and scrub is introduced and follows through the rest of the study. This chapter deals with the determination of population size structures of the six major species in selected woodland and scrub sites. Growth rates and mortality per size class are given for each species.

The factors responsible for determining vegetation change are investigated in Chapter 5. Edaphic features are examined in the greatest detail, followed by frost, while fire, elephant damage and the effects of past logging are given less attention. In the conclusion of this chapter a hypothesis is presented to explain the role of edaphic features in influencing the vegetation.

The first section of the concluding chapter (Chapter 6) combines the results from Chapter 4 and 5 to develop and test a population model of Baikiaea plurijuga.

In the second part of this chapter, a hypothesis concerning vegetation succession and the interaction of the controlling factors is proposed, in an attempt to give a better understanding of the whole Kalahari Sand system.

CHAPTER 2. THE STUDY AREA

2.1 SITUATION

Hwange National Park lies in the western part of Zimbabwe, bordering with Botswana. It covers an area of 14 600 km^2, extending from latitude $18^{o}30'$ - $19^{o}50'$S and longitude $25^{o}45'$ - $27^{o}30'$E. The study was centred in a region of ±40 km radius around Main Camp, and in the extreme west of the Park, near Mitswiri Pan (Fig. 2.1).

2.2 CLIMATE

A summary of the meteorological data for Main Camp from 1951 to 1971 is given in Table 2.1. Rainfall is very seasonal, extending from November to March, with an annual average of 632 mm. It is highly unpredictable and decreases to the west and south of the Park. Winds are predominantly from the south-east and related to the position of the South African anti-cyclone. Temperatures vary according to season, with October being the hottest month: mean daily maximum = 33,2°C, and July the coldest: 4,1°C.

Using data supplied by the Meteorological Office, Harare, the potential evapotranspiration (PET) was calculated using Penman's Formula. PET takes into account wind, radiation and humidity effects and has more biological meaning than potential evaporation. Actual evapotranspiration only equals PET if soil moisture is not limiting (Daubenmire, 1967). This environment is very dry, characterised by an annual mean minimum temperature of >5°C, and a difference between mean annual maximum and minimum of >12°C. The calculated PET is therefore an underestimation due to the advection of dry air. Fig. 2.2 shows the relationship of PET to rainfall. Recharge of soil water is only for a brief period from December to February, in years of 600 mm rainfall or more.

