire Proceedings. No. 12. pp. 219-240.

Kowal, J. M. and A. H. Kassam. 1978. Agricultural Ecology of Savanna. Clarendon Press, Oxford. 403 pp.

Kuchler, A. W. 1947. A geographic system of vegetation. Geogr. Rev. 37:233-240.

Kuchler, A. W. 1960. Vegetation mapping in Africa. Ann. Assoc. Amer. Geogr. 50:74-84.

Lamprey, H. F. 1963. Ecological separation of the large mammal species in the Tarangire Game Reserve, Tanganyika. E. Afr. Wildl. J. 1:63-92.

Laws, R. M., I. S. C. Parker and R. C. B. Johnstone. 1975. Elephants and Their Habitats. Clarendon Press, Oxford. 376 pp.

Ledger, H. P. 1968. Body composition as a basis for a comparative study of some East African mammals. Symp. Zool. Soc. Lond. 21:289-310.

Letouzey, R. 1948. Feux precoces au Cameroun. Conference Africaine des Sols. Congo Belge. Communication No. 39. pp. 1913-1918.

Letouzey, R. 1968. Etude Phytogeographique du Cameroun. Editions Paul Lechevalier 18, Rue des Ecoles, Paris VIiemė. 511 pp.

Leuthold, W. and B. M. Leuthold. 1976. Density and biomass of ungulates in Tsavo East National Park, Kenya. E. Afr. Wildl. J. 14:49-58.

L'Institut de Recherches Scientifiques du Cameroun. 1971. ORSTOM. France. 24 pp.

Lutz, H. J. 1930. The vegetation of Heart's Content, a virgin forest in north-western Pennsylvania. Ecology 11:1-29.

Moll, E. J., B. M. Campbell and T. A. Probyn. 1976. A rapid statistical method of habitat classification using structural and physiognomic characteristics. S. Afr. J. Wildl. Res. 6:45-50.

Muller, C. 1855. Geographici Graeci Minores. Volume 1. Didot, Paris. 213 pp.

Myers, N. 1972. National parks in savannah Africa. Science. 178:1255-1263.

Nie, N. H., C. H. Hull, J. G. Jenkins, K. Steinbrenner and D. H. Bent. 1975. SPSS. Statistical package for the social sciences. 2nd edition. McGraw-Hill, Inc. N.Y. 675 pp.

Nye, P. H. and M. H. Bartheux. 1957. The distribution of phosphorus in forest and savanna soils of the Gold Coast and its agricultural significance. J. Agr. Sci. 49:141-159.

Nye, P. H. and D. J. Greenland. 1960. Increases in the carbon and nitrogen contents of tropical soils under natural fallows. J. Soil Sci. 10:284-299.

Pelleway, J. S. 1971. Cameroun. O.R.S.T.O.M., Centre de Yaounde. Cameroun. 68 pp.

Pianka, E. R. 1974. Niche overlap and diffuse competition. Proc. Natl. Acad. Sci. 71:2141-2145.

Porter, J. H. and R. D. Dueser. 1982. Niche overlap and competition in an insular small mammal fauna: a test of the niche hypothesis. Oikos 39:228-236.

Pugh, J. C. and A. E. Perry. 1960. A Short Geography of West Africa. Univ. London Press, Ltd. 332 pp.

Ramsey, J. M. and R. Rose Innes. 1963. Some quantitative observations on the effects of fire on the Guinea savanna vegetation of northern Ghana over a period of 11 years. Sol. Afric. 8:41-85.

Richards, P. W. 1952. The Tropical Rain Forest - An Ecological Study. Univ. Press. Cambridge, London. 341 pp.

Richards, P. W., A. G. Tansley and A. S. Watts. 1939(a). Ecological studies on the rain forest of Southern Nigeria. I. The structure and floristic composition of the primary forest. J. Ecol. 27:1-61.

Richards, P. W., A. G. Tansley and A. S. Watts. 1939(b). The recording of structure, life-form and flora of tropical forest communities as a basis for their classification. Imperial Forestry Inst. Paper No. 19. Oxford, England.

Sachs, R. 1967. Liveweights and body measurements of Serengeti game animals. E. Afr. Wildl. J. 5:24-36.

Sale, P. F. 1974. Overlap in resource use and interspecific competition. Oecologia 17:245-256.

Schnell, R. 1950. La foret dense: Introduction a l'etude botanique de la region forestiere d'Afrique Occidentale. Publie sous le patronage de l'Institut Francais d'Afrique Noire. Paris: Paul Lechevalier. 531 pp.

Soule, M. E., B. A. Wilcox and C. Holtly. 1979. Benign Neglect: A model of faunal collapse in the game reserves of East Africa. Biol. Conserv. 15:259-272.

Stevens, W. C. 1924. Plant Anatomy. 4th ed., Philadelphia: Blakiston. 275 pp.

Talbot, L. M. and M. H. Talbot. 1964. First wildlife census of the entire Serengeti-Mara region, East Africa. J. Wildl. Manage. 28:815-827.

Tunstall, B. R., J. Walker and A. M. Gill. 1976. Temperature distribution around synthetic trees during grass fires. For. Sci. 22:269-276.

Ward, J. H. 1963. Hierarchical grouping to optimize an objective function. J. Amer. Statist. Assoc. 58:236-244.

Wishart, D. 1975. Clustan IA User Manual. Computing laboratory. Univ. of St. Andrews, Scotland. 135 pp.

