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PARTNERS IN BIODIVERSITY

The Zambezi Society
P O Box HG774
Highlands
Harare
Zimbabwe
Tel: +263 4 747002-5
E-mail: zambezi@mweb.co.zw
Website : www.zamsoc.org

The Biodiversity Foundation for Africa
P O Box FM730
Famona
Bulawayo
Zimbabwe
E-mail: bfa@gatorzw.com
Website: www.biodiversityfoundation.org

The Zambezi Society and The Biodiversity Foundation for Africa are working as partners within the African Wildlife Foundation's Four Corners TBNRM project. The Biodiversity Foundation for Africa is responsible for acquiring technical information on the biodiversity of the project area. The Zambezi Society will be interpreting this information into user-friendly formats for stakeholders in the Four Corners area, and then disseminating it to these stakeholders.

THE BIODIVERSITY FOUNDATION FOR AFRICA (BFA is a non-profit making Trust, formed in Bulawayo in 1992 by a group of concerned scientists and environmentalists. Individual BFA members have expertise in biological groups including plants, vegetation, mammals, birds, reptiles, fish, insects, aquatic invertebrates and ecosystems. The major objective of the BFA is to undertake biological research into the biodiversity of sub-Saharan Africa, and to make the resulting information more accessible. Towards this end it provides technical, ecological and biosystematic expertise.

THE ZAMBEZI SOCIETY was established in 1982. Its goals include the conservation of biological diversity and wilderness in the Zambezi Basin through the application of sustainable, scientifically sound natural resource management strategies. Through its skills and experience in advocacy and information dissemination, it interprets biodiversity information collected by specialists like the Biodiversity Foundation for Africa and uses it to provide a technically sound basis for the implementation of conservation projects within the Zambezi Basin.

THE PARTNERSHIP between these two agencies was formed in 1996 as a result of mutual recognition of their complementarity. They have previously worked together on several major projects, including the biodiversity component of IUCN's Zambezi Basin Wetland project and the evaluation of biodiversity in Tete province described in detail in the first Four Corners TBNRM Biodiversity Information Package

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CHAPTER 4. VEGETATION OF THE FOUR CORNERS AREA

Susan Childes

4.1 INTRODUCTION

A knowledge and understanding of the vegetation of an area is fundamental to wildlife conservation and natural resource utilisation. Over the past century, but particularly during the past 30 years, numerous surveys and maps have been produced that encompass the study area, but these are usually at different scales and with different objectives. This review attempts to paint a broad description of the vegetation, its evolution, controlling factors and trends, in order to provide the context in which to view conservation and resource use in the Four Corners Area. It draws attention to major problems, to gaps in our knowledge, and briefly discusses vegetation monitoring.

The boundaries of the Four Corners study area have little biological basis. However, a unifying feature that underlies much of the area is the deciduous woodland on sandy soils. In the north of the study area, *Brachystegia* dominates the woodland, and in the south, *Baikiaea*. Just as *Brachystegia* is synonymous with the miombo woodlands of central Africa, so too is *Baikiaea* with the Kalahari sand woodlands.

This review concentrates on terrestrial vegetation as the aquatic/wetland vegetation types of the area have already been reviewed by Timberlake (2000). However, it is important to not lose sight of the importance to biodiversity of the wetlands. They are 'islands' of moisture available to plants, animals and humans in what is otherwise an arid to semi-arid environment. The mosaic of habitats thus formed gives diversity, and hence resilience, to the system. (Resilience is defined as the ability of a system to recover from major perturbations, for example, drought).

Given the volume of papers, maps and the geographic coverage of the study area, the review is general and descriptive. There is some overlap with the reviews on plants (Timberlake, Chapter 5) and ecological processes (Robertson, Chapter 3).

4.2 EVOLUTION AND DEVELOPMENT OF VEGETATION

The interaction of past and present climatic systems, together with underlying geology and past and present geomorphology, determine the present vegetation in the Four Corners area. This is further modified by localised edaphic (soil) and biotic factors (fire, herbivory). Werger & Coetzee (1978) describe the vegetation structure and general ecology of south central Africa, providing a useful overview for the study area.

4.2.1 Climate

The climate over this part of Africa is the consequence of two major systems, the wet Inter Tropical Convergence Zone (ITCZ) and the dry high-pressure system over the South Atlantic acting together with the cold Benguela current. This has led to a strongly seasonal summer rainfall that decreases in annual total from north to south and from east to west. The drier west experiences a greater diurnal range in temperature than the moister and warmer north, and winter frosts are frequent. Temperature changes during the Quaternary (caused by periods of glaciation in the northern hemisphere) had a profound impact on the climates of southern Africa (Van Zinderen Bakker 1978). During a glacial period, the summer rainfall area diminished in size; it received less precipitation and consequently the more arid vegetation types (Karoid and

Kalahari) expanded. With the return of warmer conditions, the ITCZ extended further south, the dry westerly wind systems shifted to higher latitudes, and there was amelioration of temperatures, leading to an expansion of more mesic (moist) vegetation. The present vegetation of the Four Corners is a meeting place of the mesic broadleaved woodlands from the north, with the xeric microphyllous woodlands and scrub from the south and west.

Frost (1996) comments that the palaeohistory of miombo woodland is hampered by the lack of accurately dated pollen profiles, and the fact that most of the dominant miombo species are insect pollinated, leading to under-representation in the palynological record. Considering the limited dispersal mechanism for many of the miombo dominants (a explosively dehiscent pod), the marked contraction in the range of *Brachystegia* in the past 1000 years implies that relatively minor shifts in temperature and moisture regimes can cause marked changes in miombo population dynamics. This is probably even more pertinent to *Baikiaea* (which has the same seed dispersal method) in the Kalahari woodlands in the west and south of the study area, given the more arid nature of that area and the fact that the species is probably at the environmental limits of its range.

4.2.2 Geology and Geomorphology

Cole (1986) discusses the distribution of present savanna woodlands in relation to geomorphology in central and southern Africa. Relatively uniform woodlands are found on the gently undulating plateaux landscapes of the African and post-African planation surfaces. The underlying geology is Precambrian with intrusive granites or gneisses, overlain in places by sedimentary formations (e.g. sandstones). This low relief has resulted in slow moving, diffuse drainage systems and the consequent formation of swamps and flooded grasslands. Because of the flat nature of the landscape, relatively minor tectonic shifts can cause major changes in direction and volume of water flow in the drainage systems such as the Okavango. Following periodic warping and differential uplift of the continental shield, the rejuvenation of the rivers such as the Zambezi, and changes in watersheds through river capture, led to increased erosion of the pediplains and exposure of the underlying bedrock. The improved drainage and erosion provided for conditions of soil renewal at the periphery of the plateaux and the formation of discrete vegetation types associated with these soils, e.g. mopane woodland in the Zambezi Valley. This is elaborated upon in the chapter on geomorphology (Moore, Chapter 2).

Overlying the western section of the African planation surface are the Kalahari sands, deposited in the interpluvial phases and eroded in the pluvial phases of the more recent Pleistocene. This blanket of aeolian and fluvial loose-grained sand has a low water holding capacity, but conversely it readily releases water for plant uptake. This factor, coupled with adaptations of plants found here, has given rise to the characteristic Kalahari sand woodland type dominated by mesic species that are only able to exist under the relatively low rainfall conditions through the high availability of water from the sands.

4.2.3 Biogeography

The rich flora of the Zambezian Domain changes gradually over the plateau of south central Africa, possibly as a result of the lack of strong relief and other contrasting physiographic factors (Werger & Coetzee 1978). As a large proportion of the species have a very wide distribution and the floristic changes are gradual, only broad or diffuse centres of endemism are distinguished. White (1965) defined the Barotse Centre of Endemism using species confined to the Kalahari sand area of Barotseland and adjoining areas of the Upper Zambezi, Cuando-Cubango of southeastern Angola and adjacent Caprivi, Botswana and western Zimbabwe. Typical species are *Baikiaea plurijuga*, *Acacia fleckii, Alchornea occidentalis* and *Baphia massaiensis*. There is considerable floristic and physiognomic variability towards the edges of the Barotse Centre. The

Zambezian Centre of Endemism is characterised by species confined to the hot, low-lying valley of the Middle Zambezi – most of which falls outside the Four Corners area.

The genus *Baikiaea* has its greatest diversity in the Guineo-Congolian rainforests and is thought to have evolved there (Brummitt 1986). *B. plurijuga* is the only species of the genus that has adapted to the drier savanna conditions of southern Africa; its spread southwards from the rainforests would have been favoured by the warmer and more humid conditions of pluvial periods in the Pleistocene. Huckabay (1986) considers the species to be at its present climatic limit; an important factor when considering the threats to it and its woodland habitat. A species or community at its environmental limits will be more vulnerable to fluctuations in external controlling factors such as fire and rainfall.