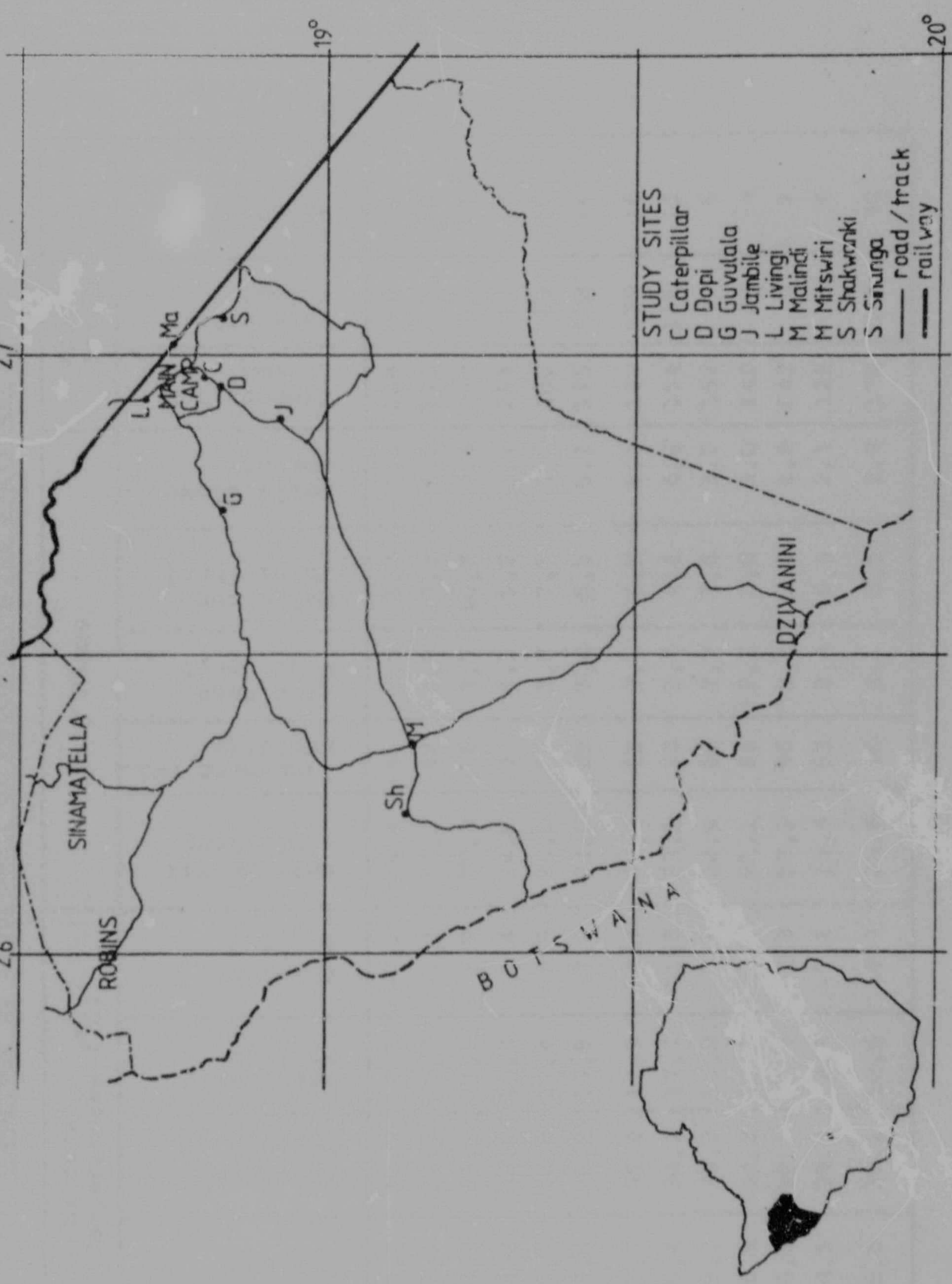

Fig. 2.1. Map of Hwange National Park showing situation and study sites.

TABLE 2.1. Meteorological Data for Main Camp Hwange National Park, 18°44'S 26°57'E 1077m Period: July 1951 - June 1971 (Courtesy of Department of Meteorological Services)

	Extreme Temperatures (°C)				Monthly Means					Monthly Totals		
	Mean Daily Maximum	Absolute Maximum	Mean Daily Minimum	Absolute Minimum	Mean of Max + Min Temp	24hr Mean Rel. Humidity	24hr Mean Wind Speed	Daily sun shine (hrs)	Daily Cloud Amount	Evaporation (mm)	Rainfall (mm)	Raindays
JUL	24,7	30,7	4,1	-7,2	14,4	48	2,5	9,7	1,3	134	0	0
AUG	27,5	34,0	6,7	-4,2	17,1	42	3,0	10,3	1,0	173	1	0
SEP	30,9	36,2	11,8	1,9	21,3	36	3,7	10,2	0,9	230	3	1
OCT	33,2	39,2	16,4	6,4	24,8	39	4,1	9,2	2,1	263	23	3
NOV	30,7	38,8	17,6	9,9	24,1	57	3,9	7,9	4,5	200	69	10
DEC	29,0	36,2	17,9	7,2	23,5	69	3,4	6,5	5,1	175	138	14
JAN	28,7	35,4	17,9	10,7	23,3	73	3,1	6,9	5,1	167	158	16
FEB	28,4	34,2	17,7	11,8	23,1	75	2,7	6,6	4,8	154	136	13
MAR	29,0	36,3	15,8	7,8	22,4	68	2,7	7,6	3,6	167	75	8
APR	28,9	34,3	13,3	2,5	21,1	62	2,7	8,8	3,0	149	24	4
MAY	26,8	32,7	7,8	-2,8	17,3	55	2,4	9,0	1,8	142	5	1
JUN	24,5	29,9	4,6	-7,1	14,5	53	2,4	9,3	2,1	129	0	0
YEAR	28,5	39,2	12,6	-7,2	20,6	56	3,1	8,5	2,9	174	632	70