APPENDICES

Appendix I

Plants of Benoue National Park

DICOTYLEDONAE

ACANTHACEAE

Monechma ciliata (Jacq.) Milne-Redhead

Hygrophilia senegalensis T. Anders

Phaulopsis barteri (T. Anders) Lindan.

Blepharis glumacea S. Moore

AMPELICACEAE

Cissus flavicans (Bak.) Planch.

C. adenocaulis Hochst ex A. Rich.

C. populnea Guill. & Perr.

C. rubrosetosa Gilg. & Brandt

C. rufescens Guill. & Perr.

C. waterlotii A. Chev.

C. crotolarioides Planch.

ANACARDIACEAE

Heeria pulcherrima Schweinf. O. Ktze.

Haematostaphys barteri Hook. f.

Lannea fruticosa (Hochst. ex A. Rich.) Engl.

L. acida A. Rich.

ANNONACEAE

Xylopia parviflora (A. Rich.) Benth.

Annona senegalensis Pers.

APOCYNACEAE

Voacanga thouarsii Roem. & Schult.

Calotropis procera (Ait.) Ait. f.

BIGNONIACEAE

Kigelia africana Benth.

Stereospermum kunthianum Cham.

CAESALPINIACEAE

Afzelia africana Sm.

Burkea africana Hook.

Cassia kirkii Oliv. var. guinenesis Steyaert

C. sieberiana D.C.

Daniellia oliveri (Rolf) Hutch. & Dalz.

Detarium microcarpum Guill. & Perr.

Isoberlinia doka Craib. & Strapf.

I. tomentosa (Harms.) Craib. & Strapf.

Piliostigma thonningii (Schumach.) Milne-Redhead.

CELASTRACEAE

Maytenus senegalensis (Lam.) Exell.

COCHLOSPERMACEAE

Cochlospermum tinctorum A. Rich.

COMBRETACEAE

Combretum hypopilinum Diels.

C. binderanum Kotschy.

C. ghasalense Engl. & Diels.

C. paniculatum Vent.

C. molle R. Br. ex G. Don

C. sericeum G. Don

C. nigricans Guill. & Perr.

Terminalia macroptera Guill. & Perr.

T. laxiflora Engl.

T. avicennoides Guill. & Perr.

Anogeissus leiocarpus (D.C.) Guill. & Perr.

COMPOSITAE

Ageratum conyzoides L.

Aspilia angustifolia (Oliv.) & Hiern.

A. africana (Pers.) C.D. Adams var. ambigua C.D. Adams

A. helianthoides (Schum. & Thonn.) Oliv. & Hiern.

Chrysantellum americanum (L.) Vatke.

Conyza aegyptiaca (L.) Ait. spp. aegyptiaca

Vernonia amygdalina Del.

V. colorata (Willd.) Drake.

V. nigritana Oliv. & Hiern.

V. purpurea Sch. Bip.

CONVOLVULACEAE

Ipomoea argentaurata Hall. f.

DIPTEROCARPACEAE

Monotes kerstingii Gilg.

EUPHORBIACEAE

Bridelia scleroneura Muell. Arg.

Hymenocardia acida Tul.

Phyllanthus sp.

Securinega virosa (Roxb. ex Willd.) Baill.

Uapaca togoensis Pax.

Antidesma venosum Tul.

FLACOURTIACEAE

Oncoba spinosa Forsk.

HYPERICACEAE

Psorospermum spp.

LABIATAE

Haumaniastrum lilacinum (Oliv.) K. Morton

Hoslundia opposita Vahl.

Platystoma africanum P. Beauv.

Scutellaria paucifolia Bak.

LOGANIACEAE

Strychnos spinosa Lam.

LORANTHACEAE

Tapinanthus bangwensis (Engl. & K. Krause) Danser.

MALVACEAE

Urena lobata L.

Sida rhombifolia L.

MELIACEAE

Pseudocedrela kotschyi (Schweinf.) Harms.

Trichilia roka (Forsk.) Chiov.

Khaya senegalensis (Desv.) A. Juss.

MIMOSACEAE

Acacia ataxacantha D.C.

A. hockii De Wild.

A. dudgeoni Craib. ex Holl.

A. polyacantha Willd.

Prosopsis africana (Guill. & Perr.) Taub.

Mimosa pigra L.

Entada africana Guill. & Perr.

Parkia clappertoniana Keay

MORACEAE

Ficus glumosa Del. var. glaberrima Martelli

F. gnaphalocarpa (Miq.) Steud. ex A. Rich.

F. ingens (Miq.) Miq. var. ingens

F. vallis-choudae Del.

MYRTACEAE

Syzigium guineense (Willd.) D.C. var. guineense

S. guineense var. macrocarpum Engl.

OCHNACEAE

Ochna schweinfurthii F. Hoffm.

Lophira lanceolata Van Tiegh. ex Keay.

OLEACEAE

Ximenia americana L.

OPILIACEAE

Opilia celtidifolia (Guill. & Perr.) Endl. ex Walp.

OXALIDACEAE

Biophytum petersianum Klotsch

PALMAE

Borassus aethiopium Mart.

PAPILIONACEAE

Crotalaria bongensis Bak. f.

C. macrocalyx Benth.

C. microcarpa Benth.

Desmodium adscendens (Sw.) D.C. var. robustum Schubert

D. gangeticum (L) D.C. var. maculatum (L) Bak.

D. velutinum (Willd.) D.C.

Eriosema glomeratum (Guill. & Perr.) Hook f.