Scholes *et al*. (2002) examined the trends in savanna structure and composition along an aridity gradient on the Kalahari sands. They found that members of the Mimosoideae (mostly *Acacia*) dominate the tree layer in the southern and western sections that receive 200-400 mm mean annual precipitation. These are replaced by either the Combretaceae (*Combretum* and *Terminalia*) or *Colophospermum mopane* (a somewhat aberrant caesalpinoid species) between precipitation levels of 400 and 600 mm. Above 600 mm the Caesalpinioideae dominate. This group are considered characteristic of the old landforms of the Africa planation surface. They are thought to be the more ancient of the legumes, while the Mimosoideae evolved more recently under the hotter, drier conditions that prevailed after the break-up of Gondwanaland.

Many of the Caesalpinioideae are adapted (or perhaps pre-adapted?) to existence on the Kalahari sands through a combination of several strategies. The sandy nature of the soils allows for low water run-off, high water infiltration, good aeration, and low soil-water tensions; all are conditions that promote plant root development and growth. Woody plant roots can penetrate deep into the subsoil and tap the season's rainfall. But, despite the relatively high availability of soil moisture for much of the year, the long dry season has induced a deciduous habit in most species.

4.3 VEGETATION TYPES

The vegetation types of the Four Corners area are discussed below in very broad terms of overall structure. Much more detail is available through the published surveys and maps of individual countries.

4.3.1 Dry Forest

The *Cryptosepalum* forests of northern Zambia are found on Kalahari sands receiving more than 1000 mm rainfall per annum. This is the only true forest type in the study area, but its extent here is very small.

4.3.2 Woodland

Moving south, mean annual rainfall decreases from 1000 to 600 mm and the Kalahari sands support mesophytic *Baikiaea* forest that grades into *Baikiaea* woodland in the drier southern parts. Much of the woodland has been disturbed and shows a range of dominant species. Edaphic factors also influence the vegetation and help to create a mosaic of species and structure.

Miombo woodland (woodland dominated by *Brachystegia* and *Julbernardia* species) are related to moist, frost free or mild frost conditions on generally dystrophic soils. Their structure reflects the north-south rainfall gradient. Wet miombo woodland in the north of Kafue National Park is taller and denser than the dry miombo woodland in the south and east around Victoria Falls. At a smaller scale, the variety in miombo vegetation structure results from local differences in soils and landform. Termites play an important role in this system by creating patches high in soil nutrients that support plants that are otherwise confined to nutrient-rich areas (see Ecological Processes - Robertson Chapter 3). Narrow riparian fringes along the major rivers provide suitably moist micro-environments for several forest species, increasing their range into an otherwise arid environment. These range extensions contribute to the complexity and diversity of habitats for other plants and animals.

Separating the miombo and *Baikiaea* woodlands from the dry bushveld of the Central Kalahari lying to the south of the study area, is a belt of sclerophyllous arid *Colophospermum mopane* low woodland or bushveld. This formation encompasses the hot, dry Makgadikgadi, Okavango and Middle Zambezi drainage systems and occurs on basic, clay rich soils in zones where frost is infrequent.

Acacia open woodland or microphyllous thorny bushveld occur on fine-textured soils with a high clay and mineral content. Rain infiltration is poor, run-off is high, and the soil moisture is tightly bound to the clay particles. Root penetration on the heaviest soils is retarded by mechanical expansion and contraction of the clays, while poor aeration further hinders root development. Extreme examples of this type are the *Acacia nilotica* - *Ischaemum afrum* grasslands near Pandamatenga. Interestingly, the physiological adaptations to withstand arid conditions, e.g. high turgor pressure also enable these plants to tolerate frost.

4.3.3 Grassland

Most grasslands in the area are determined by soil properties, and species composition varies with the levels of soil moisture. The typical habitat is seasonally anaerobic grassland, mostly on sandy oligotrophic (very low nutrient) soils that are waterlogged and badly aerated for part of the year and dry (at least in the upper layers) for the dry season. The sparse open grasslands of the Barotseland plains show a great concentration of geoxylic suffrutices (White 1976). Many of these "underground trees" have closely-related, large above-ground species. Secondary grasslands occur in areas of woodland clearance, and may be maintained by regular late season hot fires.

Within the study area the halophytic (salt-tolerant) grasslands of the Makgadikgadi Pan complex and the *Cenchrus - Chloris* grasslands of the Mababe Depression are unique.

4.3.4 Wetlands

Wetlands form a mosaic of channels of open water, swamps and floodplains within the woodlands. In Zambia, dambos and pans interdigitate between the miombo woodland that grows on the higher interfluves. The canopy cover of the woodlands plays a critical role - one that is not yet fully understood - in determining the flow of groundwater into the dambos. Further south, the pans along ancient drainage courses and lacustrine deposits in Hwange and Botswana create limited sources of moisture and sinks for nutrients in an arid, oligotrophic environment. The same applies on a much greater scale to the Okavango Delta – a vast endoreic swamp in the dry Kalahari. The Barotse floodplain and the Chobe-Linyanti swamps form interconnecting routes for the distribution of aquatic plant and animal species in a relatively stable moist environment. However, they also can form barriers to species' movements (see Cotterill, Chapter 6).

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4.4 NATURE AND PATTERN OF THE MOSAICS: THE BASIS FOR BIODIVERSITY CONSERVATION

The biodiversity importance of the study area can be better understood by interpreting the patterns and mosaics of the vegetation, and therefore of the environment. A better understanding of biodiversity should lead to wiser conservation measures. One of the ways to approach this is to have in mind the *scale* of the mosaics or patterns. Just as the scale of a map determines the resolution of the units, so the scale affects the detail of the pattern and the appropriate level of conservation practices.

4.4.1 Large Scale

a) Landscape

The low relief and relative uniformity of the Central African plateau is interrupted by the easterly draining Zambezi River system and the large inland delta of the Okavango. The other macro features are the shallow Makgadikgadi Pans and the ancient dunes and fossil drainage lines of the Pleistocene. The sluggish upland drainage of the Upper Zambezi with the deposition of sediments and formation of swamps, is in sharp contrast to the fast-flowing, highly erosive power of the Middle Zambezi with the spectacular Victoria Falls and Batoka Gorge.

b) Geology

Much of the plateau is formed from Basement Complex rocks. In places these rocks have been covered with a variety of sedimentary formations (mostly Karoo sandstones) and intruded by narrow bands of basic rocks such as dolerite and gabbro (Frost 1996). Triassic basalts near the Victoria Falls flowed over the Karoo sandstones. To the west and south the extensive sheet of Kalahari sands overlying the plateau forms part of the mega-Kalahari Basin.

c) Vegetation

At a broad scale the predominant vegetation type is woodland. Dissecting the woodland, following the drainage channels, are grasslands. These vary in type according to the amount and timing of water availability, ranging from swamps to dry grasslands. To the drier west the woodland becomes more open and lower, meeting the desert scrubland of the central Kalahari. The saline grasslands of the Makgadikgadi Pans are a distinct type. The wetlands and swamps of the Okavango and Linyanti and Barotse form another distinct mesic type within the otherwise arid area.

4.4.2 Medium Scale

d) Soils

The plateau soils are loamy sands, sandy loams and sandy clay loams. They are deep, highly weathered and acidic with a low cation exchange capacity, low nitrogen and low phosphorus. Laterite is characteristic of these soils, indicating previous limits of the watertable.

The Kalahari soils are deep, loose, highly oligotrophic sands with very little clay and minerals. Both the plateau soils and the Kalahari sands are permeable and free-draining, permitting the development of a predominantly woody vegetation.

e) Vegetation

The woodlands are subdivided floristically into miombo (characterised by *Brachystegia* and *Julbernardia*), Kalahari sand woodlands (characterised by *Baikiaea*), mopane woodland and *Acacia* woodland/bushland. The grasslands are subdivided into dry (*Loudetia* and *Hyparrhenia*), and wet or flooded grassland.

4.4.3 Small Scale

f) Topography

On the plateau in Zambia fairly minor changes in topography have led to a mosaic of woodlands interrupted by narrow dambos or wetlands at the head of drainage systems.

In the Okavango, micro-changes in topography and biotic factors such as accumulations of plants, and even hippo tracks, open or block channels in the delta and re-direct the waterflow. This gives rise to a changing network of channels, swamps, grasslands and riparian woodland, surrounded by a dry semi-desert. The waterflow is not uniform so the mosaic changes in time as well as in space. This is an important consideration in any proposed alterations to water flows from the source.

g) Soils

On Kalahari sands, the regular pattern of fossil dunes is mirrored by a regular catenary pattern: *Baikiaea* woodland on the dune crests, grading into *Terminalia* scrub along the edges, with *Burkea* or *Acacia* open woodland at the base, lining the fossil drainage lines. The permeability of the sands in the dune troughs may be further modified by underlying layers of calcrete and ferricrete, and differential depositional conditions. The seasonal pans scattered along the fossil drainage lines and basins of the Kalahari sands provide sources of water and minerals, forming piospheres and contributing to the mosaic (Figure 4.1).