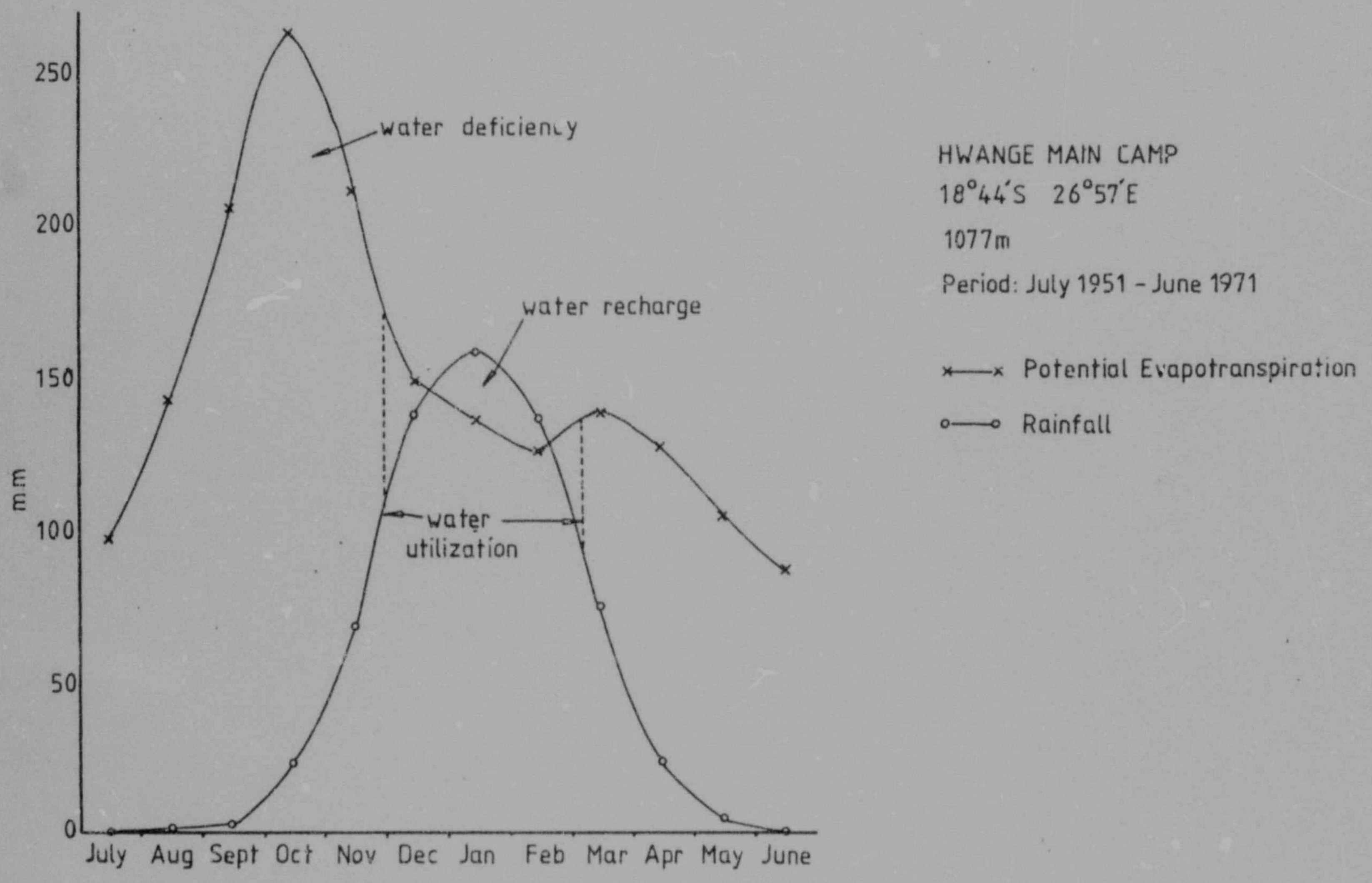

Fig. 2.2. Annual rainfall and potential evapotranspiration for Main Camp indicating periods of water deficiency, water recharge and utilization.

Utilization of the soil moisture by vegetation is from November to March - the growing season.

During the dry season clear skies, a relatively flat plateau surface, and the high reflectivity of the sands, result in a considerable diurnal temperature range and a high incidence of frost. Severe frosts occur approximately once every three years (see Table 2.2).