Indigofera conjugata Bak. var. conjugata

I. stenophylla Guill. & Perr. var. stenophylla

Lonchocarpus sericeus Poir. H.B. & K.

Meliniella micrantha Harms.

Pterocarpus erinaceus Poir.

Tephrosia bracteolata Guill. & Perr.

T. platycarpa Guill. & Perr.

Afrormosia laxiflora Harms.

PODOSTEMACEAE

Tristicha trifaria (Bory) Spreng.

POLYGALACEAE

Polygala petitiana A. Ric.

Securidaca longipedunculata Fres.

POLYGONACEAE

Polygonum senegalense Meisn.

PROTEACEAE

Protea angolensis Welw.

P. elliottii H.C. Wright var. elliottii.

RHAMNACEAE

Ziziphus mucronata Willd.

ROSACEAE

Parinari curatellifolia Planch ex Benth.

RUBIACEAE

Gardenia erubescens Stapf. & Hutch.

G. lutea Fres.

Crossopteryx febrifuga Benth.

Canthium multiflorum (Schumach. & Thonn.) Hiern.

Fadogia agrestis Schweinf. ex Hiern.

Borreria octodon Hepper

Macrosphyra longistyla (D.C.) Hiern.

Nauclea latifolia Sm.

Pentodon pentandrus (Schum. & Thonn.) Vatke.

Rothmannia whitfieldii (Lindl.) Dandy

Tricalysia okelinsis Hiern.

SALICACEAE

Salix ledermannii Seeman

SAPINDACEAE

Allophyllus africanus P.B.

SAPOTACEAE

Butyrospermum paradoxum (Gaetn. f.) Hepper

Malacantha alnifolia (Bak.) Pierre

SCROPHULARIACEAE

Cycnium camporum Engl.

Sopubia simplex (Hochst) Hochst.

STERCULIACEAE

Sterculia setigera Del.

THYMELIACEAE

Gnidia macrorhiza Gilg.

Lasiosiphon kraussiana (Meisn.) Butt-Davy

TILIACEAE

Grewia mollis Juss.

VERBENACEAE

Lippia multiflora Moldenke

Vitex doniana Sweet

EBENACEAE

Diospyros mespiliformis Hochst.

BOMBACEAE

Adansonia digitata L.

Bombax costatum Pellegr. & Vuillet.

MONOCOTYLEDONAE

AMARYLLIDACEAE

Crinum humile A. Chev.

ARACEAE

Anchomanes welwitschii Rendle

COMMELINACEAE

Aneilema lanceolatum Benth.

CYPERACEAE

Ascolepis protea Welw.

Bulbostylis pusilla (A. Rich.) C.B.Cl.

B. scabricaulis Cherm.

Cyperus esculentus L.

C. tonkinensis C.B.Cl. var. baikei (C.B.Cl.) Hooper

Eleocharis setifolia (A. Rich.) J. Raynal

Fimbristylis scabrida Schumach.

Lipocarpha albiceps Ridl.

Mariscus alternifolius Vahl.

M. umbellatus Vahl.

Pycreus lanceolatus (Poir.) C.B. Cl.

P. melas Ridl.

Scleria bulbifera A. Rich.

DIOSCOREACEAE

Dioscorea abyssinica Hochst. ex Kunth.

D. bulbifera L.

D. preussii Pax

GRAMINEAE

Alloteropsis semialata (R. Br.) Hitch.

Andropogon ascinodis C.B.Cl.

A. gayanas Kunth.

A. pseudapricus Stapf.

A. schirensis Hoc

A. tectorum Schum. & Thonn.

Aristida hordacea Kunth.

Arundinella pumila (Hochst. ex A. Rich.) Steud.

Beckeropsis uniseta (Nees) K. Schum.

Brachiaria jubata (Fiq. & De Nol.) Stapf.

B. brizantha (Hochst ex A. Rich.) Stapf.

Chloris pycnothrix Trin.

C. robusta Stapf.

Ctenium canescens Benth.

Cymbopogon giganteus (Hochst.) Chiov.

Digitaria ciliaris (Retx.) koel.

D. diagonalis Stapf. var. hirsuta (De Wild. & Th. Dur.) Troupin

Echinochloa colonum Link.

Elionurus hirtifolius Hack.

Eragrostis aegyptiaca (Willd.) Link

E. cilianensis (All.) Lut.

E. tenuifolia (A. Rich.) Hochst ex Steud.

Euclasta condylotricha (Hochst ex Steud.) Stapf.

Hackelochloa granularis O. Ktze.

Hyparrhenia filipendula (Hochst) Stapf. var. filipendula

H. involucrata Stapf.

H. rufa (Nees.) Stapf.

H. smithiana Stapf.

H. subplumosa Stapf.

H. welwitschii (Rendle) Stapf.

Imperata cilindrica (L) Beauv. C. E. Hubbard

Loudetia arundinacea Hochst. ex. A. Rich. Steud.

L. simplex (Nees.) C. E. Hubbard

Loxodera ledermannii (Pilger) W. D. Clayton ex Launert

Oplismenus burmannii (Retz) P. Beauv.

Panicum baumannii K. Schum.

P. pansum Rendle

P. phragmitoides Stapf.

Pennisetum giganteum A. Rich.