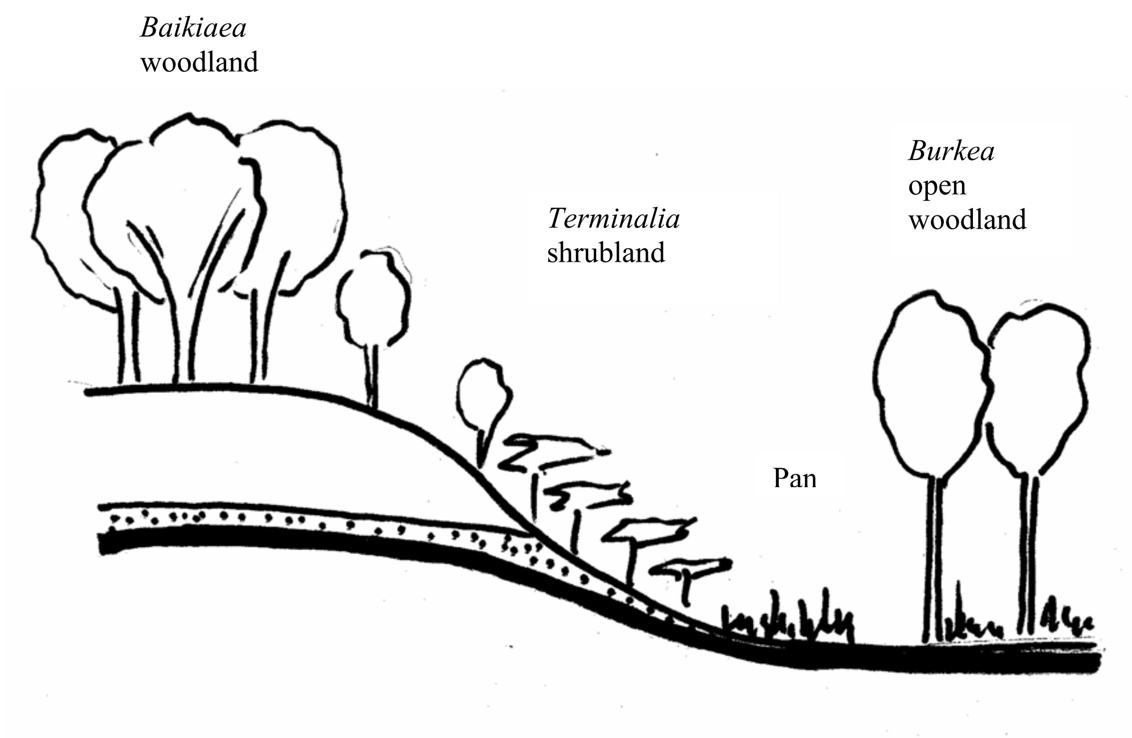

Figure 4.1. Distribution of vegetation types along a Kalahari sand dune catena.
The deep loose, horizon-less sands on the dune crest support a well developed woodland dominated by deep-rooting *Baikiaea plurijuga*. The dotted area represents a layer of fine, compacted sand. Where this layer meets the edge of the dune, shallow-rooting *Terminalia sericea* shrubland is found. Further down the slope the shrubland changes to a more open, perennial grassland. The solid black line represents a hardpan layer that is high in clay and fine material that impedes drainage, causing waterlogging of the soil and development of pans. *Burkea africana* open woodland is found along the edge of the drainage line on slightly higher ground. The soils here are gleys with characteristic orange mottling indicating temporary waterlogging. (adapted from Childes 1984).

The narrow riparian forests along the Zambezi River and its tributaries, growing on nutrient-rich alluvial soils, form a thin strip of high biodiversity in a comparatively depauperate environment. Similarly, the termite mounds in Zambian grasslands and the clay-based "islands" of woodland in Caprivi grasslands are patches of high nutrients in a poor environment. These islands also provide 'stepping stones' and a mechanism for dispersal of forest species across a savanna or grassland landscape.

h) Vegetation

Woody suffrutices (White 1976) are characteristic of the Kalahari sand grasslands. These form underground masses of woody growth in an otherwise herbaceous flora. The *Baikiaea* dwarf shell forests (Fanshawe & Savory 1964) are also thought to be a consequence of impeded drainage in an otherwise free-draining soil.

Within miombo woodland there are patches that are floristically different to surrounding types, but these cannot be mapped easily except at a very small scale, nor readily explained. In some instances the patches may be related to shifting cultivation and timber extraction. In the north of the study area there are transitions from wet miombo to dry miombo, and dry miombo to *Baikiaea* woodland. In northeastern Botswana, White (1983) does not even distinguish the floristic components of the type, simply calling it "transition from undifferentiated woodland to *Acacia* deciduous bushland". These transitions and mosaics are difficult to define and map. However, they provide important clues to the dynamics of vegetation change and are worthy of further investigation.

4.5 VEGETATION SURVEYS OF THE FOUR CORNERS AREA

4.5.1 Historical background

Botanical collections in this region began with Sir John Kirk, who accompanied Livingstone on his second expedition to Victoria Falls in 1860. Systematic collecting intensified during the early 1900s, but it was not until 30 years later that the vegetation was surveyed and described to any extent. The objectives of these initial reconnaissance surveys were to determine the distribution and logging potential of hardwood species (Martin 1940, Miller 1939), or to assess the grazing potential for cattle and other livestock (Pole Evans 1938), and vegetation types were described accordingly. The dominant timber or grass species were listed, together with a brief structural (physiognomic) classification. Harsh travelling conditions, the absence of topographical maps and the inaccessibility of much of the area meant that survey traverses were widely spaced.

With the strong focus on exploitation of the vegetation, it was only in the 1950s that conservation and controlled use began to emerge. Issues such as soil erosion, overgrazing, fire and wasteful exploitation (i.e. logging) methods were raised and appropriate management practices recommended (Judge 1993). At the same time Forest Reserves and Game Reserves were proclaimed. There was a growing realisation that a particular vegetation type reflected the sum of environmental factors - climate, geology, topography, soils and biotic influences. Surveying became more ecologically based and less floristic. The phytosociological approach grouped species that regularly occurred together; it was widely used in Europe but only became popular in southern Africa much later in the 1970-80s. Vegetation types were used as indicator of land potential or, in the case of tsetse fly control, as indicators of tsetse fly habitat. Also at this time, the advent of black and white aerial photography enabled botanists to recognise and delineate homogeneous units of land and vegetation over much greater areas. This revolutionised vegetation survey work and allowed for the rapid mapping of relatively large areas of vegetation. The adoption of a catenary concept gave a better understanding of the vegetation and was used extensively by Fanshawe (1971), although this concept had actually been used by a much earlier worker (Boughey 1961).

The perspective of vegetation surveys became more regional and continental with the formation of the Association pour l'Etude de la Flore d'Afrique Tropicale (AETFAT), the Yangambi Conference (CCTA/CSA 1956), and the start of the Flora Zambesiaca. The growing exchange of knowledge lead to a greater understanding of the regional patterns and the ecological determinants affecting the vegetation. The production of a species-based map of the Flora Zambesiaca region (Botswana, Zambia, Zimbabwe, Malawi and Mozambique) by Wild and Barbosa (1967) was, and still is, a landmark in vegetation mapping. The production of vegetation descriptions and a map of Africa by White in 1983, introduced the concept of centres of endemism, and set a regional framework that is still used by many other botanists and biologists today.

The Yangambi system of physiognomic classification, generally more applicable to moist forest ecosystems, was modified to suit savanna systems by Pratt, Greenway and Gwynne (1966). Their structural classification is still used today, with slight modifications, e.g. Tinley (1973) and Werger (1974).

Conservation and research studies of large mammals dominated the 1970s and 80s, which led to a series of habitat studies in national parks and game reserves, e.g. Simpson (1975).

The production of false colour satellite imagery (Landsat) in the late 1970s gave an important broad landscape overview of the vegetation and today remains the primary basis for landscape-scale mapping. Survey techniques changed from a subjective floristic classification to a stratified sampling approach, where areas of homogeneous texture, tone, pattern and topography are delineated on satellite images or aerial photographs. Sample plots are carefully sited on aerial photographs, avoiding any obvious environmental boundaries, before undertaking the fieldwork (Werger 1974, Craig 1983, Rogers 1993). This method relies on intensive field work and a sound knowledge of plant species (Timberlake, Nobanda & Mapaure, 1993) and is almost always based on woody plants. As a common system of surveying and mapping developed, vegetation surveys of different areas became theoretically more comparable. In reality this has not been achieved to any great extent. Landsat data have also been used to map woody cover, therefore changes in cover can be monitored over time with successive scenes.