2.3 TOPOGRAPHY AND GEOLOGY

The western and central regions of the Park are covered by Kalahari sand. This forms the eastern extremity of the Kalahari Basin which is centred in Botswana. The sands form a plateau of varying thickness 5 - 60 m, and low relief, interrupted by a series of parallel dune ridges and troughs of Pleistocene origin. The dune pattern is well defined in the south west of the Park (Fig. 2.3). In many of the troughs there are scattered seasonal pans.

In the north, north-easterly draining rivers (the Deka and Lukosi) have eroded most of the sand away, exposing the underlying Karroo Sediments and igneous intrusions (Flint and Bond, 1968). In the south and east of the Sands a series of fossil drainage lines cut through the dunes and connect with the Gwavasabuya streamway near Zibanini (Fig. 2.4).

2.4 VEGETATION

Fig. 2.5 is a map of the main vegetation types of Hwange. The map was prepared by the Forestry Commission as part of their enumeration survey of indigenous timber. It is therefore biased towards the economically important species. The heavier basalt and mudstone derived soils of the Robins and Sinamatella areas support *Colophospermum mopane* woodlands and *Combretum spp*. thickets.

TABLE 2.2. Frequency of Severe Frost at Main Camp, 1951 - 1982
Absolute Minimum Ground Temperature
(≤ -6,5°C)

Year	May	June	July	August
1951	-	-	-9,0	-
1953	-	-10,0	-11,2	-
1954	-	-	-8,4	-
1963	-	-	-8,2	-
1964	-	-7,0	-	-
1965	-	-7,6	-	-
1968	-	-7,8	-	-
1972	-	-7,0	-7,8	-14,4
1974	-	-7,8	-	-
1979	-	-	-7,0	-
1980	-	-10,0	-5,0	-

Mean frequency of severe frost: once every 3 years

TABLE 2.3. Area of Kalahari Sands Covered by Different Vegetation Communities

Community	% Area
Baikiaea Woodland	19,0
Mixed *Baikiaea* Woodland	20,0
Pterocarpus Woodland	12,0
Burkea Woodland	6,0
Acacia Woodland and Scrub	13,0
Terminalia Scrub	26,0
Grassland	4,0

Data extracted from Forestry Commission Enumeration Survey Report, 1964.

Fig. 2.3. Parallel arrangement of dunes and vegetation on the Kalahari Sands in western Hwange National Park.