P. monostigma Pilger

P. subangustum (Schumach.) Stapf. & C. E. Hubb.

Rottboellia exaltata Linn. f.

Saccharum spontaneum L. var. aegyptium (Willd.) Hack.

Sacciolepis micrococca Mez.

Schizachyrium exile (Hochst.) Pilger

S. sanguineum (Retz.) Alston

Setaria sphacelata (Schum.) Stapf. & C. E. Hubbard

Sporobolus festivus Hochst. ex A. Rich.

S. pyramidalis Beauv.

S. pectinellus Mez.

Tripogon minimus (A. Rich.) Hochst. ex Steud.

Vetiveria nigritana (Benth.) Stapf.

HYPOXIDACEAE

Curculigo pilosa (Schum. & Thonn.) Engl.

IRIDACEAE

Gladiolus unguiculatus Bak.

LILIACEAE

Anthericum pubirhachis Bak.

Chlorophytum aureum Engl.

Eriospermum abysinicum Bak.

Urginea ensifolia (Thonning) Hepper

ORCHIDACEAE

Eulophia cuculata (Sw.) Steud.

PALMAE

Borassus aethiopicum Mart.

ZINGIBERACEAE

Kaempferia aethipica (Schweinf.) Solms-Laub.

Appendix II

Mammals of Benoue National Park

INSECTIVORA

Atelerix albiventris (Wagner 1841)........................African hedgehog

CHIROPTERA

Epomophorus gambianus (Ogilby 1835)........................Gambian fruit bat

Eidolon helvum (Kerr 1792)..................................Straw-coloured fruit bat

Lavia frons (E. Geoffroy 1810)..............................Yellow-winged bat

PHOLIDOTA

Manis gigantea (Illiger 1815)...............................Giant pangolin

LAGOMORPHA

Lepus capensis (Linnaeus 1758)..............................Hare

Lepus crawshayi (De Winton 1841)...........................Crawshay's hare

RODENTIA

Funisciurus anerythrus (Cuvier 1833).......................Red side-striped squirrel

Xerus erythropus (Desmarest 1817)..........................West African ground squirrel

Myomys daltoni (Thomas 1892)................................Bush mouse

Mus minutoides (Smith 1834).................................Pygmy mouse

Hysterix cristata (Linnaeus 1758)...........................Crested porcupine

TUBULIDENTATA

Orycteropus afer (Pallas 1766)..............................Aardvark

HYRACOIDEA[1]

Procavia capensis (Pallas 1766).............................Rock hyrax

PROBOSCIDEA

Loxodonta africana (Blumenbach 1797).......................African elephant

1 Recorded outside Benoue National Park but assumed to extend into it.

PRIMATES

Papio anubis (Fischer 1829)....................................Olive baboon

Colobus guereza (Oken 1856)....................................Black and white colobus