Concurrent with the development of satellite imagery was the rapid development of computer technology that enabled massive volumes of data to be analysed rapidly, using programmes such as TWINSPAN. The approach was still phytosociological, i.e. grouping species that occurred regularly together, but the grouping of species and classification of vegetation associations or types became more objective. Plots were geo-referenced and could be re-sampled for the purposes of measuring vegetation change. Vegetation types were classified by characteristic species, and sub-types by differential species. One of the important features of many modern numerical floristic classifications is the derivation of environmental indicator species. Gradient and ordination analysis give indications of significant environmental factors accounting for species distribution in the landscape. With growing environmental awareness vegetation surveys and mapping are now becoming increasingly important in Environmental Impact Assessments and integrated landuse planning.

4.5.2 Current Situation

Timberlake (1999) gives a more detailed review of vegetation surveys in Zimbabwe and a discussion on the evolution of survey methods, while Timberlake & Nobanda (1993) give a useful annotated bibliography of all vegetation surveys in Zimbabwe up to that date.

SwedePlan (1989) summarise vegetation surveys and map coverage for the north east region of Botswana. This report also reviews the ecology of the area, commenting that most of the papers deal with the structure rather than the function of the different systems.

For the Western Province of Zambia Jeanes & Baars (1991) give a comprehensive appraisal of past vegetation surveys and maps.

Table 4.1 summarises the more readily available vegetation maps that cover all or part of the Four Corners area. Other maps that have been produced, but these are inaccessible (in unpublished reports) or lost and could not be located in time for this review. For each survey, only those vegetation types that fall within the present study area are discussed. The table is chronologically organised into two sections - regional maps and national maps. Maps are discussed with respect to both legends and vegetation types.

Regional Studies
The 1: 2.5 million scale map of Rattray and Wild (1962) only covers Zambia and Zimbabwe. It was based on published maps by Henkel (1931), and Trapnell, Martin and Allen (1962), and also on unpublished maps by Willan and Jackson. Subsequently, it formed the basis of the map by Wild and Barbosa (1967). Vegetation of the Four Corners area is divided into four physiognomic or structural types, with 11 subtypes based on species composition or floristics.

Wild and Barbosa (1967) mapped the Flora Zambesiaca region (excluding the Caprivi Strip) with the intention of showing the distribution of the plant species and the broad ecological factors governing them. Earlier maps and surveys by forestry, agricultural and tsetse departments formed the basis. Vegetation is classified into 18 structural types and 25 sub-types, based on floristics and dominant species.

White (1983) introduced the concept of biogeography to vegetation description. He identified the Barotse Centre of Endemism, which covers most of the study area. His map shows seven structural types, and he includes the new categories of forest and woodland transitions and mosaics. The 10 subtypes are also based on structure, albeit with some ecological separation, and further subdivided on dominant species.

The Terrestrial Ecoregions of Africa map (WWF US 1999) is based on White's map (White 1993) modified following discussions with regional experts and a review of the literature. The eight types present in the area are based on structure and floristics. Arising from the Terrestrial Ecoregions map is the Miombo Ecoregion vegetation map (WWF SARPO 2001a, Timberlake & Chidumayo 2002). This is by definition restricted to the Caesalpinoid woodland areas of Zambia and Zimbabwe, extending to the east of Botswana and Caprivi. The Okavango and Makgadikgadi Pans are not covered. The eight types, broadly following White (1983), are simplified to dominant species and structure.

Table 4.1. Summary of vegetation maps for the Four Corners area.

Author	Date	Title	Description of types	No. map units	Scale	Comments
A. Regional Maps						
White	1983	Vegetation map of Africa	structure, characteristic species	9	1: 5 m	
WWF-US	1999	Terrestrial Ecoregions of Africa	structure, characteristic species	8	1: 13 m	based on White's map
WWF-SARPO	2001a	Miombo Ecoregion: Miombo/ Mopane woodlands	structure, characteristic species	6	1: 10 m	based on White's map; only covers miombo areas
WWF-SARPO	2001b	Miombo Ecoregion: habitat diversity	Habitat	3	1: 10 m	only covers miombo areas
Wild & Barbosa	1967	Flora Zambesiaca vegetation map	structure, characteristic species	18	1: 2.5 m	excludes Caprivi Strip
Rattray & Wild	1960	Vegetation map of Federation	structure, characteristic species	11	1: 2.5 m	excludes Angola, Caprivi, Botswana
B. National Maps						
Angola - general						
Barbosa	1970	Carta Fitogeografica de Angola	structure, characteristic species	3	1: 2.5 m	includes area between Cuando & Cubango rivers
Botswana - general						
IUCN Botswana	1990	Nature of Botswana	structure		1: 5 m	very simplified map
Weare &Yalala	1971	Vegetation map of Botswana	structure, some topographical features	10	1: 3 m	revision of de Beer's (1962) map; rangeland potential
Soil Mapping Services	1991	Vegetation map of Botswana	soil type, associations, species, structure	22	1: 2 m	includes key to tree species & diagrammatic cross sections of land systems
Botswana - district/provincial						
Blair-Rains & McKay	1968	Northern State Lands, Botswana	structure, plant communities, species	19	1: 5 m	excludes Okavango area, includes Makgadikgadi
DHV	1980	Kalahari rangeland map	landscape elements, soils, woody and herbaceous species	6	1: 1.5 m	only covers SW part of country as far N as Makgadikgadi
Sommerlatte	1976	Survey of elephant populations in NE Botswana	structure, floristics	6		
Namibia - Caprivi						
Hines	1997	Caprivi vegetation map	structure, characteristic species	36	1: 570,000	map legend uses local common names

Author	Date	Title	Description of types	No. map units	Scale	Comments
Zambia - general						
Govt. Zambia	1998	Forest Estate	national and local forest areas	2	1: 1.5 m	study area contains 28 national forests & 17 local
Smith	2001	Ecological Survey of Zambia - Trapnell traverse records	soils, structure, characteristic species	53	1: 1 m	
Edmonds	1976	Vegetation map of Zambia	structure, climate, edaphic features, soils, topography	10	1: 5 m	correlates his types with Trapnell's
Zambia - provincial						
Jeanes & Baars	1991	Landscapes & grasslands map, Western Province	land forms, characteristic & common trees & grasses, vegetation structure	71	1: 5 m	land evaluation for extensive grazing
Zimbabwe - general						
Forestry Commission	1998	Zimbabwe woody cover map (VegRIS)	cover, structure	10	1: 3 m	no floristic information
Timberlake, Nobanda, Mapaure	1993	Communal Lands vegetation survey	structure, cover, characteristic species, soil type	7	1: 500,000	relevant section - Hwange Communal Land
Timberlake & Nobanda	1993	Vegetation survey in Zimbabwe		n/a		annotated bibliography & maps showing distribution of national small, medium, large scale surveys; also phytosociological surveys
Zimbabwe - district / provincial						
Rogers	1993	Woody vegetation survey of Hwange NP	characteristic species, structure, soils	31	1: 600,000	phytosociological survey
Mitchell	1961	Notes on portion of Wankie NP	characteristic species	3		map of 10 mile drive area near Main Camp
Childes	2001	Vegetation types, settlement & urban areas	structure, characteristic species, soils	8	1: 125,000	part of EIA report
Forestry Commission	2001	Floristic vegetation of Fuller Forest	dominant species, structure	10	1: 125,000	part of EIA report
Mapaure	1998	Vegetation map of Batoka Gorge	characteristic species, structure	5	1: 2000	part of EIA report

NB. Number of map units refers to those found within the Four Corners study area.
In addition there are several unpublished vegetation maps compiled by the Forestry Commission of Zimbabwe, but it was not possible to view them.

Table 4.2 is a general comparison of the vegetation types shown on the above five regional maps. It was not possible to make a detailed comparison in the time allocated for this review. The table also indicates the distribution of vegetation types in the Four Corners area.

It is immediately apparent that the scale of the maps correlates with the number and level of detail of vegetation types. Wild and Barbosa show 25 types at a larger scale (1:2.5 million), compared with the eight types of the Terrestrial Ecoregion map at a scale of 1: 13 million, complicating any comparison. However, the *Cryptosepalum* dry evergreen forest and the halophytic grasslands of the Makgadigadi Pans are clearly defined types on all maps, except that of the Miombo Ecoregion which excludes the Makgadikgadi. The other clear distinction of type are the grasslands which are further subdivided according to edaphic factors and dominant species by both Wild and Barbosa and White. Mopane woodland also comes out as a fairly clear type across all the maps. The distinct types are those that have discrete ecological boundaries.

Table 4.2. Comparison between vegetation types of four regional maps.

