Regeneration and management of *Brachystegia spiciformis* Benth. and *Julbernardia globiflora* (Benth.) Troupin in miombo woodland, Zimbabwe.

A thesis submitted for the degree of Doctor of Philosophy
at the University of Oxford.

Isla Mary Grundy



Wolfson College, Michaelmas Term, 1995

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Abstract

Miombo is dry deciduous woodland dominated by leguminous tree species, covering a significant area of Africa south of the equator, including large parts of Angola, Malawi, Mozambique, Tanzania, Zaire, Zambia and Zimbabwe. This woodland type reaches its driest, most species-poor limit in Zimbabwe. *Brachystegia spiciformis* and *Julbernardia globiflora* are the two main dominants of the drier form of miombo.

Miombo woodland represents a rich and diverse resource base for small-scale farmers throughout the region, the importance of which has been ignored in the past by managers and policy-makers. The development of sustainable management strategies for this resource has therefore been hampered by a lack of knowledge. For this reason, the overall objective of this research was to define the basis for sustainable management of these woodlands, firstly by developing techniques for measuring biomass and monitoring woody growth; secondly, by examining the effect of site conditions on productivity; and thirdly, by investigating biological and social aspects of the management of these woodlands.

This research has found that good estimations of standing wood biomass of these two species can be derived from diameter and stem length measurements, thus providing woodland managers with a means of assessing the standing stock. The finding that *B. spiciformis* forms annual rings can be used in ageing the trees, projecting future yields more accurately, as well as monitoring the effects of management on growth.

In the investigation of the effects of climatic and edaphic conditions on tree growth, soil depth was found to have the greatest influence, followed by mean annual rainfall and clay content. Dominant height was found to be the best morphological variable to estimate site potential, in the absence of detailed studies of soil characteristics.

The experimental findings from silvicultural trials have important implications for management. Regrowth from coppice stools was vigorous even in dry years, and greatest from medium to large stools. Productivity in general was extremely variable, both of coppiced and uncoppiced trees, due to site effects. The most productive sites are also potentially the best for agriculture and are therefore unlikely to be left exclusively for woodland management. The silvicultural techniques of coppice reduction and water harvesting were not found to enhance coppice regrowth. Browsing by livestock was found to severely reduce coppice regrowth, particularly of *J. globiflora*, at least in the initial stages, so that protection from browsing in the first year or two after felling is recommended if maximum regrowth is desired.

An assessment of the use and management of the indigenous wood resources in a resettlement area in central Zimbabwe suggests that the present harvesting of wood products is unsustainable, due largely to the lack of any woodland management policy for these areas. Local villagers feel powerless to exclude outsiders from their resource, and thus the incentives to manage it sustainably are low. Major changes in government legislation are necessary to alter this situation. In the interim, resource-sharing schemes are suggested as a method of improving the sustainability of use.

Some of the results reported here have a direct application in miombo management; these are summarised at the end of this work in the form of guidelines for management. Others identify the need for further work to expand these initial findings. One of the outcomes of this research has been the reminder of how little is known of the appropriate management of this important vegetation type.

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Publications

Grundy, I.M. 1995. Wood biomass estimation in dry miombo woodland in Zimbabwe. *For.Ecol.Manage.* *72*: 109 - 117.

1

Introduction

1.1. Miombo woodlands

A significant area of Africa south of the equator, including large parts of Angola, Malawi, Tanzania, Zaire, Zambia and Zimbabwe, is covered by a woodland type known as miombo. This woodland is typified by trees from the family *Leguminoseae*, sub-family *Caesalpinoideae*, but in particular three genera, *Brachystegia*, *Julbernardia*, and *Isoberlinia* are most important (Aubreville, 1959; Malaisse, 1978). The area covered by miombo woodland corresponds well with White's (1983) Zambezian Region (Fig. 1.1), and is considered to be the largest major phytochorion in Africa. It is thought to have the richest and most diverse flora and encompasses a wide range of vegetation types. A woodland of similar structure is found at the southern limit of the Sahel. White (1983) names this latter type as Sudanian *Isoberlinia* woodland and considers it as an impoverished variant of miombo woodland because *Brachystegia* and *Julbernardia*, the two most characteristic genera of miombo woodland, are entirely absent.

These woodlands form the boundary between the arid and semi-arid open savannas, and the closed humid forests of high rainfall areas. Although the structure and composition varies with soil quality, rainfall and land-use (Endean, 1967), miombo is distinguished by the shape of the dominant trees which have short, slender boles with markedly ascending branches and a light, shallow, flat-topped crown (White, 1983). Miombo is characteristically an open, deciduous, microphyllous woodland, with interlocking tree cover, and is associated with a sparse shrub layer and a grass-rich herbaceous stratum (Aubreville, 1959; Malaisse, 1978; plates 1.1 and 1.2). Trees grow to an average height of 15 to 20 m. In Central and Southern Africa these woodlands are found between altitudes of 400 to 1500 m; in East Africa, Mozambique, and Zaire, miombo is found at very variable altitudes, ranging from coastal vegetation to 3000 m on high ridges. The mean annual rainfall over the whole woodland type is variable, but usually ranges between 500 and 1800 mm and falls mostly between November and April (Malaisse, 1978; Werger and Coetzee, 1978). Miombo is the prevalent vegetation where the soils are freely drained, but the rooting environment is restricted (White, 1983). Typical soil types range from sands to sandy clay loams. In Zimbabwe the dominants of miombo woodland are often *Brachystegia spiciformis*



Fig. 1.1. White's (1983) Zambezian vegetation zone which corresponds closely with the miombo region in Central Africa. Climate diagrams give typical temperature and rainfall figures for the region. Dotted areas = dry periods; hatched areas = wet periods; black areas = > 100 mm rainfall.

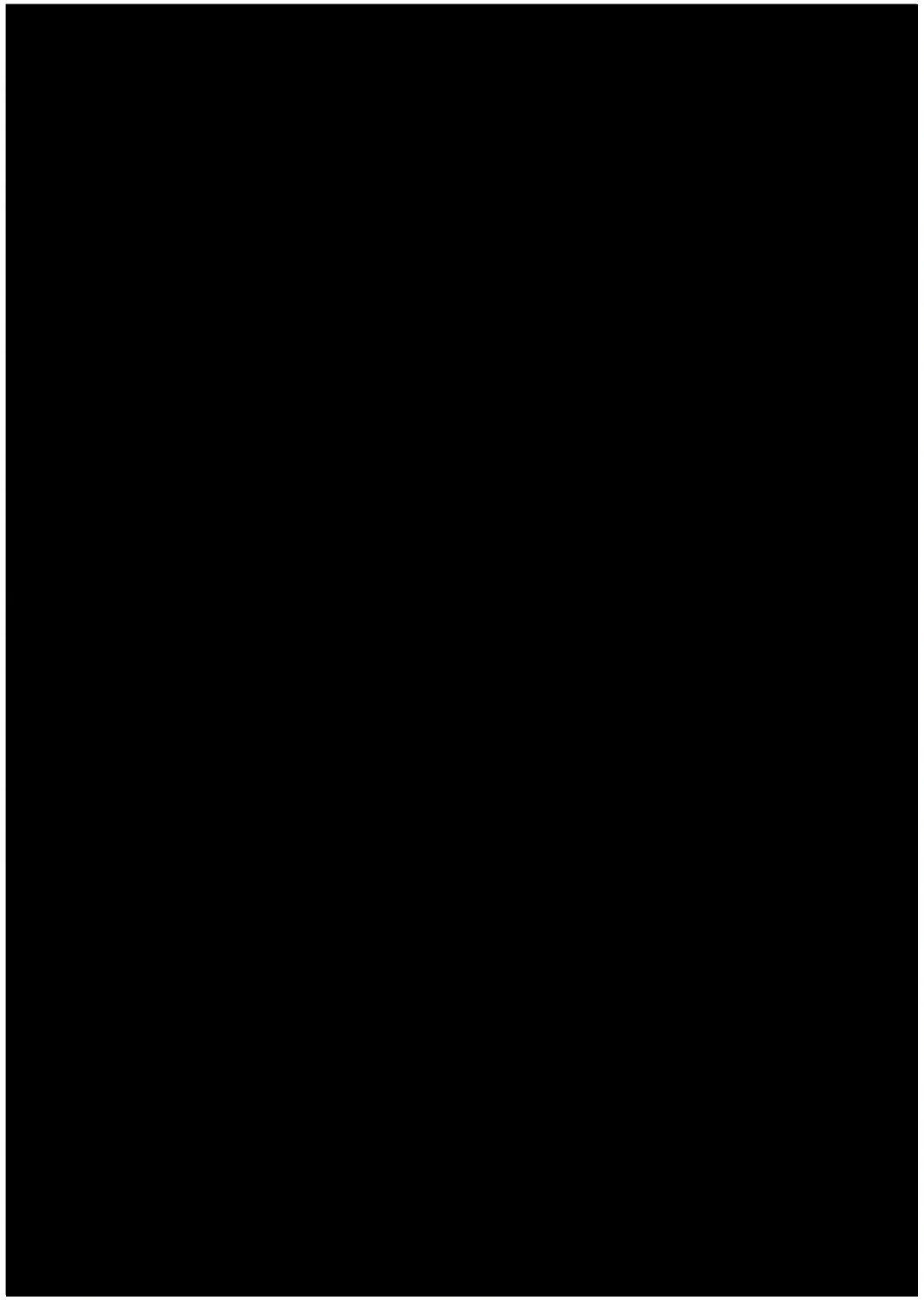

Plate 1.1. Typical miombo woodland in northern Zambia in the wet season, showing the light canopy and sparse understorey.

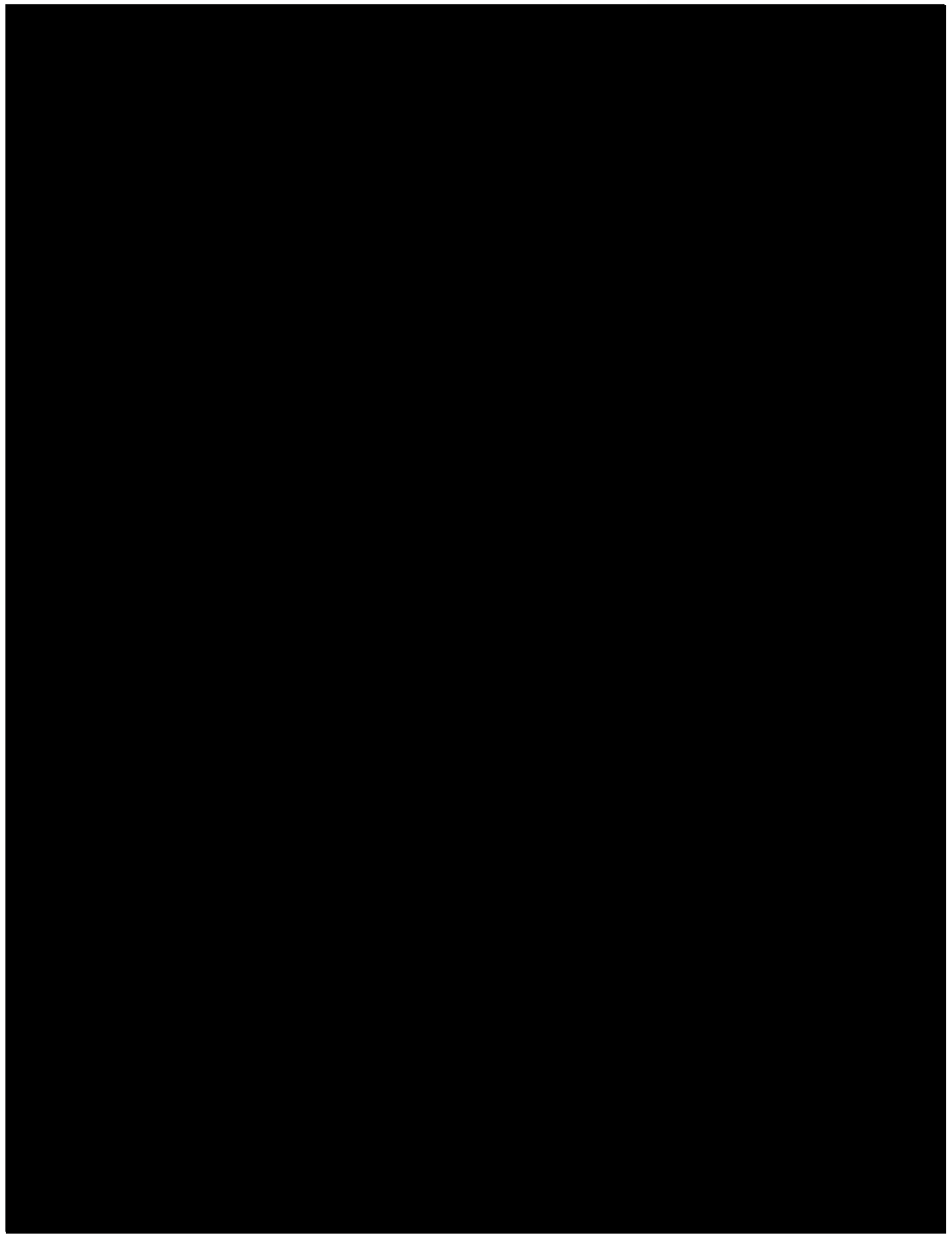

Plate 1.2. The same woodland in the dry season. (Photos: R. Lawton)

Benth. and *Julbernardia globiflora* (Benth.) Troupin.

The family, sub-family, genera and species of *B. spiciformis* and *J. globiflora* are well described by a number of authors. The following descriptions include information from Brenan (1967), Coates Palgrave and Coates Palgrave (1957), Coates Palgrave (1984), Drummond (1981), Fanshawe (1962), Hoyle (1952; 1967), Monteiro (1970), and White (1962).

Both trees belong to the widespread family *Leguminosae*, which includes trees, shrubs, suffrutices[1] and herbs. The family is characterised by its fruit, which is usually a pod, although sometimes a lomentum or a nut. Some authors divide the family into three sub-families, *Mimosoideae*, *Caesalpinoideae*, and *Papilionoideae*, based on the structure of the flower. Other authors form three separate families on this basis, but the three groups remain the same whatever taxonomic rank is assigned to them. Both *B. spiciformis* and *J. globiflora* belong to the sub-family *Caesalpinoideae*, which has zygomorphic (asymetric) flowers and leaves which are bipinnate or pinnate, rarely simple. Brenan (1967) divides the *Caesalpinoideae* into seven tribes, with the genera *Brachystegia* and *Julbernardia* belonging to the Tribe *Amherstieae*, which contains the genera *Julbernardia*, *Englerodendron*, *Tamarindus*, *Anthonotha*, *Paramacrolobium*, *Brachystegia*, *Monopetalanthus* and *Cryptosepalum*.

1.2. Genus *Brachystegia* Benth.

This genus, made up of about 30 species or major complexes, is confined to tropical Africa except for *B. spiciformis* which ranges to 25 °S in Mozambique. All species are normally trees, except for two or three natural suffrutices. The genus is of considerable importance throughout the miombo regions of Zaire, Southern Tanzania, Mozambique, Zambia and Zimbabwe. It is possibly the most difficult taxonomic group in Africa, with very complicated patterns of variation. Some species and groups are more difficult to distinguish than others, due to hybridisation. The leaflets of coppice shoots and suckers of many *Brachystegias* are often very variable in size and shape, and such shoots may sometimes bear flowers and pods near the ground. All *Brachystegias* flush before flowering, producing a striking show of colours from salmon pink to copper, dark crimson or wine red. In Zimbabwe this occurs just before the onset of the wet season, in August and early September. The genus is at its southern limit in Zimbabwe, where only seven species are found

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[1] plant in which the shoot apices are borne close to the ground. In unfavourable conditions, the aerial shoots die back.

compared to the 19 species found further north in Zambia, 19 (including varieties) in Zaire, and 15 in East Africa. Seven species are also found in Angola. Of the Zimbabwean species, only three, *B. boehmii* Taub., *B. glaucescens* Burtt Davy & Hutch., and *B. spiciformis* are common.

1.2.1. ***Brachystegia spiciformis* Benth.** (plate 1.3, from Coates Palgrave and Coates Palgrave, 1957)

Synonyms: *B. bragae* Harms., *B. edulis* Burtt Davy & Hutch., *B. hockii* De Wild., *B. randii* Bak., *B. trijuga* R.E.Fr., *B. venosa* Burtt Davy & Hutch. (among others).

Local name: musasa (Shona); igondi, umbuze, gondwa (Ndebele).

1.2.1.1. *General description*

An average mature tree is usually between 8 - 15 m in height and 30 - 60 cm in diameter at breast height, but can vary greatly depending on the characteristics of the site. Many are smaller, especially on drier sites, but occasionally they grow up to 30 m in height, these being usually on the deep Kalahari sands or on good red loam soils in northern Zambia. The crown is irregularly rounded to flat-topped, often stag-headed when old. The main branches are few and heavy, some obliquely ascending, others spreading. The bark on young trees and branches is smooth, pale grey or whitish; on mature trees it is rough and often deeply fissured and flakes in thick, irregular scales. The leaves are compound and deciduous.

Characteristically, *B. spiciformis* has both a deep tap root which can reach five metres (Savory, 1963), and an extensive surface rooting system which extends well beyond the canopy margins. Such root ramification allows the trees to extract moisture from all levels of the soil.

1.2.1.2. *Regeneration*

Seeds are dispersed by mechanical expulsion from the pod, but in most cases are not propelled more than about 6 m from the parent tree (Strang, 1965). In addition, seedlings are more likely to survive in under-canopy environments where moisture levels are higher (Grundy *et al.*, 1994). These two factors result in familial clumping.

The seed germinates well, but seedlings are difficult to transplant. Like many of the miombo species, *B. spiciformis* seedlings take a period of approximately five years to develop a well-established root system, during which time there is little above-ground growth. This is an adaptation to fire and moisture stress. Once a large enough root system is achieved, the young trees grow relatively rapidly for a period of 15 to 20 years, after which growth rates slow down

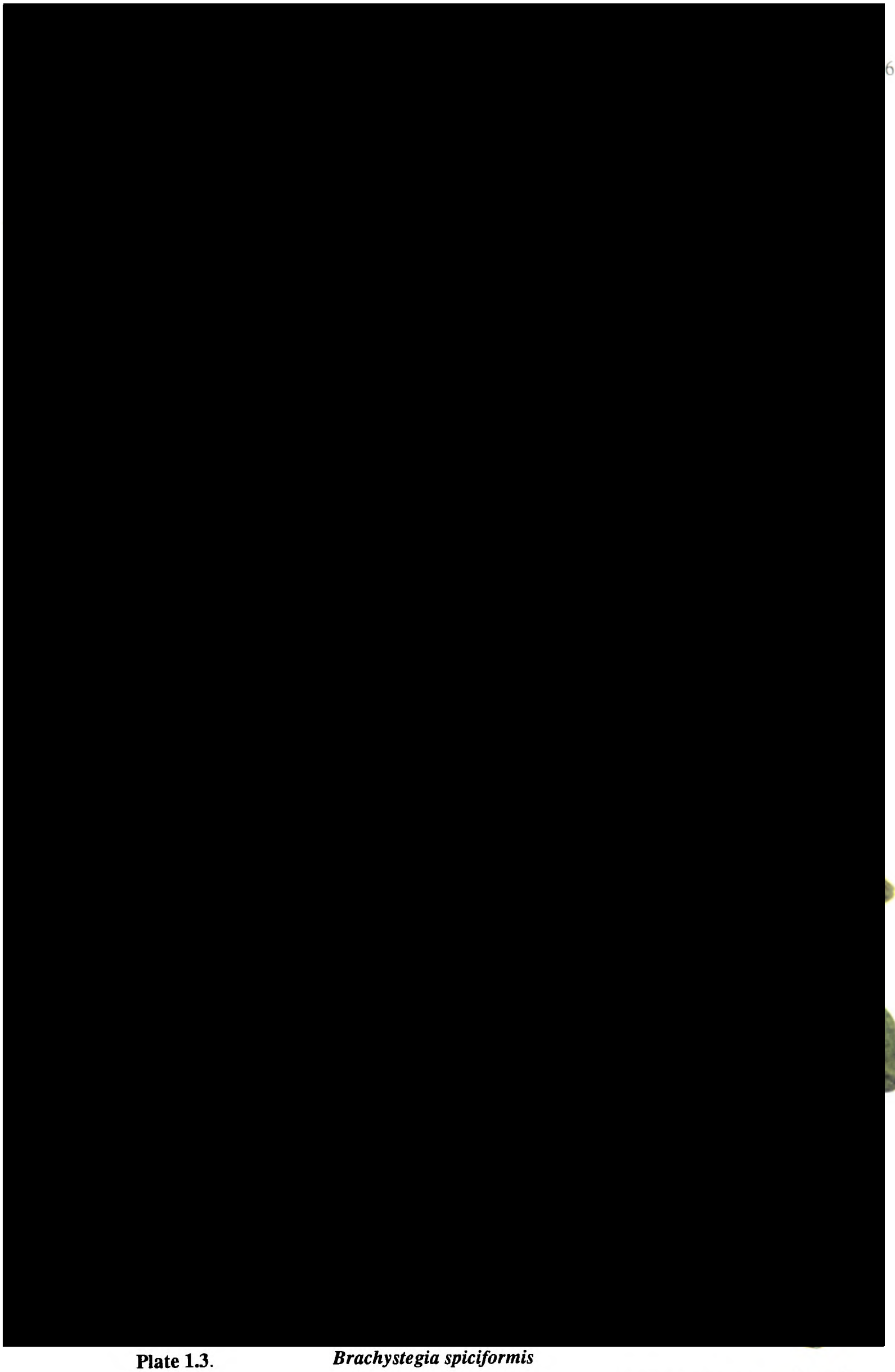

Plate 1.3. ***Brachystegia spiciformis***

1. Mature leaves.
2. Young leaves with flowers.
3. Individual flower, enlarged.
4. Green fruit.
5. Dried fruit.
6. Seed.

(Strang, 1965). On average a tree will take 80 to 100 years to reach maturity. The species does not seem to spread into grassland by seeding because of stiff competition for light and moisture from the herbaceous layer, especially during intra-seasonal droughts in the wet season. Thus its spread into grassland is largely by vegetative regrowth from root suckers (Strang 1965), which are often produced after root damage. Cut or burnt stumps produce profuse coppice regrowth which enables established trees to regenerate quickly after felling or fires. The stumps are particularly hardy and will produce coppice shoots when cut year after year for an undetermined but considerable period (Duff, 1939).

1.2.1.3. *Variation*

According to White (1962), *B. spiciformis* in Zambia, along with seven other *Brachystegia* species, occurs in more or less uniform populations but shows considerable geographic variation. Ho le (1967) however described its frequent hybridisation with *B. microphylla* Harms., and rare crosses with *B. bussei* Harms., *B. manga* De Wild., *B. longifolia* Benth., and *B. wangermeeana* De Wild. in East Africa. In Zimbabwe it also hybridises with *B. glaucescens*.

1.2.1.4. *Natural distribution*

This species is the most widespread of the *Brachystegias*, being one of the most common trees of miombo woodland, and occurring as a dominant or co-dominant from an altitude of 15 m on sandy areas near the coast in East Africa and Mozambique, to 2350 m on ridges and escarpments. It associates with most miombo species. It develops best on moist, deep red soils at medium altitudes, and usually avoids badly drained sites such as edaphic grassland fringes or over-drained or poor shallow soils. It does however tolerate a wide range of soils, climate and exposure. Young trees are frost and fire sensitive and best conserved by an early-burning fire regime (when the herbaceous layer is burnt at the end of the wet season when moisture levels are still high enough to reduce the ferocity of the fire) (Duff, 1939).

1.2.1.5. *Utilisation*

Some of the uses of *B. spiciformis* are described by Coates Palgrave and Coates Palgrave (1957), Coates Palgrave (1984), Drummond (1981), Fanshawe (1962), Goldsmith and Carter (1981). The wood is pale brown in colour, with a coarse and interlocking grain. It is of medium density, with a weight of 735 $kg.m^{-3}$ at 12 % moisture content (air-dried). The wood is liable to attack by borers, termites and fungi. Treated wood was used in the past for mine props. It seasons slowly however, twists and splits readily, warps easily and saws irregularly (although Duff (1939) maintains it is no worse than *Eucalyptus* spp. in this regard). The species has little value as a

timber tree, but has four major uses amongst small-scale farmers and as a result has great economic value in these areas.

i) It is one of the most important species in the region for firewood and charcoal.

ii) The young leaves are palatable to livestock, providing an important source of browse in small-scale farming areas at the end of the dry season (Scoones, 1990; McGregor, 1991).

iii) The inner bark of young trees provides a good quality fibre which is made into mats, bags and a variety of ropes. The root-fibre is made into fishing nets in Zambia. Both bark and roots are used in the preparation of traditional medicines. The bark is also astringent, containing 13-20% tannin, and was used locally in the past to tan game skins.

iv) fallen leaves are mixed with cattle manure and used as an organic fertiliser in vegetable gardens and fields.

In addition, the trees have a number of minor uses. In the absence of more suitable alternatives, the wood can be used for furniture joinery and in building construction, pick-handles, railway sleepers and canoe building. The flowers attract large quantities of bees, which make a superior honey from the nectar. When mature, *B. spiciformis* makes an excellent shade tree, but is rarely planted for this purpose because of its relatively slow growth rate.

1.3. Genus *Julbernardia* Pellegr.

Julbernardia is a tropical African genus of about eight species which was named after a former Governor of Gabon, Jules Bernard. It was confused at first with *Berlinia* Hook.f.& Benth., *Isoberlinia* Craib & Stapf., and given the synonym *Pseudoberlinia* Duvign. It is as widespread as *Brachystegia* but four species are found in south central Africa, and only one, *J. globiflora*, is found in Zimbabwe. *Julbernardia paniculata* (Benth.) Troupin is found in Zambia, Zaire and East Africa, while *J. unijugata* J.Leon. and *J. magnistipulata* (Harms) Troupin are found in East Africa only. The latter three are all evergreen species, although the two East African species are riverine or lowland rainforest inhabitants, while *J. paniculata* is found in wetter deciduous miombo woodland. Two other inhabitants of evergreen forest, *J. seretii* (De Wild.) Troupin and *J. brieyi* (De Wild.) Troupin are found in Zaire. *Julbernardia globiflora* is deciduous, and is found in drier areas in Zimbabwe and Zaire. The genus has been less well studied and described than *Brachystegia*.

1.3.1. ***Julbernardia globiflora*** **(Benth.) Troupin** (plate 1.4., from Coates Palgrave and Coates Palgrave ,1957)

Synonyms

Berlinia eminii Taub., *Berlinia globiflora* (Benth.) Harms., *Brachystegia globiflora* Benth., *Isoberlinia globiflora* (Benth.) Greenway, *Pseudoberlinia globiflora* (Benth.) Duvign., *Westia eminii* (Taub.) Macbr.

Local names: Munhondo, mutondo (Shona); ishungo, umshungwe (Ndebele)

1.3.1.1. *General description* (White, 1962)

An average mature tree is 5 - 12 m in height, with a rounded spreading crown. It often flowers when less than 2 m high or from short coppice shoots. The bark on young trunks and branches is a smooth pale grey; on older boles it is dark grey and rough. The leaves are compound and deciduous.

Like *B. spiciformis* this species has a deep tap root, which can reach 5 m, and far-reaching lateral roots, but the roots of *J. globiflora* do not ramify through the surface soil layers to the same extent as those of *B. spiciformis*. Both species produce root suckers after physical damage to the roots (Strang, 1965).

1.3.1.2. *Regeneration*

Julbernardia globiflora regenerates in a similar manner to *B. spiciformis* but it does not usually reach the same maximum height. Young seedlings survive better in unshaded environments than do those of *B. spiciformis* (Grundy *et al.*, 1994).

1.3.1.3. *Natural distribution*

This species, together with *B. spiciformis*, is important throughout the miombo region. In Zimbabwe it is usually a tree of the highveld (over 1000 m), but has been recorded at altitudes of 500 m or less. It is widespread throughout the *Brachystegia* areas, often co-dominant or dominant, especially in drier regions with poorer soils. It is perhaps the most common and widespread tree in Zimbabwe.

1.3.1.4. *Utilisation*

Some of the uses of *J. globiflora* are described by Coates Palgrave and Coates Palgrave (1957), Coates Palgrave (1984), Drummond (1981), Fanshawe (1962) and Goldsmith and Carter (1981).

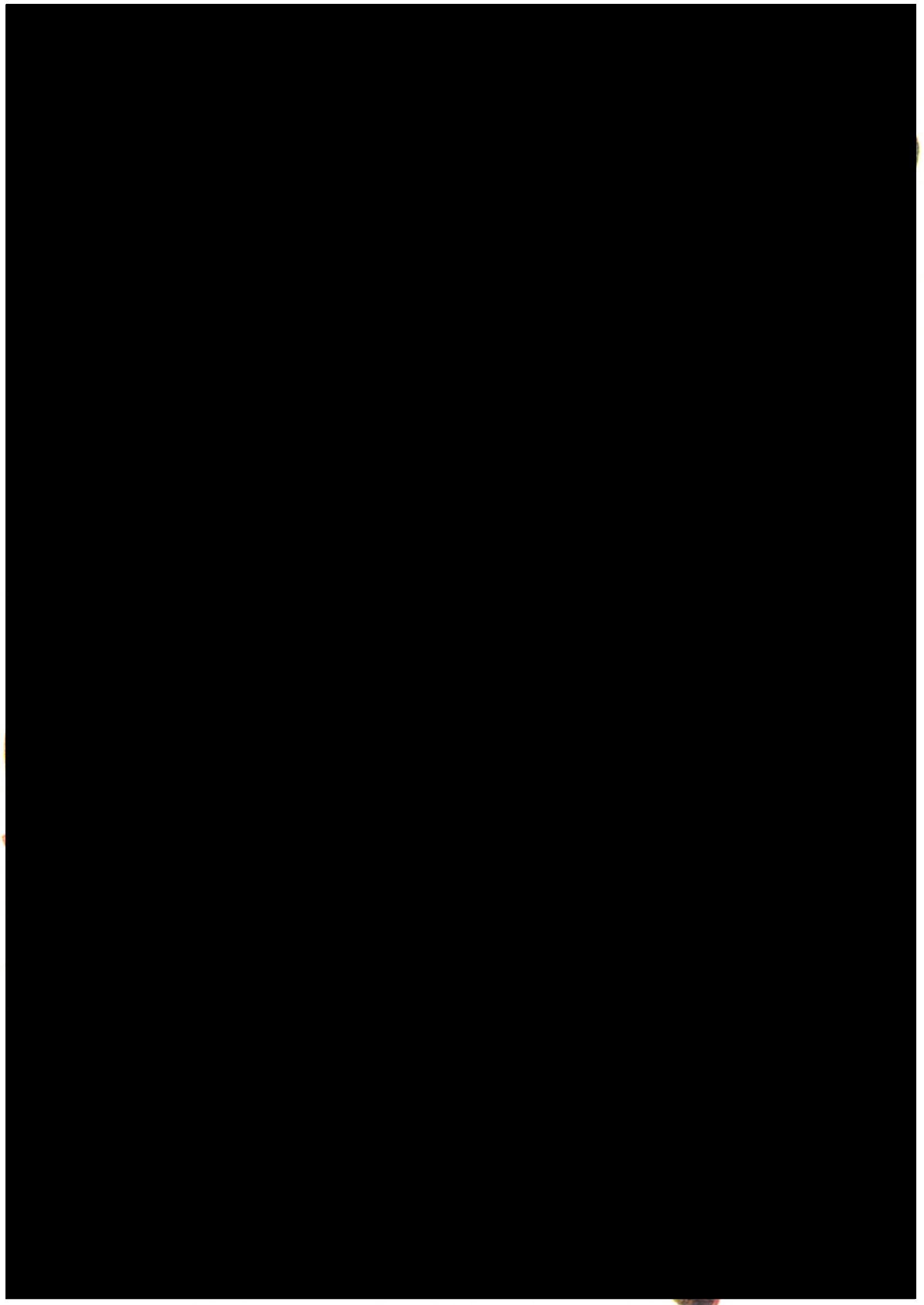

Plate 1.4. ***Julbernardia globiflora***

1. Immature leaves. 2. Mature leaves and flowers. 3. Single flower.
4. Mature fruit. 5. Old split fruit.

The wood is very hard, with a coarse, uneven grain, and is resistant to decay. It is a heavy wood, with a weight at 12 % moisture content of 800 $kg.m^{-3}$. The wood however does not work well, blunting instruments and splitting easily, so that it is best used in pole form. The heartwood is resistant to borers, but the sapwood is not, and the low proportion of heartwood to sapwood reduces the timber value of the tree. However, like *B. spiciformis*, this species is of major importance in small-scale farming areas:

i) Its main use is for firewood and charcoal, because of its high density.

ii) The leaves of *J. globiflora* are palatable to wild and domesticated animals especially in the spring before the tannin levels increase, and therefore provide an important source of browse in the dry season when little other fodder is available.

iii) As for *B. spiciformis*, the fallen leaves are mixed with cattle manure and used as an organic fertiliser in vegetable gardens and fields.

The tree has several other minor uses. The under-bark is used to make a rope when neither *B. spiciformis* nor *B. boehmii* is available, since it is of inferior quality. The fibre is used to make rope, bee hives, cornbins and sacks. Tannin extracted from the bark is also used as a laxative. Its flowers attract bees, which make large quantities of high quality honey from them. *Julbernardia globiflora* nectar is said to be some of the most plentiful and to produce the best quality honey of all miombo trees (Smith, 1966). In the past the wood was used for mining timbers. Today it is used in small-scale farming areas in the absence of more durable woods for door and window frames, general purpose poles and axe handles.

Brachystegia spiciformis is often confused with the similar-looking *J. globiflora*, but can be distinguised from it by a number of features:

1. The leaflets are in general larger, more rhomboid and usually glabrous, but particularly obvious is the larger terminal leaflet pair which causes distinctive leaf movement in the wind.
2. The bark is rougher in mature specimens, but often difficult to distinguish in younger trees, unless cut, when the slash is pink compared to *J. globiflora*'s yellow.
3. The early spring flowering period (August to November) of *B. spiciformis* differs from that of *J. globiflora*, which flowers from January to May.
4. The pods of *B. spiciformis* are glabrous and found scattered throughout the canopy, compared to *J. globiflora*'s velvety pods which are all borne at the top of the tree.
5. *Julbernardia globiflora* bears no stipels, whereas *B. spiciformis* has small ones.

1.4. **Context of this study**

The majority of the population in Zimbabwe live in the rural areas and derive their wood resources from the indigenous miombo woodland. The importance of the woodland to small-scale farmers in Zimbabwe, particularly in dry areas, has been well documented (see Whitlow (1979), Bradley and Dewees, 1993; Campbell *et al.* (1993a)). Use of woodland products by rural householders has been estimated at representing between 40 and 160 % of their annual household income (Campbell *et al.*, 1991b). The development of sustainable management strategies for these woodlands, for all products, has been hampered in the past by a lack of knowledge, however. By focusing on some of the ecological and sociological aspects of management detailed below, this study attempts both to improve the knowledge of the growth and regeneration of the indigenous miombo woodlands, and propose some useful guidelines for their sustainable management in small-scale resettlement farming areas.

1.5. **Factors influencing the sustainable management of miombo woodland**

Sustainable management can be broadly defined as being part of a policy of land use which makes full provision for the conservation of biological diversity and the maintenance of environmental stability, as well as ensuring the potential of the forest to provide forest products in the future (Poore, 1989). Present indigenous woodland management practices in small-scale farming areas in Zimbabwe are the product of past and present resource-use policies. An understanding of these policies and practices, as well as of the resource itself, is necessary in order to develop feasible options for sustainable management of these areas in the future.

1.5.1. ***Physical and biotic factors***

1.5.1.1. *Properties of miombo ecosystems - stability, resilience and hierarchies of scale*

Savanna ecosystems in general, and miombo in particular, are by nature dynamic and diverse. Miombo vegetation is adapted to stress brought about by the spatial and temporal variability in rainfall, as well as episodic disturbance from fire, humans and herbivory (Walker, 1985; Frost *et al.*, 1986; Solbrig, 1990). Such environments are well-suited to management regimes based on the regenerative ability of the woodland.

The scale at which miombo woodland is studied is determined by the end-use of the research. At a landscape level, edaphic differences result in heterogeneity of species distribution. Cole (1982) and Timberlake *et al.*, (1993) describe specific vegetation associations which distinguish different soil types over contrasting lithological units. At a smaller scale, in woodland dominated by

B. spiciformis and *J. globiflora*, site characteristics have significant effects on species composition and coppice regrowth (Grundy, 1993; Grundy *et al.*, 1994). *Julbernardia globiflora* is known to grow on more xeric sites, while *B. spiciformis* is found on deeper, more fertile soils (Timberlake *et al.*, 1993; Campbell *et al.*, 1995). Walker (1985), Frost *et al.* (1986) and Scoones (1990) all emphasise the importance of considering the possible responses of ecosystems as a whole, as well as the individual species within them, to disturbance. In common with many traditional ecological studies (O'Neill *et al.*, 1986), this study of the growth and management of woodlands for wood products emphasises the population and community level. It is beyond the scope of the work to incorporate a detailed study of the complex links with other levels of the ecosystem, but nevertheless these must be taken into account in the overall planning process. What will be the longterm effect of woodland management on the hydrology and soil forming processes of the region, or on total species diversity, for example? Will there be a shift in the tree-grass equilibrium as a result of management? Will the enhancement of one resource be at the expense of another?

A lack of understanding of ecosystem dynamics has been a common source of failure in the management of natural resources. A typical example of such a knowledge gap is evident in the early exploitation of the 'teak' (*Baikiaea plurijuga* Harms,) forests of Western Zimbabwe. Initial felling altered the natural regeneration cycle in the forest, by causing an increase in grass growth and therefore an increase in both competition for resources and in the risk of damage by fire. This, combined with continued high levels of felling and inappropriate burning regimes, caused the near depletion of the resource today (see Calvert and Timberlake, 1993). Since these early mistakes, there has been a growing body of knowledge of savanna and miombo ecosystem functioning, but as yet the responses of miombo to felling are not fully understood.

1.5.1.2. *Coppice Management*

Most regeneration after felling is in the form of coppice shoots, root suckers and suppressed seedlings (Strang, 1965; Robertson, 1984; Grundy *et al.*, 1994; Lowore and Abbot, 1995), which, because of the large root systems of many miombo species, results in relatively rapid regrowth. Fanshawe (1956a) maintains that miombo dominants are likely to be able to produce coppice shoots over the life-span of the trees. Root damage caused by deep ploughing or stumping encourages root suckers (Strang, 1965). Many miombo trees do not produce seed for the first 60 years or so (Chidumayo, 1993), and seeds are often not dispersed more than 5 m from the mother trees (Strang, 1965). A coppice system which makes no allowance for seed production may therefore result in an erosion of the genetic base (Chidumayo, 1993).

The management of coppice regrowth has several advantages over plantations. The seedling establishment period for many miombo dominants (before the trees produce any substantial aerial growth) can be up to six years (Fanshawe, 1956a). Young seedlings are susceptible to drought (Chidumayo, 1993) and the survival rate is low. Some survive better in under-canopy environments than in the open (Strang, 1965; Lawton, 1982; Walker, 1985; Grundy *et al.*, 1994). Coppice stools, by contrast, because of their relatively large root to shoot ratio, are able to survive even severe moisture stress. Both the seedlings and coppice regrowth of *B. spiciformis* and *J. globiflora* are fire sensitive (Trapnell, 1959; Grundy, 1993), particularly in the early stages. In communally-managed woodland, however, fire is seldom a threat to growth, because of the low fuel load and the high level of vigilance by local people.

In the past, most indigenous woodlands in Zimbabwe have offered a low-input, low-output production system to small-scale farmers, considered by foresters to be of little value. More recently, there has been a revival of interest in the old coppice management systems, as a method of improving growth rates as well as producing the small wood products required by rural households. Coppice management is 'oriented towards the supply of good quality fuelwood and pole matter of relatively small dimensions that can be easily harvested with the tools available' (Abbot, 1993). In addition, coppice management is easily adapted to local requirements, provides multiple products, and can be carried out with very little training, input and monitoring (Grundy, 1990; Voysey, 1987, quoted in Abbot, 1993).

1.5.2. *Early forest policies : the unpopularity of indigenous species*

Historically, indigenous peoples in Africa have sustainably managed the natural regeneration in their forests for wood and a wide variety of non-timber forest products. Early colonial botanists and foresters in southern Africa were quick to see the potential of the coppicing ability of many of the indigenous trees in the management of large tracts of miombo woodland (Duff, pers.comm[2]; Trapnell, pers.comm[3].; Piearce, 1993). Colonial foresters (particularly in Zambia) introduced a coppice with standards system to provide poles and fuelwood for the mining industry. These foresters, concerned by the relatively low growth rates, began to look for exotic species with which to 'improve' the natural woodland (see Endean, 1962 for example). Gradually, interest in indigenous trees fell away. Only with an international disenchantment with exotic species in reafforestation programmes, and a realisation that many planting programmes were uneconomic,

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[2] Colin Duff, former Conservator of Forests, Northern Rhodesia; Oxford 1993
[3] Colin Trapnell, former Forest Ecologist, Northern Rhodesia; Bristol, 1993

did attention revert to natural regeneration, both from seed and coppice shoots. Many of the ideas and proposals for indigenous woodland management which are put forward today have been made several times in the past, when the rest of the research and development world favoured exotic species.

In Zimbabwe the first colonial foresters were of agricultural origin, and therefore never showed the same interest in the indigenous trees as their Zambian counterparts. From the outset, foresters in Zimbabwe concentrated on establishing plantations, mainly of pine and *Eucalyptus* species, for timber production. In the communal farming areas, the efforts of the forestry extension workers were largely a failure, for a combination of reasons: insufficient rate of planting; low survival of the young trees due to drought and termite attack; lack of silvicultural expertise among local people; lack of local administrative support and the preference for indigenous wood by local people (Grundy, 1990). Nevertheless, the change of emphasis from planted exotic species to more suitable alternatives took a period of more than 30 years (Grundy, 199; McGregor, 1991).

1.5.3. ***Land-use policies***

1.5.3.1. *Land tenure*

Land is the key issue in the debate over the future of Zimbabwe's rural resources (Katerere *et al.*, 1993), and the dynamics of woodland management in Zimbabwe can only be discussed meaningfully in the context of agriculture and land use (Bradley and McNamara, 1993). An understanding of the past and present land tenure policies is therefore a vital part of any assessment of woodland management options.

There are four major categories of land tenure in Zimbabwe today (Katerere *et al.*, 1993):

1. State land, mainly national parks and forest land.
2. Communal areas (formerly Tribal Trust Lands), based on a usufruct tenure system.
3. Resettlement areas, based on a renewable leasehold tenure system. These were introduced after 1980 in an attempt to relieve population pressure in the communal lands.

4. Commercial farmland, based on a freehold tenure system, which includes large-scale farms (formerly European-owned) and small-scale farms (formerly African Purchase Areas).

The country is divided into five zones of agricultural potential called Natural Regions, differentiated by expected rainfall levels (Fig. 1.2) (Vincent and Thomas, 1961). Zimbabwe's present land tenure situation reflects the legacy of past colonial policies of segregated land ownership, which resulted in a highly skewed distribution of arable land in favour of European settler farmers. African farmers were restricted to densely populated farmlands, the majority of which were located in the Natural Regions of lower potential (III, IV and V) (Scoones and Matose, 1993). In addition, the changes in government land-use and administrative policies which have been instigated since Independence in 1980 have a bearing on present land use.

1.5.3.2. *The resettlement scheme*

In 1980, the Zimbabwean government began a land redistribution exercise, aimed at an acceptable and fair distribution of land ownership and use (GOZ, 1982). In this exercise, former commercial farmland was bought by the government and allocated to farmers from communal areas. In the Model A scheme, which is the most common, village settlements were planned with individual households being allocated approximately 5 ha of arable land and a grazing entitlement of four to ten livestock units, depending on the agricultural potential of the land. Farmers were drawn from a list of applicants, and tenancy was based on a permit system, withdrawable if farmers did not follow the regulations set out by the government (Murphree and Cumming, 1991). Each village was allocated an area for the planting of a community woodlot.