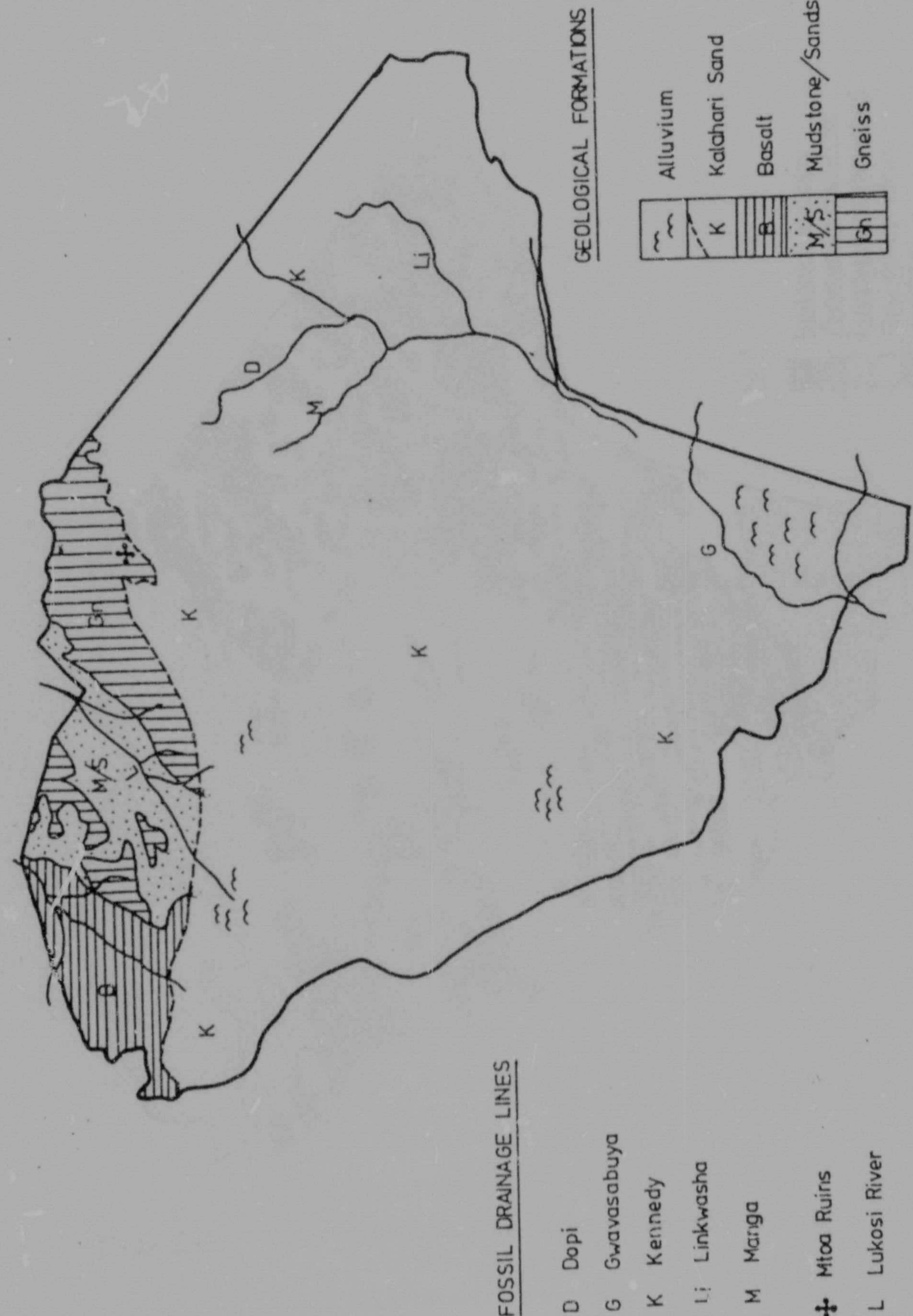

Fig. 2.4. Geology map of Hwange National Park adapted from the Geology of Rhodesia 1:1 000 000 map, Surveyor General, 1971.