Wild & Barbosa (1967)		**Barbosa (1970)**		**White (1981)**		**Terrestrial Ecoregions (1999)**		**Miombo Ecoregion (2002)**	**Countries**					**Comments**
No.	**Vegetation type**	**No.**	**Vegetation type**	**No.**	**Vegetation type**	**No.**	**Vegetation type**	**Vegetation type**	**An**	**Bo**	**Na**	**Za**	**Zi**	
3	*Cryptosepalum*			6	Zambezian dry evergreen forest	32	Zambezian *Crypto-sepalum*	*Crypto-sepalum* dry forest				•		very little in NW Zambia, small patches next to *Baikiaea* forest
4	*Baikiaea* dry semi_ deciduous forest			22a	mosaic of dry deciduous woodland and secondary grassland (Zambezian)			*Baikiaea* woodland				•		patches in SW Zambia, often next to *Hyparrhenia*
12	*Commiphora_ Combretum*			22a	under 22a			under *Baikiaea*					•	in Hwange NP
16	*Baikiaea* woodland			22a	mosaic of dry deciduous woodland and secondary grassland (Zambezian)	51	Zambezian *Baikiaea*	*Baikiaea* woodland		•	•	•	•	widespread in NW Zimbabwe, NE Botswana & Caprivi; dist-inguished from type 4 by physiognomy
17	*Brachystegia floribunda_ Julbernardia paniculata*			25	wetter Zambezian miombo (dominated by *Brachystegia, Julbernardia, Isoberlinia*			Wet miombo woodland				•		W Zambia, little in Four Corners
19	*Brachystegia spiciformis*			26	drier Zambezian miombo (dominated by *Brachystegia, Julbernardia*	50	Central Zambezian Miombo Woodland	Dry miombo woodland				•	•	Zimbabwe, mostly forest reserves N of road & Zambia E of Zambezi
23	*Brachystegia spiciformis_ Julbernardia globiflora*			26	drier Zambezian miombo			Dry miombo woodland				•		N of Livingstone, also C Zimbabwe

Wild & Barbosa (1967)		Barbosa (1970)		White (1981)		Terrestrial Ecoregions (1999)		Miombo Ecoregion (2002)	Countries					Comments
No.	**Vegetation type**	**No.**	**Vegetation type**	**No.**	**Vegetation type**	**No.**	**Vegetation type**	**Vegetation type**	**An**	**Bo**	**Na**	**Za**	**Zi**	
														Zimbabwe around Kamativi; Zambia NE of Livingstone
29	*Brachystegia boehmii_ B.allenii*			26	drier Zambezian miombo			Dry miombo woodland				•		
35	*Colopho- spermum*	20	*Colopho- spermum mopane*	28	*Colopho- spermum mopane*	54	Zambezian _ Mopane woodland	Mopane woodland	•	•	•	•	•	drainage lines, river valleys in K Sand areas & on heavy basalt soils in Matetsi/ Hwange
38	*Baikiaea_ Colophosperm um_Burkea_ Dialium* tree savanna	25	*Baikiaea _ Guibourtia _Ricino- dendron* tree and/or shrub savanna	22a	mosaic of dry deciduous woodland and secondary grassland (Zambezian)			*Baikiaea* woodland	•	•	•	•	•	Botswana/ Hwange border; SW Zambia, Kafue & Caprivi; along Rio Cuando in Angola
40	*Pterocarpus angolensis_ Pericopsis_ Acacia*			29c	Undiffer- entiated woodland (north Zambezian)			*Acacia/ Combretum*				•		very little near Kafue
46	*Commiphora_ Combretum*				n/a			n/a - close to *Acacia/ Combretum*					•	very little around Hwange
47	*Terminalia sericea*			35a	Transition from undiff. woodland to *Acacia*	58 ?	Kalahari *Acacia_ Baikiaea* woodland ?	*Burkea/ Terminalia/ Combretum*		•	•		•	dominant in NE Botswana
48	*Acacia*				n/a		n/a	n/a - close to *Acacia/ Combretum*		•		•		small patch near Shesheke, around Mababe Depression, Lake Ngami, SE of Okavango
50	*Colopho- spermum*			28	*Colopho- spermum mopane*	54 ?	Zambezian _ Mopane woodland ?	Mopane woodland		•		•	•	widespread from E edge of Okavango across to Nata
55	*Acacia luderitzii_ Acacia giraffae_ Lonchocarpus nelsii* tree savanna				under 22a	58?	Kalahari *Acacia_ Baikiaea* woodland ?	n/a - close to *Acacia/ Combretum*					•	Hwange & C Botswana
60	*Diplorhynchus*				under 22a		n/a	under *Baikiaea*				•		small patch in SW Zambia

Wild & Barbosa (1967)		Barbosa (1970)		White (1981)		Terrestrial Ecoregions (1999)		Miombo Ecoregion (2002)	Countries					Comments
No.	**Vegetation type**	**No.**	**Vegetation type**	**No.**	**Vegetation type**	**No.**	**Vegetation type**	**Vegetation type**	**An**	**Bo**	**Na**	**Za**	**Zi**	
61	*Colopho-spermum*			28	*Colopho-spermum mopane*			Mopane woodland		•			•	probably much more widespread now
65	*Loudetia*	31	*Loudetia*	60	edaphic & secondary grassland on Kalahari sand	56	Western Zambezian grassland	Wetland/ grassland	•			•	•	SW Zambia, SE Angola
67	*Hyparrhenia*			64	edaphic grassland with semi_aquatic vegetation			Wetland/ grassland			?	•		Kafue
64	Papyrus			75	herbaceous swamp & aquatic vegetation			Wetland/ grassland		•	•			Okavango & Caprivi
70	*Cymbopogon_ Panicum repens_ Andropogon eucomus*			75	herbaceous swamp & aquatic vegetation	63	Zambezian flooded grassland	Wetland/ grassland		•				Okavango & Caprivi, outer floodplain
72	*Cenchrus_ Chloris*				n/a		n/a	Wetland/ grassland		•				Mababe depression
73	*Panicum repens_ Cynodon_ Aristida congesta*				n/a		n/a	Wetland/ grassland		•				Ngami depression
74	*Aristida meridionalis_ Heteropogon_ Odyssea*			76	halophytic vegetation	69	Makgadi-kgadi Pans halophytics	Wetland/ grassland		•				Makgadikgadi Pans

In between these clear types is a range of woodlands that vary in their canopy cover and species composition from *Baikiaea*-dominated woodland on Kalahari sands in the drier west and south to *Brachystegia*-dominated woodland in the wetter east and north. White (1983) deals with these by calling them mosaics and transitions, while Wild and Barbosa (1967) subdivide them on floristics. The Terrestrial Ecoregions and Miombo maps simply lump the types into broad categories. Distinguishing and mapping these mosaics and transitional woodlands is clearly a problem that needs to be addressed.

National Studies

Angola

There is little available information on the Four Corners area of Angola, owing to the past 30 years of civil war and its remoteness. The only located map is by Barbosa (1970). Although a further study on the plants of this province has been published (Teixeira 1960), it has not been possible to locate this. Smith (1976) gives a description of the vegetation along the headwaters of the Cuando and Cubango rivers as part of his paper on the Okavango drainage system. The area between the Cuando and Cubango rivers is covered with a mosaic of savanna, with or without trees and shrubs, and a dry (semi-deciduous) forest on sand with patches of "mutemwa" (a colloquial term for a thicket containing characteristic shrubs and climbers). *Baikiaea* and *Guibourtia* are the dominant species. Groves of *Schinziophyton rautanenii* occur along the highest river terraces of the Cuando. Along sandy plains on the upper reaches of the Cuando are edaphic grasslands or "chanas" with the grass *Loudetia simplex* and a few stunted trees and suffrutices, including *Parinari capensis* and *Protea trichophylla*. Riverine woodland is sparse and *Syzygium* species line the lower reaches of the rivers as they cross into the Caprivi.

Botswana

Blair Rains and McKay (1968) mapped the Northern State Lands of Botswana, which excludes the Okavango Delta but includes the Makgadikgadi Pans. Their survey was based on aerial photos and included soil profiles from sites in each vegetation type. The map units are arranged into plant communities, with subdivisions according to characteristic species and then structure: tree >15 feet, shrub 5-15 feet and scrub <5 feet.

The provisional vegetation map of Weare and Yalala (1971) was a revision of an earlier map by de Beer (1962), incorporating information from a number of ecological and vegetation surveys (including the above) that were made to assess the potential for cattle ranching and agriculture. Their mapping units are based on vegetation structure, with some topographical features. A key feature is the 'mopane line' indicating the extent of mopane, the southern extremity of this woodland type.

The Kalahari rangeland map produced by DHV Engineers (1980) covers central and south west Botswana, only reaching into the Four Corners area at the Makgadikgadi Pans. It was based on aerial photo-mosaics, aerial surveys and field work. They divided the area into landscape elements, which are then classified according to the soil characteristics; plant nutritive values are also given. Vegetation was classified using floristics and structure. Unfortunately, it does not cover much of the study area, but illustrates a constructive landscape and soil-based approach.
The vegetation map in the SwedePlan report (1988) covers the whole Four Corners area in Botswana. It is a modified version of Weare and Yalala's map, with a physiognomic classification.