1.5.3.3. *Present natural resource management in communal and resettlement areas*

Contrary to popular opinion, an open access situation such as that described by Hardin (1968) (where, because of a lack of regulations governing the common resources, individuals benefit from their use to the detriment of the community as a whole) does not prevail in small-scale farming areas in Zimbabwe (see Scoones, 1990; Wilson, 1990; McGregor, 1991). Rules concerning the use of the indigenous wood resources do still exist, even if they are not always adhered to. A detailed description of the numerous controls over ownership and use of woodland resources in Shurugwi communal area, in central Zimbabwe, is given by Grundy (1990) and McGregor (1991). In general, the overall objective of the majority of the regulations is the

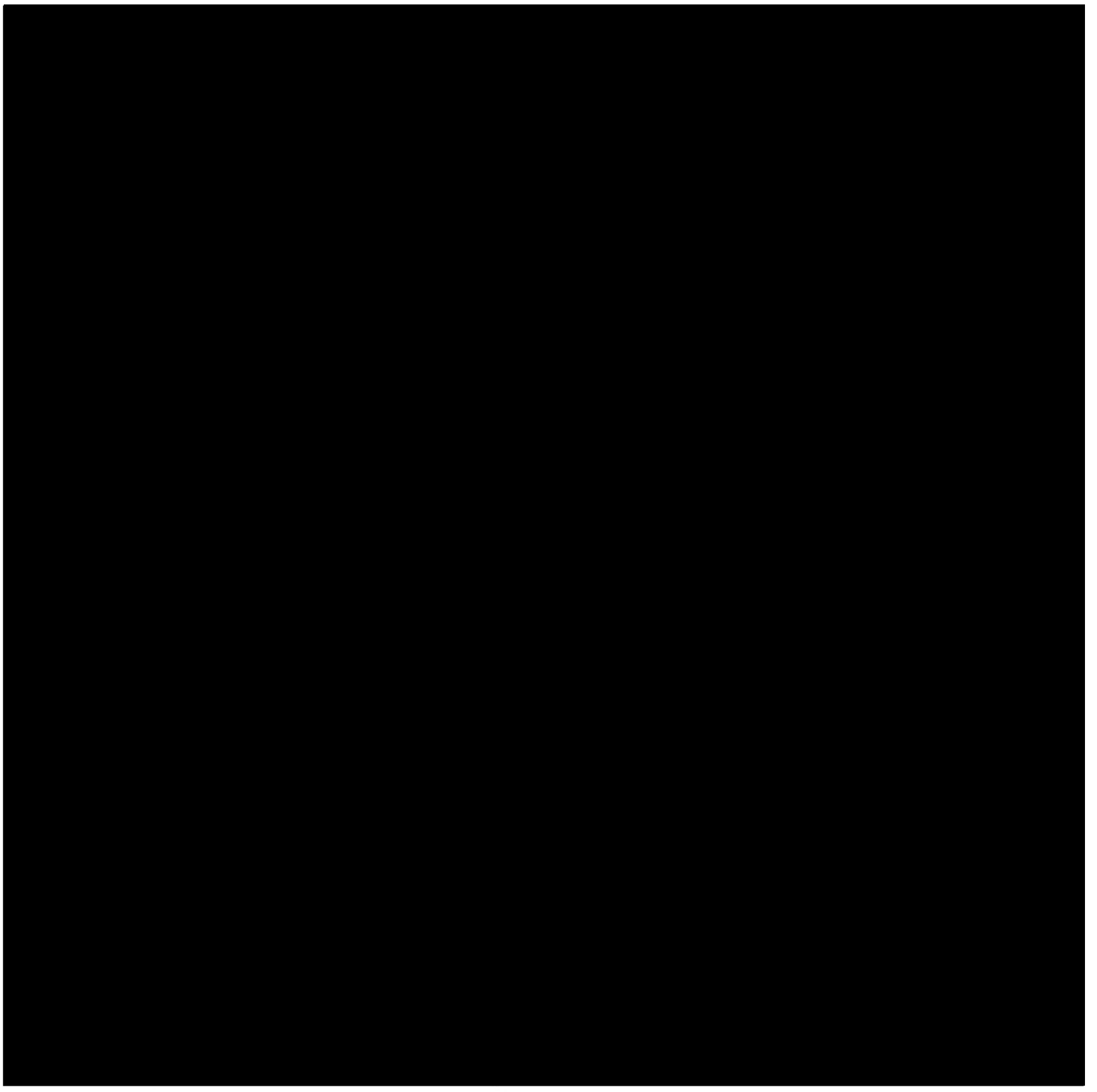

Fig. 1.2. Natural Regions, or zones of agroecological potential, of Zimbabwe (after Vincent and Thomas, 1961)

conservation and sustained management of the resource (Grundy, 1990), although this may not always have been for the benefit of the community as a whole (McGregor, 1991).

Most of the work on woodland resource management to date in small-scale farming areas of Zimbabwe (see Grundy, 1990; Campbell *et al.*, 1991a; Campbell *et al.*, 1993a; Grundy *et al.*, 1993) has shown that tree planting is not a common phenomenon except around homesteads, where exotic fruit trees are the first choice. In their use of the indigenous woodland, people cut certain tree species for particular purposes and if trees provide sought-after fruit or other products, they are usually not cut down (Grundy, 1990; Campbell and du Toit, 1988; Munslow *et al.*, 1988; McGregor, 1991; Grundy *et al.*, 1993). More active management of indigenous woodland, such as growing seedlings, enrichment planting or the initiation of a woodland management plan has seldom been recorded, although studies in Shurugwi communal area show that this does occur on a limited scale (Grundy, 1990; Matose, 1991). In other parts of Africa, the management of trees has been found to increase as the woodland resources decrease (Shepherd, 1992). In well-wooded resettlement areas in Zimbabwe, however, there is at present little incentive to manage the woodland more intensively (Scoones and Matose, 1993).

On the new resettlement farms, the regulations concerning land use were set by central government and are administered by the local resettlement officer and village development committees (VIDCO's). Since their inception, woodland management or use has not been a component of the planning process in resettlement areas (Scoones and Matose, 1993), and this has had far-reaching detrimental effects on the sustainability of the resource. At present the most rapid rates of woodland clearing in Zimbabwe are occurring in resettlement areas, where there has been a rapid influx of agricultural settlers into relatively wooded areas (Whitlow, 1988; Bradley and McNamara, 1993).

1.5.3.4. *Institutional base in Zimbabwe's rural areas*

An important condition for the sustainable use of communal woodland resources is the capacity to regulate their use. At present this is done at district or national level in Zimbabwe, with some regulation of wood cutting at the village level. If local communities in communal and resettlement areas are to be able to manage their own resources, then an appropriate institutional base must be developed at village level. Scoones and Matose (1993) discuss the skills required for this to be successful, listing eight different functions: i) planning ability; ii) financial and accounting capacity; iii) the ability to secure revenue; iv) credit worthiness; v) provision of legal support; vi) co-ordination of government and non-governmental inputs; vii) ability to regulate and

enforce; viii) accountability and representation. Since the development of a strong rural institutional base would require a major change in government policy and direction, as well as a large capital investment, such changes are unlikely to happen in the short term.

1.5.3.5. *Conflicts with alternative land uses*

Land use in the small-scale farming areas of Zimbabwe is strongly biased towards agricultural production (Moyo *et al.*, 1991; Bradley and McNamara, 1993), so that a tension exists between the expansion of arable land and the preservation of wooded areas. In addition, the woodland provides a variety of other products essential to the maintenance of the rural farming system (Campbell *et al*, 1993a), of which browse and leaf litter are two of the most important. Clearance of land for agriculture does not only limit the options for wood production from the communal woodlands, particularly for the poor and landless, but also conflicts with the many other uses of the woodland. Tuite and Gardiner (1990) document the number of tree species from miombo woodland in Tanzania which are selected for the 19 uses they studied. They give a matrix designed to highlight the incompatibility of some of these uses. In addition to clearing for agriculture, high levels of exploitation such as heavy grazing, large-scale tobacco curing and charcoal production are shown to be incompatible with options such as coppice management, agroforestry, honey production, medicines and fuelwood, among others. Wild food collection (including fruits, fungi and leafy vegetables) is an important omission from their matrix, but which is also jeopardised by high levels of woodland exploitation.

Cattle browse in the woodland predominantly in the winter when the grass has little nutritional value (Scoones and Cousins, 1991; McGregor, 1991; Bergstrom, 1992), and after the flush, when the tannin content of the leaves is low. In general, miombo browse contains higher levels of minerals and nitrogen than grass, but the normally high levels of tannin render it relatively unpalatable (Lawton, 1980; Walker, 1980; Skarpe, 1991). Browse is in direct conflict with wood production (Strang, 1965; Tuite and Gardiner, 1990), as is long-term removal of large quantities of leaf litter for use as organic fertiliser (Nyathi, 1991; Campbell *et al.*, 1993a). Any plans for exclusive designation of land for woodland management must take into account the other services the woodland provides. The challenge to foresters and socio-economists alike is to develop management regimes which continue to provide as wide a range of products from the woodland in the face of competition from agriculture.

1.5.3.6. *Incentives for management*

Crucial to the whole issue of collective management are its objectives, and how realistic they are.

Are they based on local requirements? Do they accord with local incentives for management? Will manipulation of the indigenous woodland provide sufficient return to labour? Does the work required compete for labour with other agricultural work? No management programme will succeed unless it has the support of the local user group.

1.6. **Objectives of this study**

This research had a number of interdependent objectives, directed at defining the basis for sustainable management of miombo woodland.

Tree growth and productivity

1. To calculate an individual wood yield model for *B. spiciformis* and *J. globiflora* in regenerating woodland in the Resettlement area in Shurugwi, in the Midlands Province of Zimbabwe.
2. To determine whether the age of individuals of *B. spiciformis* can be estimated from the anatomical study of xylem rings.
3. To measure the annual increase in biomass production of the two species in regenerating woodland.
4. To investigate possibilities for increasing the annual wood yield of regenerating trees of the two species by using the management techniques of coppicing, coppice reduction and water-harvesting.
5. To determine whether coppicing ability of these two species is correlated with trunk size and bark thickness, and therefore with tree age.
6. To classify yield potential on the basis of site characteristics such as climatic and soil conditions.

Woodland management by local farmers

7. To establish an improved base of knowledge of the use by communal and resettlement farmers of indigenous woodland.
8. To examine existing strategies for woodland management by rural people, and to develop a considered understanding of best-use models in the light of current social, environmental and economic constraints, and the biological information determined above.

1.7. **Thesis structure**

Each chapter in the thesis is presented in the form of a self-contained paper. Chapters 2 to 5 are concerned with the growth and regeneration of *B. spiciformis* and *J. globiflora*. The work focuses on these two species because they are usually the co-dominants of the Highveld woodland of Zimbabwe. In addition they are the two most favoured fuelwood species in rural areas (Grundy, 1990; McGregor, 1991). In Chapter 2, models for the estimation of dry wood biomass from stem measurements are developed. In Chapter 3 the presence of annual rings in *B. spiciformis* from two sites with differing rainfall regimes is investigated. In Chapter 4 the effects of site variables such as rainfall, temperature and edaphic factors on the growth of the two species is discussed. Chapter 5 is concerned with the development of growth-enhancing management techniques, with the aim of producing more, faster-growing stems for use as poles and firewood in small-scale farming areas. In Chapter 6 the present management of the woodland in a small-scale farming area is investigated, and future management options explored. The final chapter, 7, is a synthesis of the findings in the previous four chapters. The implications of these findings, and those of the published literature, for the future sustainable management of communal woodlands in resettlement areas are discussed. Guidelines for the future management of communally owned woodlands are proposed.

2

Wood biomass estimation in dry miombo

2.1 Introduction

Much of Zimbabwe is considered to have an acute shortage of fuel and construction wood (Whitlow, 1979; Harrison, 1987), a shortage which has largely been brought about by the clearing of land for agriculture (Du Toit *et al.*, 1984). The disappearance of natural woodland in communally farmed areas has been a concern since the 1930s for reasons of soil conservation, but it is only since the late 1970s that the importance of the indigenous woodland in satisfying the basic needs of many rural people has become more widely recognised (Whitlow, 1979; Beijer 1984; Du Toit *et al.*, 1984; Wilson, 1987). The six million or more people who live in the rural areas (Anon, 1983) derive their wood resources largely from a wide variety of indigenous tree species (Whitlow, 1980), but to date attempts to promote the reafforestation of communally farmed areas of Zimbabwe have mainly concentrated on the establishment of plantations of *Eucalyptus* species. In commercial farming areas, efforts in the past have been focused on the eradication of indigenous woodland to promote grazing for livestock (see Plowes, 1956; Strang 1960; Cockbill, 1961; Barnes, 1965, among others). Commercial foresters consider indigenous tree species to be inappropriate for silviculture because of their unsuitable timbers, slow growth rates and often unreliable seedling establishment (Anon, n.d.), compared with the more familiar exotic species. Much of the research effort in woodland management has therefore focused on commercial timber production for industry, using exotic species of pine and *Eucalyptus* (Chihambakwe, 1987; Harrison, 1987). Little is known about the growth rates and woody biomass yield of indigenous trees. Such information would improve the usefulness of estimates of sustainable yields and the possibilities for long term management of these areas.

Only a handful of woody biomass studies have been carried out in dry miombo woodland in the past. Stromgaard (1985, 1986), working in Zambian miombo, assessed biomass in woodland regenerating after shifting cultivation. Chidumayo (1988), also working in Zambian miombo woodland where the rainfall is higher than that of Zimbabwe, developed a model for uncultivated natural woodland. In Zimbabwe, Guy (1981) derived figures for mixed woodland, including riverine vegetation, in a protected wildlife area just south of Kariba Lake.

Biomass tables allow wood dry weight of trees of a certain species and size range to be estimated directly from variables such as stem diameter and stem length without the need for large scale destructive sampling (Stewart *et al.*, 1992). Only a subsample of trees, chosen to cover the size range of trees present, is felled for the purpose. Such tables have not been developed for miombo species in the past.

2.1.1. *Objective*

The objective of this study was to calculate simple individual tree woody biomass estimates for *B.spiciformis* and *J. globiflora* in regenerating dry miombo woodland in central Zimbabwe, and to generate biomass tables for the two species.

2.2. Study site

The study was carried out in Tokwe 3 Resettlement Area, in Shurugwi District in central Zimbabwe (Fig. 2.1.). The nearest business centre is Donga (19 ° 47'S, 30 ° 07'E), altitude 1200m, which is approximately 10 km from the southern edge of the experimental site. The study site falls into the agro-ecological region III (Vincent and Thomas, 1961) which receives an average rainfall of between 650 mm and 800 mm annually. The mean annual rainfall at Donga, for the period 1951-1986 was 766 mm (Abel *et al.*, 1989), with a coefficient of variation of over 30 %. Eighty percent of the rain falls in the wet season between November and March, although the area as a whole is subject to periodic intra-seasonal droughts. Soil moisture for plant growth is most available from November to mid-April at Donga, possibly longer depending on the extent of the late rains. The potential evapotranspiration rate peaks at 180 mm.month^{-1} in mid-October, rises slightly again to 130 mm.month^{-1} at the end of the rains in March and continues a downward trend to a winter minimum of 90 mm.month^{-1} in June. The end of the growing season is early May (Abel *et al.*, 1989).

Mean daily temperatures at the meteorological station at Gweru, 70 km to the north-west of the site, range from 17.9 °C to 20.8 °C from October to April, and from 12.1 °C to 18.0 °C in May to September (Torrance, 1981). Temperatures may be slightly higher in the study area. Frosts can occur from June to August (Abel *et al.*, 1989). The parent rock in the study area is granite, giving rise to inherently infertile sandy soils (Grant, 1976). The vegetation typical of the area is patchy light miombo woodland dominated by *B. spiciformis* and *J. globiflora.* Hydromorphic grasslands are found in the lower-lying areas. Fires seldom occur naturally in the communal grazing lands,

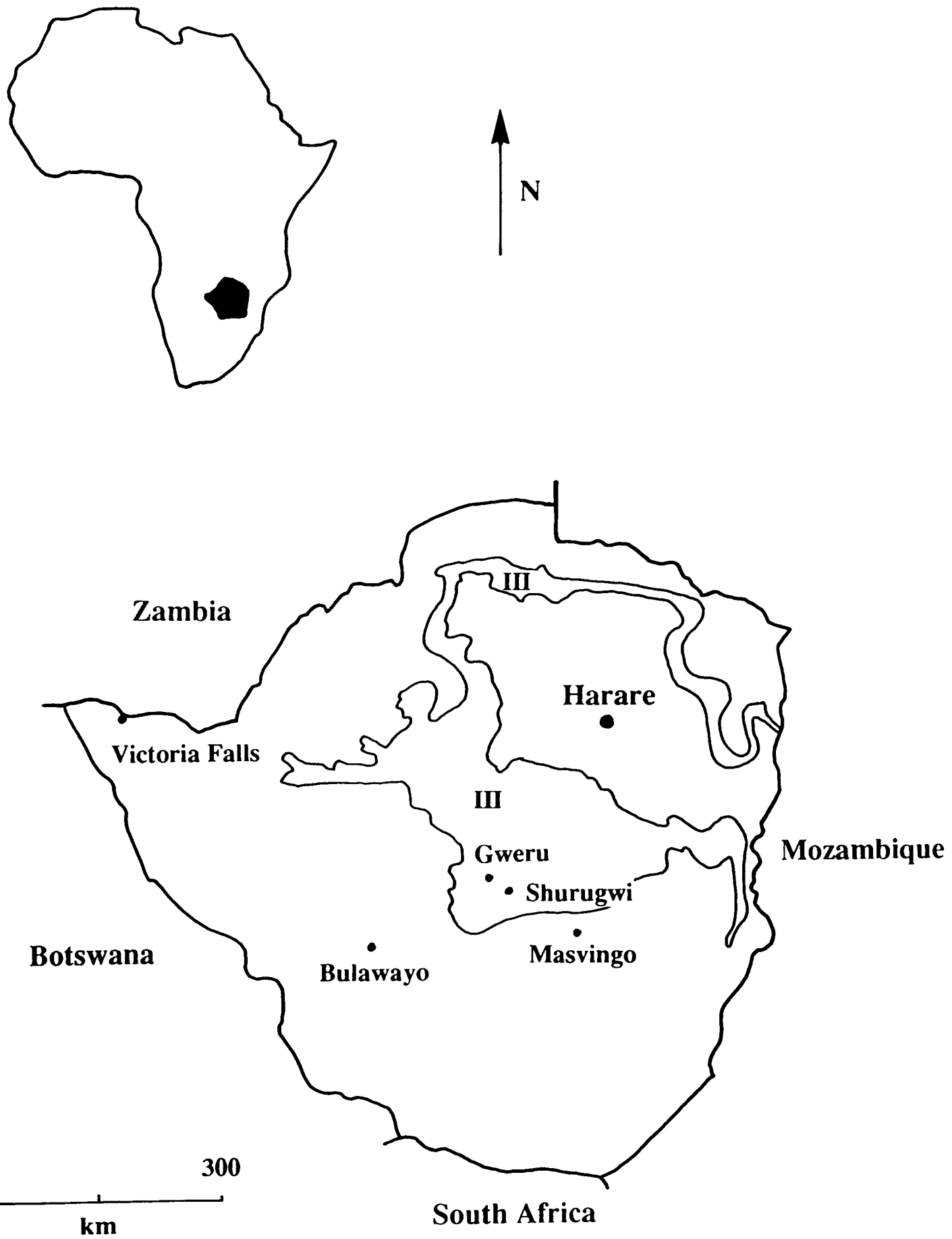

Fig. 2.1. Zimbabwe, showing the situation of Shurugwi, and the extent of Natural Region III (mean annual rainfall = 600 - 850 mm.yr $^{-1}$).

and are almost never caused by humans, despite there being enough grass biomass to fuel them, because of the importance given to grass for grazing.

The sites for this study were chosen from woodland presently used as grazing land and as a source of poles, but which in former times (at least 50 years ago) was probably partially cleared either for fields or for village sites. Previous land-use practices in the area have resulted in a woodland made up of trees of varying, unknown ages. Five sites, each comprising a half-hectare plot, were selected within approximately 30 km of one another. In each case the woodland selected was dominated by *B. spiciformis* and *J. globiflora.* All sites were on gently sloping ground.

2.3. **Methods**

At each site, at least 25 trees of each species (many of them multi-stemmed), were selected for measurement. All the trees above one metre in height within the plots were grouped into stem diameter size classes of small (1 - 6.9 cm), medium (7 - 14.9 cm) and large (15 cm and above), measured at 30 cm above ground. Approximately one third of the trees measured were taken from each size-class category so that the whole range of diameters in the area could be sampled. The trees were chosen randomly. Trees with dead or damaged stems were omitted.

For each tree, the following measurements were made: a) total height of tree (m); b) number of stems per individual; c) diameter of each stem at 30 cm above ground level (mm) d) length of each individual stem (m); e) fresh mass and oven-dry mass of wood of > 1.0 cm in diameter (kg). Stems which were not approximately cylindrical were measured twice across the longest and shortest diameters and an average diameter was calculated.

2.3.1. ***Calculation of dry woody biomass***

The percentage of moisture in the wood (on a fresh-weight basis) was calculated using at least two samples of wet wood taken at random from each stem. These samples were weighed on site immediately after the trees were cut and were then oven-dried at 105 °C to a constant weight, when they were reweighed. The moisture content of each sample was calculated using the formula:

$$\% \text{ mc} = \frac{(\text{fw} - \text{dw}) \times 100}{\text{fw}}$$

where mc = moisture content; fw = fresh weight of sample; dw = dry weight of sample.

The dry weight of each sample tree was then calculated using the following formula:

$$dw = fw\ (1\text{-}mc/100)$$

where fw and dw are the total fresh and dry weights of each sample tree.

2.3.2. *Statistical analysis*

Log_{10} transformations of the data were analysed using ANOVA and simple linear regression. The multiple stems which are characteristic of this type of regenerating woodland cause difficulties for statistical analysis. The individual stems could have been analysed separately, but in such an analysis each observation was not genetically independent of the next, thus violating one of the assumptions for ANOVA and linear regression (Snedecor and Cochran, 1967). For this reason a second set of analyses was done, in which all of the stems per coppice stool were treated as one record. Volume was estimated using four different variables, D, (Σd_i^2), $(\Sigma d_i^2)M$, $\Sigma(d_i^2L)$, where D is the diameter of the largest stem in the coppice stool, d is diameter, L is total individual stem length and M is the length of the longest stem in the stool. In each case, the data were split to give a calibration and a validation set to estimate the accuracy of the predictions given by the model (Rawlings, 1988, Appendix 1.1.). Biomass tables were developed using first $\Sigma(d^2L)$ and secondly the largest stem per coppice stool. Throughout the analyses, checks were performed to ensure that the two statistical assumptions of normality of residuals and homogeneity of variances were not violated.

2.4 **Results and Discussion**

An analysis of variance showed that site had no significant effect on woody biomass production in either species (ANOVA $F = 2.34$, $df = 4$ & 131, $p = 0.059$ for *B. spiciformis*; $F = 2.28$, $df = 4$ & 139, $p = 0.064$ for *J. globiflora*). The data for all five sites were therefore pooled for further analysis. Table 2.1 shows the range of trees used in the sample, for both species. The average diameter of the largest stem in the coppice stool was 8 cm, but ranged from 25.0 cm to 2.0 cm for *B. spiciformis* and from 25.8 cm to 1.4 cm for *J. globiflora*. The total dry woody biomass varied accordingly.

2.4.1. *Moisture content*

The average moisture content of both species in this study area between July and mid-September was approximately 40 % (Table 2.1). The percentage moisture content of wood varies for different stem diameters and at different times of the year (Crockford, 1987; Chidumayo, 1990; Stewart *et al.*, 1992). This is likely to be true of Zimbabwean miombo and is a subject for further work. The moisture content of the woodland in the present study is lower than that of the Zambian miombo given by Chidumayo (1990). If the moisture content is recalculated on a dry-weight basis to allow comparison with Chidumayo's estimates, the mean moisture content is 74 % (sd = 0.079) compared to his dry season figure of 86 %.

Table 2.1. Descriptive statistics for each species, where mc = moisture content, D = maximum diameter (at 30 cm) per coppice stool, M = maximum stem length, Bm = total dry woody biomass per coppice stool.

	B. spiciformis				*J. globiflora*			
	mean	s.d.	max.	min.	mean	s.d.	max.	min.
mc (%)	40.4	2.8	48.4	30.4	40.1	2.3	48.2	32.4
D (cm)	8.2	6.4	25.0	2.0	7.8	5.4	25.8	1.4
M (m)	5.3	2.5	11.0	1.7	4.8	2.0	10.3	1.7
Bm (kg)	36.8	62.4	287.1	0.1	28.5	54.1	351.3	0.1

2.4.2. *Variables and sample numbers*

The variables used in the regression analysis were logarithmic transformations of wood volumes per coppice stool, estimated using D, (Σd_i^2), $(\Sigma d_i^2)M$, $\Sigma(d^2 L)$ (section 2.3.2), and total dry woody biomass per stool, since the sum of the stem diameters and maximum stem lengths (Σd_i and M) alone gave r^2 values of less than 0.9 (Appendix 1.2). In each case, for *B. spiciformis* n = 132, and for *J. globiflora* n = 140.

2.4.3. ***Biomass modelling***

2.4.3.1. *Single stem functions*

An initial simple linear regression using the form $\log_{10} Bm = a + b \log_{10} (d^2L)$ (used because it gave the best fit) and which treated individual stems separately gave the results shown in Table 2.2.

2.4.3.2. *Coppice stool functions*

The results of the tests on a range of models for dry woody biomass per coppice stool are shown in Table 2.3.

The fourth model, using $\Sigma(d^2L)$ as an estimate of volume, gave the highest r^2 values for both species. For both species 98 % of the variation in total dry woody biomass is accounted for by this function. The residuals plotted against fitted values in each case had no curved pattern (Fig. 2.2 a and b). Squaring the diameter of the largest stem per coppice stool merely changed the intercept but did not improve the r^2 value of the function developed using the diameter of the largest stem, and so has not been included here. Validation of the models using independent data sets (Appendix 1.1), where observed values were regressed against predicted values and the residual errors examined, gave the percentage error in prediction for each model as shown in Table 2.4. From this it can be seen that using both $\log_{10} \Sigma(d^2L)$ and $\log_{10} D$ as the estimate of volume gave good predictive models for both species since they have the lowest percentage error in prediction. The equation using $\log_{10} \Sigma(d^2L)$ accounts for a higher percentage of the variation in the total dry woody biomass, however. All models had low prediction errors, although the functions for *B. spiciformis* were marginally more accurate than those for *J. globiflora* except where D was used.

The functions developed using the diameter of the largest stem in the coppice stool (D) as the independent variable (Fig. 2.3 a and b), despite having the lowest r^2 values of the group ($r^2 = 0.94$ for *B. spiciformis* and 0.93 for *J. globiflora*), still give acceptable values. Many of the trees in this type of woodland are multistemmed, and therefore these latter functions are likely to be the most useful in the field. Measurement of every stem in the coppice stool is time-consuming, especially in younger regenerating woodland, and the small increase in accuracy of prediction may not be worth the extra effort. The functions developed using Σd^2 also gave an acceptable fit, and would give slightly more accurate biomass tables than the model using D, but these would be less useful in the field since a calculation of Σd^2 is required. The biomass tables produced here were

Table 2.2. Single stem functions. Mean goodness of fit for both species, expressed as the coefficient of determination (r^2). d = stem diameter at 30 cm and L = stem length, Bm = total dry woody biomass per stem. The regression analysis is shown in Appendix 1.3.

	Model	r^2
B. spiciformis	$\log_{10} Bm = 2.40 + 1.02 \log_{10}(d^2L)$	0.96
J. globiflora	$\log_{10} Bm = 2.47 + 1.02 \log_{10}(d^2L)$	0.97

Table 2.3. Coppice stool functions. Mean goodness of fit for both models and species, expressed as the coefficient of determination (r^2), where a and b were determined separately for each function. d = stem diameter at 30 cm, D = diameter at 30 cm of the largest stem in the coppice stool, L = stem length, M = length of longest stem in the stool and Bm = total dry woody biomass per stool. Details of the regression analysis are shown in Appendix 1.3.

	B. spiciformis			*J. globiflora*		
Model	a	b	r^2	a	b	r^2
$Log_{10}Bm = a + b \log_{10}(D)$	3.9	2.6	0.937	4.0	2.6	0.927
$Log_{10}Bm = a + b \log_{10}(\Sigma d^2)$	3.8	1.4	0.921	3.8	1.3	0.971
$Log_{10}Bm = a + b \log_{10}(\Sigma d^2)M$	2.4	1.0	0.965	2.5	1.0	0.980
$Log_{10}Bm = a + b \log_{10}\Sigma(d^2L)$	2.4	1.1	0.977	2.5	1.0	0.984

Table 2.4. Validation of regression models: comparison of the accuracy of the prediction of each model, for the two different species separately.

	Percentage error in prediction	
Model	*B. spiciformis*	*J. globiflora*
$Log_{10}Bm = a + b \log_{10}(D)$	1.4	0.8
$Log_{10}Bm = a + b \log_{10}(\Sigma d^2)$	1.5	1.7
$Log_{10}Bm = a + b \log_{10}(\Sigma d^2)M$	1.6	1.6
$Log_{10}Bm = a + b \log_{10}(\Sigma d^2L)$	1.2	1.6

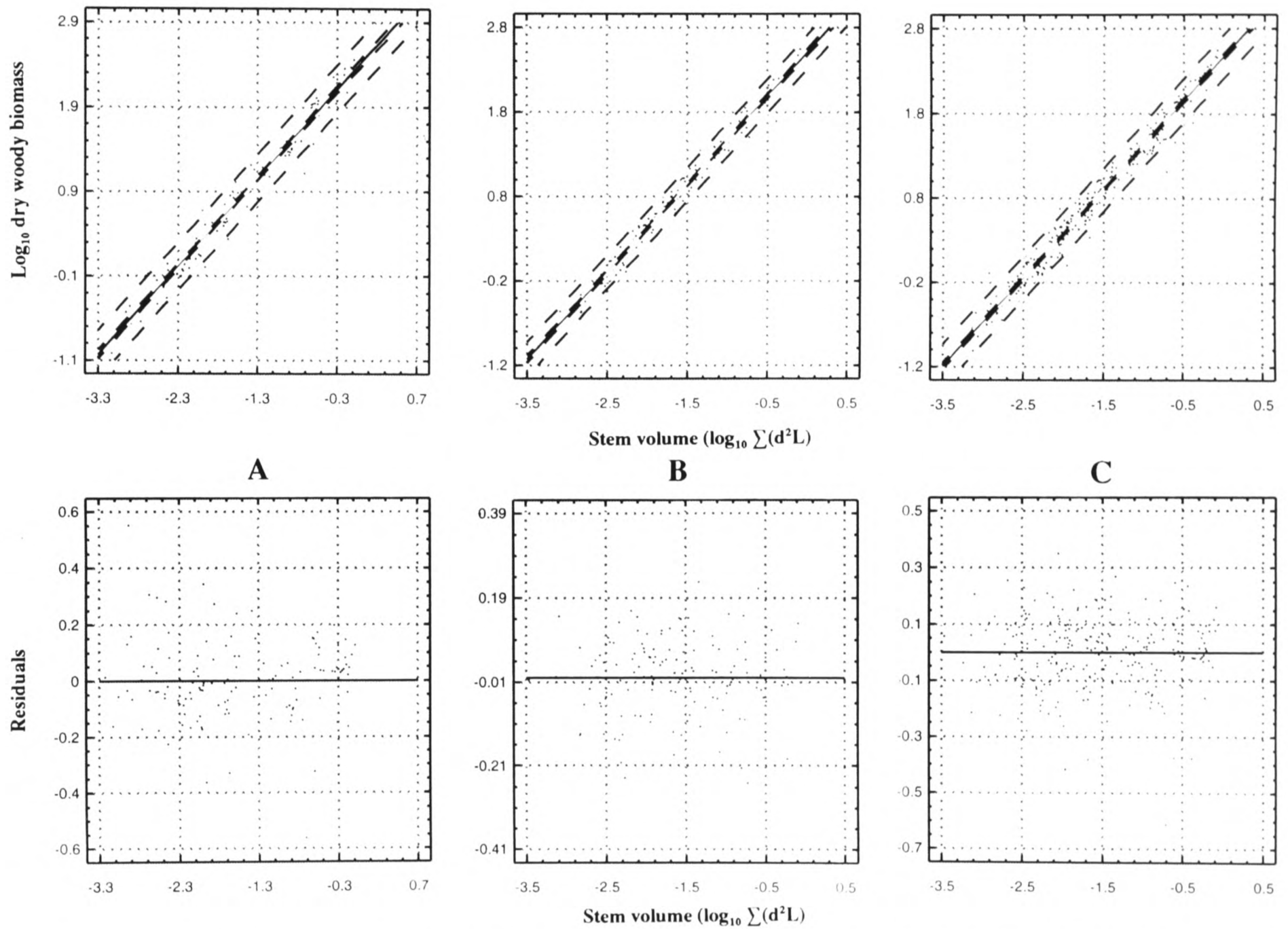

Fig. 2.2. Relationship between estimated stem volume ($\log_{10}\Sigma$ (d^2L)) and total dry wood biomass, showing regression line and residual plot. d = diameter measured at 30 cm above ground level; L = length of largest shoot from apex to base. A = *B. spiciformis*; B = *J. globiflora*; and C = both species together. For the top three figures, the lines near the regression line indicate 95 % confidence limits for the regression curve. The outer lines indicate 95% confidence limits for data points.

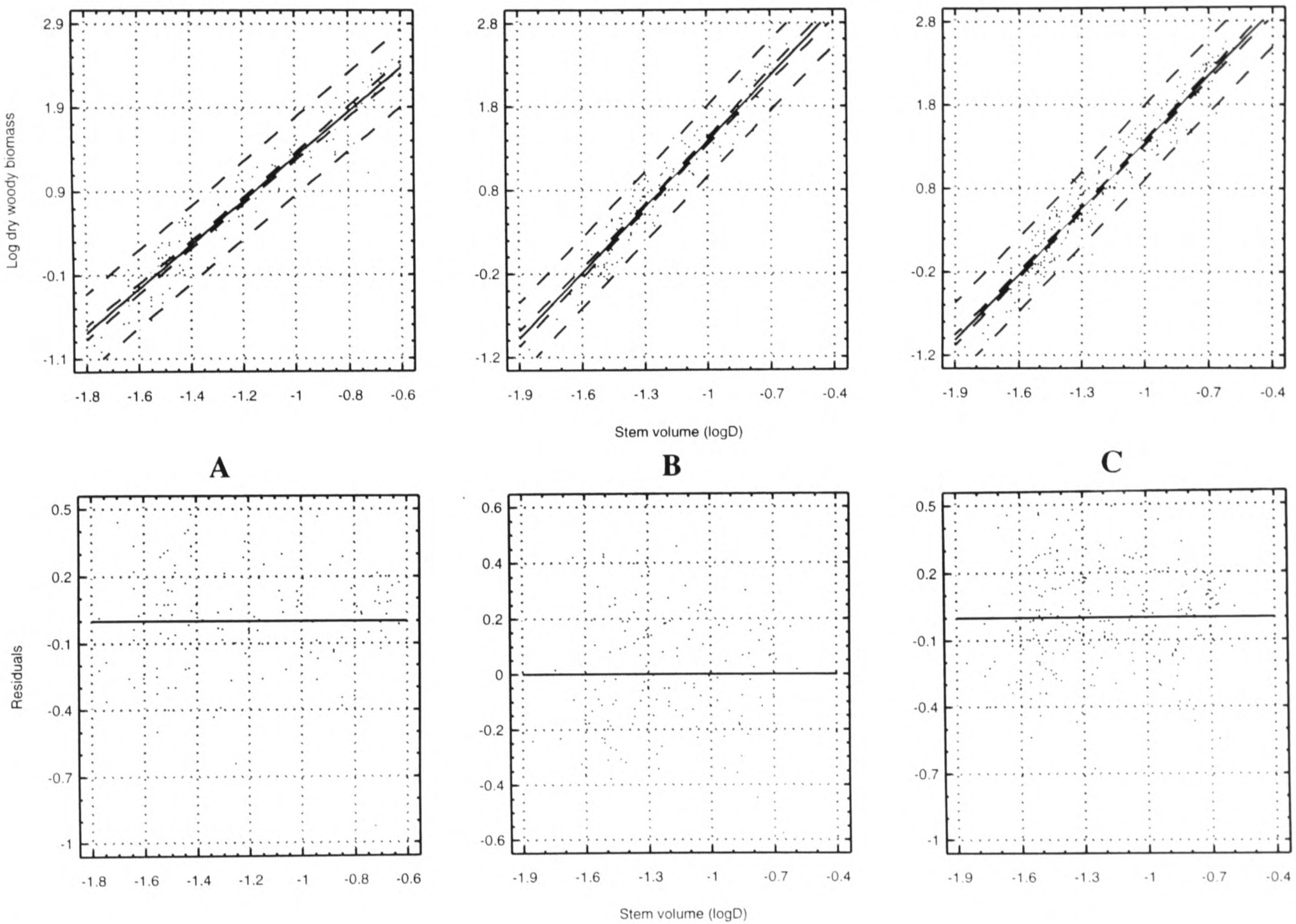

Fig. 2.3. Relationship between estimated stem volume ($\log_{10}$D) and total dry wood biomass, showing regression line and residual plot. D = diameter of largest stem measured at 30 cm above ground level. A = *B. spiciformis*; B = *J. globiflora*; and C = both species together. For the top three figures, the lines near the regression line indicate 95 % confidence limits for the regression curve. The outer lines indicate 95% confidence limits for data points.

constructed for coppice stools, first using $\Sigma(d^2 L)$ and then using D only. It should be noted that biomass estimates using the largest stem only are on the upper limit of the range calculated by using a measurement of stem length as well.

When estimating the total volume of trees, the inclusion of a form factor or mid-diameter measurement in the equation greatly enhances the predictive accuracy of the model (McTague, 1992). Form factors have not yet been determined for dry miombo woodland, and this is an area for further work. It would be difficult to improve on the r^2 values of the biomass equations developed here, however.

2.4.3.3. *Species differences*

A comparison of the two regression lines, testing the hypothesis that there is no significant difference between the two species, shows that the mean residual variation about a single regression line (i.e. both species together) is not significantly different from the mean residual variation about the two separate lines ($F = 0.05$, $df = 2$ & 268, $p = 0.001$). The data can therefore be combined and the models $\log_{10} Bm = 2.46 + 1.04 \log_{10} \Sigma(d^2L)$ and $\log_{0} Bm = 3.98 + 2.63 \log_{10} D$ used to estimate total dry woody biomass for the two species together (Appendix 1.4). Table 2.5 shows the difference in the value of the coefficient of determination between regression analyses using the combined data set and those using separate species data.

Table 2.5. The effect on r^2 of combining the data to calculate a model for both species together.

	n	r^2
Both species	272	0.977
B. spiciformis	132	0.977
J. globiflora	140	0.984

Table 2.6. Total dry woody biomass of coppice stools of both *B. spiciformis* and *J. globilfora* in dry miombo woodland in Zimbabwe. Model = Log_{10} Bm = 2.46 + 1.04 log_{10} (sum d^2 L), where Bm = biomass, d = diameter measured at 30 cm and L = stem length from apex to ground level.

Diameter	Stem length (m)											
(cm)	1.00	2.00	3.00	4.00	5.00	6.00	7.00	8.00	9.00	10.00	11.00	12.00
1.00	0.02	0.04	0.06	0.09	0.11							
2.00	0.09	0.18	0.27	0.36	0.46	0.55						
3.00	0.20	0.41	0.62	0.84	1.05	1.27						
4.00	0.36	0.74	1.13	1.51	1.91	2.30						
5.00		1.17	1.78	2.40	3.02	3.64	4.27					
6.00		1.71	2.60	3.49	4.39	5.30	6.22					
7.00		2.35	3.57	4.80	6.04	7.28	8.54					
8.00		2.71	4.70	6.32	7.95	9.59	11.24	12.90				
9.00			5.99	8.05	10.13	12.22	14.33	16.44				
10.00			7.44	10.00	12.59	15.19	17.80	20.43				
11.00			9.05	12.17	15.32	18.48	21.66	24.86	28.06			
12.00			9.92	14.56	18.33	22.11	25.92	29.74	33.57			
13.00				17.17	21.61	26.07	30.56	35.07	39.59			
14.00				20.01	25.17	30.38	35.60	40.85	46.12	51.41		
15.00				23.06	29.02	35.01	41.04	47.09	53.16	59.26		
16.00				26.34	33.15	39.99	46.87	53.79	60.72	67.68		
17.00					37.55	45.31	53.11	60.94	68.80	76.69	84.60	
18.00					42.25	50.97	59.75	68.56	77.40	86.27	95.17	
19.00					47.22	56.98	66.79	76.63	86.52	96.43	106.38	
20.00					52.49	63.33	74.23	85.17	96.16	107.18	118.24	129.32
21.00						70.03	82.08	94.18	106.33	118.51	130.74	143.00
22.00						77.07	90.33	103.65	117.02	130.43	143.89	157.38
23.00						84.46	98.99	113.59	128.24	142.94	157.69	172.47
24.00						92.20	108.07	124.00	139.99	156.04	172.14	188.27
25.00							117.55	134.88	152.27	169.73	187.24	204.79

Figs. 2.2c and 2.3c show the relationship between biomass and volume for the whole data set. The combined models give more useful estimations of biomass since the two species are often found in close association with one another. Biomass tables, using $\Sigma(d^2L)$ and D as the predictors for both species are given in Tables 2.6 and 2.7.

Table 2.7. Dry woody biomass for coppice shoots of both species, using D (diameter of the largest stem) as the predictor and the model $\text{Log}_{10}\text{Bm} = 3.98 + 2.63 \log_{10} D$.

D (cm)	Bm (kg)	D (cm)	Bm (kg)
1.0	0.1	14.0	57.9
2.0	0.4	15.0	69.4
3.0	1.0	16.0	82.2
4.0	2.2	17.0	96.3
5.0	3.9	18.0	111.9
6.0	6.3	19.0	128.9
7.0	9.4	20.0	147.5
8.0	13.4	21.0	167.6
9.0	18.2	22.0	189.3
10.0	24.0	23.0	212.7
11.0	30.8	24.0	237.8
12.0	38.7	25.0	264.6
13.0	47.7	26.0	293.2

2.4.3.4. *Reduction in sample number*

Table 2.8 shows the effect on r^2 of reducing the number of samples used in the regression analyses, using the model $\text{Log}_{10}\text{Bm} = a + b \log_{0} \Sigma(d^2L)$. For these two species, a reduction in number of samples to 20 gives little reduction in r^2 values. The slight variation in the r^2 values is due to the random selection of samples from the original data set. Indigenous woodland in communal grazing areas in Zimbabwe tends to be made up of a wide range of size classes, often comprising a few large trees and many smaller coppice stools with multiple stems. Stewart *et al.* (1992), working with Central American dry zone species, recommend a sample size of 12 to 16 trees.

Table 2.8. The effect on r^2 of randomly reducing the number of samples in the regression analyses.

Model: $Log_{10}Bm = a + b \log_{10} \Sigma(d^2L)$

	r^2	
Number of samples	*B. spiciformis*	*J. globiflora*
All	0.977	0.984
45	0.981	0.987
35	0.986	0.981
30	0.978	0.988
25	0.989	0.988
20	0.989	0.977

2.4.4. *Applications of the models*

The models developed in this work apply to trees of the two species within the range of diameters measured. Extrapolation beyond the limits of the range of diameters is not recommended, since the predictions are likely to be inaccurate. The trees measured in this study represent the average range of stem sizes encountered in Zimbabwean miombo woodland, except for the Kalahari sand areas to the west of the country. Here the trees grow much taller and reach diameters of 50 cm and more. Trees as large as this do occur in other areas, but are becoming increasingly rare. Site characteristics are a determining factor in the growth of these trees (Grundy, 1993) and therefore the models may only apply to these two species growing under similar site conditions.