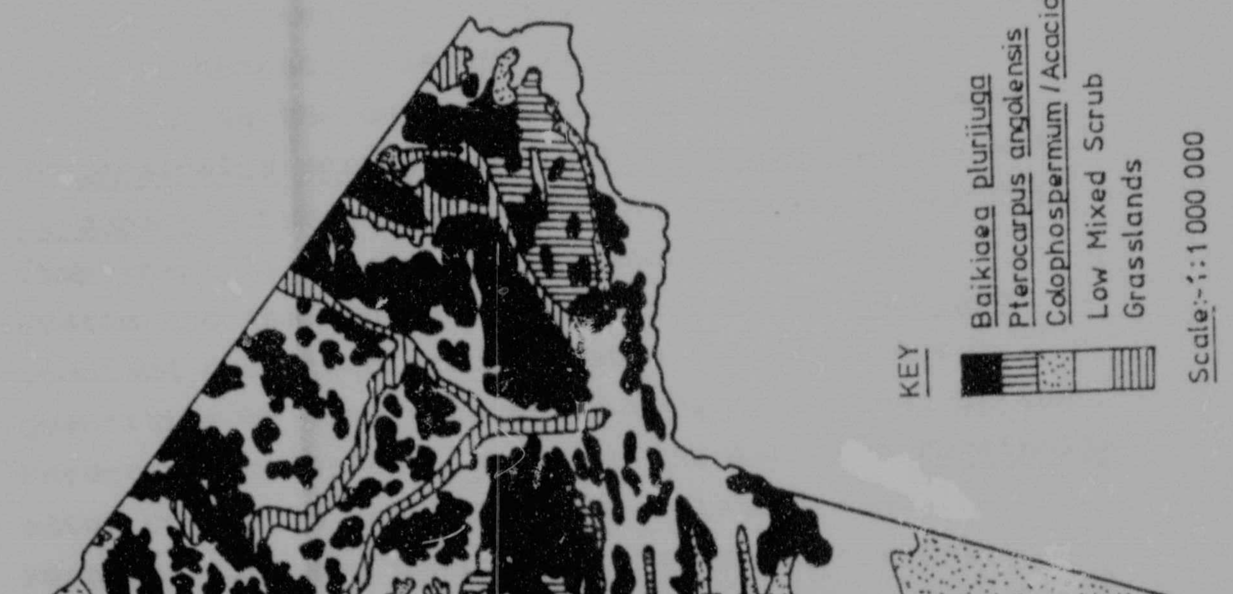

Fig. 2.5. Vegetation map of Hwange National Park

Despite the comparatively low relief, the vegetation on the sands does show a distinct catenary pattern (Fig. 2.6). The vegetation on the dunes is characterised by _Baikiaea plurijuga_ woodlands on the dune ridges, surrounded by a zone of _Terminalia sericea_ and _Combretum spp._ scrub, with _C. mopane_ scrub/grassland in the troughs. Near Main Camp there is no obvious evidence of the dune system and the vegetation is a mosaic of _Baikiaea_ woodland and mixed scrub. Table 2.3 lists the quantities of each vegetation type as defined by the Forestry Commission. _Baikiaea_ woodland and _Terminalia_ scrub cover 39% and 26% of the Kalahari Sands respectively, and constitute the dominant vegetation types.

2.5 BIOTIC INFLUENCES

2.5.1 Animals

Since the Park was gazetted in 1928, the populations of some game species have increased dramatically; elephant being the most ecologically important. Davison (the first Warden of the Park), estimated the population to be 2 000+ in 1930, and the latest (1982) aerial census results put the total at around 21 000 (D.H.M. Cumming, pers. comm.).[1] The increase has been due to an influx from hunting areas surrounding the Park, but the greatest factor has been the introduction of permanent, pumped water. This has enabled the elephants to remain in what were previously only wet season feeding grounds. The additional supply of food and water has caused a rapid population growth. Population estimates for the other major herbivores are listed in Table 2.4.

2.5.2 Humans

Archaelogical findings at Mtoa and Bumboosie Ruins indicate that there have been several eras of human occupation. Early and late Stone Age artefacts have been found throughout the

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[1] Chief Ecologist, Department of National Parks and Wildlife Management, Harare.

Fig. 2.6. Bottom of a fossil drainage line near Manga 3 Pan, Hwange National Park. *Baikiaea plurijuga* woodland dominates the ridge in the background with *Terminalia sericea* scrub lower down the slope.

TABLE 2.4. Population estimates for the main herbivore species in Hwange National Park

Species	Approx.Nos.	Crude Density per km²
Elephant	21 668 *	1.49
Buffalo	15 000 **	1.03
Sable	2 610 *	0.18
Zebra	1 691 *	0.12
Giraffe	2 130 *	0.15
Gemsbok	291 *	0.02
Wildebeeste	1 526 *	0.11
White Rhino	83 *	0.005
Black Rhino	149 *	0.01
Kudu	-	2.87
Impala	-	3.5

* 1983 Aerial Survey (Oct)

** 1982 Aerial Survey

Data courtesy of Dr D.H.M. Cumming, Department of National Parks and Wildlife Management.

Park, centering around pans and drainage lines. Although these early hunters may have moved seasonally through the Park, the large quantities of artefacts found suggest they spent some time around the more permanent pans. The climate was probably wetter than present (D.S.G. Thomas, pers. comm.).[2]

In more recent times, groups of nomadic Bushmen used the Park as a hunting ground, leaving evidence of their passing in the names of several seeps and pans. White hunters and game catchers operated in the Park until the proclamation in 1928. With the construction of the Victoria Falls - Bulawayo railway line in 1904, a series of lumber companies cut timber in what is now the Park (see Chapter 3). There were also a string of railway farms in the Park from Dete to Kennedy (see Fig. 3.1).

2.5.3 Fire

Although not strictly a biotic factor, the increase in fire is directly linked to human presence (see Chapter 3 and 5). Davison's fire policy was one of widespread burning throughout the season. Early burns formed a patchwork and helped in fire control later in the season. The grasslands were annually subjected to late burns to create a 'green bite' for the grazers. A fire policy was only drawn up in 1968 when a peripheral firebreak and a series of internal breaks were proposed (Wankie National Park Plan, 1974). The fire breaks were completed in 1972 and have since been maintained. The vegetation has therefore only been actively protected for the last fourteen years. Even the effectiveness of this protection is debatable.

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[2] School of Geography, Oxford University, England.

CHAPTER 3. LITERATURE REVIEW

3.1 GEOLOGY

3.1.1 Geological History of the Kalahari Sands

The Kalahari Sands are extensive continental deposits which have accumulated in a great downwarped basin. Fanshawe (1961) tabulated the probable details of the geological events that formed the Sands.