A later map by the Soil Mapping and Advisory Services (1991) of the Ministry of Agriculture, also done at a scale of 1:2 million, groups vegetation largely according to soil type: sandveld, hardveld, miombo, recent lacustrine, fossil lacustrine, recent alluvium, transition sandveld-hardveld, mopane, wetland, and non-vegetated area. These 10 groups are further subdivided into associations based on typical or characteristic species, generally woody plants. The next level has 19 physiognomic or structural subunits. Schematic cross sections of land systems and a diagrammatic key to tree species are very helpful inclusions. The authors make comments and corrections to the maps of both Weare and Yalala and White.

Other key papers on the vegetation of Botswana are those by Simpson (1975) covering the Chobe National Park, and Smith (1976) who describes the vegetation of the Okavango drainage system.

There is a current project in the Chobe National Park that includes vegetation mapping (M. Chase, pers. comm.). No further details are available.

Namibia – Caprivi

The environmental profile and atlas of Caprivi by Mendelsohn and Roberts (1997) is a very useful document that presents a good visual summary of the factors affecting the environment in the Caprivi. Its primary use is for agriculture / planning purposes. The section on vegetation by Hines (1967), defines 36 different vegetation units described and mapped from satellite imagery, aerial and ground surveys. The mapping units (not vegetation types) are distinguished by their location and structure, and the descriptions include the dominant or typical species, percentage woody cover, soil and topographical features. Unfortunately the author chose to use common and local names for the vegetation units, which makes quick comparisons with other more conventional nomenclature difficult.

Zambia

The vegetation/soil map of Zambia by Trapnell, Martin & Allan (1962) was considered of such importance and relevance today that it has been re-published by Smith (2001). Climate, geomorphology, geology, topography and soils are discussed with respect to the Pleistocene and modern times. Their classification of vegetation structure followed the Yangambi system, and vegetation descriptions included physiognomy, characteristic species (mostly woody plants), site, soil, distribution, subtypes, derivations, catenary sequence and catenary subtypes. The more common woody species in each vegetation type are listed. A total of 53 units are used and mapped at a scale of 1:1 million. These studies were used as a basis, along with his own extensive plant surveys, for the vegetation description of Zambia by Fanshawe (1971).

Following these major works by Trapnell and Fanshawe, Edmonds (1976) produced a series of maps at 1:500,000 scale covering the whole of Zambia. The maps were based on airphoto mosaics, published vegetation maps, unpublished Forestry Department maps and field work. The primary classification is on structure, with secondary divisions on ecological factors (climate and edaphic), and finally floristics. A constructive addition to Edmond's comprehensive work is his comparison with the vegetation types of Trapnell *et al.* (1962).

Jeanes & Baars (1991) extended Edmonds' approach, but at a more detailed scale, to include the extensive rangeland work of Verboom (1970) and a survey by Jeanes (1985) in Western Province (see Tables 6 and 8 of their report). They approached their vegetation survey from a different perspective - that of a land evaluation exercise to determine potential carrying capacity for domestic livestock. They devote a whole chapter to grasses and grass associations, with diagrams showing the topographical catenary sequences of grasses and woody plants. This refreshing move reduces the bias placed on woody plants and emphasises the grass component in the ecosystems, which are the fundamental base for wild and domestic ungulates. In their map of landscapes and grasslands (Jeanes & Baars 1996), produced in conjunction with Baars' (1996) thesis, Jeanes and Baars use a hierarchical land classification and delineated the 71 map units on the basis of land forms, dominant and common tree and grass species and vegetation structure. Their units are derived from earlier maps, satellite imagery, aerial photomosaics and fieldwork. Structure is based on tree height: tree >5m, shrub <5m, sub-shrubs and grasses < 0.5m.

There is a recent vegetation map of the Kafue National Park compiled by Greenforce but it was not possible to locate it for this review.

Zimbabwe

To produce the Zimbabwe woody cover map (Forestry Commission 1998) Landsat TM imagery was visually interpreted and combined with extensive fieldwork. Although it gives an indication of cover types, and could therefore be used to monitor changes in cover of woody plants if it was repeated, it has a very limited use since no floristic information was included.

The primary work that falls within the study area is that of Rogers (1993) in the Hwange National Park. She undertook a reconnaissance survey, following the method developed by Craig, Martin & Mahlangu (1984). Data from a vegetation survey in the Sinamatella area by Tafangenyasha (1987) were incorporated. Her report describes 30 phytosociological types of woody vegetation with respect to location, woody species composition and environmental conditions. The inter-relationships between the types are proposed and represented diagrammatically. The author noted that an estimate of relative species abundance in each sample would help with the type descriptions. She compared the types derived from her survey with those of Mitchell (1961), Wiltshire (1964), Robinson (1975), and Childes and Walker (1987), all of whom covered various parts of the National Park.

Concurrently, vegetation of the Matetsi Complex was surveyed by Childes (1989) using aerial photographs and the same stratified sampling methods as Craig *et al.*(1984). A report for the Department of National Parks and Wild Life Management was produced but unfortunately the 1:80,000 scale and 1:250,000 scale maps have been lost. Childes describes four major categories, classified into 10 types based on woody species composition, with 18 subtypes based on structure, soil type and topography. That these were generally similar to the types described by Rogers (1993) reinforces the repeatability of the survey method, despite a change in observers. The broad categories of the Matetsi work agreed with an earlier survey by Hill (1969) of the Zambezi National Park (part of the Matetsi Complex) and descriptions by Wild (1964).

Timberlake, Nobanda and Mapaure (1993) surveyed the vegetation of the communal lands of Zimbabwe including Hwange Communal Land, a section of the Four Corners area. They used a phytosociological approach, basing their initial stratification on aerial photos, using Landsat imagery for the final mapping. Within the study area they identified seven physiognomic and floristic classes which are described according to the characteristic species, structure, geomorphology, geology, soil and level of disturbance. They noted the difficulties of sampling and describing the mosaic and catenary nature of some of the vegetation.

In addition to the above studies, there have been several enumeration surveys and ecological studies in the Kalahari sands area; the reader is referred to the annotated bibliography by Timberlake (1994) for more details.

Environmental Impact Assessments for development and planning purposes also feature in this part of the study area. The comprehensive IUCN report (IUCN ROSA 1996) attempted to provide a basis for the joint development of Victoria Falls and Livingstone. This was followed by a report by the Victoria Falls Consortium (2001) including a vegetation map of the Zambezi National Park and Fuller Forest Area. Also relevant to the study area is the detailed EIA report for the Batoka Dam (Mapaure 1998) with a small scale vegetation map of the gorges and immediate surrounds.

4.6 VEGETATION TYPES AND PLANT ASSEMBLAGES OF CONSERVATION IMPORTANCE

4.6.1 Vegetation Types

Since the above vegetation surveys have been undertaken for a variety of objectives, mostly from a utilisation or descriptive perspective, very few authors have commented on the conservation status of the vegetation types. The only ones found are those listed in Table 4.3.

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In Botswana, one of the most important plant assemblages is the Okavango Delta with its mosaic of wetland, grassland and riparian woodland. The relatively undisturbed part of the Chobe-Linyanti wetlands and the black cotton soil grasslands at Pandamatenga were considered to be of high conservation value (SwedePlan 1989). These grasslands extend into Zimbabwe and are protected in the Kazuma Pan National Park (NP) and the south western part of the Matetsi Safari Area. The Makgadikgadi Pan and the Mababe Depression grasslands are open areas surrounded by *Colophospermum mopane* and *Terminalia sericea* open woodland and shrubland and thus add to the biodiversity of the region.

In the Caprivi, Hines (1997) considered the Zambezi woodland, Okavango-Kwando valley woodland, Omuramba fringe woodland, Teak woodland and Impalila woodlands to be important. Of these types, only one – the Okavango-Kwando valley woodland - is partially protected; the remainder are unprotected. Some of Hines' types are similar to those identified by Childes, viz. Upper Zambezi riparian woodland, *Acacia kirkii* woodland at Kazungula, *Baikiaea* woodland on deep Kalahari sands in the south of Zambezi NP, Matetsi and parts of Hwange NP, and *Colophospermum mopane – Brachystegia boehmii* woodland at the base of basalt hills and along drainage lines in Matetsi and Zambezi NP.

Rogers (1994) noted that her Types 19 (*Combretum hereroense – Hyphaene* bushed grassland on calcrete), Type 29 (ecotone *Baikiaea plurijuga – Commiphora mossambicensis* woodland and thicket) and Type 30 (*Burkea africana – Terminalia brachystemma* bushland) in Hwange NP occur nowhere else in Zimbabwe.