2.4.5. *Comparison with other biomass models*

It is difficult to compare the models developed in this study with those of other workers because different variables have been used in each case. Stromgaard's (1985) models have been revised (Stromgaard, 1986). These models, developed in Zambian miombo, use DBH, total height of tree and fresh weight, and give no r^2 values. His trees appear to be bigger than those in this study, but the biomasses calculated are of the same order of magnitude. Chidumayo (1988), working in mixed Zambian miombo, used circumference at 30 cm and stem height, but did not give an r^2 value for the equation. A better relationship could possibly have been developed if d^2 had been used instead of

circumference, as was found in the present work. Later Chidumayo (1990) developed another set of linear functions for mixed miombo, using diameters at stump height (30cm) and at breast height, which accounted for most of the variation in wood biomass. Guy (1981) gives little information about the origin of his function, the unit of biomass measurement, or whether the biomass was calculated on a fresh or dry mass basis. Assuming biomass was dry mass measured in kg, a comparison with his figures shows that they correspond very closely with those found in this study. This suggests that the equations developed in the present work may be less site-specific than first thought. None of the three studies includes a validation of the models, so it is not possible to assess how accurate they are in predicting biomass.

2.5 Conclusions

In this chapter, models for the prediction of biomass from stem measurements of *B. spiciformis* and *J. globiflora* have been developed. This work adds to the scant but growing number of studies which demonstrate good relationships between some stem characteristic and total tree woody biomass in miombo woodland, from which reliable biomass tables have been derived.

3

Age determination using growth rings

3.1. Introduction

One of the hinderances to the production of effective cutting rotations and sound management of miombo woodland in the past has been the difficulty in determining the ages of the trees, and therefore their rates of growth. The use of permanent sample plots for successive measurement of trees requires long-term studies and secure experimental sites which, because of the historical lack of interest in indigenous species in Zimbabwe, combined with a lack of continuity within research institutions, and the relatively slow growth rates of some of the trees, has meant that such plots are rare. Counting growth rings in the stem wood would be a useful means of ageing trees, but is dependent on the definition of the rings and their association with seasonal variation (Gourlay and Barnes, 1994). In the past it has been generally accepted that, unlike trees from temperate climates, growth rings cannot be reliably used to age trees in southern Africa (Lilly, 1977; Celander, 1983). In the 1930s, however, annual rings were commonly used by forest managers to age miombo woodland in Zambia (then Northern Rhodesia) (Fanshawe, 1956a; Duff, pers.comm.[1]) and more recent research has shown that some tropical and sub-tropical species do in fact produce rings which correlate with age (Fahn *et al.*, 1981; Jacoby, 1989; Prior and Gasson, 1990; Gourlay and Barnes, 1994). Zimbabwe's subtropical climate shows moderate temperature and large moisture seasonality, giving rise to conditions which support woodlands with a dry-season leaf fall and a wet-season flushing. The trees may only be leafless for a period of two to three weeks, but this seasonality should be long enough to induce dormancy and the associated anatomical change which produces well-defined cyclical growth rings. There is likely to be high variablility in ring formation within the same species, however, depending on the prevailing site conditions (Jacoby, 1989).

Growth rings are known to occur sporadically in the legumes generally, and when present they may be discontinuous (Metcalfe and Chalk, 1950). Work by Gourlay and Barnes (1994) has shown that African species of *Acacia* can be aged on the basis of fine marginal parenchyma bands

[1] Colin Duff, Former Conservator of Forests, Northern Rhodesia; Oxford, June 1993

which are produced in response to growth periods. In *Acacia*s, these can be unimodal or bimodal, depending on the pattern of rainfall. Fouarge and Gerard (1964), among others, have shown that several members of the Caesalpinaceae from Central Africa produce visible parenchyma rings. Preliminary work by Robertson (pers. comm.[2]) suggests that *J. globiflora* in Zimbabwe does the same. However, it has not yet been ascertained whether, in areas of unpredictable rainfall and frequent intra-seasonal droughts, rings are still produced annually.

3.1.1. ***Objective***

The objective of this chapter was to determine whether *B. spiciformis* makes annual growth rings in dry miombo woodland in Zimbabwe, and if so, whether these rings are clear enough to be useful in age determination of the trees. *Julbernardia globiflora* was not included in this experiment because of the previous, unpublished, work-in-progress on this species by Robertson (pers.comm.[2]).

3.2. **Study sites**

Two protected miombo sites, one more xeric than the other, were chosen. The first was situated in Mashonaland Province at Grasslands Research Station (18° 10' S, 31° 29' E), 55 km SE of Harare and 10 km west of Marondera at an altitude of 1640 m (Fig. 1.2, page 17). The mean annual rainfall is 885 mm (Anon, 1977). Mean monthly temperatures range from 12.3 °C in July to 19.7 °C in October (Torrance, 1981). The soils are derived from granite (Thompson and Purves, 1970). The vegetation is dominated by *B. spiciformis* and *J. globiflora*. The experimental site was situated in a strip on the eastern edge of the woodland which had been cleared in 1980 as a firebreak. The site is relatively free from disturbance by humans and livestock and has not been burnt for at least 40 years. The second site was situated 5 km east of Kwekwe (18° 56' S, 29° 50' E) (Fig. 1.2, page 17), at an altitude of 1215 m, on soils derived from dolerite. The mean annual rainfall is 656 mm (Anon, 1977). Mean monthly temperatures range from 14.6 °C in July to 23.0 °C in October (Torrance, 1981). The site is situated in an area of woodland dominated by *B. spiciformis* and *J. globiflora* which was clear-felled in 1980 and which has been protected from animal and human disturbance since 1985. The fire history of the site is unknown, but it is not thought to have been burnt since it was protected. The combination of a lower mean annual rainfall, which has greater temporal and spatial variability, with soils of a higher clay content make the Kwekwe site more xeric than Marondera.

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[2] Faye Robertson, Dept. National Parks; Harare, 1991

3.3. **Methods**

In June 1991, eight *B. spiciformis* stems were marked at each site by damaging the cambium in two ways: a) with a nail driven into the stem at right angles to the ground at 1.40 m (breast height) using a method adapted from Shiokura (1989); and b) by making a perpendicular scratch on the bark with a penknife. The same trees were remarked in June 1992 and July 1993. Because ring production can vary on different radii (Cutler, pers.comm.[3]), the nails were placed vertically above each other, rather than around the circumference of the stem. The trees were felled at the end of the growing season in June 1994. Two samples were taken from each stem, one of the marked portion and one at ground level. Some cores were taken for comparison with the cross-sections.

The samples were initially polished, using a band sander and progressively finer sandpaper. The parenchyma rings were then counted and measured to the nearest 0.1 mm using a travelling microscope (x 20). Two sets of measurements, across two radii of the stem from bark to pith, were taken and the mean calculated. In the case of missing rings, a third radius was measured. The samples which were measured first were remeasured after the technique had been practised, in an attempt to reduce the margin of measurement error. Skeleton plots, to demonstrate positive and negative changes in ring widths were drawn (after Schweingruber *et al.*, 1990). Microscopic sections were made from the samples to allow investigation at a greater magnification. Small blocks of wood were prepared for sectioning, staining and mounting following the procedures given in Anon (1951). Mean monthly and mean annual rainfall figures were used to investigate the effect of rainfall on mean ring width for each site.

3.4. **Results and discussion**

3.4.1. ***Methods of taking samples***

Of the two marking methods used, the first (using a nail, plate 3.1) was the only one which was successful. The scratches, although appearing to be as deep as the cambium at the time, made no mark on the wood. This method should not be used in future. Taking cores from these trees proved difficult because of the density of the wood and the difficulty in removing the cores both

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[3] David Cutler, Royal Botanic Gardens; Kew, April 1991.

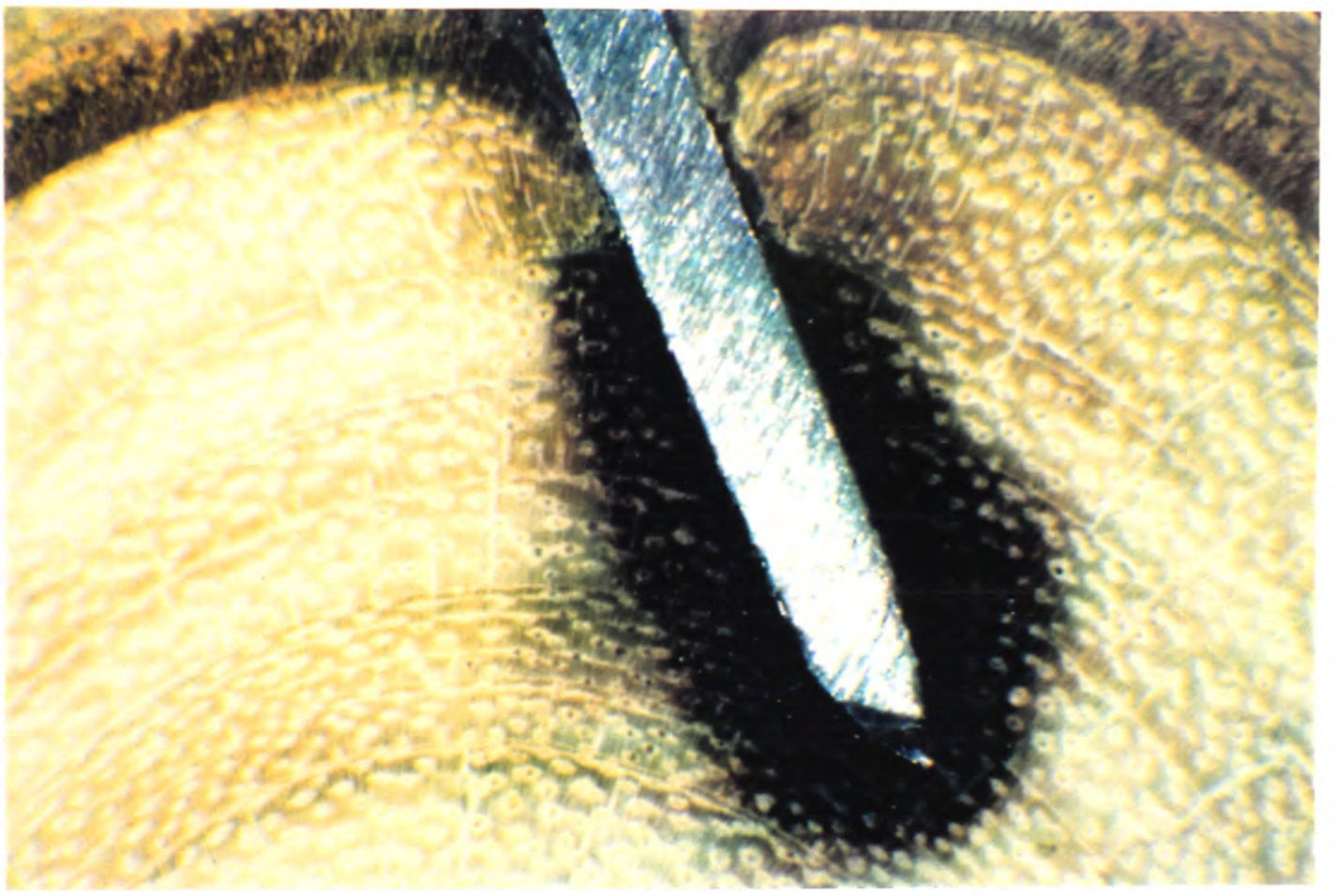

Plate 3.1. Section of *B. spiciformis* stem (x 7) showing the mark produced by an aluminium nail. Any growth after the nail was inserted is clearly visible.

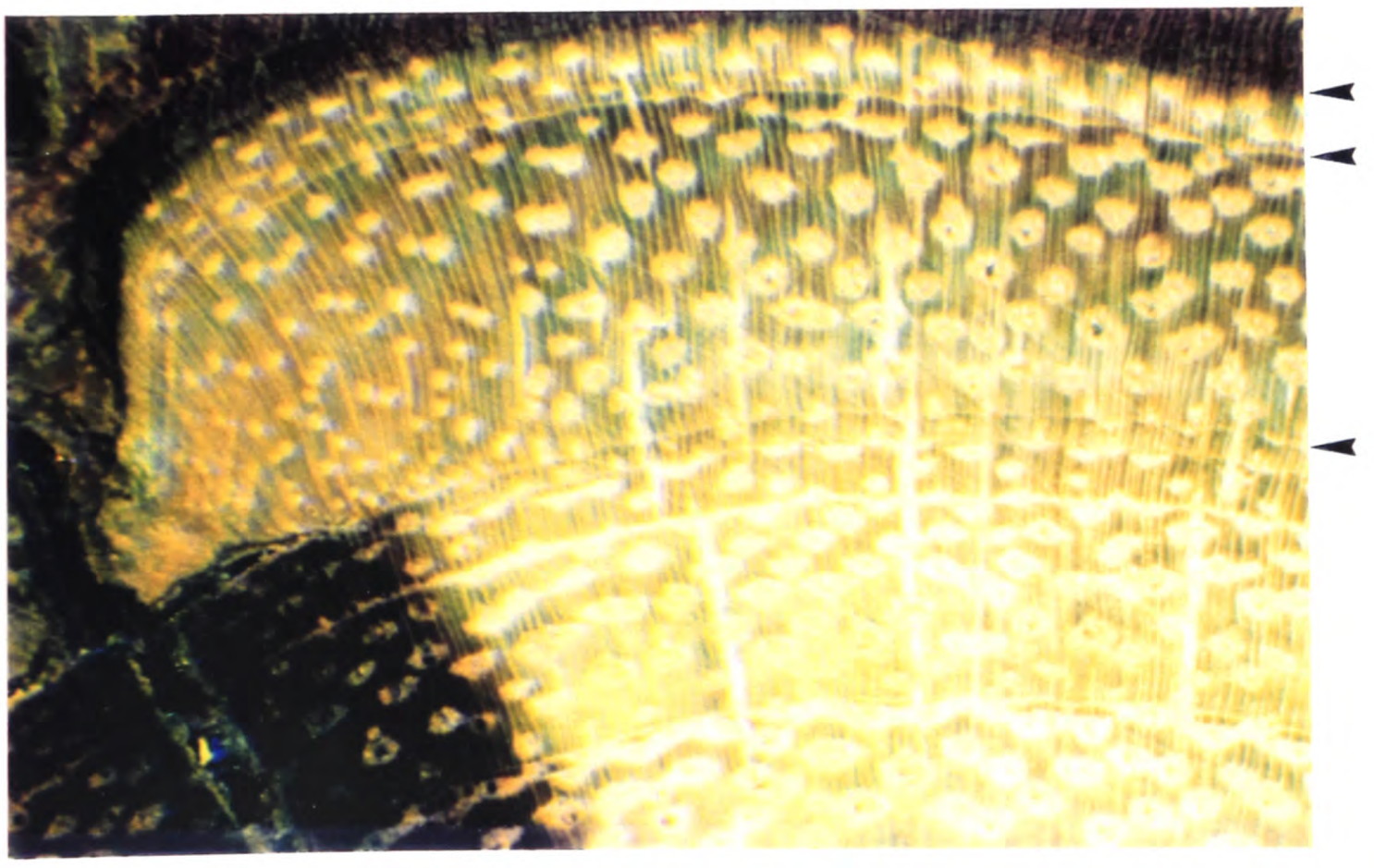

Plate 3.2. Section of marked *B. spiciformis* stem (x 18), showing annual growth rings. This stem was marked in June 1992. Two xylem bands, which have grown after the nail was inserted and which are separated by a thin line of marginal parenchyma cells, are visible.

from the stem and from the corer. Several had to be burnt from the corer and were lost, and most of the rest did not survive in one piece. To aid in sample taking, a very sharp corer should be used at all times. However, because of the likelihood of incorrect ring counts when only part of the circumference is visible, due to false and discontinuous rings, stem cross-sections are likely to give more accurate estimates of age than cores. In addition, *B. spiciformis* is susceptible to stem rot, particularly in areas where its bark is damaged by fire. The use of a corer may therefore render the stem more susceptible to fungal attack.

3.4.2. ***Ring production***

From the polished wood samples it was possible to see that the trees produced visible rings, and from the marked samples it was clear that one ring was produced every year, marked by a thin, pale line (Plate 3.2.). In some specimens the lines were discontinuous (Plate 3.3.), while in others, there appeared to be some false rings. The marginal bands may be associated with a darkening of the xylem, due to the production of flatter fibres. The darker bands are not always produced at the end of the growing season, as in temperate species, but may also be present at the beginning of the new season (Plate 3.4). This may occur because the trees usually flush before the onset of the rains. The rings from Marondera, the wetter site, were clearer and easier to discern. In general, because of their fineness, many of the rings were extremely difficult and tedious to count.

Microscopic examination showed that the wood structure of *B. spiciformis* is similar to that of other *Brachystegia* species (Miles, 1978) in that the vessels are scattered fairly regularly throughout the xylem and are surrounded by aliform parenchyma (Plate 3.5). The aliform parenchyma is not uniform across the stem. At times the cells are larger and more numerous. It would be interesting to investigate the reason for this difference. The growth rings which were visible on the polished specimens are produced by narrow bands of marginal parenchyma in the xylem (Plate 3.5), which are produced annually. In some specimens, the annual xylem and parenchyma bands are very fine, almost invisible at low magnification, but are clear at cellular level. The false rings which were also visible on the polished specimens, and which could easily be confused with the marginal parenchyma bands, are made up of a continuous band of apotracheal and aliform-confluent paratracheal parenchyma cells (Plate 3.5).

The fine and often difficult to discern rings found in *B. spiciformis* are similar to those found in other species which form marginal parenchyma bands (Detienne, 1989). Additional difficulties in defining annual growth boundaries, which can be caused by false rings, indefinite rings

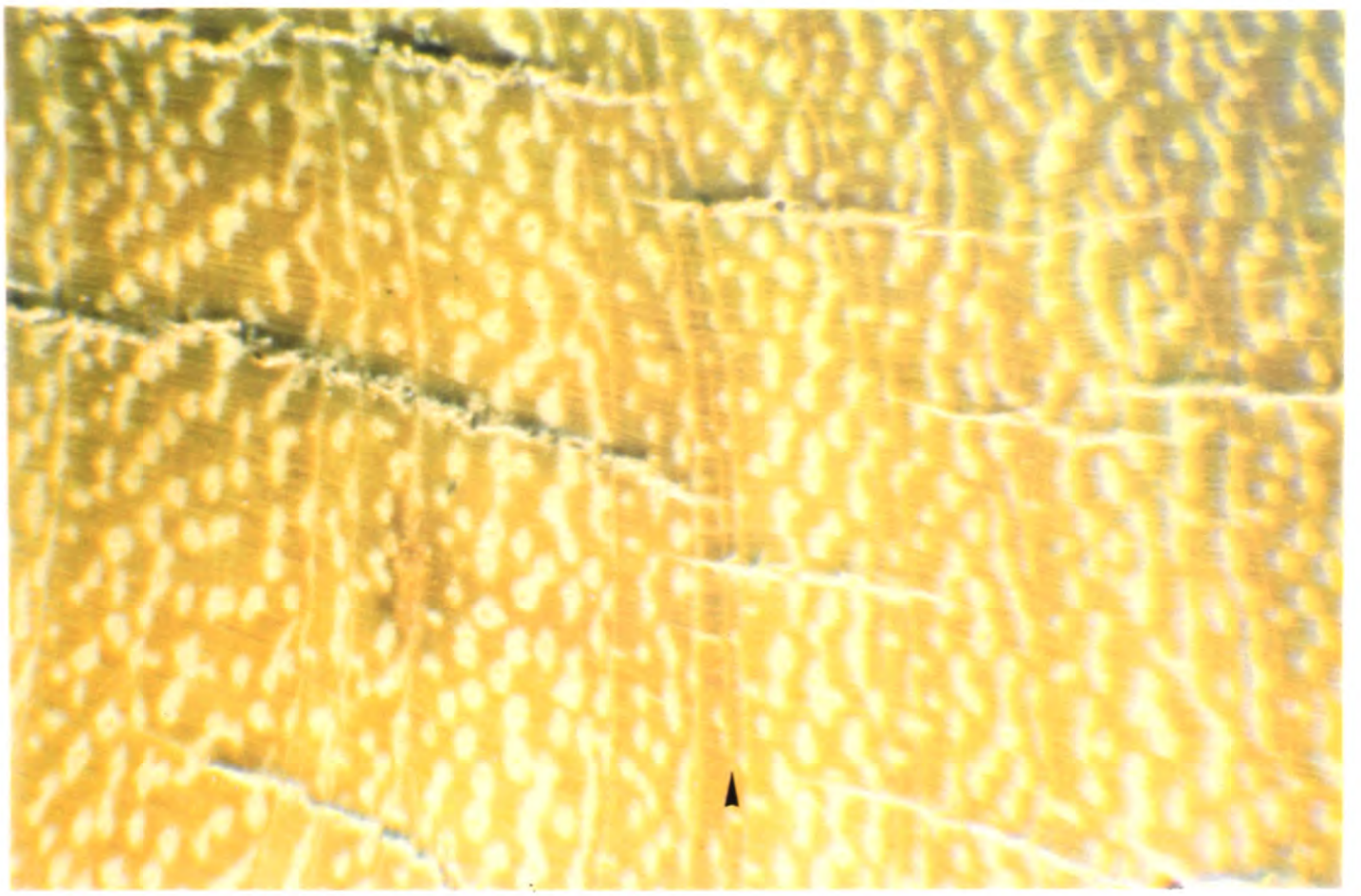

Plate 3.3. Cross-section of *B. spiciformis* stem (x 15) showing bands of xylem separated by annual bands of marginal parenchyma. The seventh band from the left is discontinuous.

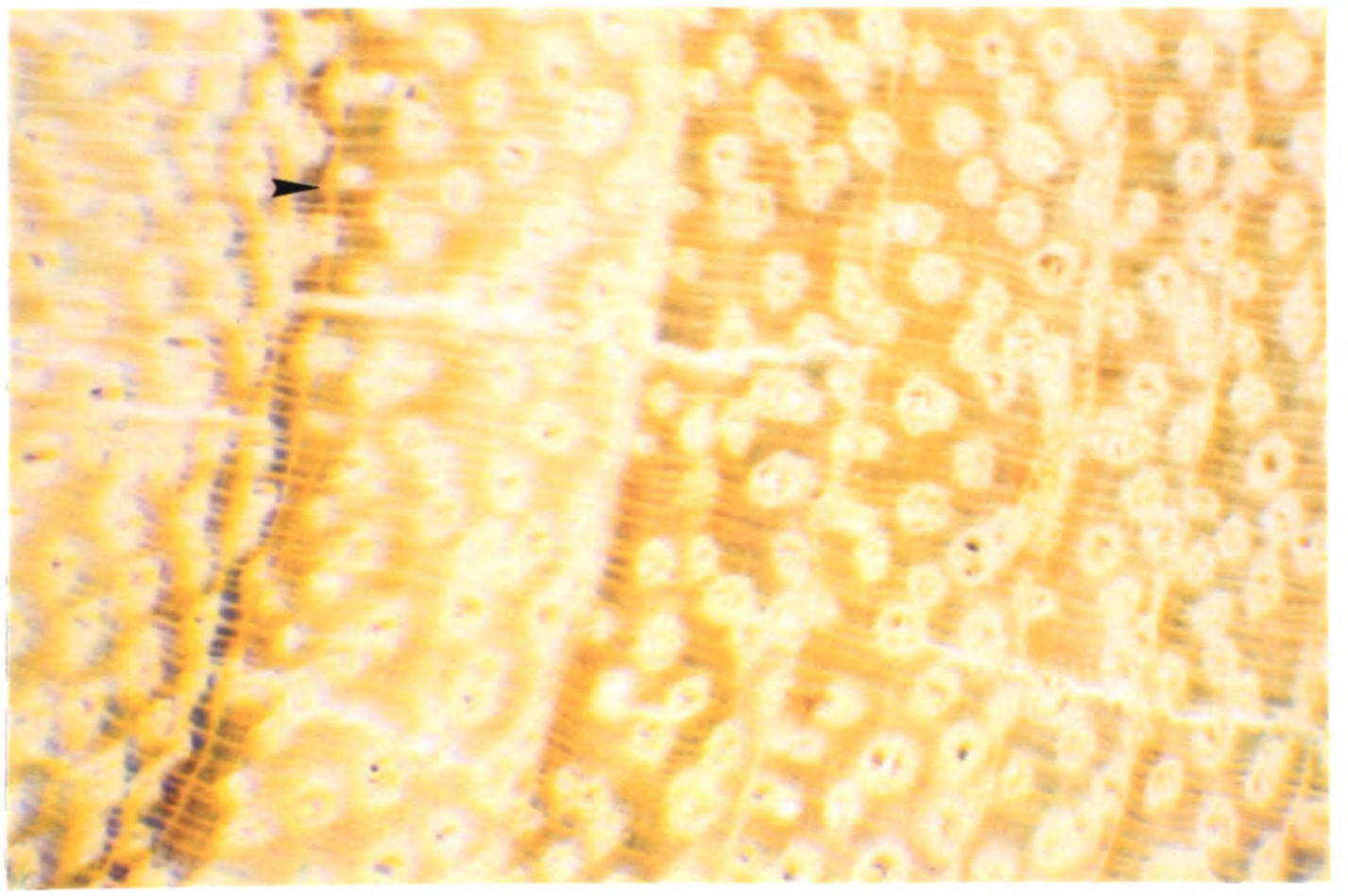

Plate 3.4. Polished cross-section of *B. spiciformis* (x 20) stem showing variation in the xylem bands. Note that the dark bank on the left is marked in the centre by an annual ring.

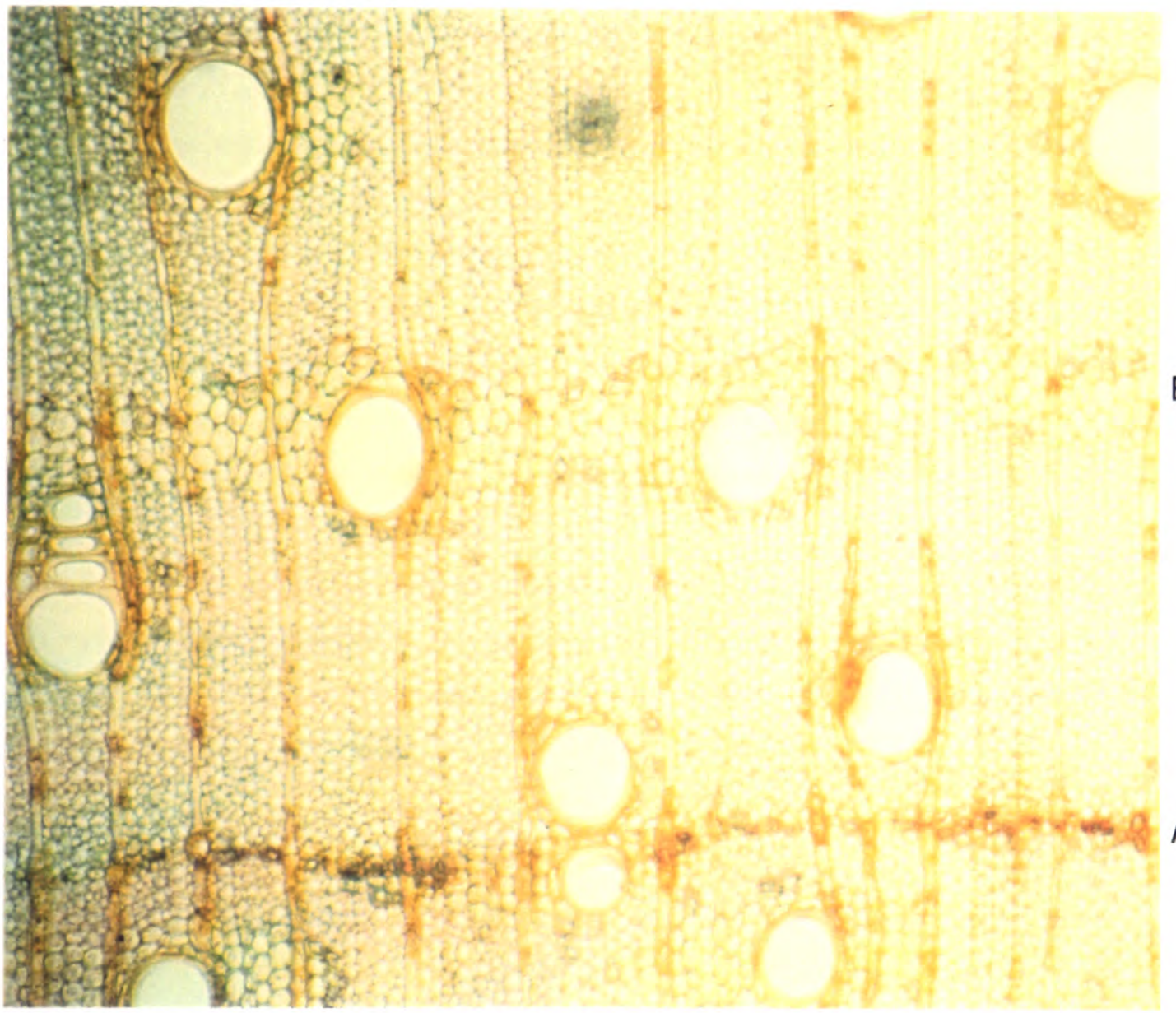

Plate 3.5. Microscopic detail of *B. spiciformis* wood (x 75). Vessels, surrounded by aliform parenchyma, are scattered throughout the xylem. A = annual ring formed by marginal parenchyma cells. B = aliform and paratracheal parenchyma.

near the pith or discontinuous rings have all been noted by Fahn *et al.* (1981), Detienne (1989), and Gourlay (1995). These problems may result in errors in measurement or dating of some of the rings, which would exacerbate the difficulties encountered in determining any trend in the ring formation at the two sites.

Skeleton plots are used to demonstrate changes in ring formation over the ring series (see Schweingruber *et al.*, 1990). Changes are depicted by plotting any abrupt increase or decrease in ring width, as well as yearly differences in vessel formation. Skeleton plots for the two sites, indicating changes in ring width only, are shown in Figs. 3.1 and 3.2. From the chronology of the Marondera site, it would seem that the years 1982, 1984, 1987 and 1992 were the best for tree growth, while 1991 was the worst. At Kwekwe the best years were 1984 and 1985, while 1991 and 1993 were the worst. A comparison of the plots for the two sites shows that the range of ring widths is greater at Kwekwe, the more xeric site, but that there are large variations in ring width from year to year for all of the trees at both sites.

The clearest rings in Zambian miombo woodland were made by the canopy dominants (Duff, pers.comm[4]). In the present work, the marked stem in each coppice stool was not necessarily the dominant one, which may have resulted in intra-stem variations in ring measurements. In future work, this would be an important factor to take into account.

3.4.3. *The effect of rainfall on ring production*

Figs. 3.3 and 3.4 show the relationships between ring width of individual trees and mean annual rainfall for both sites. Fig. 3.3 shows the Kwekwe samples taken at 1.4 m, with the rings from 1984 onwards depicted. The trees took 2 years to reach breast height, and the first ring in the sequence (1983) was omitted from the graph. In Fig 3.5 mean ring width for each site was plotted against mean annual rainfall. Fritts (1976) maintains that the average of all sample measurements gives the best indication of climatic changes, because the effects of non-climatic variations are minimised in the averaging process. For both sites, although a general trend is apparent, it seems that it is only in particularly wet or dry years that the changes in the width of the annual rings correspond closely with fluctuations in mean annual rainfall. In other years, different environmental factors appear to have a stronger influence on plant growth; in this case soil nutrients might be the most important. Mean ring width at Marondera was weakly correlated with mean annual rainfall ($r = 0.48$; $n = 13$; $p < 0.1$) and with seasonal rainfall (from October to

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[5] Colin Duff, Former Conservator of Forests, Northern Rhodesia; Oxford, June 1993

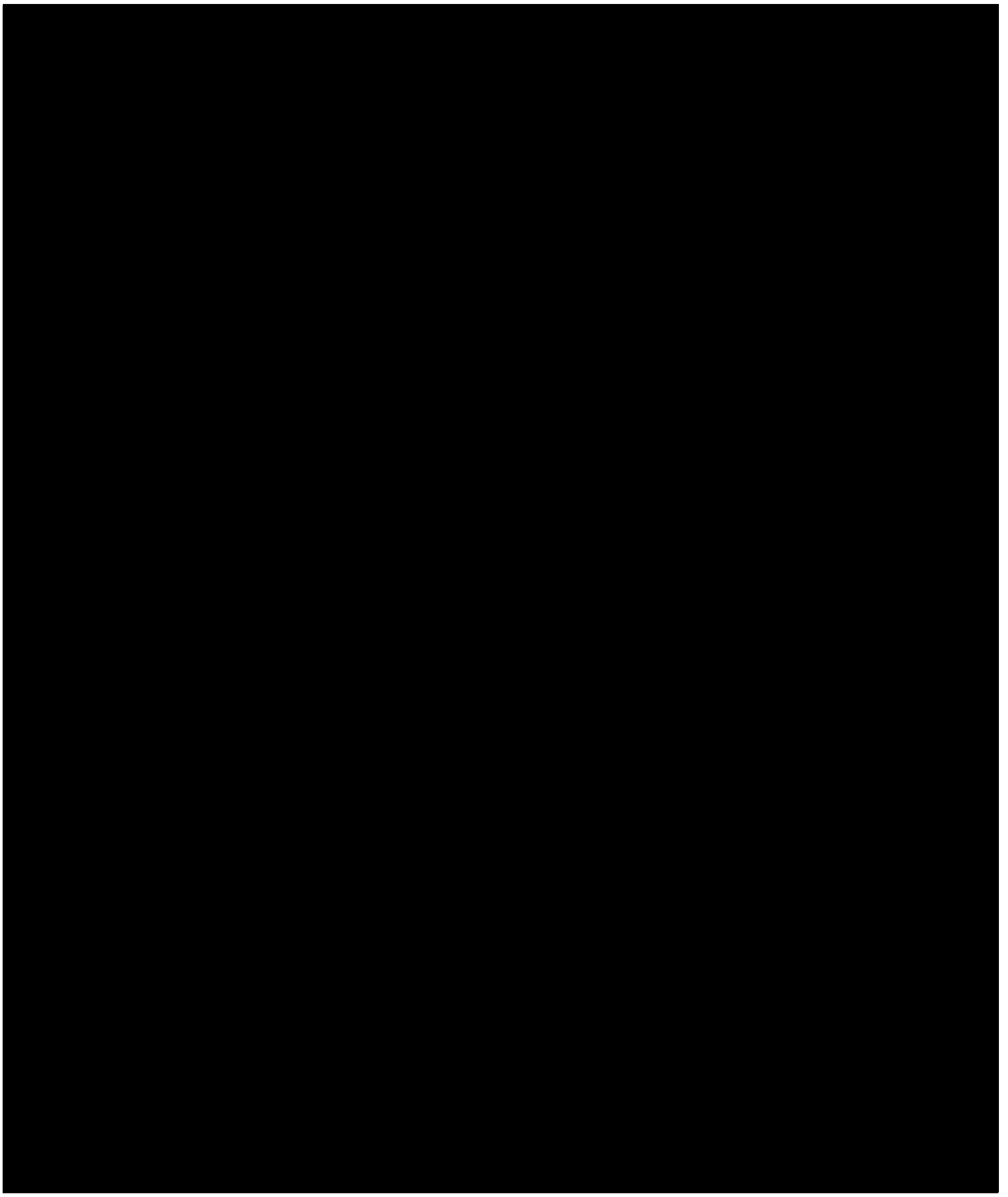


Fig. 3.1. Skeleton plots (after Schweingruber *er al.* 1990) to demonstrate positive and negative changes in ring width for the Marondera site. Increases in ring width, compared to the 'average' width, are depicted above the line and decreases below the line. The longer the line, the more abrupt the change. A plot for each sample is drawn; these are then combined to form a master plot for the whole site.

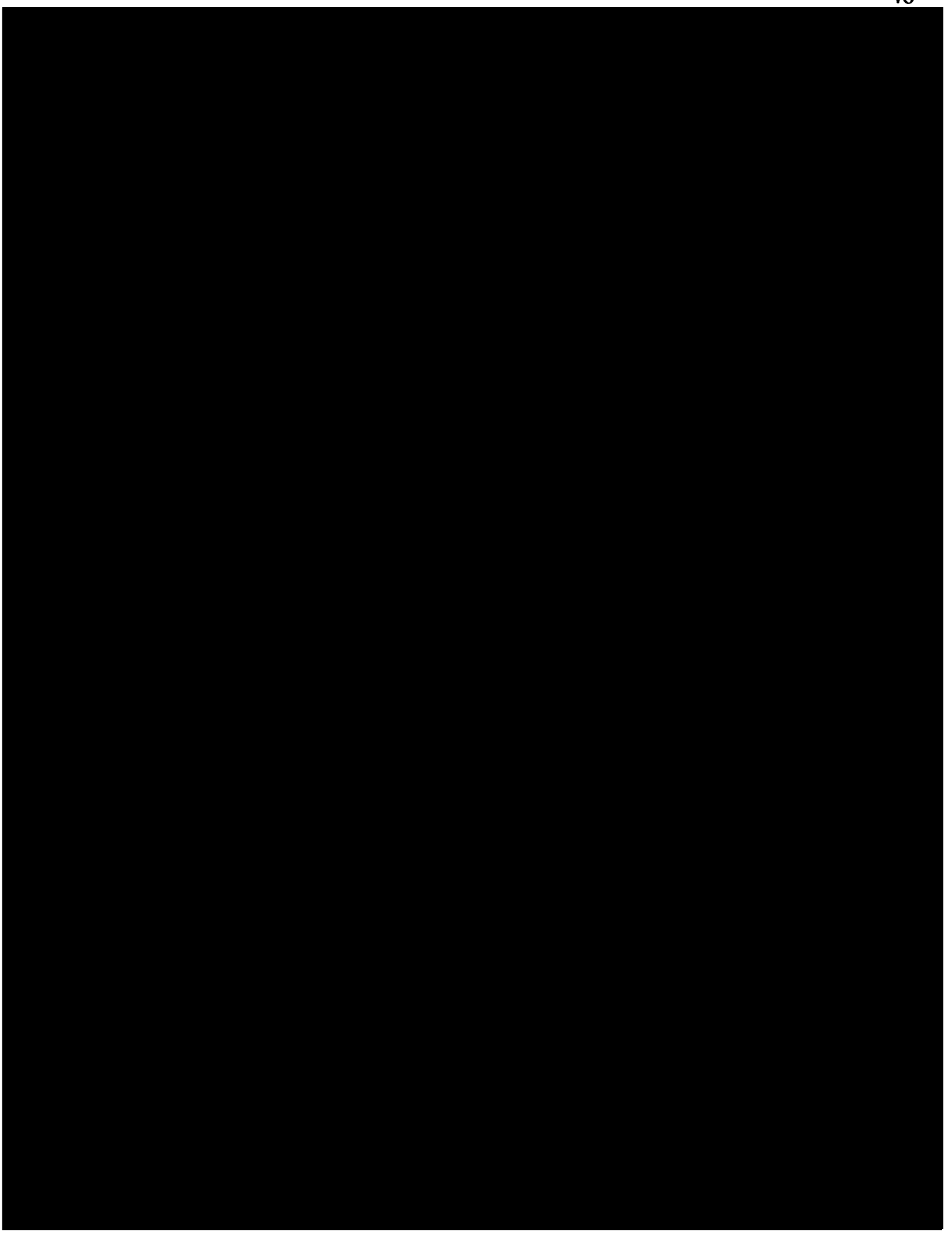


Fig. 3.2. Skeleton plots (after Schweingruber *er al.* 1990) to demonstrate positive and negative changes in ring width for the Kwekwe site. Increases in ring width, compared to the 'average' width, are depicted above the line and decreases below the line. The longer the line, the more abrupt the change. A plot for each sample is drawn; these are then combined to form a master plot for the whole site.

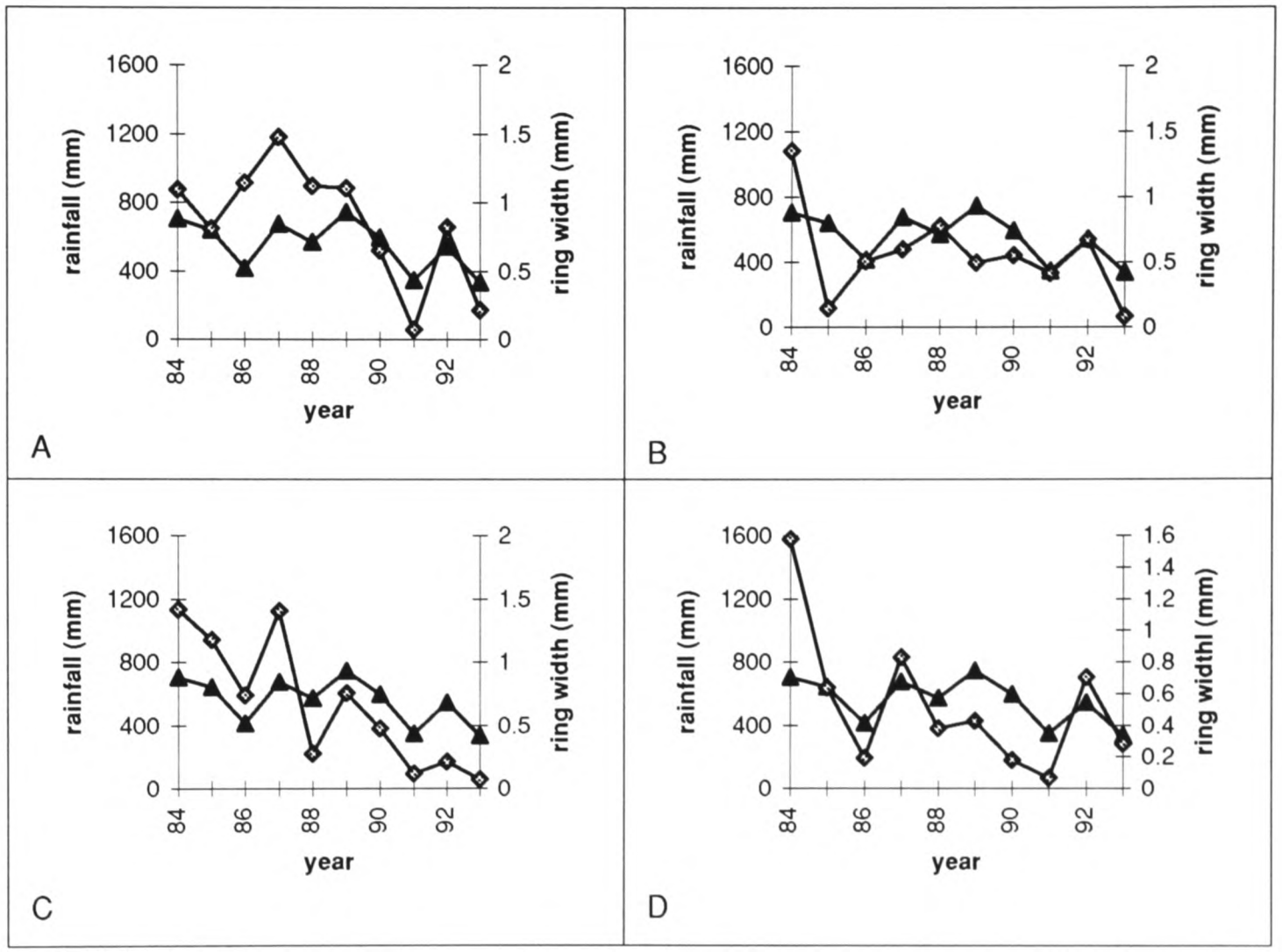


Fig.3.3. A comparison of annual ring width (open diamonds) of four *B. spiciformis* trees with mean annual rainfall (black triangles) at the Kwekwe site, Zimbabwe.