Erythrocebus patas (Schreber 1774)............................Red patas monkey

Cercopithecus aethiops tantalus (Linnaeus 1758)............Tantalus monkey

ARTIODACTYLA

Kobus kobus (Erxleben 1777)....................................Buffon's kob

Tragelaphus scriptus (Pallas 1766)..........................Bushbuck

Taurotragus derbianus (Gray 1885)..........................Giant eland

Alcelaphus buselaphus (Pallas 1766)........................Western hartebeest

Hippopotamus amphibius (Linnaeus 1758)....................Hippopotamus

Giraffa camelopardalis (Linnaeus 1758)....................Giraffe

Sylvicapra grimmia (Linnaeus 1758)..........................Grimm's duiker

Ourebia ourebi (Zimmerman 1783)............................Oribi

Cephalophus rufilatus (Gray 1846)..........................Red-flanked duiker

Redunca redunca (Pallas 1777)..............................Bohor reedbuck

Diceros bicornis (Linnaeus 1758)............................Black rhinoceros

Hippotragus equinus (Desmarest 1804)........................Roan antelope

Damaliscus korrigum (Ogilby 1876)..........................Topi

Phacochoerus aethiopicus (Pallas 1766)..............Warthog

Kobus defassa (Ruppell 1852)..................................Defassa waterbuck

Syncerus caffer (Sparrman 1779)..............................Buffalo, bush-cow

CARNIVORA

Felis caracal (Schreber 1777)................................Caracal

Viverra civetta (Schreber 1777)..............................African civet

Genetta genetta (Linnaeus 1758)..............................Common genet

Canis adustus (Sundevall 1846)..............................Side-striped jackal

Crocuta crocuta (Erxleben 1777)..............................Spotted hyena

Panthera pardus (Linnaeus 1758) ....Leopard

Panthera leo (Linnaeus 1758) ....Lion

Lycaon pictus (Temminck 1820) ....Hunting dog

Felis serval (Schreber 1777) ....Serval

Ichneumia albicauda (Cuvier 1829) ....White-tailed mongoose

Herpestes ichneumon (Linnaeus 1758) ....Egyptian mongoose

Appendix III

Reptiles of Benoue National Park

REPTILIA

CHELONIA

Kinixys belliana..Hinged tortoise

Amyada tringuis..Soft-shelled tortoise

CROCODILIA

Crocodulus niloticus....................................Nile crocodile

SQUAMATA

Varanus niloticus..Nile monitor

Chamaelo gracilis..Savanna chameleon

Agama sp..Red-headed agama

Python sebae..Rock python

P. regius...Royal python

Grayia smythii..Water snake

Naja nigricollis..Ring-necked cobra

Causus rhombeatus......................................Night adder

Bitis arietans...Puff adder

Appendix IV

Birds of Benoue National Park

ARDEIDAE

Ixobrychus sturmii....................................Dwarf bittern

Nycticorax nycticorax..................................Night heron

Ardeola ralloides......................................Squacco heron

Ardeola ibis...Cattle egret

Egretta alba...Great white egret

Ardea cinerea..Grey heron

Ardea goliath..Goliath heron

SCOPIDAE

Scopus umbretta..Hammerkop

CICONIDAE

Ciconia nigra..Black stork

Ciconia episcopus......................................Woolly-necked stork

Ephippiorhynchus senegalensis..........................Saddle-bill stork

Anastomus lamelligerus.................................Open-bill stork

Ibis ibis..Wood ibis

Sphenorynchus abdimii..................................Abdim's stork

THRESKIORNITHIDAE

Threskiornis aethiopicus...............................Sacred ibis

Bostrychia hagedash....................................Hadada

Plegadis falcinellus...................................Glossy ibis

ANATIDAE

Alopechen aegyptiacus..................................Egyptian goose

Plectropterus gambensis................................Spur-winged goose

ACCIPTRIDAE

Neophron percnopterus	Egyptian vulture
Gyps bengalensis	White-backed vulture
Trigonoceps occipitalis	White headed vulture
Neophron monachus	Hooded vulture
Circus pygargus	Montagu's harrier
Polybroides radiatus	Harrier-hawk
Terathopius ecaudatus	Bateleur
Circaetus cinerascene	Banded harrier-hawk
Accipiter badius	Shikra
Kaupifalco monogrammicus	Lizard buzzard
Butastur rufipennis	Grasshopper buzzard
Lophaetus occipitalis	Long-crested hawk-eagle
Polemaetus bellicosus	Martial eagle
Aquila rapax	Tawny eagle
Haliaeetus vocifer	Fish eagle
Milvus migrans	Kite
Elanus caeruleus	Black-shouldered kite
Elanus riocourii	Swallow-tailed kite

FALCONIDAE

Falco cuvieri	African hobby
Falco subbuteo	European hobby
Falco tinnunculus	Kestrel
Falco alopex	Fox kestrel

SAGITTARIIDAE

Sagittarius serpentarus	Secretary bird

PHASIANIDAE

Ptilopachus petrosus....................................Stone partridge

Numida meleagris....................................Guinea fowl

Francolinus bicalcaratus....................................Double-spurred francolin

RALLIDAE

Porphyrio alleni....................................Allen's gallinule

OTIDAE

Neotis denhami....................................Denham's bustard

BURHINIDAE

Burhinus senegalensis....................................Senegal thicknee

CHARADRIIDAE

Vanellus spinosus....................................Spur-winged plover

Vanellus albiceps....................................White-headed plover

Charadrius hiaticula....................................Ringed plover

Limosa limosa....................................Black-tailed godwit

Tringa glareola....................................Wood sandpiper

Tringa erythropus....................................Dusky redshank

Gallinago gallinago....................................Common snipe

Calidris ferruginea....................................Curlew sandpiper

Calidris alba....................................Sanderling

GLAREOLIDAE

Glareola pratincola....................................Pratincole

Pluvianus aegyptus....................................Egyptian plover

LARIDAE

Rhynchops flavirostris....................................Skimmer

Sterna alibifrons....................................Little tern

COLUMBIDAE

Streptopelia turtur....................................Turtle dove

Streptopelia semitorquata..............................Red-eyed dove

Streptopelia decipiens.................................Mourning dove

Treron australis.......................................Green pigeon

Treron waalia..Bruce's green pigeon

PSITTACIDAE

Poicephalus senegalus..................................Yellow-bellied parrot

Psittacula krameri.....................................Rose-ringed parrakeet

MUSOPHAGIDAE

Musophaga violacea.....................................Violet turaco

Crinifer piscator......................................Grey plantain-eater

CUCULIDAE

Clamator jacobinus.....................................Black and white cuckoo

Cuculus canorus..Cuckoo

Centropus senegalensis.................................Senegal coucal

Centropus toulou.......................................Black coucal

STRIGIDAE

Bubo africanus...Spotted eagle-owl

Scotopelia peli..Fishing owl

CAPRIMULGIDAE

Caprimulgus climacurus.................................Long-tailed nightjar

Macrodiperyx longipennis...............................Standard-winged nightjar

APODIDAE

Apus apus..Common swift

Apus affinis...Little swift

Cypsiurus parvus.......................................Palm swift

ALCEDINIDAE

Ceryle maxima..Giant kingfisher

Ceryle rudis...Pied kingfisher

Alcedo cristata..Malachite kingfisher

Ceyx picta...Pygmy kingfisher

Halcyon senegalensis...................................Woodland kingfisher

Halcyon leucocephalus..................................Grey-headed kingfisher

MEROPIDAE

Merops apiaster..Bee-eater

Merops superciliosus...................................Madagascar bee-eater

Merops malimbicus......................................Rosy bee-eater

Merops nubicus...Carmine bee-eater

Merops albicollis......................................White-throated bee-eater

Merops bulocki...Red-throated bee-eater

CORACIIDAE

Coracias abyssinica....................................Abyssinian roller

Coracias cyangaster....................................Blue-bellied roller

UPUPIDAE

Upupa epops..European hoopoe

BUCEROTIDAE

Tockus nasatus...Grey hornbill

Tockus erythrorhynchus.................................Red-billed hornbill

Bucorvus abyssinicus...................................Abyssinian ground hornbill