In the early Tertiary, Karroo Sediments were laid down on the Basement Complex. The gentle folding of these beds determined the courses of the rivers in recent times.

In the first pluvial of the early Pleistocene, a discontinuous sheet of water worn gravels was deposited. A subsequent short dry phase covered the gravels in places with aeolian (wind blown) sand. A brief wetter period followed, producing a series of shallow fresh water lakes, which soon dried out and were covered in more sand. These sands silicified into pipes sand-stones. A second pluvial deposited beds of gravel sand and clays during the mid Pleistocene. A long inter pluvial desert phase in the late Pleistocene brought in the aeolian Kalahari Sands which formed a deep mantle, several hundred metres thick. Flint and Bond (1948) state that the longitudinal dunes in Hwange (see Section 2.3) were built collectively in a vegetation free environment, under a single wind regimen.

In the third pluvial, and two post fluvial phases in Recent times, the drainage system was rejuvenated, eroding away the Sands to the north to the Zambezi, and to the south west to Lake Mgadigadi. The south westerly draining streamways e.g. Manga and Linkwasha cut obliquely across the dune ridges, running into the Zibanini mudflats. This is an area of alluvium that may represent the site of a former playa lake which connected to Lake Mgadigadi

(Thomas, 1982). Other sites of playa lakes are Ngamo and Makololo. Accumulations of plant and animal remains in the lakes formed layers of calcrete or limestone (Lockett, 1979).

The degradation of the dunes was largely through sheet erosion (Flint and Bond, 1968), although in his review of Quarternary palaeoclimates Thomas (1982) postulated that aeolian processes also contributed to the degradation. The sand representing the most readily saltated fraction may therefore have been removed from the area before the ridges became stabilised by vegetation. The fossil drainage lines post-date the dune degradation periods as it is inconceivable that these streamways could have cut across dunes of any great height (Thomas, 1982).

The origins of the Sands are not clear. According to Bond (1948), the Sands probably originated more or less locally, largely from granites and metamorphic rocks. Macgregor (1947, in Bond, 1948) proposed that the source 'can only have been the sea floor, exposed by a recession of the waters and an uplift of the continent', while Thomas (1982) felt that the origin of the Sands was a question yet to be answered. The two possibilities were: either the sand was derived from locally weathered bedrock, and reworked _in situ_ by aeolian processes, or it came from source areas outside the immediate vicinity. Ballilieul (1975) proposed that Zimbabwean Kalahari Sands were almost entirely pluvial rather than aeolian in origin.

3.1.2 Pan Formation

Lines of pans are found in the inter-ridge troughs. These are formed from an accumulation of eroded fines which created an impermeable layer (Flint and Bond, 1948).

Many pans are scattered irregularly throughout the Park and are probably related to the water and salt seeking habits of the large game species (Weir, 1960). These zoogenous pans are often associated with termite mounds which are sources of K, Na and other salts. Rain water collects in the excavated salt licks forming ideal mud wallows. As more soil is removed by animals so the wallows deepen into pans.

3.1.3 Characteristics of Kalahari Sand

Thompson and Purves (1978) classify the Kalahari Sands of Hwange as deep, highly pervious, fine to medium grained sands and loamy sands. Because of the virtual absence of clay and silt particles, weatherable minerals and available water capacity are very low. Lockett (1979) and Sutton (1979) investigated the mineralogical, surface texture and size characteristics of Kalahari Sand. Two classes are defined:

(i) Undisturbed Sand - the older original deposit of aeolian grains which are frosted and well rounded, with a markedly bimodal size distribution. Bimodalism is a feature mainly of coarse-grained water borne sediments, and this size distribution is rare in aeolian sands (Pettijohn 1957, in Lockett, 1979), but is thought to indicate diverse depositional environments and source material for the sand. The sand is red/orange in colour, weakly acidic, with low fertility and has $>80\%$ coarse grains. The red colour is due to a coating of ferric oxide about 0,02mm thick, mostly on the large and small grains. The intermediate sized grains tend to be free of the coating. The intensity of the colour is directly related to the degree of leaching. At the dune margins and at the head of vleis, the surface sand is leached to pale yellow or buff/white. The undisturbed sands form the higher well drained areas of the plateau which support _Baikiaea_ woodland. The uniform spacing of the trees reflects the consistency of soil type and water availability.