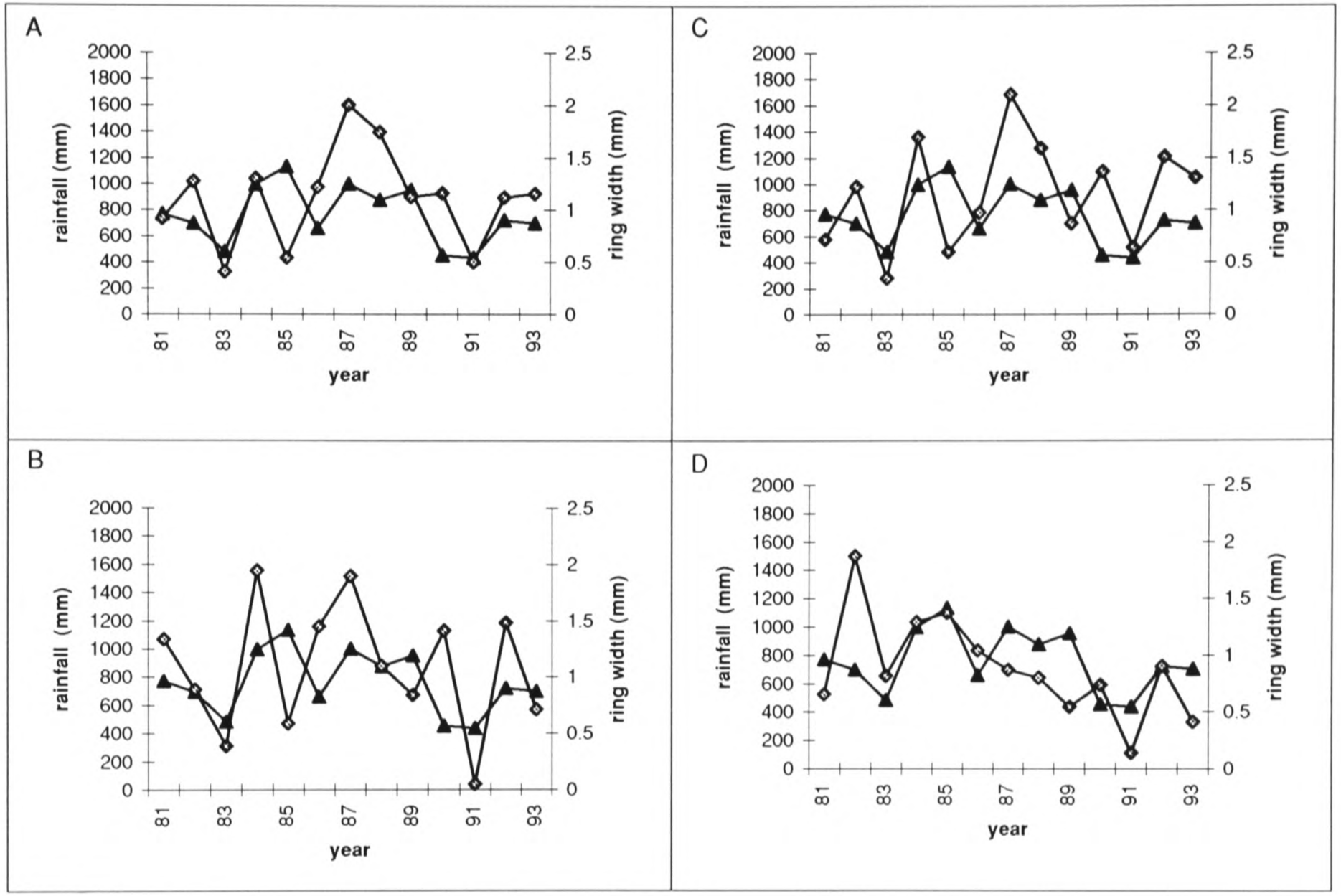
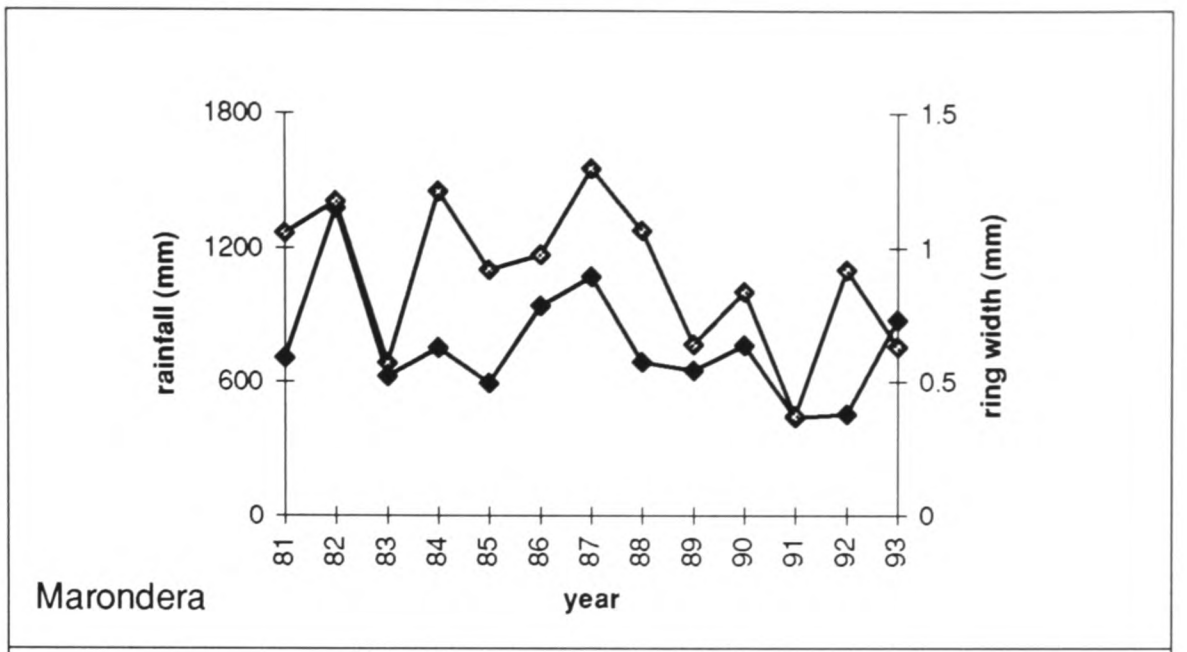


Fig. 3.4 A comparison of annual ring width (open diamonds) and mean annual rainfall (black triangles) for four *B. spiciformis* trees at Marondera, Zimbabwe.



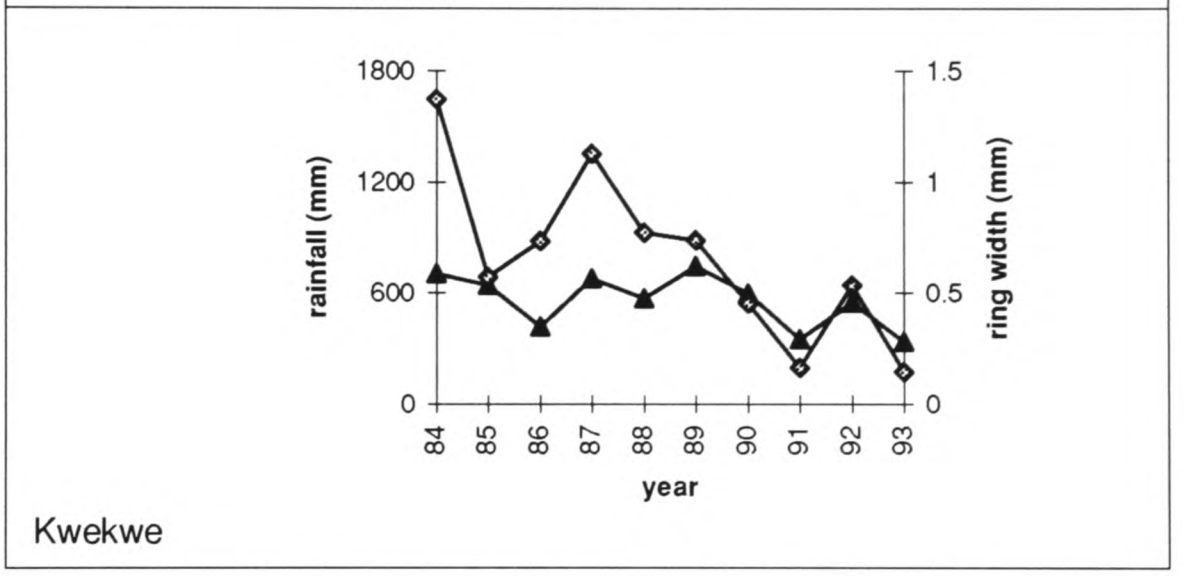


Fig. 3.5. Relationship between mean annual rainfall (black triangles) and mean ring width (open diamonds) for all *B. spiciformis* sample trees at both sites.

for the previous year ($r = 0.43$; $n = 13$; $p < 0.1$). The slightly higher r value obtained for the comparison with seasonal rainfall is to be expected, since the period from October to September corresponds more closely with the growing season than a calendar year. With a longer ring series, it is possible that this correlation would be significant at $p = 0.05$. Mean ring width is not correlated with seasonal rainfall of the same growing season ($r = 0.4$; $n = 13$; $p > 0.1$), or with annual rainfall of the previous year ($r = 0.02$; $n = 13$; $p > 0.1$). Seasonal rainfall figures were not available for Kwekwe. There was a significant correlation between mean ring width and mean annual rainfall of the same year ($r = 0.73$; $n = 13$; $p < 0.05$), but no correlation between ring width and mean annual rainfall of the previous year ($r = -0.01$; $n = 13$; $p > 0.05$). A higher correlation coefficient would be expected from the Kwekwe site, since soil moisture availability is likely to be of greater importance in limiting growth at this more xeric site than it is at Marondera.

3.4.4. *The use of B. spiciformis in dendrochronology*

For tree species to be useful in dendrochronology (the study of past events using tree rings), or, more specifically, dendroclimatology and dendroecology (the reconstruction of past climate and environmental changes from their effect on ring formation), it is essential that trees within the same stand show synchrony of annual ring development (Fritts, 1976). The rings can then be successfully matched in a process known as cross-dating. From this research, *B. spiciformis* is unlikely to be a useful species in dendrochronology because of the high variability in annual ring width within each stand. Even in particularly dry years such as 1991, some trees produced an average width of xylem, due possibly to the ability of the large root system to store water in the dry season. Furthermore, in order to obtain accurate ring sequences, it is necessary to fell the whole tree to take cross-sections of the stem, which limits the usefulness of the species for this type of study.

3.4.5. *Further work*

Now that it is known that these trees produce annual rings, there is much scope for further work in this field. It would be interesting to carry out wider-ranging and more detailed studies using miombo species. Trees growing in more stressful environments where growth is likely to be strongly limited by one factor, such as on sloping ground or at high altitudes, may show patterns of ring development which correlate more closely with environmental variables, and may therefore be more reliable indicators of change. The development of fire histories of woodland

sites would be a useful continuation of the present work. Using longer ring sequences from older trees, an attempt could be made to produce mean annual increment and current annual increment curves for miombo species.

3.5. **Conclusions**

This work has shown that *B. spiciformis* produces annual growth rings, providing a means of estimating the age and annual increment of this species. This should enable woodland managers to predict future yields more accurately and monitor of the effects of management This finding adds to the growing body of knowledge of the structure and functioning of dry miombo woodland. Such understanding is crucial to any successful woodland management plan. Because of the difficulty in measuring the often fine annual rings, and the presence of discontinuous and false rings, estimates from core samples are likely to give slightly inaccurate estimates. Rough estimates may be sufficient for a quick appraisal of miombo woodland for future management, however.

4

The effect of site characteristics on tree growth

4.1. Introduction

The evaluation of variation in forest and woodland productivity is of interest both academically, to determine the relationships between the environment and tree growth, and practically, in order to benefit economically from site differences (Ralston, 1964). Whether trees are managed for timber or small-wood products, the effects of site differences on growth will have important implications for productivity and wood quality.

The vegetation found at any site represents an integration of all the environmental factors, such as rainfall, temperature, evapotranspiration, soil texture, soil depth, soil type and nutrient status, which influence the site, tempered by historical factors such as fires and previous land use (Cole, 1985; Vanclay, 1992; Timberlake *et al.*, 1993). Ralston (1964), in a review of research on site productivity in temperate forestry in the previous two decades, found that the volume of soil readily permeable to tree roots, the effective rooting depth, is one of the most important factors associated with site productivity. This view is supported by that of other researchers working in savanna regions. O'Connor (1992) argues that, at the coarsest level, climate appears to be the overriding determinant of vegetation in southern African savannas, but at the local level, vegetation is strongly influenced by the effects of topography and substrate on soil moisture availability. Frost *et al.* (1986) propose that there are four major determinants of savanna functioning: available moisture and nutrients for plant growth, fire and herbivory. They also maintain that the most important factor is soil moisture availability, since this in turn controls soil nutrient availability, plant production and hence the extent of herbivory and fire. High rainfall and leaching result in low soil fertility, while low rainfall limits soil nutrient uptake (Walter, 1971; Walker, 1985). The point at which precipitation begins to have an over-riding effect occurs between a mean annual rainfall of 600 - 750 mm, depending on soil texture (Walker, 1985).

Rennie (1963) makes the important point that soil analyses to date have been biased towards agricultural use, and that in future, for the purposes of forest site characterisation, more useful attributes such as stoniness and the presence of laterite should be included. In miombo soils, drainage is often impeded by an impervious, sub-surface clay layer (White, 1983), and therefore

the distribution of clay particles within the soil profile could be added to this list.

4.1.1. *Site assessment*

The assessment of site productivity has been, from the outset, of major importance in temperate plantation forestry. Evaluating site potential has usually taken the form of measuring site or stand variables, or both, and using the values obtained as variables in functions and graphs, to express site potential. Such functions and expressions are usually applied to even-aged stands of trees dominated by one species (Hagglund, 1981). Do these methods apply, therefore, to natural stands which are generally made up of trees of different species, genotypes, ages and sizes, which respond differently to environmental influences (Scholes, 1991; Solbrig, 1990), and which are often disturbed by external factors such as fire or humans? Meaningful growth and yield forecasts require some evaluation of site differences, their accuracy depending on whether the vegetation can be accurately classified into homogeneous units. As yet there are few techniques by which site productivity can be accurately predicted in natural forests (Vanclay, 1992). Little of this type of work has been carried out in mimobo. Research in the past has largely been on the herbaceous layer and its importance to herbivores; less work has been done on the tree layer. Height and basal area increments are known to be affected by site differences (Grundy, 1993) but the exact effects have not been detailed.

4.1.2. *Site indices*

The influence of environmental factors on the existence of natural or semi-natural vegetation types at a particular site is well known (Clements, 1916; Makin and Rose Innes, 1987, among others). This knowledge has been used in the agricultural sector in Zimbabwe to indicate the potential of land for agricultural or forestry uses (see Vincent and Thomas, 1961). What has not been documented, however, is whether productivity varies in different climatic and edaphic environments within particular species ranges in miombo.

Because direct observation of productivity requires either destructive methods or longterm observations, indirect methods of site assessment using related attributes such as climate, ground vegetation, soil properties and tree characteristics have been used successfully in temperate forestry for more than half a century (Ralston, 1964). Climatic indices at continental scales have been used to map potential forestry areas, while productivity at smaller scales has been predicted on the basis of the ground vegetation present (Rennie, 1963). Ground vegetation in Zimbabwe, and in savannas in general, is extremely variable, being dependent on factors such as grazing

history, annual rainfall variability and fire (O'Connor, 1992; Frost, pers. comm.[1]), and is therefore not a good indicator of site quality. In Zambia, Lawton (pers. comm.[2]) could find no significant difference in the species composition of herbaceous vegetation on wet miombo sites, while Strang (1965) found no difference in herbaceous species in *Brachystegia* woodland between sites with clay and sandy soils on the highveld of Zimbabwe. Rattray (1960) identified different herbaceous species on clay and sandy sites in Zimbabwe, but the differences in soil type are obvious indicators in themselves. Useful measures of site productivity should be reproducible and consistent over long periods of time, indicative of the site's potential, and not unduly influenced by stand condition or management history (Vanclay, 1992). In this study, climate and soil properties were evaluated as useful variables for the assessment of site potential (measured in terms of tree growth) which might obviate the need for detailed analyses of edaphic and foliar characteristics. Ideally a method is required which provides an estimate of site productivity using data collected during a single visit to the site, without the need for laboratory analyses (Vanclay, 1992).

4.1.3. ***Objectives***

This study had the following objectives:

1. To define an indicator of site productivity, either from stand variables, or from site characteristics.
2. To determine whether the relationships between stem size and total dry woody biomass vary on different soils and under different climatic conditions.
3. To determine whether woody biomass can be estimated from crown diameter.

4.2. **Study sites**

Two main soil types were studied: red clays derived from dolerite and sands derived from granite (Thompson, 1965). The depth of soil to the underlying bedrock varied from less than a metre to more than 30 metres. Nine woodland sites were chosen for this study (Fig. 4.1), each representing a different combination of edaphic and climatic characteristics (Table 4.1). Sites 8 and 9 are two of the Shurugwi sites referred to in Chapter 2.

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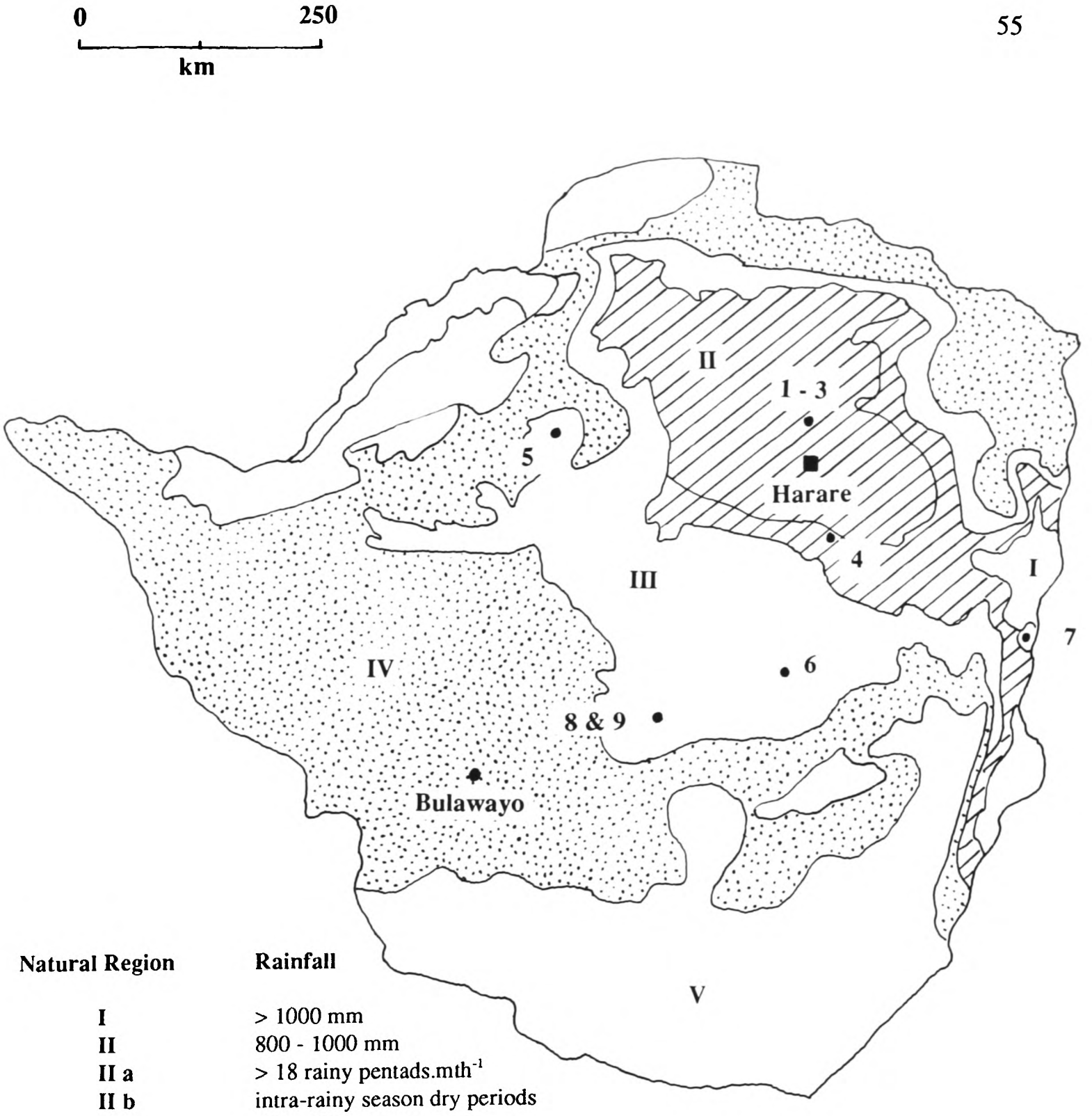
[1] Peter Frost, Dept. BioSciences, University of Zimbabwe; Harare, June 1993.
[2] Ray Lawton, former Forest Ecologist, Northern Rhodesia; Oxford, May 1995.



Natural Region	Rainfall
I	> 1000 mm
II	800 - 1000 mm
II a	> 18 rainy pentads.mth^{-1}
II b	intra-rainy season dry periods
III	650 - 800 mm
IV	450 - 650 mm
V	< 450 mm

Fig. 4.1. Zimbabwe, showing the nine miombo sites used in the assessment of site effects on woody growth. Miombo woodland is found largely in Natural Regions I to III.
Sites: 1 - 3=Mazowe; 4 = Beatrice; 5 = Mafungautsi; 6 = Chatsworth; 7 = Burma Valley; 8 & 9 = Shurugwi.

Table 4.1. Characteristics of the nine study sites, shown as means for all plots at each site. Rainfall figures are all 30 yr means. D = deep (> 3m), M = medium (1 - 3 m), Sh = shallow (< 1m); C = clay, L = loam, S = sand, Si = silt. *% B/J* = % of total basal area of each plot which is made up of *B. spiciformis* and *J. globiflora*; * = mottling in soil profile produced by fluctuating water table.

Site Name	Site No.	Soil Type	% clay content	Rainfall (mm)	Rainfall code	*% B / J*
Mazowe 1	1	MC	40	850	1	99
Mazowe 2	2	DSiC*	45	850	1	83 (B only)
Mazowe 3	3	DSiCL	30	850	1	44
Beatrice	4	MS*	8	740	3	48
Mafungautsi	5	DS	3	819	2	25
Chatsworth	6	DS*	3	791	2	92
Burma Valley	7	DS	4	877	1	14 (J only)
Shurugwi 6	8	ShS	8	766	3	86
Shurugwi 8	9	ShS	8	766	3	64

4.2.1. ***Site choice***

Although *Brachystegia/Julbernardia* woodland is common on the highveld of Zimbabwe, many areas were investigated before suitable sites of mature, relatively undisturbed woodland with a range of size classes were found. Woodland co-dominated by *B. spiciformis* and *J. globiflora* did not exist on shallow clay soils where water was limiting, while in areas prone to slight sub-surface waterlogging, such as sites 2, 4 and 6, *J. globiflora* was absent or restricted to higher ground. At site 7, *B. spiciformis* was found only on the deeper, more fertile soils, and most of them had been cleared for agriculture. There was also considerable within-site variation, with *B. spiciformis* being found more on mid-catena sites, while on the upper catenas where the soil tended to be shallower and drier, *J. globiflora* was more common. This pattern resulted in variable proportions of the two species being found at each of the sites (Table 4.1). The stocking density of the sites was also variable and as a result the area of the circular plots ranged between 0.01 and 0.08 ha. The fire histories of the sites were unknown, but there was no evidence of recent fires. All of the sites were in theory protected, but annual fires are common in indigenous woodland, particularly towards the end of the dry season. Because the work involved destroying trees at each site, finding suitable woodland for each combination of soil and climate posed difficulties. Much of the woodland on the deeper clay soils had been cleared for agriculture in the past, and farmers were reluctant to fell any more large trees. As a result of the limited site availability therefore, each of the nine sites represents a unique combination of edapho-climatic factors.

4.3. **Methods**

The fieldwork at the first seven sites was completed in April 1994. At each site, the trees were stratified into diameter size classes of small (< 10 cm diameter at 30 cm above ground), medium (between 10 and 20 cm) and large (> 20 cm). Crown size (by measuring two crown diameters at right angles to each other) and the height of the trunk to the first branch were recorded. The stem diameter and stem length (as opposed to height) of at least five trees of each category were recorded where possible. The trees were then felled and weighed as described in Chapter 2, to ascertain the total woody biomass per tree. At sites 5, 6 and 7 the fresh biomass was divided into bole and crown before weighing. All trees were measured at 30 cm above ground level. Two samples of wood were taken from each tree for moisture content analysis, weighed immediately in the field to give a fresh mass, and then air-dried. These samples were later oven-dried at 104 °C to a constant mass and reweighed. A randomly located soil pit was dug to determine the soil depth at each site, to a maximum depth of 3 m; deeper soils were considered not to limit tree growth. For the two Shurugwi sites (sites 8 and 9), the biomass equations determined in Chapter 2 were included in the analysis. Crown dimensions and bole lengths were not measured for these two sites.

To obtain information on species distribution and the stocking density of the woodland at each site, two circular sample plots were selected by using randomly selected co-ordinates. The plot diameter was adjusted to include a minimum of 30 trees above 1 m in height. Trees were judged to be inside the plot when the greater part of their basal area fell inside the plot boundary. Those whose basal areas were bisected exactly by the plot boundary were alternately taken as in and out of the plot. The following variables were recorded: number of stems by species, diameter of each stem at 30 cm, stem length (from the apex to the base) and tree height. Tree height was measured using height rods since clinometer measurements were found to be inaccurate, due to the often flat-topped nature of the crown and the subsequent difficulty in seeing the exact height of the top of the tree from the ground.

The herbaceous species composition at each site was recorded using two randomly selected plots 20 m x 20 m marked out on the ground with string. The presence of all herbaceous plants within these plots was noted and those which could not be named in the field were collected for later identification.

4.3.1. ***Statistical analyses***

The moisture content of the fresh wood at each site was determined as described in section 2.3.1. For the biomass estimations, the same procedure was followed as in Chapter 2. To test whether there were significant differences between sites, the equation relating estimated stem volume with dry woody biomass for each site was compared with a similar equation developed for all the other sites combined, using the formula shown in Appendix 1 (Mead and Curnow, 1983). The accuracy of the predictions of the combined models was tested by plotting the observed values against the predicted values obtained using the equations. Soils were analysed following standard procedures (Anderson and Ingram, 1993) for texture and clay content, as well as using a quick field test for colour and texture.[3]

From the stand measurements the following variables were calculated: dominant height (an average of the two tallest trees in the plot), Lorey's height (mean stand height weighted by basal area - $\sum(Ba.H)/\sum Ba$), see Philip, 1983); number of stems per hectare; basal area per hectare; total dry wood biomass per hectare, using the relevant regression equation; estimated dry wood biomass and estimated height of trees with diameters of 25 cm, measured at 30 cm above ground; and the percentage of the plot basal area which was made up of *B. spiciformis* and *J. globiflora.* Each of the stand variables was plotted against each of the environmental variables in turn to give a picture of the trends before the analysis was started. A correlation matrix was used to identify those variables which best correlated with the stand attributes. These selected variables were then used in the multiple regression analyses. Throughout the analyses, tests were performed to ensure normality of data sets and homogeneity of variances. Log_{10} transformations were used to correct for skewed sample distributions and non-homogeneity of variance.

The relationship between the ground flora and the environmental variables at the nine sites was analysed using a method of multivariate direct gradient analysis (Gauch, 1982). In this instance, canonical correlation analysis (Ter Braak, 1986) was chosen. A Monte Carlo permutation test was used to test statistically the effects of particular environmental variables on community composition (Ter Braak, 1987).

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[3] K. Verbeek, Dept. Soil Science, University of Zimbabwe, March 1994.

4.4. **Results**

4.4.1. ***Stand characteristics***

Table 4.2 gives the descriptive statistics for each stand and site. A preliminary investigation of the data showed no obvious trends in the relationships between the environmental variables and the stand variables. Different conclusions about the quality of the site could be drawn from the results, depending on which independent variables were used. This suggests that growth is probably not influenced by any one of the environmental factors in particular, but rather by a combination of some or all of them.

When compared over nine sites, dominant height was found to be significantly different between sites (ANOVA $F = 7.69$; $df = 8, 18$; $p = 0.002$). The Tukey Honestly Significant Different Test (Sokal and Rohlf, 1969) showed that this result is attributable to the fact that the trees at sites 8 and 9 are significantly shorter than those at sites 2, 3, and 5. Lorey's heights are significantly different over the nine sites ($F = 4.31$; $df = 8, 18$; $p = 0.017$), attributable to the trees at sites 8 and 9 being significantly shorter than those at site 1. Biomass per hectare is also significantly different (ANOVA, $F = 16.86$; $df = 8,18$; $p = <0.001$) but was not considered useful in the comparisons of stands with unknown management histories. For trees of > 10 cm in diameter at all sites except 8 and 9, bole length (the length of the trunk to the first branch) was significantly different between sites (ANOVA $F = 6.61$; $df = 6, 100$; $p = 0.000$), with the trees at site 5 (Mafungautsi) having much longer boles than at the other sites.

4.4.2. ***Indicators of site productivity***

A correlation matrix of all the environmental and stand variables is shown in Table 4.3. The stand variables which are most highly correlated with the measured environmental variables (soil depth, clay content, mean annual rainfall and minimum annual temperature), and therefore which are likely to provide good indicators of site quality, are dominant height, dominant $BA.ha^{-1}$, the percentage of *B. spiciformis* and *J. globiflora* per plot, the estimated woody biomass when the diameter is 25 cm, and the estimated height when the diameter is 25 cm. Those describing species composition (dominant basal area per plot and percentage *B. spiciformis* and *J. globiflora*) show a strong correlation with temperature, but a low correlation with the two biomass variables ($Bm.ha^{-1}$ and BmD_{25}), and are therefore unlikely to be good predictors of biomass. There is a high correlation between mean annual rainfall and clay content, due to the difficulty in finding sites

Table 4.2. Descriptive statistics for the nine Zimbabwean miombo woodland sites used to assess site quality. B = *B. spiciformis*, J = *J. globiflora*. BA = basal area, Bm = biomass, D = diameter measured at 30 cm above ground, DH = dominant height, H = total tree height, LH = Lorey's height, % B+J = percentage *B. spiciformis* and *J. globiflora* per plot, Bole = distance from ground to first branch. Soil codes: 1 = shallow (< 1m), 2 = medium (1 - 3 m), 3 = deep (> 3m).

Site	Clay (%)	Rainfall (mm)	Min.temp (° C)	Soil code	Altitude (m)	DH (m)	LH (m)	Stems (ha^{-1})	Dom BA (%)	BA.ha^{-1} (m^2)	Bm.ha^{-1} (kg)	B + J (%)	Bm_{D25} (kg)	H_{25} (m)	Bole (B) (m)	Bole (J) (m)
1	40	915	8.0	2	1304	13.2	12.1	3183	49.8	47.9	206.5	99.5	164	8.7	2.2	1.9
2	45	915	8.0	3	1304	15.9	6.8	1883	82.6	8.44	30.2	82.6	159	8.7	1.7	
2	45	915	8.0	3	1304	12.6	11.2	1234	98.5	11.5	60.8	98.5	159	17.3	1.7	
3	30	915	8.0	3	1304	11.7	9.1	1082	42.0	48.8	101.3	49.4	288	12.0		1.9
3	30	915	8.0	3	1304	15.4	9.5	541	73.5	17.8	137.1	77.5	288	9.4		1.9
8	8	766	7.4	1	1320	7.4	5.7	2067	60.6	9.0	15.8	87.7	157	9.1		
8	8	766	7.4	1	1320	7.2	5.8	2400	51.7	10.8	20.1	81.1	157	11.1		
9	8	766	7.4	1	1320	6.3	4.9	3628	57.8	13.4	21.0	77.6	157	10.6		
9	8	766	7.4	1	1320	8.7	6.7	3636	92.3	12.3	26.9	94.7	157	8.0		
4	8	739	7.9	2	1475	11.4	9.6	1559	90.6	46.2	46.2	90.6	160	11.0	1.4	2.0
4	8	739	7.9	2	1475	11.4	8.3	2014	72.6	47.2	48.2	77.0	160	11.9	1.4	2.0
5	3	819	10.6	3	1282	12.2	8.1	975	21.3	12.1	36.8	35.0	167	11.9	5.7	2.4
5	3	819	10.6	3	1282	14.8	10.0	821	29.5	12.9	48.9	33.1	167	7.6	5.7	2.4
6	3	761	7.2	3	1650	9.8	7.9	4417	91.8	47.8	202.7	91.8	239	8.9	3.0	
6	3	761	7.2	3	1650	9.8	7.9	2663	99.2	29.0	102.3	99.2	239	11.0	3.0	
6	3	761	7.2	3	1650	9.4	8.1	721	92.8	24.1	103.9	93.2	239	8.5		2.0
6	3	761	7.2	3	1650	11.2	9.9	368	86.0	16.6	101.7	86.0	239	8.8		2.0
7	4	877	12.0	3	726	12.2	10.3	341	49.9	114.9	68.8	14.1	260	8.8		1.5

Table 4.3. Correlation matrix showing the relationship between environmental and stand variables at all sites.
MAR = mean annual rainfall, MAT = minimum annual temperature, SD = soil depth, DH = dominant height, LH = Lorey's height, St.ha^{-1} = stems per hectare, BA.ha^{-1} = basal area per hectare, DB.ha^{-1} = basal area per hectare of dominant species, Bm = biomass, % B+J = percentage of *B.spiciformis* and *J. globiflora* per plot, Bm_{D25} = estimated biomass of trees of a diameter of 25 cm, measured at 30cm above ground level. Highest correlations between stand and environmental variables shown in bold.

		ENVIRONMENTAL				STAND							
		% clay	MAR	MAT	SD	DH	LH	St.ha^{-1}	BA.ha^{-1}	DB.ha^{-1}	Bm.ha-^{1}	%B+J	Bm_{D25}
Environmental variables	MAR	0.83											
	MAT	-0.13	0.34										
	SD	0.17	0.43	0.35									
Stand variables	DH	0.54	**0.70**	0.44	**0.69**								
	LH	0.36	0.52	0.36	0.59	0.66							
	St.ha^{-1}	-0.04	-0.32	-0.49	-0.54	-0.50	-0.45						
	BA. ha^{-1}	-0.16	0.12	0.46	0.22	0.10	0.38	-0.10					
	DB.ha^{-1}	0.08	-0.26	**-0.64**	0.06	-0.13	-0.03	0.23	-0.13				
	Bm. ha^{-1}	0.20	-0.27	-0.17	0.44	0.26	0.54	0.17	0.33	0.17			
	% B + J	0.24	-0.26	**-0.90**	-0.31	-0.30	-0.15	0.51	-0.43	0.76	0.23		
	Bm_{D25}	-0.05	0.25	0.05	**0.60**	0.19	0.28	-0.37	0.43	0.09	0.54	-0.22	
	H_{D25}	**0.62**	0.55	0.10	**0.66**	0.69	0.60	-0.22	0.20	0.27	0.38	0.11	0.12

with a high clay content in areas of low rainfall. There were also high correlations between some of the stand variables measured. When choosing variables to include in the subsequent analysis, those which were the least correlated and the simplest to obtain were selected.

Table 4.4. Regression models (mean goodness of fit, expressed as the coefficient of multiple determination, R^2) used to indicate predictors of site productivity. C = $\log_{10}$ % clay, R=$\log_{10}$ mean annual rainfall (mm); SD = soil depth, T = $\log_{10}$ mean annual minimum temperature (°C). DH = dominant height (m), HD_{25} = estimated height (m) when diameter = 25 cm (measured at 30 cm above ground level), Bm = biomass, BmD_{25} = estimated biomass (kg dry weight) when diameter = 25 cm, *% B.sp & J.gl.*= percentage *B.spiciformis* and *J. globiflora* per plot.

Variable	Model	*p*-value	R^2
Dominant height	LogDH = -2.72 + 0.07 SD + 1.15 R + 0.26 T	0.001	0.634
	LogDH = 0.31 + 0.07 SD + 0.003 C + 0.59T	0.001	0.723
HD_{25}	HD_{25} = - 26.1 +0.86 SD + 12.7 R - 4.33 T	0.008	0.460
	HD_{25} = 6.84 + 0.87 SD + 0.04 C - 0.717 T	0.001	0.639
$Bm.ha^{-1}$	$LogBm.ha^{-1}$ = - 0.31 + 0.29 SD + 1.04 R - 1.81 T	0.012	0.433
	$LogBm.ha^{-1}$ = 2.51 + 0.31 SD + 0.003 R - 1.64 T	0.013	0.421
BmD_{25}	$LogBmD_{25}$ = 2.36 + 0.08 SD + 0.01 R - 0.34 T	0.048	0.297
	$LogBmD_{25}$ = 2.46 + 0.09 SD - 0.002 C - 0.41 T	0.026	0.362
% B.sp. & J.gl.	Log%B+J = 3.39 + 0.49 R - 3.28 T	<0.001	0.844
	Log%B+J = 4.64 + 0.002 C - 3.12 T	<0.001	0.868

From the analyses, the height of the woodland and the biomass of individual trees appeared to be primarily influenced by soil depth, which by itself accounted for approximately 50 % of the variation in the data. Mean annual rainfall was also a useful variable, accounting for approximately 40 % of the variation in the measured variables at each site, while mean annual minimum temperature only accounted for 2 %. The analyses using dominant height as the response variable gives models with two of the highest R^2 values. Thus dominant height is likely to be the best variable to use as an indicator of site potential (Table 4.4). The shortest trees were found on shallow sand (sites 8 and 9) and the tallest on deep clay (site 2), with no clear trend in between. Because of the difficulty in locating suitable sites (section 4.2.1.) it was not possible to investigate fully the effect of the interactions between the environmental site variables on the analysis. A preliminary investigation of these interactions, using subsets of the data, showed that

the interaction of mean annual rainfall and soil depth is significant ($F = 4.8$; $df = 1, 15$; $p = 0.049$), while the interaction between % clay content and soil depth is just not significant at $p < 0.05$ ($F = 3.72$; $df = 1, 15$; $p = 0.078$). On sites with deep soils the interaction between rainfall and temperature was not significant ($F = 1.06$; $df = 2, 10$; $p = 0.413$).

The model derived from Vanclay's (1992) 'site form' (the mean height of trees of a diameter of 25 cm (Fig.4.2)) where soil depth, clay content and temperature were entered in the equation also has one of the highest R^2 values. Entering mean annual rainfall instead of clay content gives a much lower value, however. Of the four environmental variables used in the analyses, temperature is the most important influencing species composition (in terms of % *B. spiciformis* and *J. globiflora* per plot), accounting for 88.6% of the variation while soil depth accounts for only 10%.

Species lists of the ground flora found in the sub-plots at each site are shown in Appendix 2.1. The Monte Carlo permutation test, testing the effect of the environmental variables on the herbaceous plant community, gave poor results. The effects of soil depth, clay content, mean annual rainfall and minimum annual temperature on the species composition at each site are not significant ($F = 1.19$; $p = 0.26$).

4.4.3. ***Biomass estimation models***

In a similar result to that shown in Chapter 2, there were good relationships between an estimation of stem volume (using both $\sum(d^2L)$ and the diameter of the largest stem in the coppice stool (D)), and total woody biomass for both species at all sites (Table 4.5). Also, as in Chapter 2, no significant differences were found between the models for the two species at each site, and similarly there was no significant difference between models developed for different sites. This shows that the basic architecture of the trees did not vary greatly with soil depth or moisture availability and thus it was possible to develop a model for both species which can be used nationally to estimate total dry woody biomass of a stem using stem characteristics. The overall equation using $\sum(d^2L)$ compares favourably with an unpublished equation developed by Frost[4] using a smaller data set:

$$\ln Bm = -3.3176 + 1.0564 \ln (D^2H) \quad r^2 = 0.99; \quad n = 10.$$

where Bm = dry woody biomass, D = stem diameter measured at 30 cm and H = total height of tree.

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[4] Peter Frost, Dept. BioSciences, University of Zimbabwe; Harare, December 1994

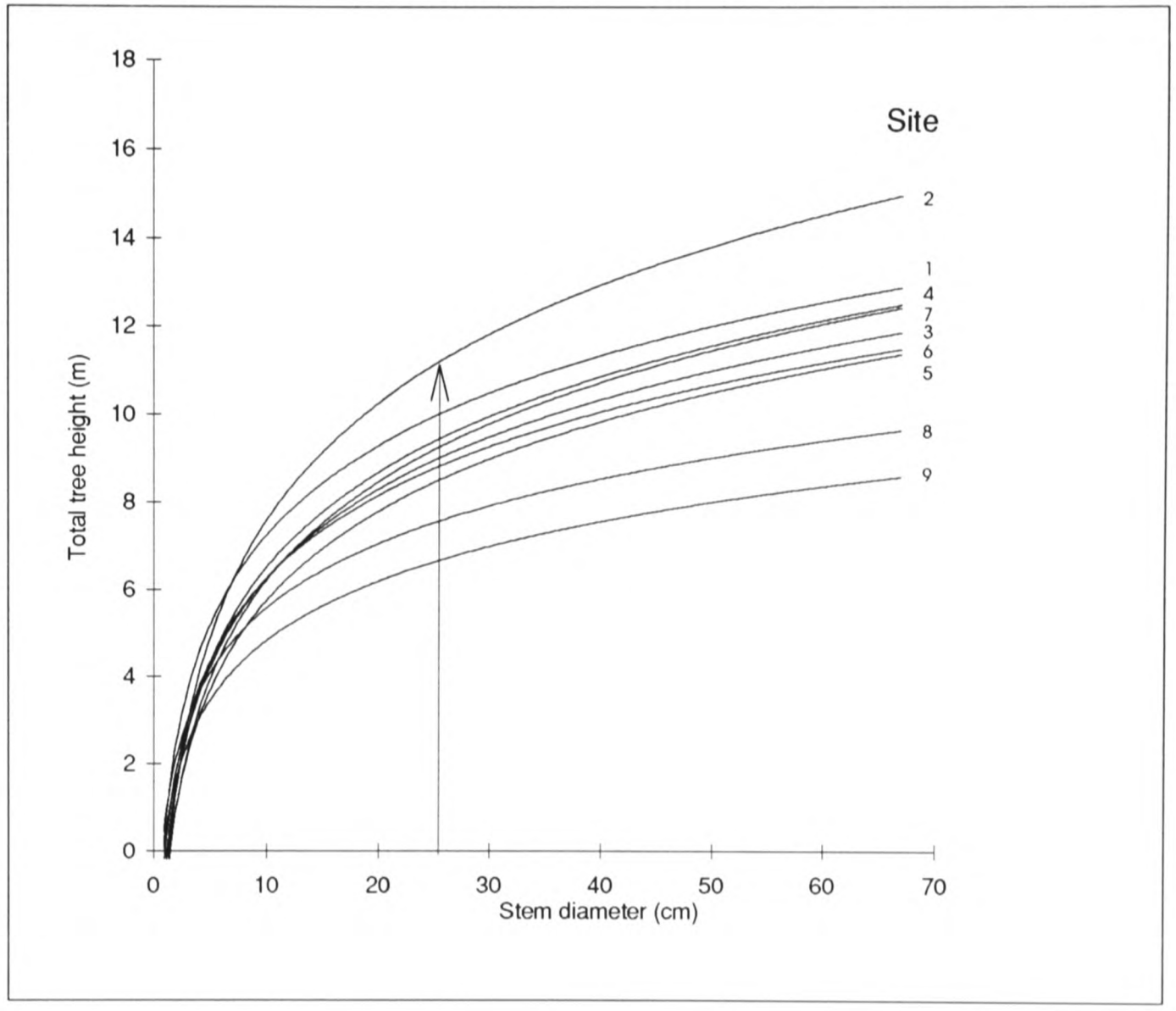

Fig.4.2 Relationship between stem diameter and total tree height in dry miombo woodland. Arrow indicates the estimated height of trees of a diameter of 25 cm.

Table 4.5. Regression models for the prediction of total dry woody biomass (Bm) from estimated volume (sum d^2L) and diameter of the largest stem in the coppice stool (D), for both species at all sites.
B = *B. spiciformis*; J = *J. globiflora*.