In Zambia Bingham and Smith (2002) considered the following habitats to be threatened:

i) Livunda *Cryptosepalum* forest in northwestern Zambia – threatened by over-exploitation and cultivation (only a small section of this type occurs in the study area),
ii) *Baikiaea* forest in the Western Province of Zambia – threatened by over-exploitation, cultivation and fires. According to G. Calvert (pers. comm.) there may be relatively intact (unlogged) Kalahari sand woodland in south west Zambia, north of Masese near the headwaters of Mulobezi River 170-180 km due north of Livingstone. This area should be checked for conservation value. The status of the *Baikiaea* forest and the adjacent plateaux grasslands in Sioma Ngwezi also need checking.

4.6.2 Other Conservation Issues

4.6.2.1 Timber exploitation

This factor is of such importance to an understanding of the current state of the *Baikiaea* woodlands in the Four Corners area that it is highlighted here. The conservation of these woodlands has to take into account the previous management history (or lack thereof) and the very slow growth rates, and therefore slow recruitment, of the trees.

Early foresters noted the deleterious impact of timber extraction (e.g. Kelly Edwards 1940) and some attempts were made to rationalise the exploitation with the introduction of minimum diameter cutting sizes. Logging companies paid minimal royalties to the state, but the lack of effective policing meant that their activities were rarely monitored. The construction of the Bulawayo-Victoria Falls railway line had a catastrophic and lasting impact on the vegetation in north western Zimbabwe as hardwoods such as *Baikiaea plurijuga* and *Guibourtia coleosperma* were felled primarily to make railway sleepers, and *Pterocarpus angolensis* for furniture.

Table 4.3. Vegetation types of conservation importance in the Four Corners area.

No	Type	Occurrence	Importance	Protection status	Ref.	Notes
1	Zambezi woodland (tall, closed canopy trees: *Parinari curatellifolia, Kigelia africana, Diospyros mespiliformis, Trichilia emetica, Acacia sieberiana, Lonchocarpus capassa* with lower trees of *Garcinia livingstonei, Piliostigma thonningii*). On clay-loams	Caprivi – occurs as series of wooded 'islands' in areas of grasslands in area of transition between western uplands and eastern floodplains	Centres of high diversity in otherwise depauperate landscapes	none	Hines 1997	
2	*Diospyros mespiliformis – Garcinia livingstonei –Trichilia emetica* tall, evergreen sub-continuous closed woodland on loamy alluvial soils with some Kalahari sand influence	Zimbabwe – Upper Zambezi riparian fringe, including the Rain Forest at Victoria Falls	High diversity (plant & animal), river bank stability, aesthetics; heavy wildlife utilisation	Zambezi NP & Matetsi SA	Childes 1989, 2001	Similar species to Type 1of Hines
3	Okavango-Kwando valley woodland (tall trees *Acacia nigrescens, Acacia erioloba, Ficus sycomorus, Kigelia africana, Lonchocarpus capassa, Diospyros mespiliformis,* with *Acacia tortilis, Albizia harveyi, Terminalia prunioides* and *Combretum imberbe* in slightly drier habitats). On loamy soils with high arable potential	Caprivi - on floodplain margins, levees and old fluvial courses	Highest species diversity (plants & birds), heavily utilised by livestock and wildlife; one of most threatened habitats	largely unprotected, except Mahango GR	Hines 1997	
4	*Acacia kirkii* medium height woodland on alluvial floodplain with few *Faidherbia albida, Acacia tortilis* and *Trichilia emetica* trees	Zimbabwe – small area near Kazungula on the Zambezi River	Rare and isolated type; very heavy elephant impact	Matetsi SA	Childes 1989	

No	Type	Occurrence	Importance	Protection status	Ref.	Notes
5.	Omuramba fringe woodland (*Acacia erioloba, Combretum imberbe, Acacia nigrescens* medium height trees, open cover) on mixture of Kalahari sands and heavier soils. Lower trees and shrubs are *Terminalia sericea, Acacia fleckii, Peltophorum africanum, Lonchocarpus nelsii, Combretum hereroense*	W. Caprivi – distinct fringe along lower slopes of dunes or omuramba margins	High species diversity; important grazing habitat for wildlife	unprotected	Hines 1997	Similar to Types 21,23 & 24 of Rogers
6.	Teak woodland (*Baikaea pluirjuga* dominant, with *Burkea africana, Ricinodendron rautanenii, Guibourtia coleosperma* & *Pterocarpus angolensis* tall trees, with *Baphia massaiensis, Bauhinia petersiana* shrubs)	Caprivi – deep, dystrophic sands on dune crests or pockets of deep sand	Severely overutilised for timber production, remaining sites of intact forest have high conservation value	unprotected	Hines 1997	
7.	*Baikiaea plurijuga – Baphia massaiensis* medium height sub-continuous closed woodland on red, orange or buff Kalahari sands on dune ridges	Zimbabwe – S of Zambezi NP, Fuller Forest, Pandamasuie Forest, Kazuma Forest and centre and east of Hwange NP	Much has been logged – up to 3 times in past 100 years. Fires a major factor limiting regeneration; unlogged, mature sites have very high conservation value	Zambezi NP, Matetsi SA, Forestry Areas (but exploited)	Childes 1989, 2001	Type 6 of Hines & Types 23, 27 & 28 of Rogers
8.	Impalila woodlands (tall woodland mosaic of wetland & dryland habitats; extreme western limits of some east-tropical species). On basalt soils	Caprivi - Impalila Island	Extremely diverse vegetation and high biodiversity	Unprotected ?	Hines 1997	
9.	*Colophospermum mopane – Brachystegia boehmii – Pterocarpus rotundifolius* tall, moderately open woodland on well drained basaltic soils, sometimes with a Kalahari sand influence	Zimbabwe – Matetsi SA – along base of the basalt hills, forming a margin along the grasslands in the drainage lines; in Zambezi NP – along low terraces and drainage lines	Important wildlife habitat – provides shade and shelter for grassland animals; heavy elephant impact	Matetsi SA and Zambezi NP	Childes, 1989 & 2001	Similar to Type 5 of Rogers

No	Type	Occurrence	Importance	Protection status	Ref.	Notes
10.	Pandamatenga grassland on black cotton soil (vertisols)	Botswana & Zimbabwe – area of grassland N of Pandamatenga, near Kazuma Pan	Only undeveloped area of black cotton soil in Botswana	Unprotected in Botswana, protected in Matetsi SA	SwedePlan 1989	Weare & Yalala's type: Ngamiland tree savanna; Childes' *A. nilotica – Ischaemum afrum* grassland
11	Okavango Delta - mosaic of wetlands, grasslands and riparian woodland	Botswana	Wetland of global biodiversity importance	Partly protected in Moremi GR	SwedePlan 1989, Smith 1976	
12	Chobe - Linyanti wetlands	Botswana	Relatively undisturbed by human activities	Unprotected ??	SwedePlan 1989	

Logging of the same species was also occurring in Zambia, Botswana and Caprivi at this time, and the advent of the railway link with Zambia meant that increased volumes of timber could be exported to South Africa. Bingham (2001) notes that logging is still an important industry in the Western Province of Zambia, with significant volumes of *P. angolensis* and *G. coleosperma* being exported to South Africa.

The history and effects of logging hardwood species, particularly those on the Kalahari sands, has been extensively discussed (see Piearce & Gumbo 1993). In essence, the impact of felling the very slow growing trees in the Kalahari sand woodlands is to open up the canopy, thereby increasing the grass cover and fuel load for dry season fires. In turn, this has a negative effect on regeneration as many species are fire-sensitive. A second factor operating in this environment is frost. Once the canopy has been opened there is an increased impact of frost, which in turn increases the fuel load and height of fires. The vegetation becomes trapped in a frost-fire cycle and regeneration is further suppressed. The dynamics of vegetation change, grow rates and the slow regeneration are discussed in Childes and Walker (1987) and Calvert (1993).

The very slow growth rates (150-300 years to maturity, depending on species), means that there has been severe over-exploitation through logging. This is illustrated in the reduction in minimum tip diameter (over bark) - 35 cm in 1936, 20 cm in 1960s and 15 cm in 1989 - for exploitable timber in north west Zimbabwe (Mushove 1993). Despite this knowledge, the trees are still being felled at an unsustainable level because exploitation has not been based on biological attributes but rather on short-term economic considerations and for political expediency. Burger (1993) comments that the current exploitation of Botswana's forests is unsustainable, disorganised and inefficient, with negative ecological and management impacts.