(ii) Redistributed Sand - a younger lacustrine deposit formed as a result of recent water action on the red sands. The mechanical polishing action of the water has reduced the proportion of heavily frosted grains (Bond and Fernandes, 1974), and sorted the grains into a unimodal size distribution. The ferric oxide coating is 0,004mm thick or less, and much of the oxide occurs with inter-granular clayey material. The sands are white or buff in colour and contain a comparative abundance of fine silt and clay. Small ochreous yellow and brown pellets of sand cemented with ferric oxide form ferricrete. Thin beds of ferricrete and silcrete occur along the margins of the sands formed by the evaporation of iron and silica charged water. The sands form a more open terrain with wide grassy vleis and open woodlands. Grant (1962), found Bo, S and Zn deficiencies in very acid, leached Kalahari Sands. Most test plants grown in Sands were found to have an abnormally low Ca concentration in the leaves.

3.2 VEGETATION

3.2.1 Forestry Activities

Initial clearing of the Matabeleland _Baikiaea_ forests by Messrs Pauling and Company commenced with the construction of the Victoria Falls - Bulawayo railway line in 1903-04 (Forestry Commission report, 1974). The Rhodesian Native Timber Concessions (RNTC) opened a sawmill at Malindi in 1921, but the most extensive exploitation started in 1925. RNTC were granted a concession including a 10 mile belt either side of the railway line, and timber in the Wankie Game Reserve within a 20 mile radius of Intundhla Siding.

Fig. 3.1 illustrates the areas and dates of timber logging in and around the Park.

Most of the timber cut was Baikiaea plurijuga - sought after as it is a hard durable wood. The heartwood, forming 80% of the mature log, is long lasting when in contact with the soil, being resistant to borers and termites. The wood was mainly used as railway sleepers with minor uses as bridge and mine shaft timbers (Martin, 1932). It was only in 1925 that some control over logging was implemented, namely a 12 inch (30 cm) diameter limit, and a Forestry Officer's mark of approval on selected trees. In 1933 further felling limits were imposed: a 13,6 inch (34cm) diameter for B. plurijuga, and a 15,6 inch (39cm) limit for Guibourtia coleosperma and Pterocarpus angolensis. In 1937 RNTC were asked to abandon all timber rights in Wankie Game Reserve in exchange for rights in the Umgusa Forest Reserve. They agreed, but then returned and continued cutting in Wankie until 1944, when a new agreement was signed cancelling all old rights (Forestry Commission report, 1974).

Prior to the 1925 stipulation, logging had been carried out without any regard to the future of the forests (Martin, 1940). Kelly-Edwards (1940) reported that extensive surveys by the Forest Service revealed that 'the forests today are a mere travesty of what they were in the latter part of the last century'. Earlier reports on exploitation remarked on the enormous amount of waste produced by the sawmills, as royalty was based on sawn output (Forestry Commission report 1974).

Wilkinson (1941) reported a shortage of semi mature trees and an irregular distribution in the smaller size classes. He advocated a system of rotational felling for the maintenance of sustained yields, warning that 'at the present rate of cutting the life of the forests was ten to twelve years'.

3.2.2 Composition and Classification

Savory (1961), Calvert (1974), and Tinley (1976), stress the importance of moisture as a controlling factor for vegetation on Kalahari Sands. In Calvert's classification of the Matabeleland woodlands, edaphic, biotic and successional influences are taken into account. He commented that there was a strong similarity between the woodlands north and south of the Zambezi. Six main vegetation types were defined:

(i) 'Sinanga' Forest. A dense thicket with little grass and a broken understorey of B. plurijuga caused by logging.

(ii) Miombo Woodland. Dominated by Brachystegia spiciformis, with or without Julbernardia globiflora. Fairly open ground cover with scattered shrubs and small trees. This type is found only in the extreme east of the Park and covers a small area.

(iii) Closed Woodland. Fairly close overstorey with a marked shrub understorey and moderate grass cover. Several species of trees are present: B. plurijuga, G. coleosperma, P. angolensis, Erythrophleum africanum, Burkea africana and Terminalia sericea.

(iv) Open Woodland. A discontinuous overstorey with a few relic B. plurijuga, G. coleosperma is more dominant with P. angolensis, B. africana, E. africanum, T. sericea and Diplorhyncus condylocarpon. The shrub layer is broken and the grass cover is moderate to dense with coarser species dominating.