CAPITONIDAE

Lybius dubius..Bearded barbet

HIRUNDINIDAE

Riparia riparia..European sand martin

Hirundo rustica....................................European swallow

Hirundo smithii....................................Wire-tailed swallow

Hirundo semirufa...................................Rufous-chested swallow

Hirundo spilodera..................................Cliff swallow

MOTACILLIDAE

Motacilla flava....................................Yellow wagtail

Anthus cervinus....................................Red-throated pipit

MALACONOTINAE

Tchagra senegala...................................Black-headed bush shrike

Laniarius barbarus.................................Barbary shrike

Corvinella corvina.................................Long-tailed shrike

ORIOLIDAE

Oriolus auratus....................................African golden oriole

STURNIDAE

Lamprotornis purpureus.............................Purple glossy starling

Lamprotornis caudatas..............................Long-tailed glossy starling

Buphagus africanus.................................Yellow-billed oxpecker

CORVIDAE

Corvus albus.......................................Pied crow

CAMPEPHAGIDAE

Campephaga phoenica................................Red-shouldered cuckoo-shrike

MUSCICAPIDAE

Cercomela familiaris...............................Red-tailed chat

Saxicola rubetra...................................Whinchat

Phoenicurus phoenicurus............................Redstart

Hippolais polyglotta...............................Melodius warbler

Hippolais pallida..................................Tree warbler

Sylvia borin.......................................Garden warbler

Cisticola galactotes....................................Rufous grass warbler

Prinia erythroptera....................................Red-winged warbler

Muscicapa striata....................................Spotted flycatcher

Hyliota flavigaster....................................Yellow-bellied flycatcher

Terpsiphone viridis....................................Paradise flycatcher

NECTARINIIDAE

Anthreptes longuemarei....................................Violet-backed sunbird

Nectarinia olivacea....................................Olive sunbird

Nectarinia verticalis....................................Green-headed sunbird

PLOCEIDAE

Ploceus cucullatus....................................Village weaver

Malimbus rubriceps....................................Red-headed weaver

Euplectes hordeaceus....................................Black-winged bishop

Euplectes afer....................................Napoleon bishop

Bubalornis albirostris....................................Buffalo weaver

Petronia dentata....................................Bush sparrow

Vidua orientalis....................................Broad-tail paradise wydah

Estrilda trogodytes....................................Black-rumped waxbill

Estrilda bengala....................................Red-cheeked cordon bleu

Lagonosticta senegala....................................Red-billed fire finch

Appendix V

Standardized Field Data Sheet for <u>Afzelia</u> Stand

Measurements

Name: ______________________________ Date: ______________________________

Plot No.: __________ Plot Area: __________ m^2.

Veld Type: ________________________ Geology: ________________________

Biotic Influences: ____

Topography: mountain peak cliff talus ridge plain
termitaria kloof valley donga pan seep
vlei river bank estuary dunes hill slope
concave convex flood plain

Site Exposure: __________ Aspect: __________ Altitude: __________

Surface Rock (mean size cms): 0 2.5 15 60 220 bedrock

Rock Cover: 0+12345 Soil Series: ____________ Soil Depth: _____cm

Soil: litter 0+12345 Soil Texture: fSa cSa fSaLm cSaLm SaClLm
humus 0+12345 ClLm SaCl Cl

Soil Colour: black grey white yellow brown red olive-brown

Site Drainage: dry seasonally moist seasonally wet permanently wet

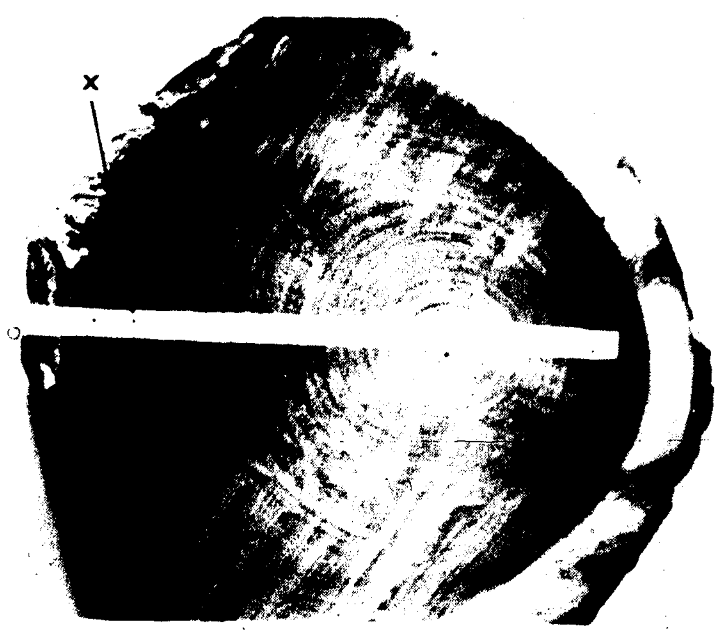
Slope: level gentle moderate steep very steep
(0-3°) (3-5°) (8,5-16,5°) (16,5-20,5°) (26,5-45,0°)
precipitous
(more than 45°)

Notes: ____

Appendix VI

Chronological Annual Ring Analysis

Sheets of 2 mm graph paper, 6 cm wide and long enough to read off the total ring sequence of each core were secured directly above each core and a "0" was placed above the pith. Likewise, strips were placed perpendicular to the annual rings on each wedge sample. A 2 mm square represented one "unit" and for each annual ring lying within a "unit", a vertical line 4 mm high was drawn directly above. Therefore, the greater the number of rings lying within a "unit", the higher the line. Annual rings with burned wood were marked on the graph paper with an "x". Line diagrams were compared until vertical lines were found to correspond or until all possibilities of correspondance had been exhausted. The place of agreement, if such was found, was the position in time when two or more trees (and therefore the ring records) were considered to cross-date.