1. Single stems using d^2L

Site no.	Site name	Biomass model	r2	n	Species
1	Mazowe 1	$Log_{10}Bm = 2.45 + 0.99 \log_{10} (d^2L)$	98.9	32	B & J
2	Mazowe 2	$Log_{10}Bm = 2.45 + 1.05 \log_{10} (d^2L)$	99.7	21	B only
3	Mazowe 3	$Log_{10}Bm = 2.74 + 1.18 \log_{10} (d^2L)$	98.1	18	J only
4	Beatrice	$Log_{10}Bm = 2.45 + 1.03 \log_{10} (d^2L)$	97.9	36	B & J
5	Mafungautsi	$Log_{10}Bm = 2.47 + 1.04 \log_{10} (d^2L)$	99.2	35	B & J
6	Chatsworth	$Log_{10}Bm = 2.65 + 1.14 \log_{10} (d^2L)$	96.8	36	B & J
7	Burma Valley	$Log_{10}Bm = 2.67 + 1.07 \log_{10} (d^2L)$	98.9	9	J only
8 & 9	Shurugwi	$Log_{10}Bm = 2.44 + 1.03 \log_{10} (d^2L)$	97.7	762	B & J
All sites		**$Log_{10}Bm = 2.49 + 1.05 \log_{10} (d^2L)$**	**97.8**	**949**	**B & J**

2. Coppice stools using sum(d^2L)

Site no.	Site name	Biomass model	r2	n	Species
1	Mazowe 1	$Log_{10}Bm = 2.46 + 0.99 \log_{10}$ sum (d^2L)	98.9	31	B & J
2	Mazowe 2	$Log_{10}Bm = 2.68 + 1.05 \log_{10}$ sum (d^2L)	99.8	15	B only
3	Mazowe 3	$Log_{10}Bm = 2.74 + 1.17 \log_{10}$ sum (d^2L)	98.7	14	J only
4	Beatrice	$Log_{10}Bm = 2.47 + 1.04 \log_{10}$ sum (d^2L)	99.0	29	B & J
5	Mafungautsi	$Log_{10}Bm = 2.47 + 1.03 \log_{10}$ sum (d^2L)	98.9	30	B & J
6	Chatsworth	$Log_{10}Bm = 2.65 + 1.12 \log_{10}$ sum (d^2L)	97.7	30	B & J
7	Burma Valley	$Log_{10}Bm = 2.68 + 1.06 \log_{10}$ sum (d^2L)	99.2	8	J only
8 & 9	Shurugwi	$Log_{10}Bm = 2.46 + 1.04 \log_{10}$ sum (d2L)	97.7	272	B & J
All sites		**$Log_{10}Bm = 2.51 + 1.06 \log_{10}$ sum(d^2L)**	**98.1**	**433**	**B & J**

3. Using D only (diameter of largest stem per coppice stool)

Site no.	Site name	Biomass model	r2	n	Species
1	Mazowe 1	$Log_{10}Bm = 3.78 + 2.51 \log_{10} D$	98.8	31	B & J
2	Mazowe 2	$Log_{10}Bm = 3.94 + 2.72 \log_{10} D$	99.7	15	B only
3	Mazowe 3	$Log_{10}Bm = 4.36 + 3.07 \log_{10} D$	96.8	14	J only
4	Beatrice	$Log10Bm = 3.84 + 2.57 \log_{10} D$	98.1	29	B & J
5	Mafungautsi	$Log_{10}Bm = 4.01 + 2.77 \log_{10} D$	99.2	30	B & J
6	Chatsworth	$Log_{10}Bm = 4.14 + 2.78 \log_{10} D$	95.8	30	B & J
7	Burma Valley	$Log_{10}Bm = 4.22 + 2.84 \log_{10} D$	99.4	8	J only
8 & 9	Shurugwi	$Log_{10}Bm = 3.91 + 2.70 \log_{10} D$	97.4	272	B & J
All sites		**$Log_{10}Bm = 3.97 + 2.73 \log_{10} D$**	**98.3**	**433**	**B & J**

No significant difference between regression slopes and intercepts for each site and the overall model, for single stems, coppice stools and the diameter of the largest stem. $p > 0.05$.

Plotting the observed biomass values obtained in the field against the predicted values obtained from the three equations (using d^2L, $\sum(d^2L)$) and D as the independent variable) shows that the equations give good predictions (Fig. 4.3).

To give a subjective comparison between the biomass equation for each site, the estimated biomass of trees of certain diameters and heights at each site were calculated. These are compared in Fig. 4.4. Trees on sites 1, 2, 4, 5, 8 and 9, although growing in very different conditions, had similar biomass estimates. Three sites gave higher biomass estimates than the others - sites 3, 6 and 7. There is a marked increase in total dry woody biomass relative to stem diameter and length after a diameter of 25 cm. When this exercise was done for each species separately, the *J. globiflora* samples always had a slightly higher biomass than *B. spiciformis*. It should be noted that the equations for sites 3, 8 and 9 were developed from trees below 30 cm in diameter and therefore these relationships may not be valid for the larger trees.

4.4.4. ***Crown dimensions***

Table 4.6 Regression models used to estimate stem diameter and total dry woody biomass from the variables crown diameter and crown area. CD = crown diameter.

Dependent Variable	Independent variable	Model	r^2
Stem diameter (D)	Crown diameter	LogD = -1.55 + 1.06 log(CD)	0.92
Total woody biomass (Bm)	Crown diameter	LogBm = -0.27 + 2.95 log(CD)	0.95

There is a strong relationship between three stem characteristics (stem diameter, $(\text{diameter})^2$ and total dry woody biomass) and crown diameter and area at all sites (Table 4.6). Crown diameters were not significantly different between sites (ANOVA, $F = 1.96$; $p = 0.075$; $df = 6, 150$). At sites 5 and 6 the proportion of the branch biomass to the total woody biomass is significantly different between the two species ($F = 11.72$; $df = 1, 50$; $p = 0.001$), with *J. globiflora* crowns having more biomass than *B. spiciformis*. At sites 5, 6 and 7, there were significant differences between the proportion of branch biomass to the total woody biomass at the three sites ($F = 3.9$; $df = 2, 50$; $p = 0.027$) and between trees of greater or less than 25 cm in diameter ($F = 12.1$; $df = 2, 50$; $p = 0.001$). Because of the lack of *B. spiciformis* at site 7, the interactions between species, site and size class could not be investigated further. Fig.4.5 shows the relative increase in crown biomass as the trunk diameter of the trees increases.

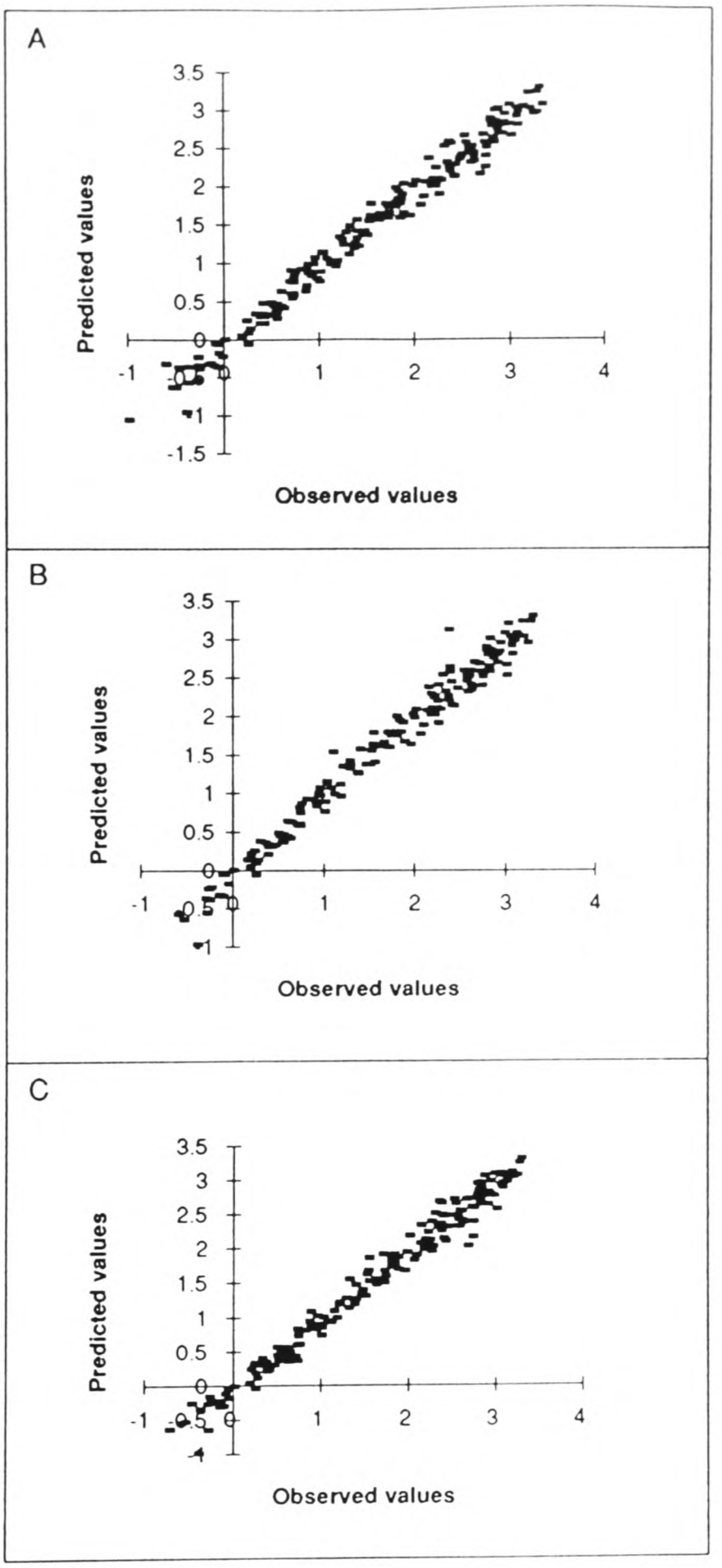

Fig.4.3. Predictive power of the combined biomass equations, showing the observed values of dry woody biomass plotted against predicted values derived from the equations for all sites. Independent variable: A = log (d^2L); B = log ($\sum d^2L$); C = log D.

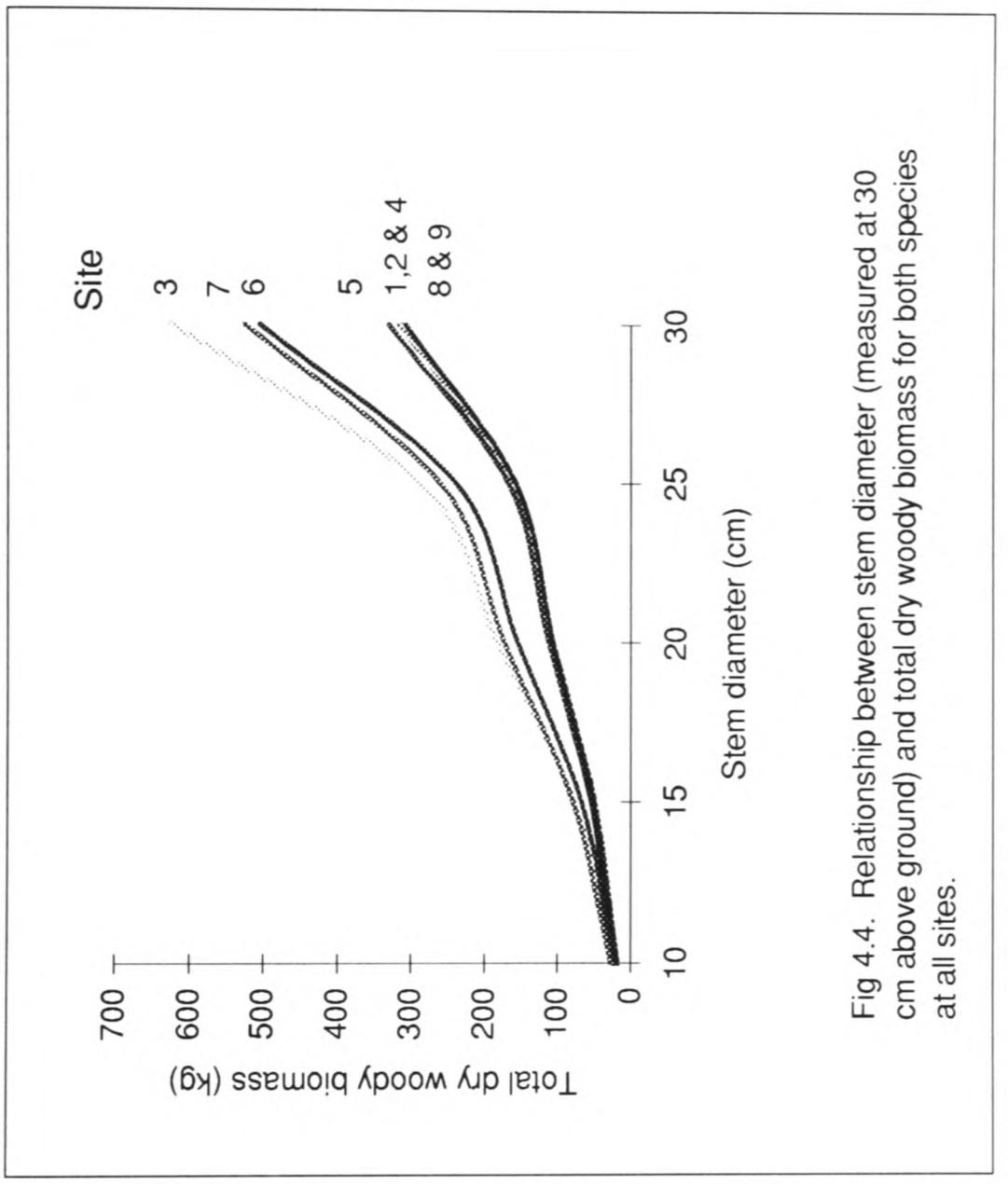

Fig 4.4. Relationship between stem diameter (measured at 30 cm above ground) and total dry woody biomass for both species at all sites.

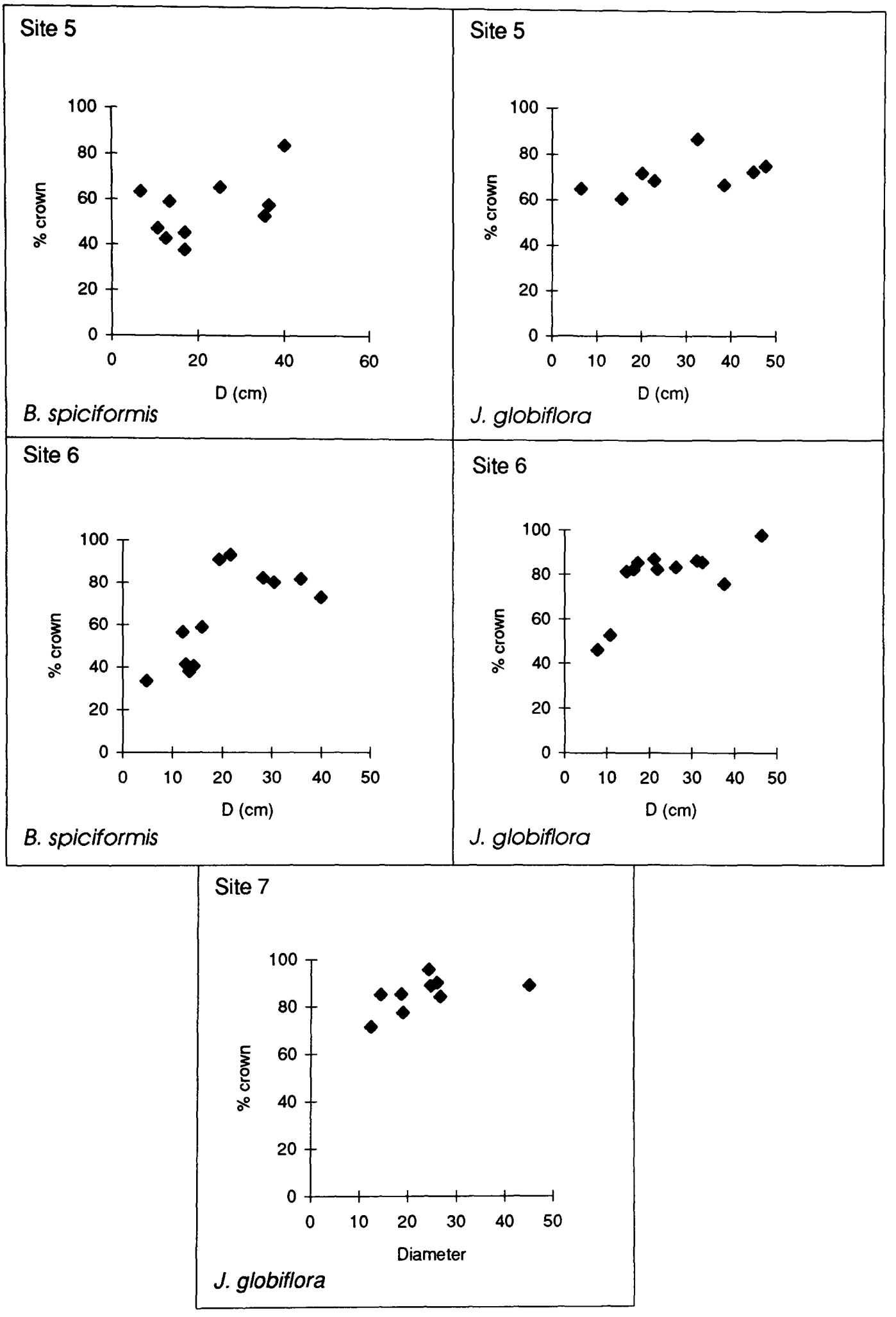

Fig.4.5. Relationship between stem diameter (measured at 30 cm above ground) and the percentage of the total woody biomass made up by the tree crown in dry miombo woodland in Zimbabwe. Sites 5, 6 and 7 only.

4.5. Discussion

4.5.1. *Species composition*

Timberlake *et al.* (1993) document the variations in dominant tree species in the different topo-edaphic zones and climatic regions of Zimbabwe. They found that woodland dominated by *B. spiciformis* and *J. globiflora* is limited to higher altitude sites (> 900 m) in areas which receive a mean annual rainfall of > 750 mm. On very shallow soils, in drier areas, or at higher or lower altitudes, this species combination is replaced by others. *Brachystegia spiciformis* was taken to be an indicator of deeper soils and more mesic conditions. Similar patterns were observed in this work when locating study areas. Although *B. spiciformis* and *J. globiflora* are said to be the dominant tree species of mesic miombo woodland overall in Zimbabwe, on a smaller scale they are not always co-dominant, as the species mix in the sample plots has shown (Table 4.2). This patchiness is possibly due in part to the way in which both *B. spiciformis* and *J. globiflora* regenerate largely from root suckers (Strang, 1965; Grundy *et al.*, 1994), and in part to the site preferences of each species and therefore of their ability to exploit the micro-environmental heterogeneity at each site. Campbell *et al.* (1993b) found similar patchiness in miombo woodland near Harare, with *J. globiflora* being dominant on more xeric sites.

The lack of correlation between the species present in the ground layer and the site variables of soil depth, soil type and mean annual rainfall was to be expected, given the similar findings of Strang (1965), McGregor (1991) and Lawton (pers.comm[5]). The ground flora present at a site would not therefore be a useful indicator of tree growth potential for woodland dominated by *B. spiciformis* and *J. globiflora*, although it may be useful over a wider range of woodland types. Timberlake *et al.* (1993) suggest the possibility of using tree species, rather than ground flora, to demonstrate environmental gradients within savanna woodland in general, and this would be an interesting continuation of the present study. Since the woodland selected for this research was already a sub-type of dry miombo woodland, this technique has less relevance here.

4.5.2. *Dominant height as an indicator of site quality*

Savory (1963) and Philip (1983) both maintain that maximum tree height is an important variable to measure in miombo woodland because it enables a comparison of fertility at different sites. In this work, dominant height has been found to be the best indicator of tree growth because it has the strongest relationship with the environmental site variables measured. Using dominant height

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[5] Ray Lawton, former Forest Ecologist, Northern Rhodesia; Oxford, May 1995.

as an indicator, the best sites for tree growth will have: a) a deep soil; b) either a clay content of 40 - 50 %, or a high mean annual rainfall; and c) mild winters. A comparison of dominant heights shows that sites 7 and 6 are the only two which do not fit these criteria. At site 7 the lower dominant height is probably due to the lack of *B. spiciformis* in the sample, while at site 6 the normal growth of the trees is likely to have been affected by some other, unmeasured factor, since the height/diameter relationship for this site is poorer than on the other sites, particularly in the stand dominated by *J. globiflora*. The slight evidence of waterlogging in the soil, due possibly to impeded subsoil drainage, may also have a stunting effect on the trees. Both species are sensitive to anaerobic root conditions (Savory, 1963; Timberlake, pers. comm.[6]). At site 6 the interfluves form 'islands of refuge' (sensu Walker, 1985) from the anaerobic conditions of the lower catena sites. These ecological 'islands' tend to be almost monospecific, probably derived from one individual, and it would be interesting to compare the genetic nature of the different isolated woodland pockets. Genetic variability between groups of trees at spatially isolated sites could be another factor which causes the differences found in dominant height, but this was beyond the scope of this study. Despite their relatively low dominant heights, sites 6 and 7 are two of the three sites with high biomass potential, which suggests that, in any study of growth potential, more than one indicator of site quality should be investigated.

4.5.3. *Alternative indicator variables*

Using the estimated height of trees with a diameter of 25 cm (or 'site form' after Vanclay (1992)) as an indicator of site quality gave disappointing results. The relationship between stem diameter and estimated total tree height showed differences between sites (Fig.4.2), and unlike Vanclay's (1992) findings, the differences were obvious even in small trees. The regression between site form and the site variables soil depth, clay content and temperature gave as high an R^2 value as that for dominant height, but using site form as a predictor gave a different ranking of the high quality sites compared to that using dominant height or estimated biomass when D = 25 cm. Vanclay (1992) does not mention whether only certain trees, such as the dominant individuals, should be measured. This technique may be more useful in closed forests, where the tree crowns are less spreading than in miombo, but merits further investigation.

4.5.4. *Choice of predictor variables*

Soil depth, % clay content, and mean annual temperature and rainfall figures are normally relatively easily obtained, and dominant height is quickly measured. All these variables fit the

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[6] J. Timberlake, Ecologist, Zimbabwe Forestry Commission, Harare, May 1994.

criteria of useful predictor variables given by Vanclay (1992). Whilst the relationship between stem characteristics and total woody biomass does not change significiantly from site to site, trees do not reach their full potential at some sites, notably those with lower rainfall and poorer, shallow soils such as sites 8 and 9. The trees are smaller than they would be on deeper soils and the poorest sites have few large trees. What is more difficult, however, is to pinpoint which site factor, or combination of factors, is responsible for these differences. This work has shown that soil depth, rainfall, clay content and temperature all affect plant growth, but it has not been possible to describe any clear trends in plant-site relationships.

Frost *et al.* (1986) and Timberlake *et al.* (1993) maintain that the major factor affecting vegetation in Zimbabwe is soil moisture availability, this being a function of rainfall, temperature, topographic position, soil texture and soil depth. A more detailed analysis, using a larger number of sites than was possible in this work, is likely to have demonstrated some of these interactions. A study of the distribution of miombo species within the woodland as a whole in Zimbabwe highlights the effects of site interactions. Timberlake *et al.*, (1993) suggest that *Brachystegia spiciformis* and *J. globiflora* are limited in their westward distribution in Zimbabwe by low soil moisture levels. These two species are not found on the xeric clay-rich soils in drier areas, even though they thrive in such habitats in areas of higher rainfall. As far back as 1963, Rennie recommended rejecting the use of undifferentiated variables such as soil texture and depth in soil-site capacity correlation studies for exactly this reason: that they fail to pinpoint the cause of any differences found, and are merely blurred reflections of aeration, water and nutrient availability, and rooting space. He maintains that they are useful only in that they give broad correlations of tree growth with some easily measured habitat attribute. For the purposes of management for total woody biomass, which is the focus of this study, broad correlations may be all that is required for the purpose.

4.5.5. ***Biomass***

The finding that one biomass estimation model can be used to determine total dry woody biomass from one or two stem measurements will have useful applications for management of miombo woodland, particularly for fuelwood production. All three combined models are very similar to those derived from the Shurugwi site, particularly the model derived from the diameter of the largest stem in the stool (D). This equation, therefore, is likely to be the most useful, although, as pointed out in Chapter 2, the estimates may be slightly higher than they would be using diameter and stem length measurements from the whole stool.

Comparing the estimated biomass of trees of particular diameters at each site (Fig.4.3) suggests that the biomass production increases quite dramatically once trees reach a diameter of 25 cm. This marked difference between sites 3, 6 and 7 and the rest, particularly after a diameter of 25 cm, could be for one or a combination of the following reasons:

i) these three sites have a 'high' potential for biomass production. This differs from an index of potential using tree height as the indicator;

ii) the predominance of *J. globiflora* at sites 3 and 7. This species tends to have a heavier crown than *B. spiciformis*;

iii) the adverse effects of winter frosts on the upward growth of the trees at site 6. The death of the growing shoot is likely to induce side branching, resulting in shorter trees with heavier crowns than those of the same diameter at other sites.

iv) extrapolation outside the original data set at site 3.

The biomass production at each site may also be affected by factors other than the edaphic and climatic characteristics considered. Miombo trees are susceptible to attack by insect pests, for example *Melasoma quadralineata*, a leaf-eating caterpillar which attacks young *B. spiciformis* leaves (Reeler *et al.*, 1991) and an un-named trunk borer. A prolonged and heavy attack by either of these pests may affect tree growth at any site. The link between sporadic defoliation and a possible decrease in biomass production is complex, depending on the timing, duration and extent of defoliation, and needs to be explored. Genetic differences have been mentioned in section 4.5.2.

4.5.6. ***Crown dimensions***

The strong linear relationship between mean crown diameter and total dry woody biomass is of practical value. It indicates that crown measurements from aerial photographs of miombo woodland may be used to estimate biomass, thus avoiding the costly and time consuming effort of field measurements. The method has been applied successfully in *Acacia* woodland in Botswana (T. Tietema, pers. comm.[7]). It was not successful in natural forest in Uganda (Karatunga, pers. comm.[8]), however, possibly because of the difficulty in determining the crown limits in closed forest. Strang (1965) also investigated the relationship between crown and stem measurements in miombo woodland in Zimbabwe, using diameter at breast height and crown diameter. His r^2 values were considerably lower than those found in the present work, however.

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[7] T. Tietema, Dept. Ecology, Free University of Amsterdam, Aug. 1992.
[8] A. Karatunga, Uganda Biomass Assessment Project, Kampala, November 1994.

4.6. **Conclusions**

Soil depth (or effective rooting depth) and its direct relationship with soil moisture availability and drainage appears to be the most important environmental factor affecting tree growth in Zimbabwean miombo. Thus, sites on well-drained deep clay loams are likely to have the greatest potential in terms of biomass production. A more detailed study of nutrient and moisture availability on different soil types would be useful, however. Dominant height appears to be the best morphological variable to measure to estimate site potential, without undertaking detailed studies of soil characteristics. It is quickly measured and shows significant differences between sites. Dominant heights should only be used as a preliminary indicator, however, because the fire and disturbance history of the site may over-ride the natural growth of the woodland. The diverse nature of miombo woodland and the uneven species distribution due to the spatial heterogeneity of the soils also means that any assessment of site quality is likely to be complex. This study focussed on woodland co-dominated by *B. spiciformis* and *J. globiflora*. The relative proportions of the two species present, or their absence, also gives an indication of site quality. *Brachystegia spiciformis* is the more site specific of the two, preferring deeper, more fertile soils, while *J. globiflora* is able to survive better on drier, often shallower sites. Neither survive well on sites with impeded drainage. Over a broader range of miombo woodland, the presence of certain other woody species combinations may also be useful indicators of site potential. The ground flora present at a site was not found to be useful in predicting site potential for tree growth.

One model for the relationship between estimated stem volume and total dry woody biomass can be used to estimate total woody biomass from stem measurements for *B. spiciformis* and *J. globiflora* growing in a wide range of environments in Zimbabwe. The equations derived from $\sum(d^2L)$ and D give similar results, although the latter is likely to give over-estimates of biomass. Given the good relationship between total dry woody biomass and crown measurements, it should be possible to estimate woody biomass from mean crown diameter on aerial photographs. These equations could also be used in conjunction with satellite imagery to provide ground estimates of woody biomass over large areas of miombo woodland.

Despite our incomplete knowledge of the functioning of miombo woodlands, and the limitations posed by this, the conclusions drawn above encompass important factors to be considered in any management plan. For the purposes of managing miombo woodland dominated by *B. spiciformis* and *J. globiflora*, the differences in tree growth between sites due to variations in site conditions appear to be important only on shallow soils and in drier areas. In the small-scale farming areas

of Zimbabwe, these are the very areas in which management is likely to be concentrated, since it is unlikely that the best sites for tree growth, which are also the most productive agricultural land, will be set aside for the management of indigenous woodland. In the forseeable future, indigenous woodland is likely to be restricted to marginal land, which includes water-logged areas and hillslopes with shallow soils.

5

The use of silvicultural techniques to improve regrowth in woodland dominated by *B. spiciformis* and *J. globiflora.*

5.1. Introduction

The essence of coppice woodland management, according to Rackham (1993), is that the regrowth shoots from a cut stump are more useful than the original tree. Coppice management is an ancient practice, common throughout the world since neolithic times when people selected particular sizes of coppice poles for particular purposes, and pollarded stems to produce leaves for their livestock to browse (Rackham, 1993). The survival of areas of woodland depended on the population density in the vicinity, and the value of the wood products to local people. In areas of relatively high population density the woodland became more sparse, but the intensity of management increased so that the woods were still able to supply basic requirements. Woodland was managed on the basis that whenever a tree was felled it would grow again or another would grow in its place (Rackham, 1993).

Until recently in Africa, because of a focus by colonising forces on their own efforts at management and a lack of anthropological data, the management of the indigenous woodlands by local people (e.g. the 'chitemene' shifting cultivation system of Zambia described by Lawton (1982)) has been largely ignored (see McGregor, 1991), or deemed to be 'primitive' or wasteful (see Willan, 1962). A recent review of tree and woodland management in Africa by Shepherd (1992) showed that management increases as the resource decreases, particularly of privately-owned trees. This is true of Zimbabwe. For example, small-scale farmers use the following cutting and conservation techniques to increase the productivity of the indigenous woodland:

i) trees may be pollarded to increase fodder production from the woodland (Scoones, 1990);

ii) trees may be cut close to the ground, leaving a cut edge which will not accumulate rainwater, to encourage vigorous regrowth (Grundy, 1990);

iii) certain indigenous tree species may be conserved for their non-timber products such as fruit and insects; (Campbell, 1988; Grundy, 1990; McGregor, 1991).

iv) over-utilised communal woodland areas may be rehabilitated by prohibiting cutting and grazing until they have recovered (Campbell *et al.*, 1993a).

Some of these practices may have been introduced by colonial extension workers in the past. Planting and intensive management of regrowth in these areas does not necessarily occur in response to wood shortages, except on private land (Matose, 1991; Campbell *et al.*, 1993a).

In the rural economy of Zimbabwe, there is no clear distinction between agricultural land use and forestry (Bradley and McNamara, 1993). Small-scale farmers rely heavily on their cattle as draught animals and as sources of organic fertiliser for crop production (Cousins, 1990). Thus, livestock are a crucial component in the maintenance and functioning of the agricultural system (Bradley and McNamara, 1993). Grazing for livestock comes from several different sources, depending on the season (Scoones, 1990) and in low rainfall areas a lack of grazing is likely to be one of the major constraints to agricultural productivity (Cousins *et al.*, 1988). The communal woodlands provide important browse, allowing farmers to boost the survival of their herds, particularly in the dry season (Scoones, 1990; Bradley and McNamara, 1993). *Brachystegia spiciformis* leaves are normally unpalatable to cattle, but are eaten when they are new or when alternatives are scarce. According to Walker (1980), new leaves have crude protein levels of 18.3 % and old leaves 10.6 %, compared to 'grass' (species unspecified) which has crude protein levels of 3 %. Cultivated land, woodland and cattle are therefore inseparable in small-scale farming systems.

Many miombo trees in southern Africa possess the ability to coppice, thought to be a survival strategy in an environment shaped by fire, herbivory and drought (Robertson, 1984). In sites subjected to frequent fires or heavy browsing, the root/shoot ratio of the woody vegetation is high, giving greater resilience to the woody plants (Rutherford, 1982). Strang (1965), working in areas of *Brachystegia/Julbernardia* woodland in central Zimbabwe which had been cleared and then left to regrow, found that the maximum current annual increment of the woodland occurred when the trees were 15 to 20 years old. Most growth was from coppice shoots or root suckers. The trees would, therefore, lend themselves particularly well to coppice management (Hursh, 1960), where a simple 'coppice-with-standards' system (Rackham, 1993; Bridge *et al.*, 1986), could be used to produce numerous useful products without the cost and effort of planting seedlings (von Maydell, 1986).

Whether the harvesting of these products from the woodland in resettlement areas is sustainable depends on the stocking and growth rate of the woodland, as well as the level of harvesting by local villagers. The average rural household consumes between 5 and 7 t of dry fuelwood per year, and a further 2 t of construction wood (McGregor, 1991; Grundy *et al.*, 1993). Most of the fuelwood is in the form of dead branches or easily-cut small wood, which is cut and carried on foot to the

homestead by women. Construction wood is chosen from stems ranging between 2 and 10 cm in diameter, depending on the end use (Grundy, 1990). Large quantities (as yet unmeasured) of fibre from young stems of *Brachystegia* species are used for all tying purposes. Short coppicing rotations would produce small poles and firewood of manageable size for use under rural cooking grates, as well as suitable young stems for rope production.

In temperate and tropical forestry to date most management regimes have been centred around the production of good quality timber from plantations. In northern Zambia, coppice-with-standards was prescribed as a management system for the miombo woodlands of the Copperbelt in the 1940s and 50s. The emphasis at that time was on the production of saw-logs and smelter poles for the mining industry at a figure of 50 - 100 trees.ha^{-1} (Fanshawe, 1959), even if it was at the expense of the coppice regrowth (Fanshawe, 1956b). The use of silvicultural techniques to improve the growth of species which have no apparent commercial value is a concept which has only recently been introduced in Africa (Leach and Mearns, 1988; O'Keefe and Munslow, 1988). In managing indigenous woodland for total woody biomass, the focus and techniques are different from those of timber production. The aim is to produce as many stems as possible on as short a rotation as possible, but the methods for achieving this are yet to be developed. In the past, forestry extension workers in rural areas in Zimbabwe have encouraged the growth of *Eucalyptus* species from seed to fulfil local wood needs, much of which has been a failure (Grundy, 1990; McGregor, 1991).

Jackson (1989) maintains that only a small increase in the mean annual increment of indigenous woodland would result in substantial biomass increments, because of the large areas they cover. The problem in small-scale farming areas of Zimbabwe is often not one of productivity, but one of access to and local availability of wood (Dewees, 1989). In such cases, far more intensive management of all available wood resources is required. Lowore and Abbot (1995), in a study of different aspects of coppice regrowth in Malawian miombo, have made some useful recommendations for management, based on their findings. They suggest that woodland should be managed under a selective felling regime, to protect the ground from excessive erosion, even though the regrowth is likely to be slightly reduced due to competition from the canopies of uncoppiced trees. They also recommend the 'nicking' of the cut edge of the stump, to induce more coppice shoots, presumably by damaging a larger area of the cambium. These techniques have still to be tested on a broader scale, however.

In the face of an ever-growing need for agricultural land, fodder and wood, can management techniques be used to increase the productivity of the existing indigenous woodland? Reducing the

number of coppice shoots on a cut stump to two or three is commonly used in the production of high quality *Eucalyptus* poles in Zimbabwe (Anon, n.d.). It is also recommended for present-day management of indigenous woodland by Lowore and Abbot (1995), to produce firewood and other small wood products from Malawian miombo. In Shurugwi Communal Area, farmers will harvest one or two stems at a time from a coppice stool, as a conservation measure (McGregor, 1991), and in addition will practice coppice reduction on trees growing on the contour ridges in their fields in an attempt to improve the growth of the remaining stems (Matose, 1991). Small-scale farmers in the south of the country use this technique in conjunction with branch pruning to encourage the upward growth of *Acacia* species in deforested areas (pers. obs.). Microcatchments for rainwater harvesting (Fig. 5.1a), where a bund is constructed to cause temporary ponding of rainfall runoff and improve water availability to the roots of planted trees, have been used successfully in dry and degraded areas in Africa in the past (Rocheleau *et al.*, 1988), while water-harvesting bunds constructed along contour lines have been effective in natural *Acacia* woodland on shallow, fertile soils in semi-arid areas of Zimbabwe (pers.obs).

To date there is little information available on the growth rates of non-commercial indigenous trees under different management regimes in southern Africa (Grundy, 1990), or potential silvicultural systems for the enhanced production of non-timber products. The effectiveness of both coppice reduction and water harvesting in miombo woodland has not been investigated before. Similarly, the effect of browsing by livestock on the productivity of the woodland, particularly at the end of the dry season when the trees produce their annual flush, has also not yet been documented. In this chapter, the results of several experiments in woodland management are described, and their implications for management discussed.

5.1.1. *Objectives*

This chapter has the following three objectives, aimed at addressing some of the above issues.

1. To investigate the annual wood biomass production of the two species in regenerating woodland.

2. To investigate the possibility of increasing the annual wood yield of regenerating trees by coppicing, coppice reduction, water-harvesting and protection from disturbance by humans and livestock.

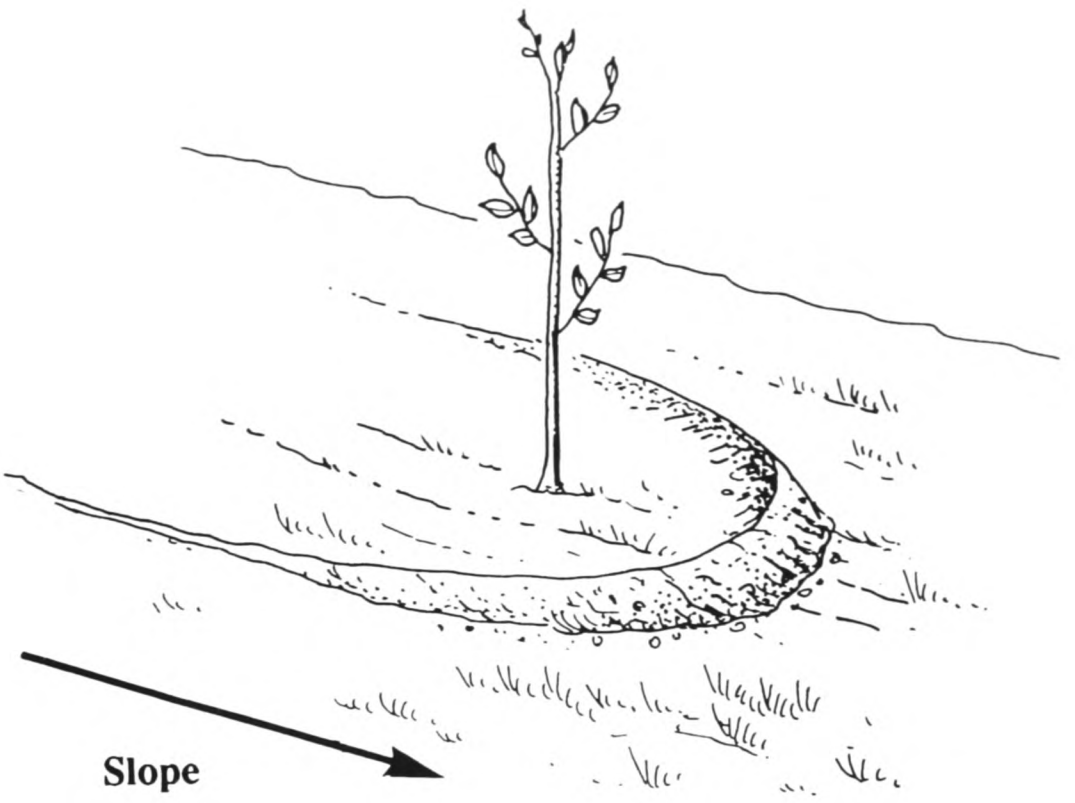

Fig. 5.1a. A water catchment. The semi-circle is marked out using a spirit level, so that the ends point uphill. Soil is then removed from inside the semi-circle and piled up in a bund as shown. In these experiments, the distance from the top of the semi-circle was 2 m.

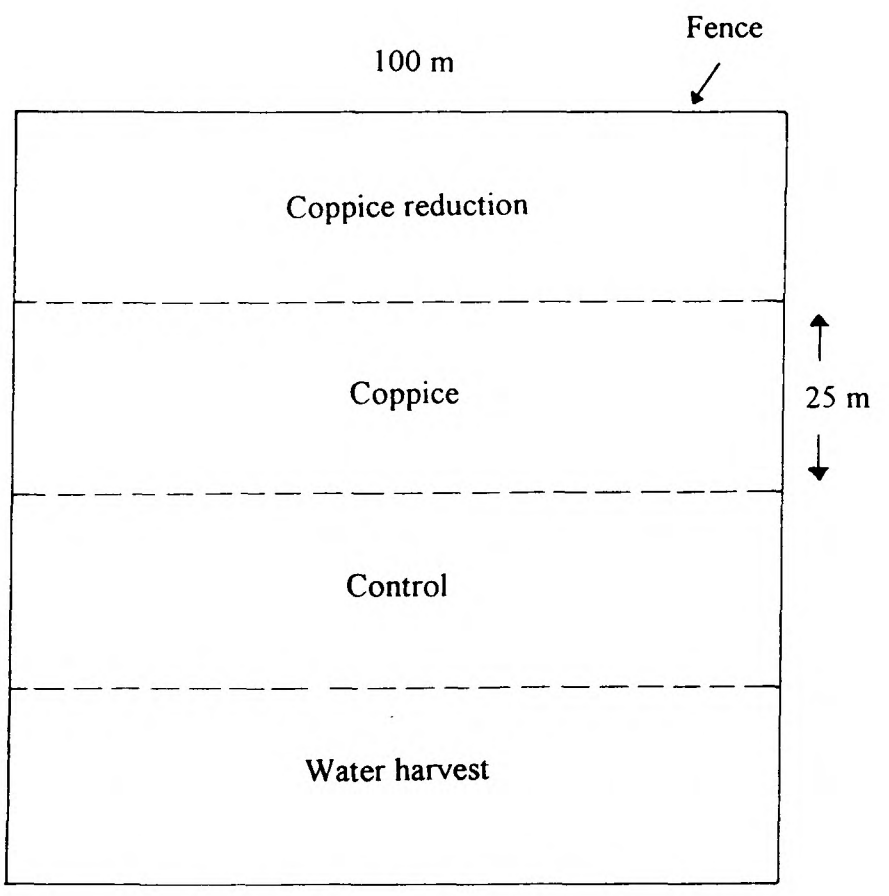

Fig. 5.1b. An example of the protected experimental plots. The water harvest plot was placed in the down-slope position, while the others were randomly located. The unprotected plots were situated outside but adjacent to the fence. There was a gentle slope at all sites.

3. To determine whether coppicing ability of these two species is correlated with trunk size and bark thickness, and therefore with tree age.

5.2. **Study Area**

The growth and management experiments were carried out in Tokwe III Resettlement Area, in Shurugwi District in Zimbabwe. Five sites were chosen in woodland dominated by *B. spiciformis* and *J. globiflora*, these being the same as those used in the biomass estimation exercise. The sites have been described in detail in Chapter 2. Site numbers relate to the villages adjacent to each site.

The five one-hectare sites were fenced in 1991 to prevent unplanned disturbance from humans and livestock. Replicates of four experimental treatments were applied to the five sites. In addition, two further treatments outside the fence, but adjacent to it, were introduced at four sites, there not being a sufficient amount of homogeneous woodland outside the fenced area at site 2. All plots measured 0.25 ha. The treatments were laid out across the slope in order to minimise the site variation within the plots (Fig. 5.1b).

5.3. **Statistical Analysis**

The research was divided into three sections:

i) annual increase in biomass (control and coppice treatments);

ii) management techniques to increase wood yield; and

iii) shoot production after felling.

For each treatment, the dry woody biomass increase was estimated using the formulae for moisture content and biomass developed in Chapter 2.

Because of the patchy spatial distribution of the trees, as well as wood harvesting which had taken place since the area was resettled, the woodland in each plot had a very uneven size-class distribution with a high proportion of small trees and few medium-sized or large ones. This resulted in unequal numbers of trees for analysis. The numbers of trees per plot were too unequal

to use a standard method which achieves balance by estimating mean values, so other solutions had to be sought. Because ANOVAs using unequal sample numbers have little protection against violations of assumptions, particularly heterogeneity of variance (which data transformation is usually not successful in stabilising (Milligan *et al.*, 1987)), different analyses of the same data can lead to inconsistent results which may be entirely due to the unequal sample numbers in each plot/species/treatment/size class combination (or 'cell' in the analysis). Where there is no option but to use unequal data sets, the results should be supported by other evidence (Milligan *et al.*, 1987). With this in mind, for each experiment, using analysis of variance, an unbalanced analysis was compared with a balanced one which was contrived by sampling from the data. Sampling was random in the coppice/coppice reduction experiment and for shoot production, and systematic in the others (by taking the maximum, minimum and median biomass value for each cell) since the number of trees in these experiments did not allow random sampling. Where heterogeneity was a problem in the unbalanced analyses, rank transformations as suggested by Conover and Iman (1981) were tried. The two analyses for each experiment were then interpreted using descriptive statistics with scattergrams. The final results reported are those supported by several strands of evidence. The F values and significance for each analysis are given in an ANOVA table in appendix 3.1, except where shown in the text.