Although there have been lengthy recommendations on forest management to encourage regeneration, the lack of funding and staff are cited as reasons for poor implementation of appropriate practices. This is compounded by the paradoxical attitude that forests must "pay for themselves", yet the timber is underpriced to encourage exploitation! (Mujakachi 1993). Mushove (1993) recommended that the current forest pricing policies and obligations of the concessionaires be revised. He suggested that a concession should include compulsory management of forest areas, and not just timber exploitation. This valuable suggestion needs to be implemented immediately. The introduction of the Forest Stewardship Certification (FSC) process, which is still in its first stages in Zimbabwe and has not begun in the other countries, is a major advance as it emphasises sound ecological and environmental practices and sustainable harvesting. However, this certification system only applies to importing countries in the west, the Asian market has no known restrictions on African hardwoods. None of the timber species found in the Four Corners area are yet listed by CITES (Convention for International Trade in Endangered Species). However the current high levels of exploitation of *Pterocarpus angolensis*, *Afzelia quanzensis* and *Baikiaea plurijuga*, both as timber and for the carving / curio trade around Victoria Falls and Livingstone, are cause for great concern and need further investigation. This is clearly an opportunity for a transfrontier initiative on trade in timber and wooden curios. 'Green' labelling and tourist / market education coupled with effective policing and protection measures would help the long term survival of the species.

4.6.2.2 Elephants

Forming over 90% of the mammalian biomass in northwestern Zimbabwe and north east Botswana, these megaherbivores are generalists, feeding off a range of plants in a range of vegetation types (see Conybeare, Chapter 15, Elephant Impacts). They influence biodiversity at many different levels, but with regard to woody plants there are two major impacts: (a) elephants actively select particular trees leading to localised declines in those species; and (b) they change the structure of the vegetation by opening up woodland leading to increased grass growth and increased fires. The woodlands ultimately become shrublands or fire-climax grasslands. This effect is exacerbated by the additional influences of logging and frost. Woodland regeneration is, and will continue to be, impeded under conditions of high elephant density. Conservation authorities have to make the decision whether to permit the elephant population growth to remain unchecked, and thereby lose the woodlands and the associated biodiversity and environmental services, or not.

4.6.2.3 Fire

Fire is a natural phenomenon in all savannas, but the incidence and timing of fires has changed markedly over the past century with the increase in human population and activities. The construction of the Bulawayo-Victoria Falls railway line not only led to the felling of timber from Kalahari sand woodland along the line of rail, but as the locomotives were steam-powered there was an great increase in fire in the Gwayi, Hwange and Matetsi / Zambezi areas from flying sparks. Similarly, steam locomotives run by the Zambezi Sawmills Railway increased fire incidence from Livingstone to Shesheke and Mulobezi in Zambia (Calvert 1986a). The woodlands of north east Botswana and the Caprivi have also been severely affected by fire (C.Hines, pers. comm.) which leads to a shift in dominance from fire-sensitive species, e.g. *Baikiaea plurijuga*, to those that are more resistant, e.g. *Terminalia sericea* and *Burkea africana* (Calvert 1986b). *Baikiaea* is considered to be at the limits of its range and cannot be expected to regenerate fully under the current fire regime unless there are effective protection measures. The effects of fire, fire management and control measures have been debated at length, but most managers agree that fire control is vital to the continued existence and rehabilitation of the Kalahari sand woodlands. This is particularly applicable to any long-term or 'sustainable' utilisation forestry programmes and should be borne in mind when planning any community based natural resource management projects. A transfrontier initiative on practical fire protection would help consolidate conservation actions in the various countries.

4.6.2.4 Global Climate Change

There is a general consensus that global warming will lead to higher temperatures and lower, more erratic rainfall in the southern African region (Hulme 1996). The implications are that this will probably lead to a decrease in the more mesic species where they occur at the edges or extremes of their range, e.g. *Baikiaea plurijuga* and *Guibourtia coleosperma*. There will be a contraction of the woodlands and forests and an increase in shrubland and grasslands as the vegetation moves towards drier formations.

4.7 GAPS IN KNOWLEDGE

1. There appears to be a serious gap in our knowledge of the conservation value of the various vegetation types. This has obvious implications for directing conservation and research effort. The vegetation types throughout the study area need to be assessed for:
   a) their relative rarity or uniqueness,
   b) their diversity of species and structure,
   c) the level of disturbance, i.e. a mature stand of *Baikiaea* will have a higher conservation value compared with an area that has been logged and burnt regularly,
   d) the current level of protection – even if a type is theoretically protected within a national park or forest reserve, how effective is the protection?

2. There is an overall lack of understanding of the dynamics of the ecosystems (with the possible exception of the Okavango), particularly for the mosaic vegetation types. For example:
   a) the interaction between the *Brachystegia* / miombo elements and the *Baikiaea* / Kalahari sand elements in the woodland mosaics in southwestern Zambia and northwestern Zimbabwe,
   b) the dynamics of the woodland 'islands' in the floodplain grasslands of the Caprivi, western Zambia and northern Botswana,
   c) the dynamics of the dry deciduous woodland and secondary grassland mosaic (White's type 22a),
   d) the patterns of *Terminalia sericea* tree savanna (Wild's type 47, White's type 35a, Rogers' types 21, 24, 25, 26) with respect to edaphic, climatic and biotic factors,
   e) the functioning of dambos and other wetlands with respect to the adjacent woodlands on the interfluves,
   f) the impact of woodland loss on carbon fixing.

3. There is little knowledge or understanding of the small, but ecologically important pans and narrow riparian fringes.

4. A vegetation map would be useful, one at a suitable scale (greater than the 1:2.5 million of Wild & Barbosa 1967) that crosses international boundaries and covers the study area in sufficient detail. Another gap is the lack of readily locatable vegetation surveys and maps for the Kafue and Sioma Ngwezi National Parks.

5. Perhaps the single most important gap in our knowledge is the correct valuation (economic and ecological) of the vegetation resources, particularly the hardwood timber species. An understanding of the ecological value of a species, especially a dominant tree like *Baikiaea* is vital to an understanding of the pattern and dynamics of the vegetation. Understanding its true economic value is important in making conservation management decisions.

4.8 MONITORING

In order to monitor something there must be clear objectives; the exercise should be undertaken to answer specific questions. Monitoring is the tracking of change over time, and at least three sets of data need to be collected in a repeatable manner to indicate any trend. All natural systems are by their nature dynamic; it is the degree and pattern of change that is of interest. The decision to monitor is either academic – is there a change and is it real? (i.e. not just an artefact of the method used); or for management purposes – what is the level of change, and the corollary question, is this acceptable? What are the probable factors causing the change? In the latter case, monitoring makes little practical conservation sense unless the likely factors contributing to the changes are also identified and tracked. The issue of monitoring, particularly without very specific, well-defined questions, is fraught with debate as it is time-consuming and relatively costly. In order to be statistically significant and to extrapolate from the results, the sampling design needs to be fairly complex. It should include a minimum of five replicates per site, and each site should be chosen for the uniformity of the external determinant factors (soil, rainfall, fire, disturbance, etc.).

With respect to vegetation monitoring, once again the scale of the question that is being asked will determine the resolution of the method used. Vegetation monitoring ranges in scale from individual species regeneration and life cycle studies, to line transects, fixed plots, aerial photo and satellite image interpretation. Table 4.4 gives examples of some general objectives and possible methods for monitoring vegetation.

Within Zimbabwe, the Forestry Commission currently has ten (there were originally 48) permanent sample plots in Kalahari sand woodland scattered from near Bulawayo to Victoria Falls. The first plots were established in the 1930s to monitor recruitment and growth rates of the main timber species. The Commission should be commended and encouraged to continue with this valuable work. Similar plots probably exist or used to exist in other countries, but the details of these are not known – another gap in our knowledge.

A useful transfrontier project would be to identify all the past and present vegetation monitoring sites and synthesize the results of all this work. This would help direct any future monitoring programmes.

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Table 4.4. General objectives and examples of methods for monitoring woody vegetation

Objective / Question	Appropriate Method	Product and Comments
Regeneration of timber species or species of conservation concern	Permanently mark individuals of each woody species and record dbh, height, age of first reproduction. Repeat records after periods that are appropriate to the speed of growth of the plants	Population dynamics and life table model for the species ⇒ growth rates of each size class ⇒ potential for sustainable use (forestry) or regeneration (conservation). Time consuming. Zimbabwe Forestry Commission already have 10 plots; more in other countries
Does the community change in structure and composition ?	Permanently marked (relocatable) known size plots in which every individual woody plant is identified and measured. Repeat measurements after appropriate time	Relative species abundance, biomass contribution per ha and community composition and structure. Time consuming and needs experienced field botanists
What is the pattern and change along a catena ? or What are the changes in the mosaics ?	Line transect (relocatable) down a catena or across the boundaries of a mosaic. Record and measure species and take soil samples at appropriate intervals along the line	Correlation between soil type, catenary position and vegetation type. Changes over time in species distribution recorded, e.g; invasion of grasslands by *Terminalia*. Time consuming
Measure changes in canopy cover	Aerial photos, SPOT or Landsat imagery, depending on the size of the area to be studied and scale of investigation	Photos and images have to be taken at the same season otherwise phenological and fire differences will confuse the results. Differences in geology, topography, groundwater can further complicate interpretation. It is possible to identify some tree species from aerial photos, but not possible with satellite images. Both techniques give little indication of changes in vegetation structure. Suitable for large areas. Some field reconnaissance needed, but mostly desk work

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