Appendix VII

SYMAP Program

```
C     PROGRAM FOR PRE-PROCESSING POINT COORDINATES FOR SYMAP PROGRAM
C
C     CONTROL AND DATA CARDS FOR THIS PROGRAM
C
C   CARD  COL.     FORMAT  VARIABLE
C
C    1     1        I1       NUMBER OF CATEGORIES, NCAT<10.
C    2     1-54     9F6.0    FILL VALUES, E.G. 999., 666., 333.
C    3     1-32     4F8.0    X-MAX, Y-MAX, X-MIN, Y-MIN.
C
C                            FOR EACH OF THE NCAT CATEGORIES, ONE CARD
C
C          1-6      A6       THE WORD."POINTS"
C          7-11     I5       THE NUMBER OF POINTS FOR THIS CATEGORY (NP)
C
C                            FOLLOWED BY NP DATA CARDS.
C
C     THE FORMAT FOR THE DATA CARDS IS STATEMENT 606 IN THIS PROGRAM.
C
      (REAL Z(120,198)/23760*-999.0/,SUBS(2,2000),VALUE10)
C      REAL Z(200,330),SUBS(2,2000),VALUE(10)
C
C      NOTE: I & X ARE ABSCISSAS; J & Y ARE ORDINATES.
C
       INTEGER NTEST/'POIN'/
       NOBS=0
       IMAX-120
       JMAX=198
       JMP1=JMAX+1
C      READ NUMBER OF CATEGORIES (SYMBOL TYPES) <10.
       READ (5,600) NSYMB
C      READ "FILL VALUES" FOR THESE CATEGORIES.
       READ (5,601) VALUE
C      READ MAX-X, MAX-Y, (MIN-X, MIN-Y).
       READ (5,602) XMAX, YMAX, XMIN, YMIN
       YRANGE=YMAX-YMIN
       XRANGE=XMAX-XMIN
       YCONST=JMAX/YRANGE
       XCONST=IMAX/XRANGE
       YDEL=YRANGE*0.0000001
       XDEL=XRANGE*0.0000001
       DO 40 ISM=1,NSYMB
       VAL=VALUE(ISM)
C      READ NUMBER OF DATA POINTS FOR CATEGORY ISM.
       READ (5,603) ITEST,NPOINT
       IF (ITEST.EQ.NTEST) GO TO 10
       WRITE (6,604) ISM
       GO TO 60
    10 CONTINUE
       IF(NPOINT.LE.2000) GO TO 20
       WRITE(6,605) ISM,NPOINT
       GO TO 60
    20 CONTINUE
       READ(5,606) ((SUBS(I,J),I=1,2),J=1,NPOINT)
```

```
      DO 30 INP=1,NPOINT
      X=SUBS(2,INP)
      Y=SUBS(1,INP)
C.     FOR DATA CHECK, REMOVE 'C' FROM COL. 1 OF NEXT CARD.
C     IF (X.LT.XMIN.OR.Y.LT.YMIN.OR.X.GT.XMAX.OR.Y.GT.YMAX) GO TO 50
      NOBS=NOBS+1
      I=INT((X-XMIN-XDEL)*XCONST)+1
      J=INT((Y-YMIN-YDEL)*YCONST)+1
C     J=JMP1-J
      Z(I,J)=VAL
   30 CONTINUE
   40 CONTINUE
      DO 45 ILN=1,JMAX
      WRITE(4) (Z(J,ILN),I=1,IMAX)
   45 CONTINUE
      WRITE (6,608) NOBS
      GO TO 60
   50 CONTINUE
      WRITE(6,609) ISM,INP,XMIN,XMAX,X,YMIN,YMAX,Y
   60 STOP
  600 FORMAT (I1)
  601 FORMAT (10F6.0)
  602 FORMAT (4F8.0)
  603 FORMAT (A4,2X,I5)
  604 FORMAT (' *** "NUMBER OF CASES" CARD IS MISSING FOR CATEGORY',
     1 I2)
  605 FORMAT (' *** CATEGORY',I2,' HAS',I5,' POINTS.'/
     1'        MAXIMUM=2000.  ALTER SECOND DIMENSION OF SUBS.')
  606 FORMAT (F5.2,5X,F5.2)
  608 FORMAT ('0 *** NORMAL END OF JOB.',I7,' POINTS PROCESSED.')
  609 FORMAT (' *** DATA ERROR AT CATEGORY',I3,':  POINT',I5/
     1 '    X-RANGE =',G14.6,' TO ',G14.6,': X-VALUE =',G14.6/
     2 '    Y-RANGE =',G14.6,' TO ',G14.6,': Y-VALUE =',G14.6)
      END
C      PROGRAM FOR OVERLAYING ANIMAL DATA ON OUTPUT OF
C      GEOGRAPHIC DATA (PROCES(1,100).
C
C         CARD       FORMAT      VARIABLE
C          1          I1          NA     NUMBER OF ANIMALS
C         2-N1+1     ISN 601     ORDINATE, ABSCISSA, DENSITY
C
       REAL Z(120,198)
       DO 5 J=1,198
       READ(4) (Z(I,J),I=1,120)
     5 CONTINUE
       READ(5,600) NA
   600 FORMAT (I4)
       DO 10 IP=1,NA
       READ(5,601,END=20) J,I,N
   601 FORMAT(I2,I4,I3)
C       CORRECT THE COORDINATES FOR THE NEW SCALE.
       IF(I.LT.1.OR.I.GT.40) GO TO 50
       IF(J.LT.1.OR.J.GT.66) GO TO 50
       IF(N.LT.1.OR.N.GT.5) GO TO 50
```

```
      I=I*3-1
      J=J*3-1
      Z(I,J)=N
   10 CONTINUE
      GO TO 30
   20 WRITE(6,602) IP
  602 FORMAT (/1X,I4,' ANIMALS WERE PROCESSED.')
   30 DO 40 J=1,198
      WRITE(8) (Z(I,J),I=1,120)
   40 CONTINUE
      STOP
   50 WRITE(6,603) IP,J,I,N
  603 FORMAT (' ANIMAL ',I4,': COORDS.',3I4)
      GO TO 10
      END
```