5.4. **Annual biomass production**

5.4.1. ***Protected control vs protected coppice***

5.4.1.1. *Methods*

In July 1991 the trees within the coppice plot were divided into three categories based on diameter measured at 30 cm from the ground, as part of the biomass estimation exercise (Chapter 2). For the purposes of the present experiment, the two larger categories were pooled, so that the trees were divided into two categories for analysis, small (1-6.9 cm) and large (> 7 cm). The trees in the control plot were divided accordingly. At the outset of the experiment, all the trees in the control plot at site 2 were measured. This being too time consuming, the numbers in the other control and

coppice plot were reduced to 21 randomly selected trees of each of the two species. This accounts for the wide range in the numbers of trees measured within the five plots. Between seven and fifty-nine trees from each category were marked and measured. The number of stems.ha^{-1} was calculated from randomly chosen circular plots at each site in the same manner as in Chapter 4.

In the control plots, the following measurements were taken:

1. number of stems;
2. diameter at 30 cm above ground level; and
3. length of largest stem, measured from apex to base.

At the end of the growing seasons in 1992, 1993 and 1994 the same trees were relocated and remeasured.

In the coppice plots, the sample trees were randomly selected from the stumps remaining from the biomass estimation exercise. At least 21 trees were marked and measured in 1991, remeasured at the end of the 1992 growing season, and each consecutive year for three growing seasons. The following measurements were taken:

1. number of coppice shoots;
2. diameter of largest shoot at 30 cm from its base;
3. length of the largest shoot, measured from base to tip.

Both these two species are known to produce numerous small coppice shoots after felling, many of which die before the end of the first growing season. Therefore only the largest shoot of each stool was measured, to give a meaningful indication of the growth of the whole plant.

5.4.1.2. *Results*

The annual growth of the trees in the control and coppice plots was compared using the woody biomass production of the largest stem as an indicator (Table 5.1).

Table 5.1. Results of balanced and unbalanced analyses of variance of mean dry woody biomass of the largest shoot in the control treatment, compared with that of the coppice treatment, showing the significant results, and the insignificant effect of site and species.

	Analysis using balanced data set			Analysis using unbalanced data set		
Variable	F	df	p	F	df	p
Site (S)	0.44	4, 119	0.782	2.16	4, 430	0.073
Species	0.14	1, 119	0.711	1.63	1, 430	0.203
Treatment	16.49	1, 119	<0.001	180.97	1, 430	<0.001
Size	14.52	1, 119	0.001	173.60	1, 430	<0.001
S x Sp	0.61	4, 119	0.665	3.77	1, 430	0.005
T x S	8.61	1, 119	0.004	18.57	1, 430	<0.001

In this analysis, neither site nor species differences had significant effects on the growth of the sample trees in the coppice and control plots. Over the three years, the trees in the control plot produced significantly more woody biomass than the coppice shoots (Fig. 5.2.). Larger trees produced significantly more biomass, approximately three times as much as small trees. The interactions of site and treatment were also significant.

The growth of the control trees

In the control plots at the five sites, the trees grew slowly and extremely variably, both within and between sites. There was no significant difference between sites or species ($F = 1.19$; $df = 4, 217$; $p = 0.315$ and $F = 0.22$; $df = 1, 217$; $p = 0.64$ respectively). The growth of the two species, calculated as a relative diameter increment to allow the comparison of a wide variation of tree sizes (Hunt, 1990), is shown in Table 5.2. For all sites and both species, the relative mean annual diameter increment was 0.27 $cm.cm^{-1}.yr^{-1}$. The estimated mean annual increment of dry wood biomass per stool for both species and size classes was 1.4 kg.yr-1 (+/- 0.2). Trees of < 7cm in diameter, as expected, grew significantly less than larger trees ($F = 162.2$; df 1, 217; $p < 0.001$). For coppice stools where the diameter of the largest stem was > 7 cm, the estimated mean increment was 3.6 $kg.yr^{-1}$ (+/- 0.5), while for stools with a largest stem of < 7 cm in diameter, it was 0.4 $kg.yr^{-1}$ (+/- 0.04). Using these figures and the average number of 3284 $stems.ha^{-1}$ from all sites, an

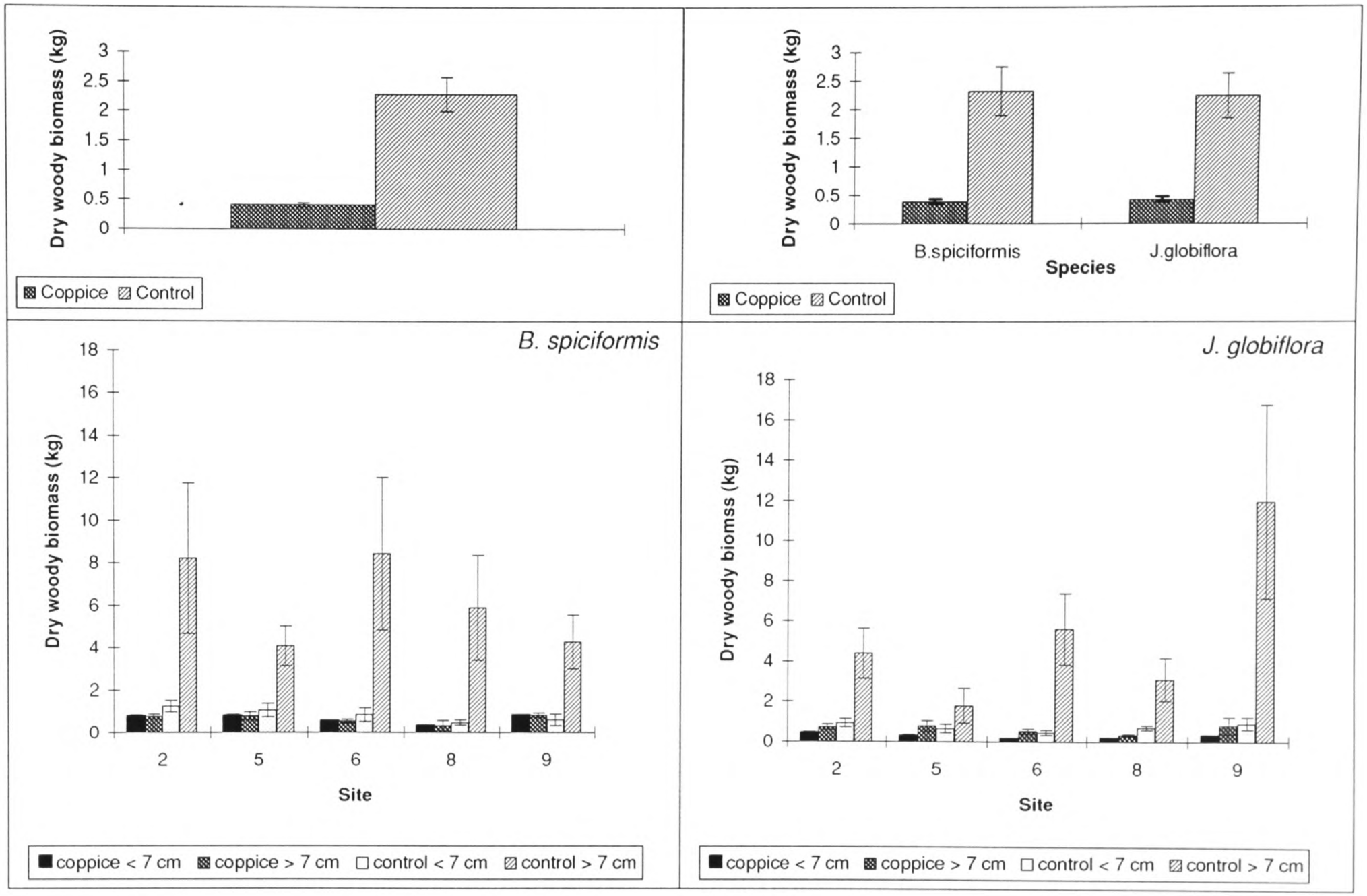

Fig. 5.2. A comparison of woody biomass production in the coppice and control treatments, using the mean annual woody biomass increase of the largest stem in the stool as an indication of growth.

approximate mean annual wood increment for this woodland of 3 $t.ha^{-1}.yr^{-1}$ (but possibly ranging between 1 and 5 $t.ha^{-1}.yr^{-1}$) can be calculated.

Table 5.2. Mean annual relative diameter increment (I) per stem of control trees at all sites ($I = \log((D_{94} - D_{91})/3)$), where D_{91} and D_{94} are the diameters of the largest stem of the stool measured in 1991 and 1994 respectively.

	Mean annual relative increment ($cm.cm^{-1}.yr^{-1}$) (+/- SE)					
Site	n	> 7cm diameter	n	< 7cm diameter	n	Mean
2	11	0.35 +/- 0.1	60	0.28 +/- 0.2	71	0.29 +/- 0.2
5	11	0.32 +/- 0.1	26	0.23 +/- 0.1	37	0.26 +/- 0.1
6	20	0.30 +/- 0.1	16	0.26 +/- 0.1	36	0.27 +/- 0.1
8	16	0.28 +/- 0.1	25	0.23 +/- 0.2	41	0.27 +/- 0.1
9	8	0.31 +/- 0.1	25	0.25 +/- 0.1	33	0.25 +/- 0.1
Mean	66	0.31 +/- 0.04	152	0.25 +/- 0.02	218	0.27 +/- 0.01

Coppice regrowth

Of the coppice trees, almost all of the cut stumps coppiced vigorously in the first year. The amounts of dry woody biomass produced by the largest stem in the coppice stool (which made up approximately a third to a half of the biomass of the stool) are shown in Table 5.3. The regenerating stems of both species, at all sites, grew to a mean height of 2.1 m +/- 0.7 (0.7 $m.yr.^{-1}$ +/- 0.2).

Table 5.3. Mean annual dry woody biomass increment of the largest coppice shoot of both species at all sites ($kg.yr^{-1}$).

		Stump diameter		
	n	< 7 cm (SE)	> 7 cm (SE)	Mean (SE)
		n = 30	n = 30	n = 60
B.spiciformis	60	0.22 (.05)	0.52 (.08)	0.37 (.07)
J.globiflora	60	0.25 (.04)	0.54 (.01)	0.44 (.08)

5.4.1.3. *Discussion*

From a comparison of the mean dry woody biomass produced by the largest stem in the coppice stool in the first three years of coppice regrowth, these results show that to coppice the trees does not increase the annual woody biomass production compared to uncut trees. However, in management of the indigenous woodland in communal and resettlement farming areas, the issue of whether to coppice or not is unimportant since the trees are felled in any case for poles and firewood. The important concern is whether or not the regrowth after harvesting can be managed to better effect. Local communities use small wood for poles, firewood and other household utensils (Grundy, 1990; Grundy *et al.*, 1993), which coppice management on short rotations could provide.

The growth of the control trees was slow and very variable in the three years under study. Because two out of the three experimental years were drought years, it is not clear whether this growth rate is typical. Drought is a factor which must be included in any assessment of tree growth in Zimbabwe's dry miombo woodland, particularly towards the south of the country where low rainfall is a common, though not regular, occurrence. Growth was also very variable, both between and within sites, probably caused by differences in local rooting depth, soil fertility and soil moisture availability. Variations in tree growth due to edaphic factors have been discussed in Chapter 4.

The estimated mean woody biomass production of 3 $t.ha^{-1}$ for this woodland falls within the limits of other published estimates for miombo productivity. Because the growth in the control plots was so variable, and in addition this figure was estimated using a biomass equation developed from measurements of the diameter of the largest stem of each coppice stool (see Chapter 2), it is only a very approximate figure and is likely to be an overestimate. Wormald (1984) gives estimates of between 1 m^3 for dry to 3 m^3 for wet miombo. Lowore and Abbot (1995) give a figure of approximately 2.2 $t.ha^{-1}.yr^{-1}$ for 33 year-old coppice in Malawi. In the past, a figure of approximately 0.75 $t.ha^{-1}.yr^{-1}$ (the approximate equivalent of 1 $m^3.ha^{-1}.yr^{-1}$) has been quoted for Zimbabwe (BI, 1984), which may have included the scrub miombo found in many communal farming areas. The important point to note here, however, is the extreme variability of the results.

5.5. Management techniques for possible increased wood yield

5.5.1. *Protected coppice reduction*

5.5.1.1. *Methods*

At each site, as for the coppice plot, 21 randomly selected stems of varying sizes, which had been cut in 1991 for the biomass estimation experiment (Chapter 2), were used for this experiment. The trees had been divided into three classes originally, but for this analysis, the large and medium trees were combined, giving two size classes (> 7 and < 7 cm). There were at least seven trees in each class. In 1991 stem diameters were measured at 30 cm above ground level. In 1992 and after each growing season for three seasons, the following measurements were taken:

a. Numbers of new shoots per stem;

b. Diameter of largest new shoot, measured at 30 cm from its base;

c. Length of largest new shoot, from base to tip.

At the end of each growing season, the number of new shoots was reduced to two per cut stem (Fig. 5.3).

5.5.1.2. *Results*

As in the coppice plots, the regrowth in the coppice reduction plots was vigorous after felling, and throughout the duration of the experiment. Coppice reduction after the first year resulted in the production of numerous additional small coppice shoots in the second and third growing seasons. The growth of the coppice stools for both species and treatments, estimated as kilograms of dry woody biomass of the largest stem produced over three years, is shown in Fig. 5.4. An initial analysis using site as a blocking factor showed that, in a comparison of these two treatments, site variations significantly affected the biomass production of the largest stem ($F = 3.74$; $df = 4, 239$; $p = 0.006$). A second analysis, where the variables site, treatment, species, and size were entered together, showed no significant effect of treatment. Thus reducing the number of stems per coppice stool did not significantly increase the biomass of the remaining stems (Table 5.4). There were,

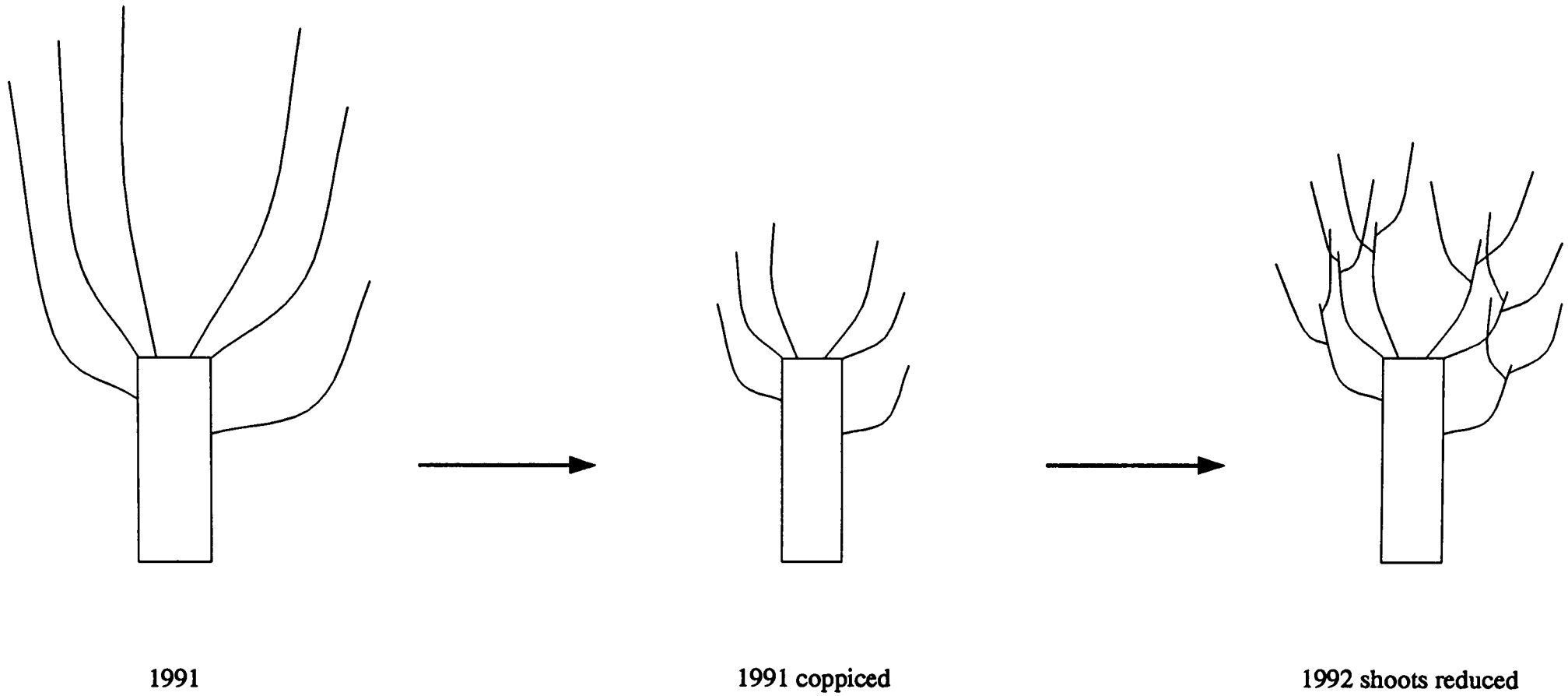

Fig. 5.3. Schematic diagram to illustrate the coppice reduction process. After felling in 1991, each cut stump produced numerous coppice shoots. In 1992, the number of shoots per cut stem was reduced to two.

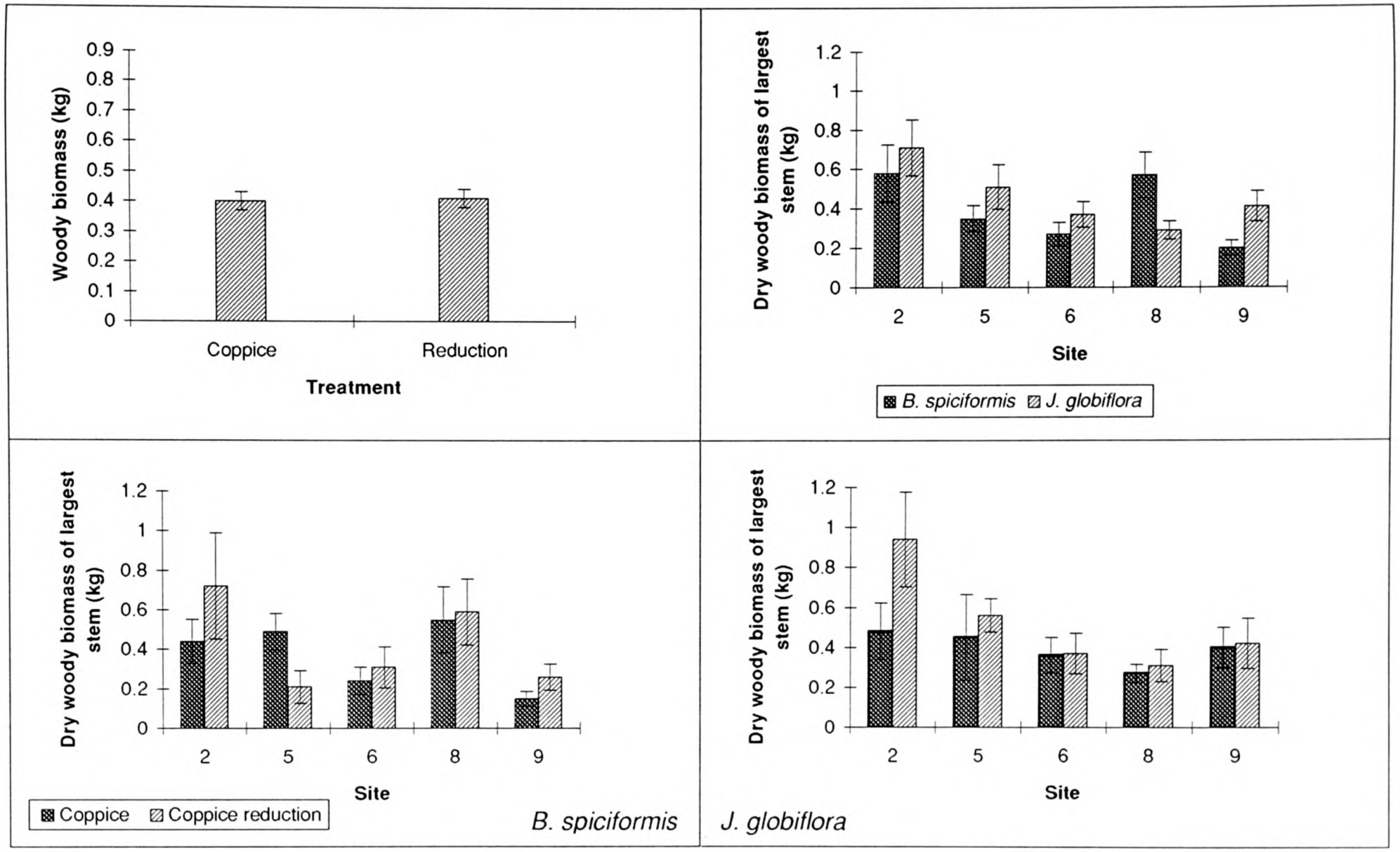

Fig. 5.4. Increase in dry woody biomass of the largest stem of the coppice shoot, comparing coppice and coppice reduction treatments. A = treatment differences; B = species differences; C & D = treatment differences for each species.

however, significant effects of site, species and stump diameter. The productivity of the two species significantly depended on site (Fig. 5.4b), with *J. globiflora* producing more biomass on all sites except 8. There were also significantly different species responses in the two treatments on the five sites. The best regrowth was from *J. globiflora* at site 2 in the coppice reduction plot, while the poorest was from *B. spiciformis* in the coppice plot at site 9. At the other sites, regrowth was very variable with no obvious pattern. Coppice reduction of *B. spiciformis* at site 5 produced a marked decrease in biomass. Figures 5.4c and 5.4d show these interactions.

Table 5.4 Significant results of analysis of variance of mean dry woody biomass of the largest stem of coppice stools in the protected coppice treatment, compared with those of the coppice reduction treatment. T = treatment.

	Analysis using balanced data set			Analysis using unbalanced data set		
Variable	F	df	p	F	df	p
Site (S)	4.08	4, 239	0.003	7.95	4, 419	<0.001
Stump diam. (St)	66.00	1, 239	<0.001	140.91	1, 419	<0.001
Species (Sp)	4.73	1, 239	0.031	8.37	1, 419	0.004
S x T	1.28	4, 239	0.281	2.49	4, 419	0.043
S x Sp	2.54	4, 239	0.041	5.33	4, 419	<0.001
S x T x Sp	4.36	4, 239	0.002	4.13	4, 419	0.003

5.5.1.3. *Discussion*

Coppice reduction

Reducing the number of coppice shoots in a stool did not increase the growth of the remaining stems in this particular experiment. A similar result was found in a year-long study of the regrowth of these two species after felling (Grundy, 1990). In that study, as in this, the biomass produced by the regenerating coppice stool was not a function of species, but was significantly affected by site variation and stump diameter. Possible reasons for the results obtained in this experiment are:

i) the short experimental time: three years is a relatively short time to monitor tree growth;

ii) the numerous stems (sometimes between five and ten) on the original coppice stool before felling (Fig. 5.3). In the coppice reduction exercise, two shoots per cut stem were left to grow. The resulting multi-stemmed individual may therefore not have been sufficiently different from the control multi-stemmed individuals to have shown a significant difference in growth due to the reduction treatment.

iii) detrimental changes in photosynthetic area. The numbers of stems may have been reduced too early, before a large enough photosynthetic area had been established, thus adversely affecting the ability of the trees to regrow. Alternatively, the stems remaining after reduction may not have been able to support a large enough photosynthetic area to allow an increase in growth. The plants may have responded to coppice reduction by producing numerous additional small stems rather than increasing the girth of those already there, thus maximising the leaf area with the minimum investment in structural tissue. Measuring the girth of the largest stem would not take this into account; and

v) the variability of the age and size of the original root stock, and therefore of the plant's coppicing ability;

Since the results from this work are so variable, it is likely that a number of the above factors have had an effect on the experimental trees.

Species differences

When the coppice regrowth of trees in the coppice and coppice reduction plots was assessed, in general *J. globiflora* produced more woody biomass than *B. spiciformis*. A comparison of the growth of older trees in the control plots, however, showed the opposite. Because the study period included two drought years, it is difficult to distinguish whether the differences were due to decreased rainfall (which may have favoured the slightly more xeric-adapted *J. globiflora*) or to differing growth strategies. *Julbernardia globiflora* may simply have a higher initial current annual increment than *B. spiciformis*. Such a difference in growth pattern could explain the postulated differing successional positions of the two species - *J. globiflora* is thought to be an early-successional species in secondary woodland, while *B. spiciformis* is thought to be a late successional species (Frost, pers.comm.; Timberlake, pers. comm.[1]). *Brachystegia spiciformis* appears to regenerate better in under-canopy environments (Grundy *et al.*, 1994) and may therefore benefit from the more favourable environment for seedling growth induced by the presence of already established trees (Lawton, 1982).

5.5.2. ***Unprotected coppice***

This experiment was set up to test the effect of excluding unplanned human and animal disturbance from the woodland by fencing the regrowth of *B. spiciformis* and *J. globiflora* after felling.

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[1] Peter Frost, Department of BioSciences, University of Zimbabwe; Harare, June 1991.
Jonathan Timberlake, Ecologist, Zimbabwe Forestry Commission; Harare, May 1994.

5.5.2.1. *Methods*

In 1991, in each of the four unfenced coppice plots, the woodland was divided into categories as before. Ten trees of each species and varying sizes were selected by choosing the nearest tree to randomly selected co-ordinates. The same measurements as for the protected coppice treatment were taken, and compared.

5.5.2.2. *Results*

At the end of the second and third growing seasons some of the unprotected *B. spiciformis* individuals outside the fence had been damaged by young children collecting fibre for rope.

The mean growth of the largest stem in each coppice stool in both treatments is shown in Fig. 5.5. In this experiment, the effect of fencing the trees resulted in highly significant differences in biomass regrowth (Table 5.5). The effects of species and the initial size of the felled stem were also highly significant, as were the interactions of treatment with species and species with site. *Brachystegia spiciformis* shows a similar pattern of regrowth both inside and outside the fence, although the unfenced trees were slightly smaller at the end of the three years than the fenced ones (Fig 5.5c). *Julbernardia globiflora*, however, shows marked differences in size between the fenced and unfenced individuals, the trees outside the fence being very small at the end of the three years due to browsing (Fig. 5.5d). For this experiment, site differences did not significantly affect regrowth. A comparison of the balanced and unbalanced analyses shows that when using balanced data sets, the initial size of the felled stem also appears not to be an important factor. The balanced data set was contrived, however, possibly resulting in a loss of information. In this case, the unbalanced analysis may give a more realistic result.

Table 5.5. Mean dry woody biomass of the largest stem of coppice stools in the protected coppice treatment, compared with that of the unprotected coppice treatment (significant results only). Treat = treatment.

	Analysis using balanced data set			Analysis using unbalanced data set		
Variable	F	df	p	F	df	p
Treat (T)	11.1	1, 95	0.001	36.7	1, 240	<0.001
Stump d (St)	1.4	1, 95	0.235	22.7	1, 240	<0.001
Species (Sp)	0.2	1, 95	0.001	4.5	1, 240	0.035
Sp x T	12.0	1, 95	0.001	9.8	1, 240	0.002

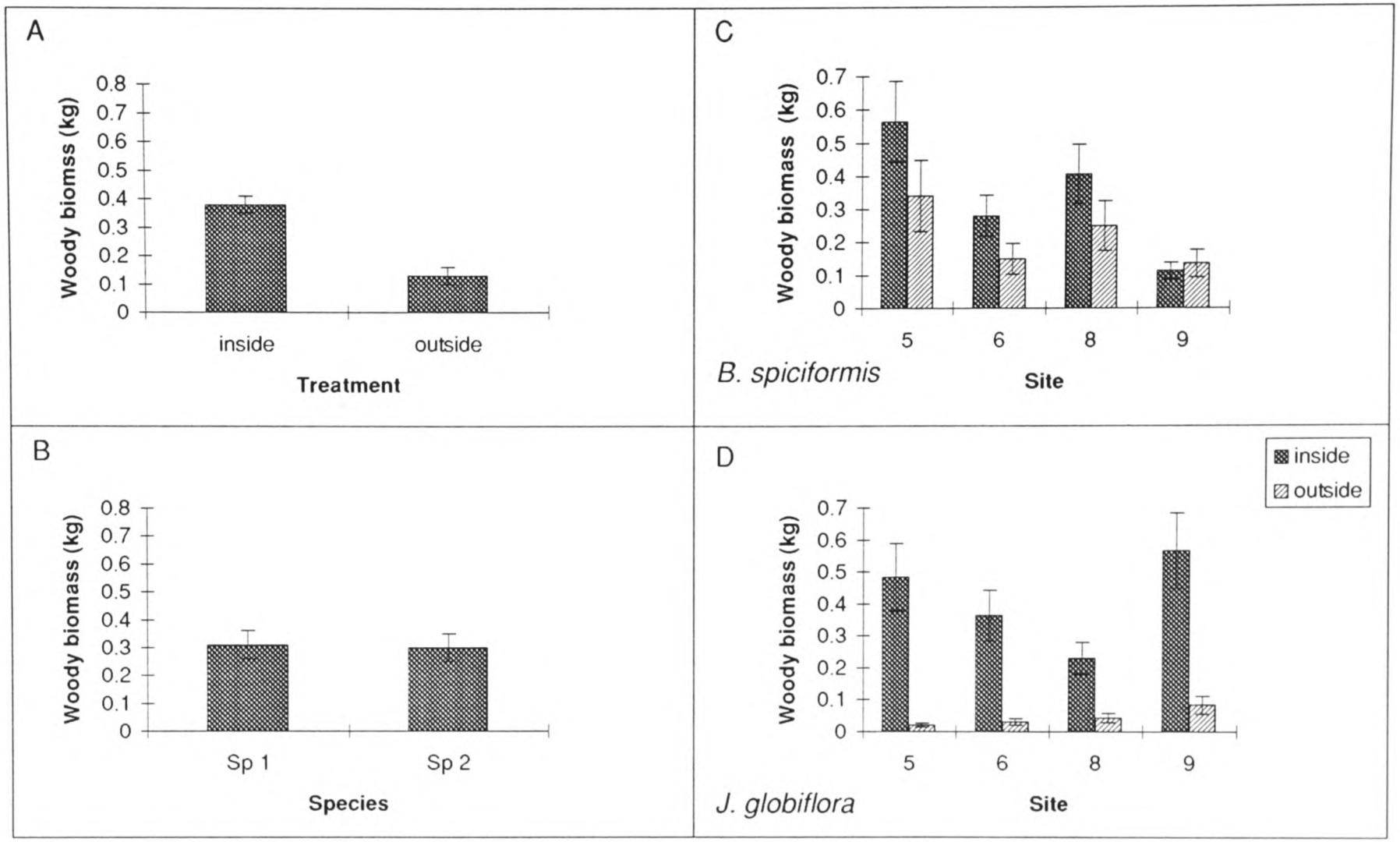

Fig. 5.5. A comparison of coppice regrowth in fenced and unfenced environments, for both species at all sites. Sp 1 = *B. spiciformis* , Sp 2 = *J. globiflora* . A = treatment differences; B = species differences; C & D = treatment differences for each species.

5.5.2.3. *Discussion*

Protection from browsing and human disturbance is necessary to allow young coppice shoots to regrow as fast as possible. This could be in the form of some kind of fencing, or by changes in livestock management so that cattle and goats are herded away from designated woodland management areas. Protection against browsing should only be necessary initially, at the beginning of the first two or three growing seasons.

It would be useful to know how much more wood is produced annually by protected coppice, compared to unprotected coppice, and thus calculate the effect of browsing on the total woody productivity of the woodland. This type of calculation is not possible from the results of this experiment, however, because the level of browsing in the woodland is so variable. Larger plots and monitored grazing experiments would be necessary. The experimental plots were placed near to villages for security reasons, but this may have resulted in increased levels of browsing compared to woodland further away. The unprotected coppice plots were all situated close to the fence, which may also have resulted in increased browsing. In addition, the drought may have influenced the amount of browse consumed, since there was relatively little grass growth in the first and third years of the study.

5.5.3. ***Water harvest***

5.5.3.1. *Methods*

In this experiment, the effect of increasing the water infiltration around the roots of existing small trees was investigated. Ten small trees (< 7cm in diameter, measured at 30 cm) of each species were randomly chosen within the plot. Following Rocheleau *et al.*, (1988), water catchment bunds were constructed in a semi-circle below each tree, at a distance of 2 m from the stem (Fig. 5.1a.). Care was taken not to sever or damage any of the lateral roots which may have been exposed in the catchment area. The following measurements were taken at the outset of the experiment, and again after the end of the growing season for three consecutive years:

a. stem diameter (m) measured at 30 cm above ground level;

b. height (m).

5.5.3.2. *Results*

A comparison of the dry woody biomass produced by the small control trees and the trees in the water harvest experiment inside the fence showed that catching the run-off in an attempt to increase the infiltration to the roots of the trees does not result in an increase in biomass produced

(Table 5.6). In fact on average the water harvest trees produced significantly smaller quantities of woody biomass than the control trees (Fig.5.6). Thirteen percent of the water harvest trees died, or were dying, compared to 4 % of the control trees, which was a significant difference ($X^2 = 1.86$; df = 1; $p < 0.01$).

Table 5.6. Mean dry woody biomass of the largest stem of trees in the water harvest treatment, compared with that of the control treatment. Treat = treatment.

	Analysis using balanced data set			Analysis using unbalanced data set		
Variable	F	df	p	F	df	p
Treat (T)	3.8	1, 59	0.058	18.5	1, 204	<0.001
Species (Sp)	0.3	1, 59	0.575	7.3	1, 204	0.008
Site	0.9	4, 59	0.498	3.1	4, 204	0.017

The growth of the control trees does not change greatly over the five sites, but the water harvest trees fare best at site 2 (Fig. 5.7). For both treatments, *B. spiciformis* grew significantly less than *J. globiflora*. At sites 2, 5 and 6, the differences are not large, but at sites 8 and 9, *J. globiflora's* growth is greater. Significantly more *B. spiciformis* than *J. globiflora* trees died, or were dying, as a result of the experiment ($X^2 = 2.6$; df = 4; $p < 0.01$). Once again, growth is very variable at all sites. Figure 5.7b and 5.7c show these results. From the balanced analysis, site factors and species diffferences did not significantly affect growth, while the opposite is true for the unbalanced analysis. In this case the unbalanced result is more likely to reflect the actual situation, since the X^2 test shows significant species differences.

5.5.3.3. *Discussion*

Water harvesting does not necessarily improve the growth of these two species. This could be for three reasons:

i) the roots of the trees were waterlogged for short periods after the rains as a result of the catchments;

ii) the removal of soil at the base of the tree to form the bunds damaged the roots; or

iii) the catchment construction caused drying out of the surface soil and the roots of the young trees.

B. spiciformis and *J. globiflora* are known to produce a dense mat of shallow lateral roots and a single tap root (Savory, 1963; Rutherford, 1982; Timberlake and Calvert, 1993). The initial

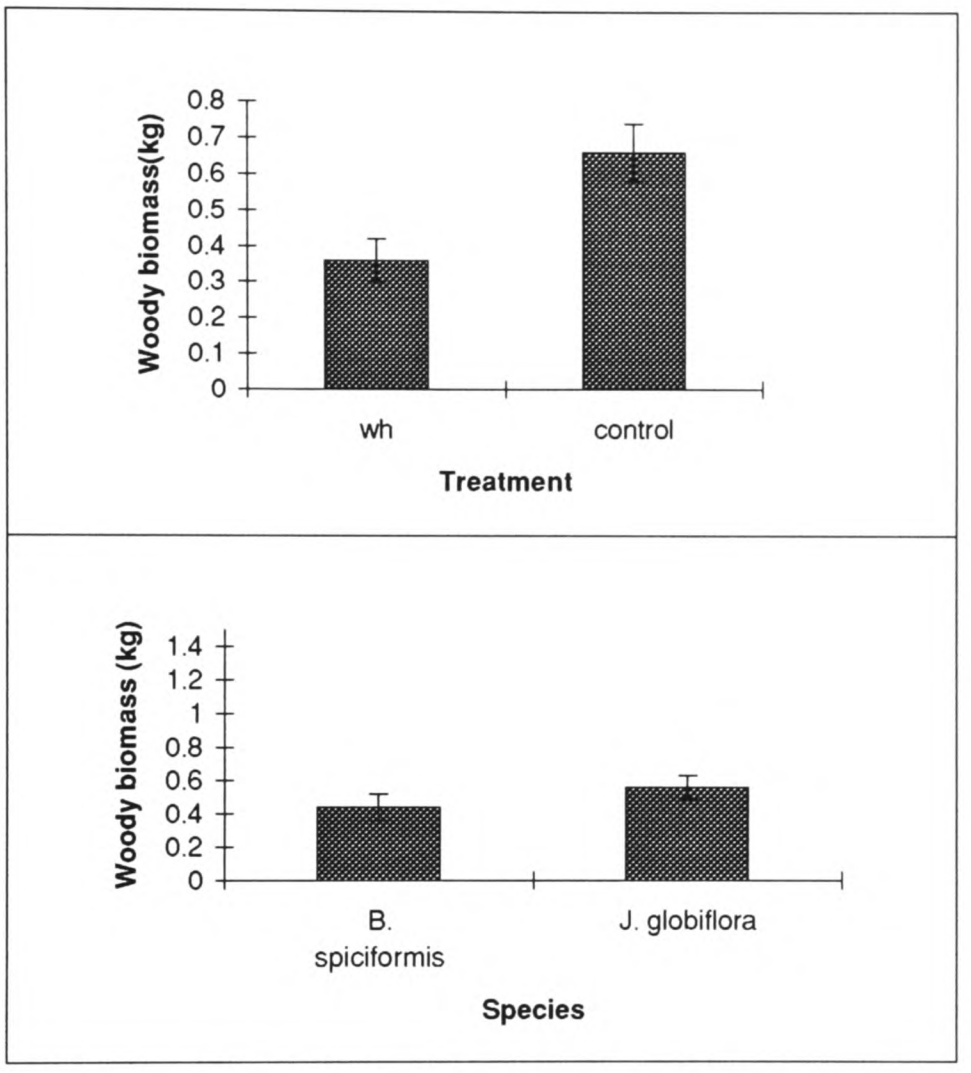

Fig. 5.6. Dry woody biomass produced by the trees in the water harvest (wh) treatment compared to the small control trees.

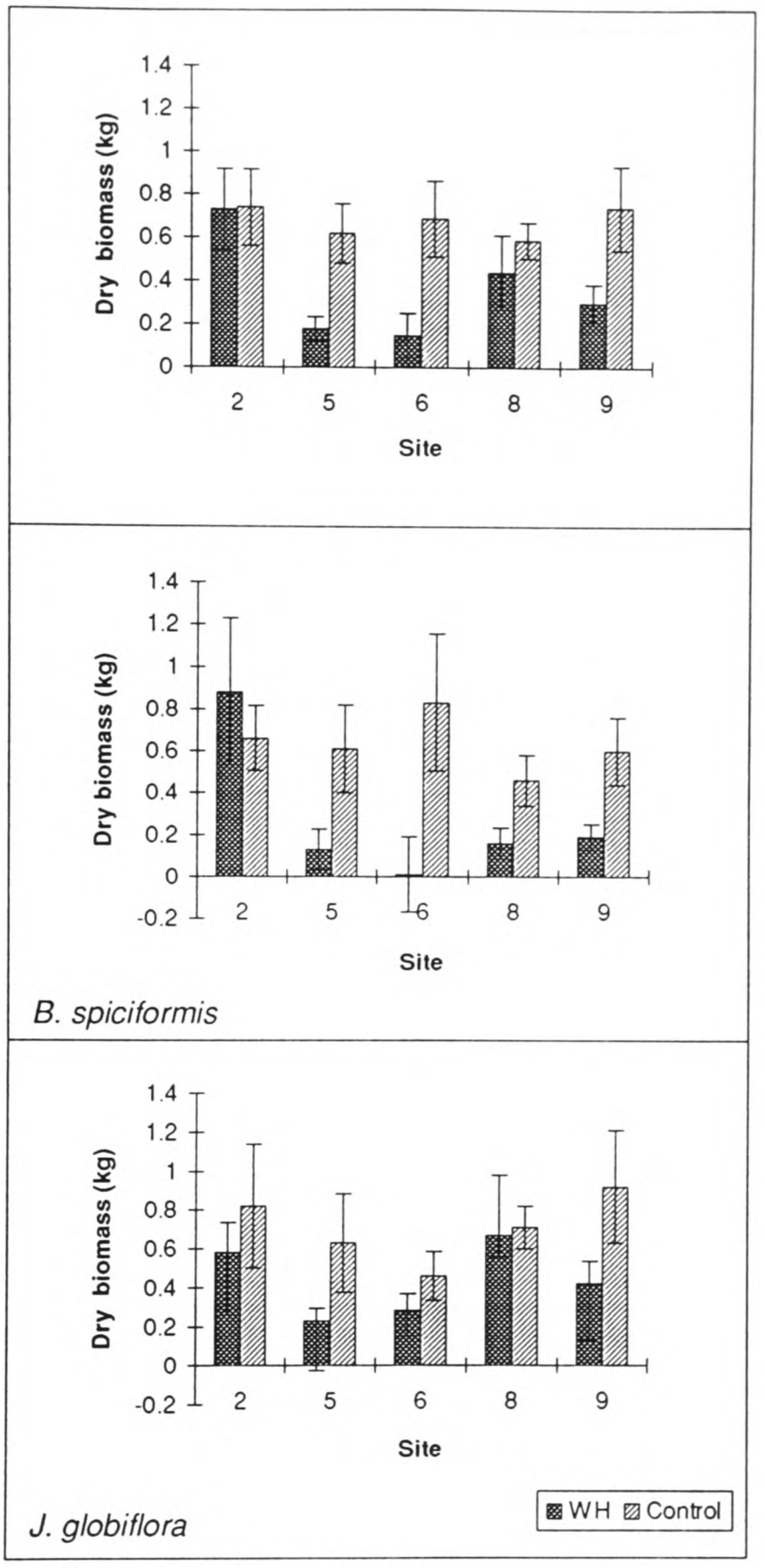

Fig. 5.7. Dry woody biomass produced by the largest stem of water harvest trees compared to the largest stem of control trees, for both species.
A = both species; B = *B. spiciformis*;
C = *J. globiflora; WH* = water harvest.

catchment excavation may have resulted in damage to the fine root system. Alternatively, the catchment excavation may have resulted in root stress and death by exposing some of the lateral roots to the air. This does not explain why the trees at sites 8 and 9 showed increased growth compared to the other sites, while in the coppice experiments these tended to be the poorer sites. This result suggests that it is not root damage which has a detrimental effect on the trees in the other plots, since all the water-harvest bunds were constructed in the same manner. It also seems improbable that the roots became waterlogged for long enough for anaerobic conditions to develop, but this needs further investigation. Poor drainage due to a lateritic layer has been found to stunt the height growth of these species where they grow on bottom-catena sites (Grundy, 1990). Impermeable layers, formed of leached clay particles, are common in granitic soils on the Highveld of Zimbabwe (White, 1983; Timberlake, pers. comm[2]) and may also occur in the study area. Building a water harvest bund on shallow soil is in effect attempting to create deep-soil conditions in a shallow soil, which may not be successful. The death and top die-back of 13% of the trees suggests that this form of management, applied without a more detailed knowledge of the species and site, is not useful in improving the growth rate of the trees.

5.5.4. ***Unprotected water harvesting***

5.5.4.1. *Methods*

The effect of protecting water-harvest plots from damage by humans and livestock was tested by selecting 10 trees of each species in a plot outside the fence, adjacent to the water harvest plot. The same measurements as for the protected water harvest treatment were taken over the period 1991-1994, and the end results compared. During the rainy season, the water catchment areas were cleared of silt and grass.

5.5.4.2. *Results*

The water catchments tended to fill with silt, and required frequent clearance during the rainy season. Thus they needed constant maintenance, whether inside or outside the fence.

Protecting water-harvest plots from human and animal disturbance has no significant effect on the dry woody biomass production of the experimental trees, nor do the influences of the different site characteristics significantly affect growth (Table 5.7). The two species produced significantly different amounts of biomass, *J. globiflora* always being greater, but they did not react differently

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[2] Jonathan Timberlake, Ecologist, Zimbabwe Forestry Commission; Harare, May 1994.

to the two treatments. Figure 5.8. shows these results.

Table 5.7. Mean dry woody biomass of the largest stem of coppice stools in the protected water harvest treatment, compared with that of the unprotected water harvest treatment. Treat = treatment.

	Analysis using balanced data set			Analysis using unbalanced data set		
Variable	F	df	p	F	df	p
Treat (T)	0.3	1, 47	0.595	1.2	1, 117	0.216
Species (Sp)	3.2	1, 47	0.081	7.5	1, 117	0.013
Sp x T	0.1	1, 47	0.809	0.05	1, 117	0.620

5.5.4.3. *Discussion*

From this experiment, it seems that trees in the water harvest plots did not require protection from humans or livestock. The bunds need careful monitoring during the rainy season, however. Comparing the results of this experiment with those of the protected and unprotected coppice experiment (Table 5.5) highlights the fact that it is only the young coppice shoots which need protection from browsing.

5.6. *Shoot production after felling*

5.6.1. *Methods*

The relationship between shoot production after cutting and trunk size and bark thickness (and therefore age) was investigated. The bark thickness and stump diameter of the trees cut for the biomass estimation exercise in Chapter 2 were measured on cutting in 1991. The numbers of buds and new stems were counted after a period of three months' growth, and at the end of one growing season (nine months).

5.6.2. *Results*

Shoot production after felling is dependent on site characteristics, species type, and the initial stump size (Table 5.8). The interactions between site and species, and site and size class are also significant. Mean shoot numbers, both initially and after one growing season, are shown in Table 5.9. Of all the stumps, 1% had not produced shoots by the end of one growing season. By the end of three years, 4% of the larger trees and 2 % of the smaller trees had no living shoots. Figures 5.9a

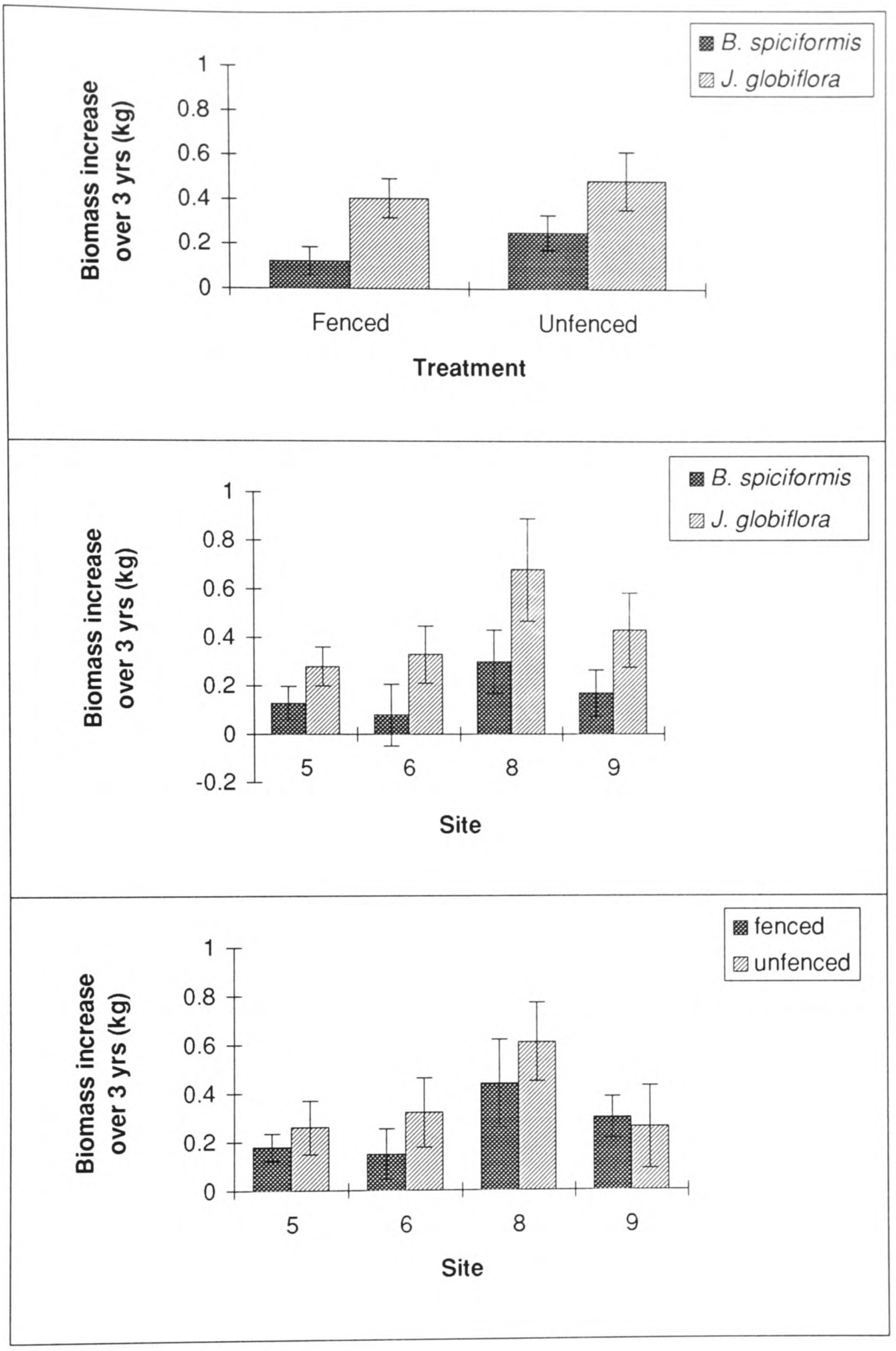

Fig. 5.8. The effect of fencing on the growth of water harvest trees, shown by a comparison of the dry woody biomass of the largest stem of both species at all sites.

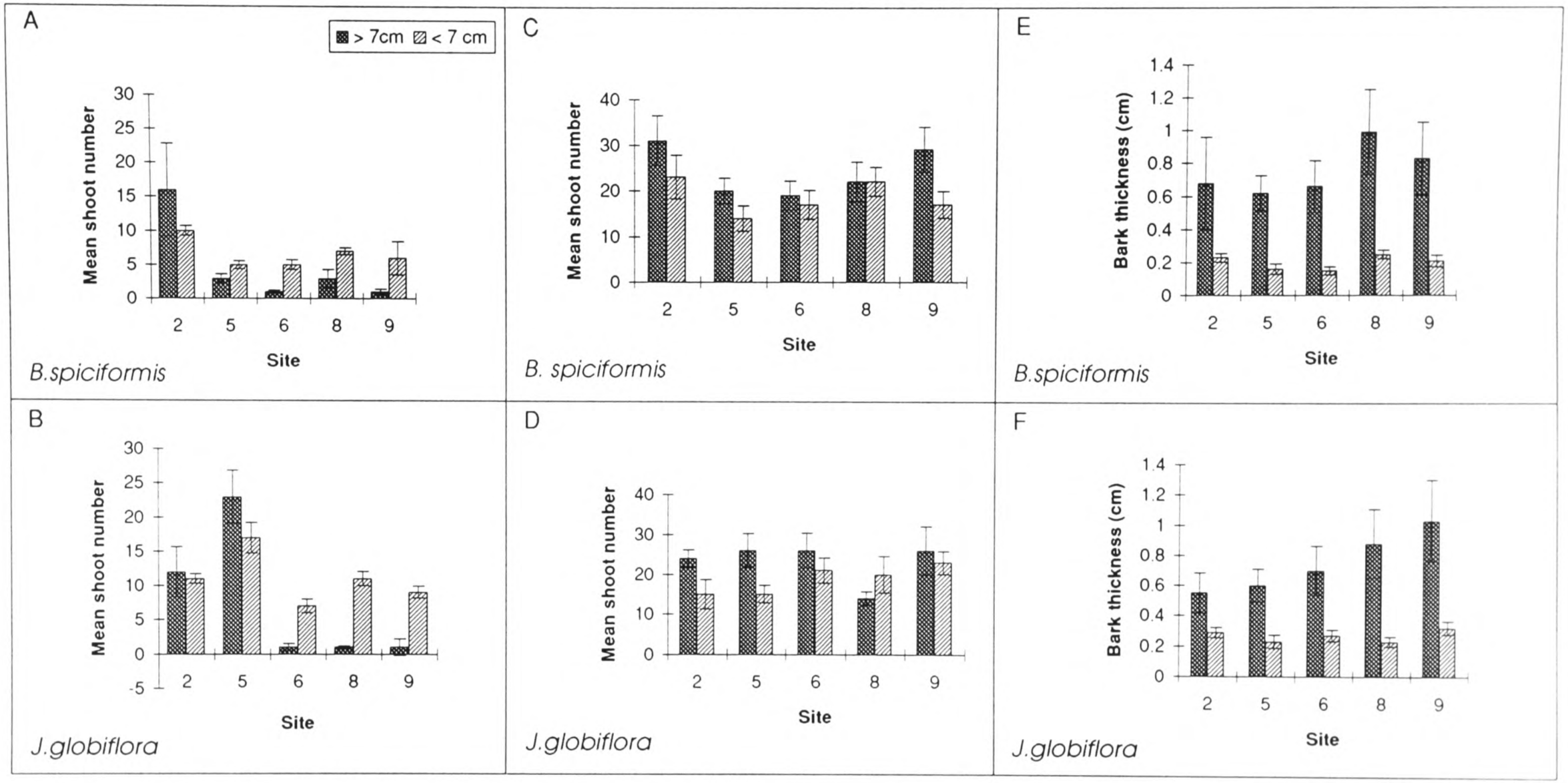

Fig. 5.9 A - D Shoot production after 3 months (A&B) and after one growing season (C&D) on cut stumps of *B. spiciformis* and *J. globiflora*. Diameters measured at 30 cm above ground level. E - F A comparison of the bark thickness of small and large trees of both species at all sites.

and 5.9b show that initial shoot production was variable, being highest at site 2 for *B. spiciformis*, and at site 5 for *J. globiflora*. At sites 6, 8 and 9 for both species, larger trees produced fewer shoots than smaller trees. There is a significant correlation between numbers of shoots and the original number of stems (Spearmans' Rho = 0.43; n = 120), as would be expected, and a significantly negative correlation between the original stump diameter and the number of shoots (Spearmans' Rho = - 0.31, n = 120), i.e. as the stump size increased, the number of shoots produced decreased. This result is complicated by the finding that the numbers of buds produced was also dependent on site differences, however, and thus the regressions of stump diameter against shoot numbers, after three and nine months, gave extrememly low r^2 values. The larger trees at sites 6, 8 and 9 produced fewer buds than the smaller trees (Figs. 5.9a and 5.9b). In addition, the last three sites contained, on average, larger trees than the other two sites.

Table 5.8. Mean shoot production on stumps of *B. spiciformis* and *J. globiflora* three months after tree felling (significant results only).

	Analysis using balanced data set			Analysis using unbalanced data set		
Variable	F	df	p	F	df	p
Site (S)	6.8	4, 119	<0.001	38.9	4, 755	<0.001
Species (Sp)	4.6	1, 119	0.044	20.7	1, 755	<0.001
Stump size (St)	9.0	1, 119	0.003	83.1	1, 755	<0.001
S x Sp	4.0	4, 119	0.005	20.3	4, 755	<0.001
S x St	4.8	4, 119	0.001	17.2	4, 755	<0.001
S x Sp x St	1.8	4, 119	0.145	4.3	4, 755	0.001

Table 5.9. Mean shoot numbers for both species at three and nine months (one growing season) after felling.

	Stump diameter					
	After three months			After nine months		
	< 7 (SE) cm	> 7 (SE) cm	Mean(SE) cm	< 7 (SE) cm	> 7 (SE) cm	Mean(SE) cm
B.spiciformis	7 (0.52)	3 (0.64)	6 (0.43)	23 (1.8)	19 (1.2)	20 (1.0)
J.globiflora	11 (0.53)	11 (1.69)	10 (0.58)	24 (1.6)	21 (1.3)	21 (0.9)
Mean	9 (0.38)	7 (0.94)	8 (0.30)	23 (1.2)	19 (0.8)	20 (0.7)

When the initial shoot numbers were compared with the shoot numbers at the end of the growing season, a different pattern emerged. Large trees produced more shoots than smaller ones, and the correlation between initial size and numbers of shoots was no longer a negative one ($r = 0.14$, $n = 420$; $p < 0.05$). Over all sites the two species did not produce significantly different numbers of shoots but there were significant interactions between site and species, and site and class. Figures 5.9c and 5.9d illustrate these results. Both species had similar thicknesses of bark (Figs. 5.9e and 5.9f). Bark thickness is significantly positively correlated with stump diameter ($r = 0.92$, $n = 120$; $p < 0.05$) (Fig. 5.10), but shows a weak negative correlation with shoot production ($r = - 0.11$, $n = 120$; N.S.).

5.6.3. *Discussion*

The production of shoots after cutting is highly variable, being dependent on site differences, and stump diameter (and therefore presumably root stock size). The differences between initial shoot production and shoots remaining after one growing season suggest that the larger stumps are slower to produce buds after felling than smaller ones, particularly on sites with shallower soils, but that over the whole growing season, larger stumps produce more shoots than smaller stumps. This finding consolidates earlier work (Grundy, 1990) where regrowth of these two species in the first year after felling was found to be highly correlated with the amount of woody biomass removed at felling. It also confirms other work by Fanshawe (1959), Cannell (1983), Rutherford (1982) and Robertson (1984) who found that wood biomass of trees is a function of root stock size. Both *B. spiciformis* and *J. globiflora* show the same pattern, but *J. globiflora* produces shoots more rapidly after felling. This adds evidence to the theory that *J. globiflora* is an early successional species in miombo. Other miombo species in Zambia have been found to take between two and five years to sprout after felling (Fanshawe, 1959), with a stem mortality of between 11 and 35% (Fanshawe, 1956a). These figures are much higher than the figures for Shurugwi in this study, where between 2 and 4% died. Larger stump size may account for Fanshawe's findings. Further work is needed to determine the critical diameter for bud production in trees of > 7 cm in diameter.

Bark thickness does not significantly affect shoot production after felling. This may be partly because the trees are able to produce shoots from the root collar, where the bark is thinner, and partly because, in larger stools, the problems of a thick bark can be avoided by producing shoots from between the stem and the bark, close to the cut edge.

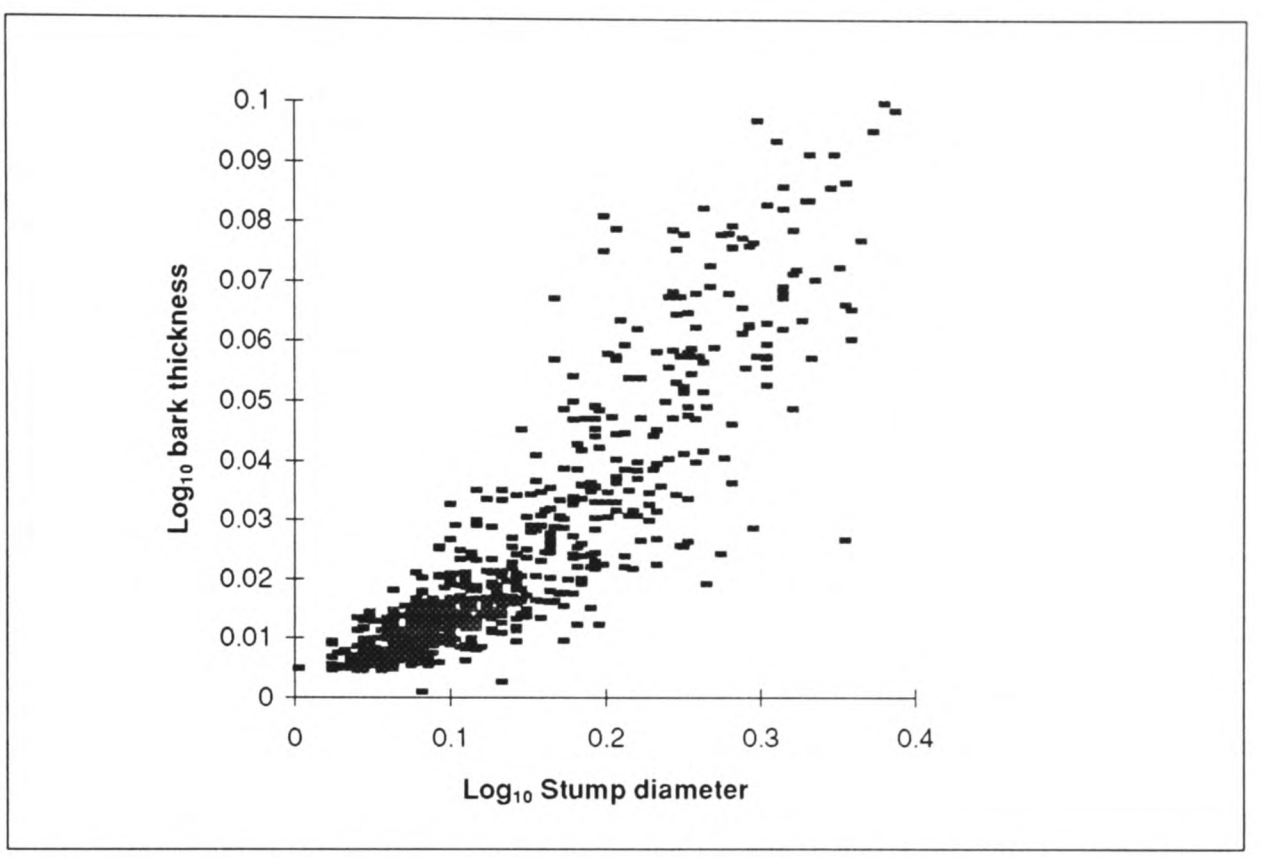

Fig. 5.10. Relationship between stump diameter and bark thickness of *B. spiciformis* and *J. globiflora* in dry miombo woodland in Zimbabwe.

5.7. Comparisons with other work

Most of the early research on the silvicultural potential of miombo woodland was done in Zambia (then Northern Rhodesia) by employees of the Forest Department, such as Duff, Fanshawe, Trapnell and Endean, among others. Their accounts were often based on years of work in the woodland, but were not necessarily quantified. Much of the more recent, quantifiable research re-iterates their findings. Fanshawe (1959), using his experience from Zambian miombo, maintained that young tree seedlings spend the first eight years establishing a large enough root stock to withstand fire, and it was this root stock which enabled the plant to resprout so easily after burning or cutting. From ring counts of root stocks, seedlings were estimated to take eight to ten years to reach the sapling stage (approximately 2 m) (Fanshawe, 1956a). Fanshawe (1959) also maintained that the coppice stool had a life-span of between 100 to 120 years. He quoted a maximum number of 15 new shoots produced on large stumps immediately after felling; this is lower than the mean figure of 23 from large stools found in the present study.

Since so little research has been done in the area of coppice management in miombo woodland in Zimbabwe, it is difficult to determine whether the results of these preliminary experiments relate specifically to this soil type and rainfall combination or whether they are typical of the country as a whole, and of miombo in general. The amount of wood biomass produced annually by the largest stem of the stool in the coppice experiment is similar to that found in a shorter study carried out at three different miombo sites, although once again the amounts of biomass produced were very variable (Grundy, 1990). This suggests that the results of this work may be applicable over a wider area than just the study site in Shurugwi.

5.8. Implications for management

Site characteristics have a strong influence on the regrowth of coppice shoots. From this work, as in Chapter 4, it has not been possible to determine exactly which site factors are responsible for the differences shown in tree growth. Soil depth is likely to be the most important factor, with soil fertility and soil moisture relations having strong influences. For management purposes the importance of site variability depends on the scale at which the woodland is to be managed. In a small-scale village woodlot, the importance of the edaphic micro-variations is great; over a large woodland area it is less so. For villagers, the high variability in the growth of both species at all

sites highlights the importance of choosing suitable sites for tree growth. In order to maximise the returns to labour invested in any intensive or semi-intensive management exercise, the most marginal sites (particularly those on shallow soils) should be avoided where possible. In highly populated areas where arable land is at a premium, indigenous woodland may be restricted to these marginal sites, however. In such cases, trees on field boundaries and contours are likely to be more productive and give higher returns to labour investment.

Stumps of medium size (between approximately 7 and 15 cm in diameter) provide the best regrowth, particularly on shallow sites, and therefore trees of these diameters should be selected for felling where feasible. Using this size class would take advantage of the initial fast-growing phase of regrowth noted by Strang (1965), and would provide poles and wood of the preferred size for local consumption (Grundy, 1990).

Because of the apparently negative effect on the growth of *B. spiciformis* and *J. globiflora*, water harvesting should not be used in miombo woodland, except on well-drained sites, until further research is carried out.

In a previous study, reducing the number of coppice shoots to one resulted in the increase in girth of that stem (Grundy, 1990), but this is management suited more to commercial timber production than to biomass production. In a situation where the objective is to increase pole production in shorter time-spans, reduction to three or four stems may be more effective. The real benefit of coppice reduction may be that poles are available more frequently than they would be if all the stems were left to grow into larger trees, without exposing the soil to erosion after felling. Small pole-sized stems of > 7 cm in diameter (measured at stump height) could be removed from the coppice stool between three to five years after felling, leaving three or four shoots per stump to continue growing. The poles could be stripped to make bark fibre and the wood used for fuel while the remaining stems in the stool are left to grow to a larger size. Stripping the bark of young live saplings to produce fibre for rope, as practiced in all rural areas in Zimbabwe, is one of the most destructive uses of the woodland, resulting in bent and damaged saplings. Instead, cutting the stems before stripping them would allow the stools to produce healthy, straight, rapid regrowth. Coppice reduction is practiced informally in most miombo woodland in small-scale farming areas in

Zimbabwe and this practice could be reinforced.

Wire fencing to protect new tree shoots from browsing in an area which has been specifically set aside for woodland management is expensive and often difficult to safeguard from theft. Some other form of protection, such as the herding of animals away from the area, would therefore be more satisfactory. If the products from the woodland were seen in the same light as crops, this could be a successful solution to the problem of browsing. Livestock movements are carefully monitored in the growing season in Zimbabwe, to prevent important crops from being eaten, and woodland management areas could be included in this herding strategy at least until the end of February/ March. Damaging the bark of *B. spiciformis* and *J. globiflora* will induce sprouting at the point of damage (pers. obs), and this technique could be used to produce new shoots for livestock towards the end of the growing season in times of shortage. In this way, the trees could still be used as a source of browse, but the growing shoots of the young trees could be protected. Alternative strategies could be

i) to dig a pit around the perimeter of the management area, as was sometimes done in medieval times in Europe (Rackham, 1993) and in parts of India (pers. obs.);

ii) to construct a brick wall or a fence made of local materials (both of these options require the use of wood resources); or

iii) to pollard the trees at a height out of reach of livestock.

5.9. **Conclusions**

This work has shown that:

- site variations strongly influence woody biomass production in miombo woodland;
- neither coppicing, nor coppice reduction necessarily enhance woody biomass production;
- in the management of coppice regrowth for maximum pole production, coppice reduction is not necessarily successful;
- browsing by livestock is in direct conflict with woodland management for wood products in communally owned indigenous woodlands, and therefore young coppice needs to be protected from livestock if maximum regrowth in the first few years is desired. Once the stems are

established, browsing no longer has such a large effect on woody growth;

- the construction of a water-catchment at the base of young *B. spiciformis* and *J. globiflora* trees has a detrimental effect on tree growth, at least in the short term;
- coppice production from large stumps is not necessarily impeded by the thick bark or the age of the stem, except on shallow soils.

6

The Management of the Indigenous Woodland by Local Inhabitants of Tokwe III Resettlement Area

6.1. Introduction

One of the common myths among people of urban areas and developed countries is that small-scale farmers in rural areas of developing countries are wanton destroyers of their environment, or at best have an exploitative attitude to the natural resources available to them (see for example NCR, 1920-1930; Troup, 1940; Campbell and du Toit, 1988)). On the strength of this, numerous development projects have been set up to 'teach' local inhabitants how to manage their own resources in a more sustainable manner. Many such initiatives have failed because local farmers' needs and opinions have not been considered in the planning of the project, because they often ignore the local management practices already in place, or because the project offers a simplistic solution to wood scarcity when physical shortage may not be the underlying problem (Casey and Muir, 1988; Dewees, 1989; McGregor, 1991; Fortmann and Nhira, 1992). The constraining effects of land and labour shortages may also force farmers to use their natural resources in ways they would not ordinarily choose.

In this chapter, some of these issues are examined in a case study of indigenous woodland management for poles and firewood by the local inhabitants of Tokwe III resettlement area (Fig. 6.1.).

6.1.1. *Historical overview of resource management in small-scale, communal farming areas*

Murphree and Cummings (1991) describe pre-colonial savanna land use as being typified by an agriculturally-biased system of land management, regulated through communal property regimes, clearly bounded and with explicit rules of inclusion and exclusion, rights and obligations. Compliance to the regime was effected from within, through the dynamics of social conformity, and formalised by the weight of religious sanctions (Murphree and Cumming, 1991). These sanctions not only prevented common people from using certain natural resources while allowing access to religious and community leaders, but also strengthened leaders' power over their communities (Scoones and Wilson, 1989). The arrival of the colonial administrative forces, with their policing attitude towards resource management in communal areas, saw the erosion of this

power, combined with a diminishing of the land base and a narrowing of the flexibility of usage which the complex ecological and social conditions required (Murphree and Cumming, 1991; Scoones and Matose, 1993). This resulted in a perception by local communities that they no longer had the autonomy required for effective self-management, which in turn saw a gradual non-conformity to collective control of resources (Murombedzi, 1990; Murphree and Cumming, 1991). Traditional systems, upheld by traditional institutions, could no longer be enforced (Gumbo, 1993). Colonial inputs into this system, via a rigid agricultural extension programme, were technicist and authoritarian. For example, failure on the part of farmers to comply with enforced conservation measures could result in loss of farming and grazing rights (Murphree and Cumming, 1991; Scoones and Matose, 1993).

6.1.2. *Common property regimes*

In theory, the indigenous woodlands in resettlement areas are held as common property resources. A common property regime is based on some concept of equal access to a resource by all members of a clearly defined use group (Murombedzi, 1990). The common property literature is extensive, and the debate over common property resource use is ongoing. Arnold (1993) has summarised contemporary thinking on the requirements for the success of a common property regime, which can be divided into four categories:

1. The resource

Does the resource lend itself to communal use? Successes in the past indicate that any resource which can be divided between users (as woodland can) is more difficult to manage than one which cannot (such as grazing lands or fish stocks). Can outsiders be excluded from the resource?

2. The user group

a) Is the user-group clearly defined? Does this group have a shared view as to the use of the communal resource? Is it of a manageable size? Are there internal structures for making and administering rules? Does the user-group have the ability to police the resource?

3. Benefits

What are the actual benefits of management? Are the benefits of local value or for sale elsewhere? Do these benefits accrue to a restricted elite? Will the benefits accrue quickly enough to be perceived as a worthy investment? In the latter case fodder and fuelwood are easier to manage communally because the relatively quick returns give more incentives for sustainable management than poles or timber.

4. The role of the State

Is the State willing to transfer authority over the resource to the user-group? This authority is essential if outsiders are to be successsfully excluded from the resource. Is the State prepared to intervene on behalf of the users to police the resource? Does the State provide the necessary investment capital and technical assistance to maintain and enhance the resource? Is it more appropriate, in the circumstances, for the State to manage the resource?

6.1.3. *The present situation*

At Independence in Zimbabwe, from a background of insecurity of tenure and weakened collective controls, farmers from the communal areas were resettled on pockets of former commercial farmland. Many came from areas of acute wood shortage. The resettlement programme, still based on the colonial model of centralised bureaucratic control with assumptions about appropriate technology strategies for resource use, far from reinforcing any collective control, further marginalised locally-evolved ecological knowledge and inhibited the institutional dynamics required for effective common property resource management regimes (Murphree and Cumming, 1991).

6.1.4. *Objectives*

The objectives of this section of the research were to investigate:

1. attitudes to indigenous woodland management of the inhabitants of Tokwe III resettlement area;
2. the present management regime; and
3. the implications of these two for the future management of the resource.

6.2. **Study Area**

The respondents to questions in this study came from the same villages in Tokwe III resettlement area in the Midlands Province of Zimbabwe which had been selected to take part in the woodland management project in 1991 (see Chapter 2). The resettlement area is typical of the resettlement areas in Natural Regions III and IV. In 1985, at the time of resettlement, it was a well-wooded area, having been used for livestock ranching over the past 50 years (Figs. 6.1 and 6.2.). Prior to its appropriation for commercial farmland in the 1930s, it would have been farmed by small-scale farmers under a bush-fallow system (evidenced by piles of stones cleared off old fields, ridged patterns in the soil, the 'mortar' used for house-building, and old grave sites). Many of the large



Fig. 6.1. Aerial photograph of Tokwe III resettlement area (left) and Shurugwi communal area (right) taken in 1985 at the time of resettlement. The bare patches in the resettlement area represent newly ploughed fields.

1: 15 000

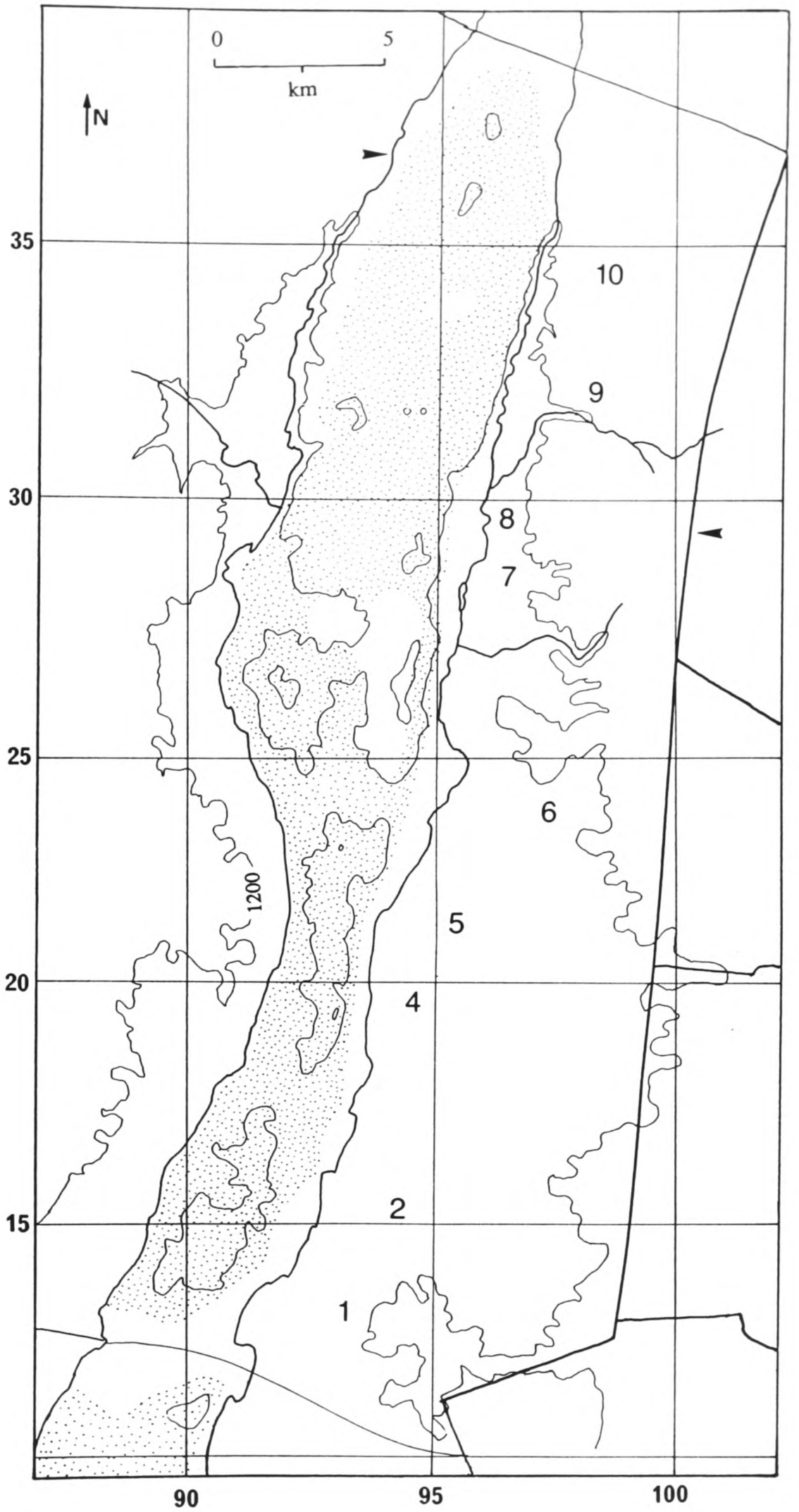

Fig. 6.2. Tokwe III Resettlement Area, bounded on the West by the Mtebekwe River and to the East by Shurugwi Communal Area (marked with arrows). The shaded area shows the extent of the Chironde Range, where the largest wood reserves, particularly of construction wood, are found. The numbers on the map indicate the location of the study villages.

trees were not felled. Thus a mixed-aged woodland existed at the time of resettlement. Intensive cutting of the intermediate sizes since resettlement, however, has resulted in a woodland with a 'U'-shaped distribution curve, with more small and large trees than medium sized ones.

6.3. **Methods**

The study was carried out in June 1992, in two ways: first, by holding group discussions in the form of participatory workshops with groups of villagers, and second, by holding informal interviews with village leaders. A house-to-house survey was not carried out because the desired information could be obtained using the other two methods. Nine of the 14 villages in the resettlement area were randomly selected for participation in the study, giving a sample of 64% of the households in the area.

6.3.1. ***Group discussions***

Meetings were arranged with the help of a former Forestry Commission employee who lives in the nearby communal area, and who is a well-known figure because of the active role he plays in the local farmers' union. Every household was asked to send a male and female representative to each meeting, there being between 25 to 30 households per village. Women and men were asked to attend separate meetings in order to promote greater participation of women in the discussions. It was thought that women, especially those of low status such as the young and the husbandless, would be more likely to air their views if no men were present. The sessions were led in Karanga (the local Shona dialect) by a young Forestry Commission employee who is a trained sociologist and well-versed in participatory rural appraisal (PRA) techniques. He had previously lived and worked at Donga, the nearest commercial centre, where he was well-known and liked. Notes were taken in English. Villagers had had no previous experience of PRA methods, which had not been used in the resettlement area. Some of the techniques had been used by the Forestry Commission in the nearby communal area, but on a very limited scale.

To begin the discussion, villagers were asked to draw a map of their village area. In each case the map was drawn on the ground, using a stick. Piles of fresh green tree leaves were provided to be used as indicators of woodland areas, while pods and sticks were provided to show areas of fuelwood and pole collection respectively. A minimal explanation was given at the beginning of the exercise so that people could use their own initiative in drawing the map, but if villagers did not include houses, fields and woodlands in the map of their own accord, they were encouraged

to do so. During the map-drawing, key questions were asked about the supply and demand of local indigenous woodland products (particularly poles and firewood), tenurial issues, as well as present and future management techniques.

Once there was agreement amongst drawers and observers as to the accuracy of the wood resource map, the group was asked to indicate its perceptions of the change in the woodland over the past five years by using tree seeds to represent tree stocks. In the early sessions seeds were placed in a single line on the ground, where a longer line indicated more trees, but in later sessions villagers were asked to place relative amounts of seed in circles drawn on the ground. They were then asked to represent what they thought indigenous wood stocks would be like 10 years hence, relative to present amounts.

A similar procedure, using seeds placed in a circle drawn on the ground, was used to investigate tree planting in the resettlement area. Villagers were asked to place different numbers of seeds inside the circles depending on how many fruit trees had been planted by individuals in their village, how many timber trees and how many had been planted for other purposes.

6.3.2. *Informal interviews with village leaders*

Discussions were held with the community leader from each village. Although the interview was informal, a series of topics was covered. These included the same topics covered in the group meetings, as well as the sale of wood from resettlement areas and the possibility of more active management of the indigenous woodland in the future.

6.4. **Results and Discussion**

6.4.1. *The Participatory Rural Appraisal approach*

All of the group meetings were extremely successful for several reasons. The exercise generated a vigorous and high level of debate amongst villagers, far more than would have occurred if questions had been asked of individual household members. Interest in woodland resources was aroused at village level, and all households were included in the discussions. This gave the study a higher status than would have been the case if a household survey had been conducted. One disadvantage of group meetings over individual discussions is that some people may have felt overwhelmed by the group dynamics and may not have been able to openly disagree with group decisions. It is also not possible to investigate the issues of interest in great depth using

participatory methods with groups. If this were the aim of the study, individual interviews would be necessary.

Attendance at all the meetings was high, both for men and women. This could be for several reasons. There are few development projects in the resettlement area and this particular project differed from others in that, until the time of the meetings, it had been essentially of an experimental nature, with little input from the villagers apart from the initial stages. Forestry extension was almost non-existent over most of Tokwe III, and what little there was had been focused on nurseries and tree-planting. Projects concerned with managing the existing woodland were unheard-of. So, from the outset, villagers were curious. In addition, the meetings were arranged by a well-respected member of the local farming community. A third factor, the provision of light refreshment at the end of each meeting, was, in the eyes of some members of the community, a strong drawing point given the lack of food in the area as a result of the drought. Whatever the reason, the results were very gratifying. In some cases, the heads of households did not attend, especially the males, because many village members had left the area to seek employment.

Villagers responded differently to the request to draw a map in the sand. In some cases older members were hesitant about their ability to draw such a map, saying they had not been to school, and encouraging the younger members to take the initiative. Others were unsure of what was required. In general, either a leader or one of the younger members took the initiative and began drawing. Sometimes more than one started, or one started and then others took over. After the first few minutes, a lively discussion began in which the majority of the villagers took part. In most cases, the boundaries were drawn first and stones were used to demarcate hills. Men drew fields, roads and cattle dips on the map first while the womens' priorities were usually houses and fields. The attention to detail varied from drawer to drawer. A few spent time ensuring that each household's homestead and fields were represented, while others sketched in an overall impression. There was much debate amongst group members over this aspect. Communal fields or woodlots, set up as part of a development project, were demarcated with pride.

The greater overall mobility of boys and men compared with girls and women, due to a differentiation in the nature of male and female labour, was highlighted when some women were not able to draw the complete boundaries of their village area and had to refer to the crowd for advice. For men, the road network is more important than for women because it is they who generally take an ox-cart to the commercial centre by road, to sell produce, attend to family

business or collect provisions. Women, whose labour is mainly used in the fields and around the homestead, seldom go into town and if they do, will usually go on foot and take shortcuts along paths. Roads did not feature highly in the order of importance, however, probably because there is no public transport in the area as a result of the poor state of repair of the roads.

It should be borne in mind that a study of this nature captures a set of views at one particular moment in time. At the time of the meetings, people were preoccupied with the drought and this could have affected some of their responses. Fortunately, however, issues of woodland management at this gross level are not greatly influenced by the climate. It is also important to note that there is a distinction between what people say and what they actually do. How villagers perceive the questioners, or the benefits of a certain line of response, will often affect their answers, and they may make their situation appear better or worse than it is. In this case the emphasis was on forestry issues, and therefore villagers may have appeared to be more positive about future tree planting and woodland management than they actually were.

6.4.2. ***The indigenous woodland resource***

6.4.2.1. *Wood products*

Sources of poles and firewood were indicated on the village map with equal confidence among men and women. Discussion revealed that, in general, these resources were collected from wherever they were available. Poles were more difficult to find than firewood because of the need to be more selective. The main sources for both fuel and poles were the grazing lands and hilly areas which surround all of the villages and farmers were able to supplement this from the shoots of coppicing trees growing on the boundaries and contours of their fields. Some firewood was collected from fields. Some new fields were still being cleared of woodland before planting, and this source produced large quantities of wood. River banks yielded poles for different purposes, e.g. *Acacia* species for brush fencing and firewood or cattle kraals.

According to the villagers, the supply of woodland products varied with the product. Firewood was still in plentiful supply, although in some cases carts were used to collect it from further afield. Most leaders said that there was no need to conserve firewood since there was still plenty to be found. Some, however, thought that people did conserve wood because they had been resettled from areas which suffered from wood shortages. These findings are similar to those of Grundy *et al.*, (1993) in Mutanda resettlement scheme in the south-east of Zimbabwe. All types of wild fruits were still to be found, and village leaders had not noticed a decrease in this

particular woodland resource in the seven years they had been living in the resettlement area. However, all villagers said they had to walk further than before to find poles of their choice. The best poles were presently to be found in the more remote hilly areas on the western border of the resettlement area, on the opposite side from the communal area.

Responses to the question 'What do you think the state of the woodland will be in 10 years from now?' were varied. Some people thought that wood stocks would not be much different from present levels because no expansion of agricultural land is officially allowed, and in some cases is not feasible because of geographical features such as hills and rivers. Some were of the opinion that trees which had been cut in the early years of resettlement would have regenerated and their branches by then would have reached a useful size, so that cutting of new trees would be unnecessary. Some said that tree stocks, especially of large trees, would continue to be depleted for the next year or two until people had completed their housing to the standard required by the resettlement officer, after which time tree-cutting would stabilise and the woodland would have a chance to recover. The majority of people, however, felt that unless present practices were changed, the woodland would continue to decrease, and it would become increasingly difficult to find poles of the required species and size.

Farmers in the adjacent communal area equate many environmental problems with the decline in tree cover over the past 40 to 50 years, including increasing soil erosion and consequent soil infertility; increasing windiness; droughts and the drying up of springs and wetland areas due to reduced rainfall infiltration (McGregor, 1991). It is likely that the resettlement dwellers, many of whom have moved from areas of high population density and woodland stress, hold similar views, but this is a subject for future work.

Only one old man, a village leader, thought that an area of woodland should be set aside so that he could show his children what the woodland used to look like. His response presupposes that the woodland will be greatly diminished or changed in the future. That he was the only one to propose this action suggests that the issues of biodiversity and conservation of the woodland for its own sake, which dominate so many contemporary forestry debates, are not priorities for these resettlement people.

6.4.2.2. *Changes in the woodland between 1987 and 1992*

The general consensus among all villagers, including the leaders, was that the woodland had been reduced considerably since they first arrived, although there were still adequate supplies of wood

for their needs. The reduction in woodland observed was attributed by the villagers to several causes. These have been divided into i) a reduction in woodland area; and ii) and reduction in woodland density.

i) reduction in woodland area:

In many areas new fields had been opened up after the initial allocations had been cleared. This was for three reasons.

a) In areas close to the Chironde Range (Fig 6.2), the soil was found to be high in toxic chromium ores, which impede plant growth. Villagers who had been allocated fields in these areas were allowed to move their fields to more productive land. Similarly, villages which had originally been built on dolerite dykes were moved to granitic areas where it was easier to dig latrines and cultivate vegetables. Both of these moves resulted in the clearing of additional woodland, leaving the original areas to regrow.

b) Resettlement villages in Tokwe III were planned as central units, surrounded by fields. Many villagers had to walk up to a mile from their homes to reach their fields. Apart from the inconvenience of having to work at some distance from the homestead, it was also difficult to protect their crops from destruction by marauding troops of baboons. In 1990, therefore, some villages were split into two and one half of the inhabitants moved nearer their fields. This again required clearance of woodland for village placement and housing construction.

c) In this particular resettlement area the expansion of agricultural fields is another cause of woodland degradation. Villagers apply to the agricultural extension worker for more land if their family numbers increase and to date have all been allowed to clear more of the grazing land for crop production, despite this being contrary to the original resettlement plan.

ii) reduction in woodland density:

a) In all villages, even those which did not share a boundary with the neighbouring communal area, the most common cause cited for woodland depletion, and one which villagers believed could eventually cause the total destruction of their woodland resources, was the uncontrolled use of the woodland by local people living in the adjacent communal areas. Large amounts of wood for fuel and poles were being removed daily from the resettlement area by cart, much of it to be sold in the communal area villages. Villagers living on the resettlement boundary said communal area dwellers also cut poles, collected firewood and grazed their cattle on their land without permission to such an extent that these resources were now scarce in border areas. In addition, some labourers

who came in from the communal area were paid in wood by their resettlement employers. Many resettlement dwellers have watched the gradual depletion of the woodlands over the years and prophesied that their communities would be in the same position of wood shortage as their neighbours in the communal areas if nothing were done to change the present situation.

b) According to resettlement policy, any new buildings constructed by villagers were to be of a certain design and were not, apart from the roof timbers, to contain poles. Each homestead was eventually to comprise one five-roomed house and at least two large round huts, all made of burnt bricks. Thus villagers had been cutting large trees to burn bricks.

c) Although new houses were built with burnt bricks, people still cut poles for fence posts for gardens and animals kraals. In years of good harvests, many new poles were cut to improve grain storage facilities.

d) Many trees have died in the drought.