Appendix VIII

Spatial Overlap Program

The program solves for D, the distance between circle centers using a series of iterations with a modified bisection method. Radius 1 produces a circle whose area is proportional to frequency 1, and radius 2 produces a circle whose areas is proportional to frequency 2. The distance (D) between circle centers causes [illegible] of overlap (if one exists) that is proportional to frequency (1+2) overlap. Circle radii lengths are left to the discretion of the researcher. Using "Fisher's Exact Method" (Keeping 1962), probabilities of spatial overlap were calculated by 2 x 2 tables using the same set of marginal frequencies (observations).

```
 400.   2.
30   .01
356  319   22
170  165    6
498  356    3
279  170    1
365  356    9
170  110    2
356  113   12
170   10    4

C      GIVE RADII AND DISPLACEMENT FOR PROPORTIONALITY
C      OF AREAS AND OVERLAP OF TWO CIRCLES.
       PI=3.141593
       READ(5,598) VOLUME,RADIUS
  598  FORMAT(2F7.0)
       CONVRT=1.0
       IF(VOLUME.LE.O.O.OR.RADIUS.LE.O.O) GO TO 5
       CONVRT=RADIUS/SQRT(VOLUME/PI)
    5  CONTINUE
       READ(5,599) MXITER,CRIT
  599  FORMAT (I3,F8.0)
       IF(CRIT.LT.0.00001) CRIT=.001
       IF(MXITER.LE.0.OR.MXITER.GT.500) MXITER=50
   10  READ(5,600) AN,BN,CN
       IF(AN.EQ.O.O) GO TO 80
  600  FORMAT (3F4.0)
       IF(AN.LT.BN.OR.BN.LT.CN) GO TO 50
       IF(CN.LT.O.O.OR.BN.EQ.O.O) GO TO 60
       A=SQRT(AN/PI)
       B=SQRT(BN/PI)
       C=SQRT(CN/PI)
       D=2.0*B
       IF(C.EQ.B) GO TO 40
       D=0.0
       IF(C.EQ.O.O) GO TO 40
       ITER=0
       DZ=(CN/BN)2.0*B
       EXPN=2*AN/(AN+BN)
   20  D-D+DZ
       ITER=ITER+1
       IF(ITER.GT,MXITER) GO TO 70
       CALL AREA(A,B,D,EN)
       DIFF=CN-EN
       IF(AES(DIFF).LT.CRIT) GO TO 40
       IF(DIFF.LT.O.O) TO TO 30
       DZ=(2*B-D)*(DIFF/(BN-EN))
       GO TO 20
   30  DZ=D*DIFF/EN*(A+B)/(2.0*A)
       GO TO 20
   40  D=(A+B-D)*CONVRT
       A=A*CONVRT
       B=B*CONVRT
       WRITE(6,601) A,B,D,AN,BN,CN,DIFF,ITER
```

```
  601 FORMAT (3F9.3,3F7.1,F10.6,I4)
      GO TO 10
   50 WRITE(6,602) AN,BN,CN
  602 FORMAT (3F10.3,' *** NUMBERS ARE NOT SORTED.')
      GO TO 10
   60 WRITE(6,603) AN,BN,CN
  603 FORMAT (3F10.3,' *** NUMBERS SHOULD BE NON-NEGATIVE.')
      GO TO 10
   70 CONTINUE
C  70 WRITE(6,604) DIFF
C 604 FORMAT (' *** NUMBER OF ITERATIONS=MAX.'
C    2 ,' CN-EN=',F10.4)
      GO TO 40
   80 STOP
      END
      SUBROUTINE AREA(A,B,D,EN)
      T=A+E-D
      X=(T*T+B*B-A*A)/(2.0*T)
      H=SQRT(B*B-X*X)
      EN=ARCOS((T-X)/A)*A*A+ARCOS(X/E)*B*B-H*T
      RETURN
      END
```