6.4.2.3. *Tree planting*

People in every village have planted trees since their arrival in 1985. In general these plantings have been around the homestead and in gardens. As in the nearby communal area (Grundy, 1990), the number of trees planted varied from individual to individual. The majority were fruit trees, with fewer being planted for poles and very few for other purposes. Some, such as *Jacaranda mimosifolia* D.Don, were planted for shade or ornamentation, but in most cases shade in homesteads and fields was provided by existing indigenous trees which had been protected for their useful products. The fact that almost everyone had planted trees for fruit, but very few for construction or other uses shows that people were still able to fulfil their needs for poles from alternative sources, and that planting trees for this purpose was not cost effective. Planting trees to provide fodder for animals is not a practice which is found in this area. Even though the villagers' tenure in the resettlement area is dependent on their agricultural productivity, they still plant trees around their homes. Since tree planting requires both a financial and a labour investment with delayed benefits, this suggests that villagers are confident of their right to remain on the land, a situation also noted by Cusworth and Walker (1988).

The response of farmers to future scarcity of the preferred indigenous species for poles will be, according to some villagers, to use other less desirable species, and according to others, to set up plantations of exotic species to provide for their needs. Some villages were situated near

Eucalyptus plantations which were established by the commercial farmers who formerly occupied the land. According to the original resettlement plans, all villages were to have set up a communal woodlot, planted with *Eucalyptus*, which would provide poles for roofing and fencing (GOZ, 1981). To date, this has not been done, partly because of the lack of input from the Forestry Commission, who were to have supplied the seedlings and helped with the technical aspects, and partly due to lack of protection against browsing of the young trees by goats. The only woodlot planted by 1992 was part of a women's income-generating scheme, which indicates the lack of urgency to grow trees for poles.

6.4.2.4. *Sale of wood from resettlement areas*

It is illegal to sell wood from the resettlement area to outsiders and therefore this is a sensitive issue to investigate. Many of the village leaders said that their people did not do so. Others, however, said that villagers sell wood unofficially and that there was no enforcement of the legislation to prevent this. During the time of the survey, carts heavily laden with wood destined for the communal area market were regularly encountered on the roads at night. This indicates that some villagers acknowledge the existing pragmatic controls over wood sale but flout them anyway. On other occasions, laden carts were seen by all those attending village meetings, as they passed through the villages in the middle of the day, indicating that such an activity was not considered reprehensible. It is apparent that sale of firewood will continue as long as people in the resettlement area can find a market (many households in the deforested communal area are forced by necessity to buy wood, even families of people involved in natural resource management) and as long as the regulations concerning illegal cutting of wood in resettlement areas are not forcibly applied. Fortmann and Nhira (1992) attribute the continuing wood sales to the compelling need for financial income in resettlement areas. Most resettlement dwellers recognise the need to conserve the woodland and manage it more formally, but at the same time accept that village members need to earn money. This being the case, the short-term financial needs of a few are at present jeopardising the prospects of satisfying the basic needs of the whole community in the future. It is also evident from this study that farmers experience split loyalties in the issue of resource management. The villages are made up of groups of people of many different clans and religious beliefs, thrown together by the allocation system of the resettlement authority. When pressurised by relatives to share their resources more widely than the village limits, villagers feel bound more strongly by family than by village ties. A further complication was that some villagers unofficially maintained two homes, one in the communal area and one in the resettlement area, taking wood from the resettlement area to support both households.

6.4.3. *Land use*

6.4.3.1. *Conflict with other forms of land use and woodland management*

Although in theory resettlement farmers are not allowed to engage in employment outside the resettlement area, this regulation was not usually enforced in Tokwe III, and because of almost total crop failure in 1991/1992, many heads of households were employed or seeking employment in the towns and on neighbouring commercial farms. Some were employed in illegal gold panning in the nearby Mtebekwe River. If the regulation were to be enforced in the future, it is likely that there would be even greater pressure on the woodlands to provide products for local income-generating industries, apart from the sale of firewood and poles.

In the past, clearance of land for agriculture has been said to be the greatest cause of woodland loss in small-scale farming areas (Du Toit *et al.*, 1984). Since independence, it has been the expectation in communal areas that everyone has a right to land, and that more land will become available to farmers in order to relieve the over-crowded conditions. This is an unrealistic expectation, however, bearing in mind the rate of population growth of nearly 3% pa., the finite area of arable land, and the present importance of the large-scale commercial farms in capital-intensive production of food and export crops (GOZ, 1989; Murphree and Cumming, 1991). At a local level, pressure for land could result in a change in the existing resettlement policy, which restricts further settlement or the clearing of additional land other than that originally allocated. In Tokwe III this regulation is already being broken and a recent Government report on progress in resettlement areas shows this to be an increasing problem: up to 30% of settlers had increased their arable land holdings in some areas (DERUDE, 1991). If woodland is not given greater priority in future overall agricultural policy, it will continue to diminish with the expansion of arable land, at the same time being increasingly depleted as a result of intensive cutting for poles and fuel.

In deforested areas of communal lands throughout Zimbabwe, villagers are resorting to privatisation of portions of communal woodlands, usually those adjoining their homesteads or fields, to ensure a continued supply of wood products to the household (Matose, 1991; Campbell *et al.*, 1993a). This strategy was not mentioned by the villagers as a possible consequence of decreasing wood stocks in their area in future, and to date is not practiced in the resettlement area, even with indigenous fruit trees adjoining villagers' fields. Wild fruit is still a communal resource.

6.4.3.2. *More intensive woodland management schemes in the future*

All leaders thought that areas within their village boundaries could be set aside for more intensive management of the woodland, although some had reservations about the willingness of communal area people to respect these areas (see 6.4.2.1). At the time of the study, resettlement dwellers were powerless to enforce their own management rules, and believed they would not be able to do so without government backing. Thus lack of security of resource tenure, and the inability to enforce regulations, are likely to be the major constraints in any new woodland management initiatives. Any new scheme would also have to have the cooperation of all local people, and for this each villager would have to be persuaded of the individual benefits of communal management of the resource. Fencing is expensive and provides a temptation to thieves, and is therefore problematic. Some system which combined rotational grazing, as suggested by some of the villagers, or which involved herding animals away from certain areas during the first two years of regeneration would be a more practical solution. Herders already keep animals away from croplands during the rainy season and an adaptation of this practice is unlikely to be problematic. Villagers in the neighbouring communal area have shown that, providing cattle have other areas in which to graze, this latter practice is successful in allowing the regrowth of severely degraded woodland (Grundy, 1990).

One of the few development projects in the resettlement area has been the introduction of grazing schemes where cattle are grazed in demarcated paddocks on a rotational basis. Some villagers (particularly the women) thought that a woodland management scheme could be set up in conjunction with the grazing schemes. Certain areas could be cordoned off, selectively felled and the trees left to coppice, while others, where the trees were no longer in danger of being damaged by browsing, could be used as grazing land on a rotational basis. In view of the capital investment required to fence a woodland plot (approximately £400 ha^{-1} without labour), this would seem to be the most practical suggestion. Both *B. spiciformis* and *J. globiflora* are browsed by cattle (although only the young shoots of *B. spiciformis* are eaten) so that some sort of protection would be necessary if maximum regrowth of the trees were to be encouraged (see Chapter 5).

At the termination of the research on woodland regeneration and management (Chapter 5) in July 1994, the fencing from the experimental plots adjacent to villages became the property of the villagers. When asked what plans they had for the fencing, most villagers wanted to set up communal vegetable gardens close to the river. Only one old man suggested that the fencing should be used to circumscribe another woodland management area. This highlights the fact that food production is the major priority for villagers, and it is probable that woodland management

would come third after livestock management. In times of stress, these priorities are even more marked. If droughts continue to impoverish local communities, the woodland will be increasingly sacrificed to provide a much-needed cash income. If a simple management scheme could be incorporated into the farming system without disrupting the existing mechanisms to any great extent, then there is a possibility that a more intensive system could be introduced in the grazing lands. The use of the project fencing to make vegetable gardens provides another opportunity to reinforce existing tree planting practices. Small tree nurseries could be set up alongside the vegetable seedbeds, where the seedlings would benefit from the protected environment.

6.4.4. ***Tenure and control of woodland resources***

6.4.4.1. *Usufruct in Tokwe III resettlement area*

In Tokwe III resettlement area, every village was found to have rules about the use of the woodland. Some rules, such as not cutting all one's pole requirements from one place and not cutting certain species of trees, were common to all villages, while others related specifically to one area. In general, people said that these rules are not respected. The blame for this was placed on the communal area people whom, it was said, would cut trees that resettlement villagers had been conserving, so that the incentive to preserve the trees was diminished.

The findings of this study are in keeping with those from other areas in Zimbabwe. In research covering a range of communal and resettlement areas in different ecological zones, Fortmann and Nhira (1992) describe the existence of similar sets of rules governing woodland use. They divide controls into four types: sacred controls, based on traditional beliefs; pragmatic controls or norms of behaviour designed to ensure a steady flow of a particular product; civil contracts or restraints on avaricious behaviour; and recent regulations laid down by new controlling institutions such as VIDCOs and natural resource committees. This division is questionable, however, because the different types of control are not so clearly defined. Traditional controls contain elements of both pragmatic controls and civil contracts, whilst the latter two are not obviously distinct. In addition, a civil contract presupposes the agreement of all parties, which may not always be the case.

6.4.4.2. *Resettlement village boundaries*

There were conflicting responses about the village boundaries which divide the woodland between communities within the resettlement area. Some said the only boundaries which restricted use of the woodland were those dividing communal and resettlement land. Others said that village boundaries had to be respected and any cutting in a neighbouring area had first to be allowed by

that area's leader. Thus no clear understanding of use-rights for each village exists, although village woodland limits are clear in people's minds.

6.4.4.3. *Control of woodland use in the resettlement area*

When asked why villagers allowed people from the communal area to use their wood resources, several reasons were given. In general, if their neighbours asked for firewood for funeral or wedding celebrations, or poles for roof-building, resettlement inhabitants did not refuse because they were sympathetic to the fact that wood is essential for such important functions. Some of the communal area dwellers did not ask, however, because they believed they had a right to the resources in the resettlement areas after having fought the liberation war to gain access to more land. In addition, many villagers had relatives in the nearby communal areas who also believed they should have access to the same resources which their relatives enjoyed. Resettled people did not feel they had the power to prevent the poaching of their resources by outsiders, and believed this was the main reason for their inability to control the use of the woodland since they arrived in 1985. They felt that local government by-laws and support from the local government agencies such as the resettlement office, the Department of Natural Resources and the Forestry Commission, would be necessary to enable them to punish intruders.

The resettlement office, apart from warning offenders, makes no attempt to enforce the rules governing removal of woodland resources from the area and, as yet, has not been involved in any conflict management measures. Villagers were generally of the opinion that they themselves used their woodland resources sustainably, and that if it were not for this problem of wood poaching, they would continue to find all their wood and other requirements in their areas *ad infinitum*. A handful of villagers disagreed with this view, however, saying that to blame the communal area people was merely using them as a scapegoat, and thought that the resettlement people too should change their behaviour if enough woodland were to survive to provide for their needs.

In the adjacent Shurugwi communal area, rules about woodland use are broken on a daily basis (Grundy, 1990) for a variety of reasons including land shortages, population pressure, a breakdown of traditional controls due to Western influence, and a belief that use of the woodland is an undisputable right (Abel *et al.*, 1989; Grundy, 1990; Matowanyika, 1991; McGregor, 1991). Most of these reasons do not apply to the resettlement area where wood resources are plentiful. The common factor between the two areas, however, is the lack of enforcement of existing rules, as a result of successive Government policies on resource management. In the communal area local leaders have no power to manage their resources due to the long-term erosion of traditional

controls and because these controls are impractical in the absence of alternative wood sources. In the resettlement area 'top-down', bureacratic policy-making has left villagers powerless to enforce rules, either traditional or new. Lack of cohesion amongst villagers and a mistrust of elected local government leaders are contributory causes.

6.4.4.4. *The present role of government institutions in woodland management*

Each resettlement area is administered by a resettlement officer and two or three assistants. Housing and office space is provided at business centres within the resettlement area so that these administrators can be in close contact with the people under their supervision. In Tokwe III, however, the resettlement officer lives and works at a distance of at least 30 km from the area he oversees, and, due to transport problems over the past five years, he has not been accessible to local people to attend quickly to their problems. Without the support of the resettlement officer on the ground, any collective woodland management initiative in the resettlement area is unlikely to succeed.

The resettlement programme suffers from acute personnel and financial shortages. Infrastructural problems, such as the lack of passable roads, a dearth of vehicles to transport commodities to and from resettlement areas, as well as boundary disputes and more pressing agricultural issues have priority in such circumstances, and issues of woodland management are virtually ignored (although not unacknowledged). In addition, forestry and agricultural extension in this particular part of the resettlement area is almost non-existent, due to a lack of human resources and transport in the local Forestry Department and incompetence on the part of the agricultural extension worker. Many people are interested in planting trees but do not have the encouragement or backup to do so. The lack of any support on the issue of wood poaching by communal area neighbours is also keenly felt. These are common complaints in resettlement areas in general in Zimbabwe, since the increase in the number of small-scale farmers as a result of the resettlement schemes was not accompanied by an equivalent increase in agricultural and forestry extension personnel. In addition, forestry extension workers in small-scale farming areas have acted in the past as purveyors of technical packages, rather than consultants, facilitators and catalysts of change (Scoones *et al.*, 1993). This is clearly demonstrated by their concentration on the planting of *Eucalyptus* species as a replacement for dwindling supplies of indigenous wood stocks, rather than on more appropriate multipurpose trees (Grundy, 1990).

6.4.5. *The potential for collective control of the indigenous wood resources*

At present, few of the requirements for a successful common property regime, listed in section 6.1.5., are fulfilled in Tokwe III and it is therefore not surprising that the communal resource is being used unsustainably. This paints a gloomy picture for the future sustainability of the resource. Until changes, in the form of new legislation and regulatory structures, are made on the part of the government, the indigenous woodlands in the grazing areas will continue to be over-exploited.

6.5. Conclusions

6.5.1. *Attitudes to indigenous woodland management by Tokwe III inhabitants and present management regime.*

The inhabitants of Tokwe III resettlement area believe they are managing their indigenous woodland sustainably by abiding by rules of prudent use. They are aware that some of the villagers are not adhering to these rules, but do not believe they have the power to prevent this. They are keenly aware that the resource has diminished rapidly since their arrival in the area. Some believe that their demand for wood products will be reduced in the future, now that their farms are well-established, while others think the resource will continue to be degraded. As yet, there have been no locally-inspired attempts to increase the intensity of management of the woodland. This may be because of the apparent abundance of the resource, or due to the heavy demand for woodland products from people outside the resettlement area. Villagers do not believe they have the right to regulate the use of the resource by outsiders, and therefore the incentive to manage the woodland sustainably is low.

6.5.2. *Implications of the findings for the future management of the resource.*

This study has highlighted the two overriding issues in the management of the communal woodlands in the resettlement area: lack of security of resource tenure and lack of institutional support for any management initiative. Given the need for wood products from unofficial user groups in the communal area and the competition with agriculture for land, the future survival of these woodlands as providers of wood products seems slim. The woodland still forms an integral part of the farming system, however, and by allowing poor farmers struggling with infertile lands and highly unpredicitable climatic conditions to spread their risks, its benefits are invaluable. At present the indigenous woodland is minimally managed, and, in view of its importance, a multi-

faceted approach to woodland management is suggested to ensure a continued supply of wood products. A locally negotiated resource-sharing scheme with neighbouring communal area farmers on portions of the wooded and wetland grazing areas would reintroduce the civil contract controls which have so far been lacking in these areas and would alleviate the problems of exclusive tenure of the woodlands. A more intensive management regime in the remaining woodlands, using rotational cutting in conjunction with livestock exclusion would encourage faster regrowth of the existing woodland. Finally a reduction in wood demand to reduce the demand for wood products from the indigenous woodland is necessary. This is two-fold and involves a) a concerted effort on the part of government extension officers to increase tree planting (not only the planting of multi-purpose trees on home sites and gardens but also of small woodlots of fast-growing poles which are more pest and drought resistant than those favoured at present); and b) an improvement in use efficiency of woodfuel and poles as well as the encouragement of the purchase of poles from external sources.

Although the situation of the resettlement areas is unique, many of the above suggestions are not new, nor do they require the use of expensive or locally unattainable techniques. What is required, however, is recognition from an essentially agriculturally biased administration that the survival of the woodland in resettlement areas is crucial to the well-being of the people living in and adjacent to these areas, and that, without a considerable change in administrative focus, it will either become so impoverished that it will be unable to yield the variety of goods and services required, or else it will disappear.

7

"Keeping or restoring the balance of the ecosystem is not only a matter of technology but also of an ordered social life"

(Schoffeleers, 1978)

The sustainable management of indigenous woodlands in resettlement areas

7.1 **Introduction**

Sustainable management of woodland resources is a delicate balance between the availability of the resource, the demand for woodland products and their value, the incentives for management, and the ability of the user group to manage the resource sustainably. In this chapter the options for the sustainable management of miombo woodland are reviewed in the light of the findings of this research. In the final section, the conclusions from the different components of the research, in conjunction with information from the literature, are drawn together in an attempt to formulate guidelines for the sustainable management of communally-owned miombo woodland.

7.2 **Factors influencing sustainability of woodland use**

7.2.1. ***The woodland resource***

7.2.1.1. *Productivity*

The equations developed in Chapters 2 and 4 will enable managers to generate more accurate estimates of standing biomass and productivity of miombo woodland in Zimbabwe than have been possible in the past. Estimates of standing biomass from different sites can be made using a general equation developed for miombo woodland (Chapter 4).

This work has shown that the growth rate of trees in dry miombo is slow and extremely variable, and depends on the site conditions and the structure of the woodland. The estimated annual productivity of dry woody biomass of 3 $t.ha^{-1}$ of a mature, mixed-aged woodland (Chapter 5) is higher than previous predictions. The published growth rates for miombo woodland are variable

and difficult to compare because of the variability in standing volume and the different units of measurement used. In the past a figure of 1 $m^3 ha^{-1} yr^{-1}$ (approximately 0.7 $t.ha^{-1}$) has been used (Beijer, 1984), although this may have been an average growth rate for all miombo, including the shrub woodland which exists in many of the communal farming areas. Estimates range from 0.7 to 6.7 $t.ha^{-1}.yr^{-1}$ (Beijer, 1984; Frost, 1985; Chidumayo, 1990; Abott, 1993). Growth and production rates are dependent on a number of interrelated factors, including climatic and edaphic site characteristics, species, age, standing volume, present and previous land use. Therefore growth for each site must be estimated individually. The annual growth rings made at least by the dominants of wet miombo (Fanshawe, 1959) and dry miombo (Chapter 3) should allow past growth rates to be estimated with greater confidence in future.

Variable growth rates are characteristic of dry deciduous woodland in Africa. Kemp (1963), working in woodland closely allied to miombo in northern Nigeria, found a wide range of growth rates within size class ranges, with some trees growing twice as fast as others. He calculated a rotation time of at least 100 years for maximum volume production. In dry miombo in Zimbabwe, where the rainfall is approximately half of that in Kemp's study area, the trees are likely to take longer to reach this point. Maximum volume is not a useful objective of management in small-scale farming areas, however, because of the unwieldy nature of the trunk and branches of trees of this size.

7.2.1.2. *Site influences*

In dry miombo woodland, soil depth, with its consequent effect on soil fertility and moisture availability, has the strongest influence over tree growth. Rainfall, clay content and temperature are also important determinants of growth (Chapter 4). Well-drained sites on deep fertile soils will therefore have the highest productivity. The management of the woodland will differ according to site differences (Chapter 5). On shallow sites, *J. globiflora* is likely to coppice better after felling, while on deeper sites, the better regrowth will be from *B. spiciformis*.

Because tree planting and woodland management have a low priority in the lives of rural farmers, in many cases good quality soils are only of interest for their agricultural potential. In an ideal situation, land for woodland management would be selected by choosing the sites with the tallest trees. Only in cases of the rehabilitation of degraded land would planting regimes be necessary and species and soil types need to be matched. With the increasing shortage of arable land in communal and resettlement areas, however, it is more likely that only sites which are unsuitable for agriculture will be left as woodland. The challenge to foresters in the future, therefore, is to

develop appropriate management regimes which will enhance woody growth even on these marginal sites.

7.2.1.3. *Coppice management*

Brachystegia spiciformis and *J. globiflora* both coppice vigorously after felling (Grundy, 1990; Chapter 5). *Julbernardia globiflora* responds the faster of the two, but does not produce more biomass than *B. spiciformis* by the end of the growing season. Thus, since the two species are co-dominant in most of the woodland areas in this region, and are also the preferred species for fuelwood (Grundy, 1990; McGregor, 1991), they are ideal choices for inclusion in more intensive management schemes.

As yet there are too few experimental plots which have been established for long enough to draw any definite conclusions about different management options. A coppice-with-standards system should reduce the erosion which may occur with clear-felling, and at the same time leave mature seed-producing trees to replenish the seedling bank. The short rotations of the coppice trees, in the region of seven to fifteen years, with thinning after three to six years, will take advantage of the initial fast growth rate of the coppice shoots (Hursh, 1960; Strang, 1965; Grundy, 1990). The standards, managed on longer rotations, will produce large poles for cattle pens, as well as the slow-burning wood required for brick-making. The stumps of these standards should coppice as vigorously as those of smaller trees (Chapter 5). Trees should be felled at 15 cm and an angle of 45 ° from the ground, using a sharp axe or saw to encourage vigorous regrowth from the stump (Grundy 1990). The use of other silvicultural techniques, such as water-harvesting or coppice reduction needs further investigation (Chapter 5). Bark stripping to make rope leaves damaged and useless stems (Grundy, 1990; McGregor, 1991). From this study, coppice reduction appeared to be beneficial only for the production of small poles and bark in mid-rotation, while water-harvesting was detrimental to tree growth.

7.2.2. ***Local wood requirements for fuel and construction***

In Shurugwi communal area, the total annual wood consumption was estimated at 6.4t.household^{-1}.yr^{-1} of dry woody biomass (McGregor, 1991), detailed in Table 7.1.

Another study of wood consumption, in a resettlement area in southeastern Zimbabwe, estimated that total annual wood consumption per household was 8.9t.yr^{-1} (Grundy *et al.*, 1993). McGregor's (1991) lower estimates above could demonstrate the resource-saving which is practiced in areas of wood scarcity.

Table 7.1. Annual consumption of fuel and construction wood per household in Shurugwi communal area (t.household^{-1}.yr^{-1}).

	Live wood	Dead wood	Recycled from construction	Total domestic fuel
Domestic fuel	1.8	2.7	1.3	4.9
Brewing	1.3			
Brick burning	0.4			
Construction	1.3			
Total live wood	4.8			
Total dry wood[1]	2.9	2.4	1.1	

[1] figures converted to dry wood using the estimate of 40% moisture for wet wood calculated in Chapter 2 and 12 % for air-dried wood (Goldsmith and Carter, 1981).

Using McGregor's (1991) figures, a communal woodland grazing area for a village of 30 resettlement households would be required to produce a total of approximately 200 t.yr^{-1} (dry weight). On average, each village in the resettlement area was allocated 1800 ha of grazing land, which would include large areas of edaphic grassland and possibly small wooded hill-top areas ('kopjes'), depending on the topography (GOZ, 1981). Assuming that half of the grazing area is unwooded, this leaves an average of 900 ha per village. Using the estimate of growth for these woodlands of 3 t.ha^{-1}.yr^{-1} (Chapter 5), and the rate calculated above, the woodland provides surplus and sustainable supplies of wood products for the resettlement communities alone, without any concerted efforts at management. The same conclusion was drawn by Grundy *et al.* (1993). Even if the actual wood consumption were double the estimates, and the rate of growth half, the present offtake of wood from the woodlands by the local communities would still be sustainable. This does not include wood leaving the resettlement area.

7.2.3. *Conflicts in land use within the resettlement area*

The conflict between the use of land for agriculture or woodland grazing is, in theory, non-existent in resettlement areas, since the land use categories were delineated from the initiation of the schemes (GOZ, 1981). This policy is not adhered to in Tokwe III, however, only seven years after resettlement (Chapter 6). With the increasing shortage of land, caused by high birth rates, increased poverty in the wake of the Economic Structural Adjustment Programme, and

government incentives to convert to a cash economy (see Cousins, 1993), conflicts in land use are likely to increase.

A major potential source of conflict is in the use of woodland for wood products and woodland for browse. Farmers obtain valuable browse from indigenous woodland for their livestock in the dry months when the nutritional value of grazing is low (Scoones, 1990). The cattle manure, in conjunction with leaf litter, is in turn an essential input into the agricultural system as organic fertiliser. Swift *et al.* (1989) calculate that an average communal farmer requires the browse and grazing from 14 ha of savanna woodland to support the sustainable production of 2 $t.ha^{-1}$ of maize. Given that arable holdings in the Tokwe resettlement area are 5 ha each (GOZ, 1981), a village of 30 households will require at least 2100 ha of grazing land to support their maize production. Assuming half of this were grassland, each village would require over 1000 ha of indigenous woodland in which to browse their cattle. Thus there is unlikely to be enough land available for the demarcation of woodland plots exclusively for wood production and yet coppice regrowth (particularly of *J. globiflora*) is significantly faster when protected from browsing, at least in the initial stages (Chapter 5). Cattle represent wealth to rural Zimbabweans (Scoones, 1990). In addition, regulations requiring farmers to reduce their cattle herds are too reminiscent of the colonial era to meet with success. Any woodland management programme would therefore have to be incorporated into the existing grazing schemes to be effective.

The annual productivity of the woodland in this study was calculated from the growth of trees in unbrowsed plots (Chapter 5). Published figures for the reduction in annual wood production in the tree layer due to browsing are rare. Walker (1980) gives figures in the region of 2 $t.ha^{-1}.yr^{-1}$ for mixed semi-arid woodland. Levels of browsing in indigenous woodland vary greatly depending on the stocking rate, the time of year, and the availability of more palatable species, and therefore direct comparisons with other sites could be misleading. The dominants of miombo are less palatable than many of the trees in the *Colophospermum mopane* woodlands from which Walker's figures were derived, so that the reduction in biomass is likely to be less than 2 $t.ha^{-1}.yr^{-1}$, depending on the stocking rate. In the absence of any other figures, this rough estimate suggests that the use of the woodland by the resettlement dwellers alone for browse and wood products may be unsustainable in the less productive areas. When the illegal and extra offtake which is transported to the nearby communal areas is taken into account, as well as the gradual reduction in woodland area in the process of increasing arable holdings, it is even more likely that the present use of the woodland is unsustainable. This is an urgent subject for future research and government action.

7.2.4. *Land tenure and control of the woodland resource*

7.2.4.1. *Present tenure*

Land in the resettlement areas is currently held under short term leases, the renewal of the lease being at the discretion of the resettlement officer, and being dependent on the productivity of the farmer. This has implications for any long-term activity such as tree planting and sustainable woodland management. The regulation of the system has also been shown to be inefficient, technocratic and needlessly bureaucratic (Murphree and Cumming, 1991; Ziana, 1995). These problems have been recognised, however, and the system is currently under review. Ultimately, as Scoones and Matose (1993, p190) point out, the issue is not a simple alternative between tenure types, but a question of developing the appropriate incentives and institutions for sustainable resource management and investment.

> "The incentives to manage a resource, under any tenure setting, are centred on management and institutional capacities, appropriate, enabling legal frameworks and co-management arrangements between local (individual or group) and central authorities. It is a question of institutions, and the structures within which they operate, rather than the tenure and title themselves."

The people of Tokwe III appear to be confident of their right to remain on their land, evidenced by the widespread planting of mainly fruit trees in secure areas near homesteads, but are not confident of their right to control the communal woodland resources. In Chapter 6, the issue of whether or not the resettlement woodlands should be collectively managed by local people, or whether the State should play a more dominant role in resource management was discussed. There is clearly a need for a rapid change in the *de facto* tenure of the woodlands, if they are to continue to produce wood products for local people. In the present undesirable situation the State has neither given complete control to local people, nor provided the necessary framework for successful State control.

Giving resettlement dwellers control over the management of their woodlands, and denying access to outsiders, is fraught with difficulties. Many communal area people would feel alienated by such legislation since the war of liberation is seen as one fought over land. The redistribution of land is a very emotive subject in Zimbabwe, and of great political importance (Murphree and Cumming, 1991). In addition, the farms which now make up the resettlement areas have supplied woodland products to communal area people since the first Tribal areas were set up more than 50

years ago (McGregor, 1991). The alternative of increasing State control over the woodlands seems even less likely to succeed, however, given the problems observed in the control of indigenous state-owned forests (Matose and Clarke, 1993; Nhira and Fortmann, 1993).

7.2.4.2. *Resource sharing*

Experience of efforts to exclude communal area people from State land containing much-needed wood resources has in the past shown that such measures are unsuccessful in maintaining the resource (Nhira and Fortmann, 1993). Consequently, resource-sharing programmes which would encourage communal area users to maintain and use the resource on a sustainable basis have been recommended (Fortmann and Nhira, 1992). Since the exclusion of communal area people from woodland in resettlement areas is such a sensitive issue, a similar resource-sharing programme is likely to have more success in providing for the wood needs of both user-groups in the long term than any legislation which withdraws use-rights from communal area people. The introduction of resource-sharing schemes to allow communal area dwellers access to indigenous woodland resources on State and commercial farmland is suggested by McNamara (1993), Nhira and Fortmann (1993), Scoones and Matose (1993), among others, to alleviate pressure on the resources in their own areas. In the case of Shurugwi communal area, which abuts Tokwe III, the farmers do not have access to such State or commercial farmland, and they therefore rely on the woodland resources in the resettlement area for the same purpose (Grundy, 1990).

The introduction of a resource-sharing scheme between the communal and resettlement areas is a new concept which would be beneficial to both user-groups, in that there would be greater control over the use of the woodland in an attempt to provide wood resources on a sustainable basis. The potential of such a scheme seems obvious, but as yet workable strategies have still to be developed. The major obstacle would be the delineation of the user-group. Resource-sharing schemes are in their infancy in Zimbabwe (see Matose and Clarke ,1993; Bradley and Dewees, 1993), and as yet there are few results to discuss.

7.2.4.3. *Use of private wood resources*

If the current tenurial situation in the resettlement area were to remain unchanged in the future, then a wood management scheme which encouraged tree planting around homesteads and in vegetable gardens is likely to be more successful than one involving the management of communal woodland. Previous work (Campbell *et al.*, 1993a; Scoones and Matose, 1993) has shown that the most intensive tree management in communal areas has been where user-rights are clearly defined. Resettlement farmers already plant trees where their use can be controlled, and

this practice should be encouraged. Tree-planting on private land should not be emphasised at the expense of a communal woodland management scheme in the grazing lands, however, since this will restrict access to essential resources by the poor and the landless in the longterm (Arnold, 1993). A broader scheme for tree management which encompasses both planted and existing indigenous woodland needs careful consideration.

7.2.4.4. *The future role of government institutions in woodland management*

Chapter 6 has shown that there is an obvious need for a more 'bottom-up' approach to forestry extension than exists at present, and a new breed of extension worker. A recent review of existing forestry extension in Zimbabwe has brought this, and other issues, to light (Scoones *et al.*, 1993). It has long been suggested that the benefits and techniques of social forestry (including agroforestry) would be best researched by the Farming Systems Research units of the Department of Agriculture, with inputs from a multi-disciplinary team of researchers, including foresters. The information would then be disseminated amongst farmers by the already-existing network of agricultural extension workers, aided by inputs from forestry agents (Casey and Muir, 1988). This suggestion, although practical, has some limitations. It is true that there is a good network of agricultural extension workers on the ground, who do have experience in dealing with farmers' needs. Most, however, have a didactic approach to extension and often ignore local farmers' innovations. In addition, these extension workers have focused solely on agriculture, to the detriment of trees; for example, a common agricultural practice until recently has been to encourage the eradication of all trees from arable areas (Casey and Muir, 1988; Fortmann and Nhira, 1992). Further, the incorporation of forestry work into the brief of the agricultural extension worker would mean that the arena of forestry development in rural areas would be taken out of the control of the Forestry Commission, a situation which Scoones *et al.* (1993) see as unsatisfactory. Instead, it has been recommended that a new approach be taken to forestry extension, using participatory techniques which put farmers' needs first, backed by a completely new training and retraining programme. This would involve close co-operation with agricultural extension agents to take advantage of the Department of Agriculture's greater human resources on the ground in rural areas (Scoones *et al.*, 1993).

The work and policies of the Zimbabwe Forestry Commission were recently the subject of a World Bank review (Bradley and McNamara, 1993). Existing legislation was examined, and appropriate alterations advocated. Scoones and Matose (1993) discuss this at length, detailing the changes in legislation which would be necessary for the success of locally-based resource management schemes. In summary, they advocate that restrictive policies should be replaced by

enabling legislation which will emphasise the local communities as beneficiaries; allow flexible, adaptive management based on local inititatives; and result in local institution strengthening. Without such a framework, any woodland management programme has little chance of success.

7.2.4.5. *Constraints to successful common woodland management regimes*

In a recent review of land tenure in communal and resettlement areas, a return to the old 'traditional' [1] village structure, led by chiefs and headmen, was advocated as a means of bolstering the government's agricultural policy (Ziana, 1995). The introduction of a new administrative system at Independence, where villagers are represented by elected village development committees which report to ward development committees, has resulted in conflict between the old and new regimes (Alexander, 1994). Murombedzi (1990) points out the importance of the legitimacy of any local regulatory institution in the eyes of those it seeks to regulate, and that each community's particular ecological, economic and social conditions must be considered in the establishment of such institutions.

In the absence of any 'traditional' leadership in the resettlement areas, the most obvious regulatory group is the village. A major obstacle to any communal resource management intitiative in resettlement areas, however, is the fact that the farmers (drawn from a wide range of ethnic, religious and age groups) form incohesive groups with little collective decision-making ability. Economic differences between neighbours were emphasised by the lack of investment, particularly of roads and marketing systems, in the resettlement areas which benefited wealthier farmers, or those with access to cattle. In addition, many farmers have stronger links with relatives in the near-by communal areas than they do with their neighbours in the resettlement villages. Fortmann and Nabane (1992) and Bradley and Dewees (1993), among others, warn of the pitfalls of regarding rural dwellers as uniform in their response to management initiatives. According to Fortmann and Nabane (1992), poorer households are less likely to participate in community woodlot projects, and are less likely to plant trees (for a number of different reasons related largely to access to labour and cash incomes), while the opposite is true of rich households (which often include local leaders), who in addition are more likely to benefit from the community schemes.

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[1] Most researchers in this field now agree that what in the past has been called 'traditional' is a mixture of colonial and pre-colonial ideology, while 'traditional management' has evolved from colonial extension messages and indigenous technical knowledge (see Gumbo, 1993).

7.2.5. *Incentives for management*

At present there are few incentives to manage the woodland sustainably in Tokwe III resettlement area. There are apparently large supplies of most woodland products, the illegal sale of which provides a good income for a few villagers, and the *de facto* owners of the woodland have no legal means of enforcing their exclusive rights to the resource. In such a situation, it is unlikely that a more intensive management scheme in the communal woodland area will be effective. Villagers are aware that their resource is being rapidly eroded on the edges of the resettlement area, however, and this may provide the incentive to investigate possible changes in future management.

7.3. **The way forward**

Like the recommendations for institution-building in rural areas (Chapter 1, section 1.5.3.5), the changes that Scoones and Matose (1993) and others suggest would require major new legislation on the part of the Government, and this is unlikely to happen in the short term. What must be done in the interim is to work within the existing framework as far as possible, with the co-operation of the various government departments, and aided by non-governmental organisations which are involved in natural resource management. The introduction of financial incentives to manage resources sustainably, similar to those given in the old Intensive Conservation areas of the commercial farming areas (McNamara, 1993; Scoones and Matose, 1993) could be used as the initial catalyst. At the same time, an interim programme developed at village level could be introduced to decrease wood consumption until more enabling legislation came into being. The effectiveness of such a scheme would be dependent on its acceptance by the user-group. Interventions could include using various wood-saving techniques such as the preservation of construction wood from attack by borers, fungi and termites (Grundy, 1990); the reduction in fuelwood demand by using more alternative fuels such as dung or crop residues (McGregor, 1991), or the many fuel-saving techniques such as cooking-fire management and improved brick kilns (Hancock, n.d.; McGregor, 1991); and having stricter controls over the illegal sale of wood from the resettlement areas. The use of neither dung nor crop residues is likely to affect crop production (McGregor, 1991). Dung for fuel is collected from the grazing areas, and would otherwise be eaten by termites, while the crop residues burnt are usually maize cobs (after the removal of the grain), which do not make good quality organic fertiliser. Maize cobs may, however, be fed to cattle in times of need, and at these times there may be a conflict of usage here. Improved wood stoves have not been found to be cost-effective in decreasing wood consumption, except in acutely deforested areas.

An intensive rotational management regime, which is approved by the user groups from both the communal and the resettlement areas, could provide a steady albeit reduced flow of wood products including browse, poles and firewood. The appreciation that the woodland in the resettlement area is not a free resource is, however, fundamental to the success of any such scheme.

In addition to any communal management programme, there is wide scope for both private and group initiatives to produce wood for sale on a profit-making basis. Small woodlots of multipurpose trees planted on individual land, or larger ones on communal land allocated to community groups could provide wood supplies for the ever-needy communal area population. A wood trade already exists, and there is an opportunity to build on that market in order to alleviate the pressure on the indigenous woodland. The impact of commercialisation on formerly communal resources is little understood (Arnold, 1993), but it appears that a gradual change is more likely to succeed than a rapid increase in commercialisation.

In the long term it is envisaged that farmers will be less and less reliant on the indigenous woodland for the satisfaction of their basic needs (Grundy, 1990; Nhira and Fortmann, 1993; McNamara, 1993). The development of on-farm wood and fruit resources, as well as community woodlots, should provide an alternative source of tree products which can be more intensively managed to provide surpluses for sale.

7.4. **Guidelines for management**

Effective management of indigenous woodlands by local people should involve low-cost, easily executed, locally acceptable, and environmentally sound interventions in order to be successful. A possible conclusion which could be drawn from section 7.2 is that the issues at stake, both ecological and social, are so complex, and the management process potentially so easily derailed that the development of sustainable management plans is at best an academic exercise. A successful development process is seldom straightforward, however, and so the following guidelines for sustainable use of the communally-managed woodlands in resettlement areas are proposed. The effectiveness of communal management depends on many of the changes to government legislation and direction which were advocated in section 7.2. The desired end point of these changes is the devolvement of management to the village level, so that these people have the power to manage their own resources. Any woodland management initiative should be multi-

pronged, and carried out with the co-operation of the community, as well as all the institutions involved in natural resource management. The process is seen as an iterative one, with continual adjustment and adaptation depending on the results of the previous stages.

7.4.1. ***Recommendations***

7.4.1.1. *Techniques to improve the growth of existing woodlands*

i) Manage woodland according to land availability and site characteristics

Site characteristics have their most significant effects on regenerative ability. Since many of the indigenous woodland management sites in small-scale farming areas are likely to be in areas of marginal agricultural potential due to the pressure for arable land, *J. globiflora,* which is known to grow on more xeric sites, may be more useful than *B. spiciformis. Julbernardia globiflora* is also the more preferred of the two for fuel and browse (McGregor, 1991). It makes an inferior bark fibre, but *Brachystegia boehmii* Lindau, which makes the best bark fibre of all, is often co-dominant with *J. globiflora* in drier areas and would provide this product. In areas where land is not limiting, woodland management areas should be demarcated on sites appropriate to the tree species to be managed. *Brachystegia spiciformis* will be more productive on deeper, more fertile soils.

Miombo trees continue to grow even during a drought, as indicated by the production of annual rings in *B. spiciformis*. This allows an accurate estimate to be made of the productivity of a site, and the most suitable areas for management to be chosen. Tall trees indicate deep soils and good biomass production, and where available these sites should be utilised. Such high quality sites are often found in small pockets dispersed within the woodland which would be too fragmented to be cultivated, but where coppice management could be used effectively to enhance wood production.

ii) Use a management system which will preserve the resilience of the ecosystem

A coppice-with-standards system is recommended to prevent widespread soil erosion. Trees could be coppiced in narrow strips interspersed with mature woodland, or alternatively the coppice-with-standards system could be used over large areas. The coppice would provide small poles on a short rotation, while the standards would provide larger poles over a longer period. Seed from *B. spiciformis* and *J. globiflora* is not dispersed far from the mother tree and therefore the presence of seed trees within 5 m of the coppice areas is essential if the seedling banks are to be replenished naturally. Most

of the annual biomass increase occurs in the first three months after the spring flush (August - early September in Zimbabwe), and therefore trees should be felled during the dry season. Trees should be felled at 15 cm from the ground at an angle of 45° to the stem, using a sharp axe or saw to encourage vigorous regrowth from the stump. Once the stands are established, two further interventions could be introduced: i) the number of coppice shoots could be reduced after a period of three to five years, to provide small poles for fuel and rope, leaving the remaining shoots to grow either into larger poles, or to provide subsequent crops of small poles; ii) the density of stems in sparse areas could be increased by damaging the roots of the existing trees, causing the production of root sprouts.

iii) **Control all stripping of saplings for bark and investigate alternative sources of fibre**

Because the practice of stripping the bark from young saplings to make rope causes large-scale damage to young trees in the woodland, this practice should be prevented. Instead, stems should be removed as part of a thinning or coppice reduction exercise, and the bark removed for rope-making once they have been cut. In most cases the bark is not a necessary component of the products - stems are usually stripped before making into poles, and barkless stems make equally useful firewood. The coppice stool will produce new, straight shoots which will grow at a faster rate, and provide useful end products, compared with the bent and damaged stripped stems which are of little value and which may cause the parent stool to become diseased. Alternative sources of fibre, such as sisal (which is already grown around homesteads), should be investigated to supplement bark fibre where possible.

iv) **Manage coppice on short rotations of seven to fifteen years**

Coppice shoots grow rapidly until the age of 15 to 20 years, at which point they slow down, so any management scheme where one of the main objectives is the increased production of poles should take this into account. By the time trees reach their maximum mean annual increment, they may be too large for use as poles or firewood in rural homes.

v) **Protect young coppice shoots from browsing by cattle**

Because of the palatability of *J. globiflora* foliage, and of all young leaves during the spring flush, it is advocated that cattle should be herded away from woodland

management areas. The availability of grazing land may be scarce, in which case there are two possible solutions: a) cattle could be herded away from the woodland, or parts of the woodland where coppice stools are producing new shoots, until February or March, by which time the shoots will no longer be so palatable, and the trees will have produced most of their woody growth for the year; b) trees could be pollarded at a height of 2 m so that new shoots are produced out of reach of cattle. This management suggestion may apply only to cattle, since Strang, (1965) found that the presence of goats in the woodland resulted in relatively little damage to the trees in comparison to cattle. In the absence of livestock, the ground layer may be reduced by controlled burning early in the growing season.

vi) **Avoid water harvesting techniques in miombo**

Water harvesting (the catching of rainwater with a soil bund to increase infiltration to the roots), which is practiced successfully in more arid environments, has been shown in this work to result in poor growth and crown die-back in *B. spiciformis* and *J. globiflora* and is therefore not recommended for use on these two species except on particularly steep slopes. Since woodland areas are often located on marginal, sloping ground, contour ridges could be constructed within the management areas to prevent excessive rainwater run off and erosion.

7.4.1.2. *Techniques to alleviate pressure on indigenous woodland areas*

i) **Investigate the possibility of incorporating woodland management schemes into the existing grazing schemes**

The pioneers of community resource management in small-scale farming areas were the livestock grazing schemes, and experiences from these have been invaluable in planning further initiatives. Because woodland use under one of the coppice systems relies on compartments and a rotational timetable much as grazing schemes do, the two types of management appear to be compatible, although the woodland rotations would be on a longer cycle than the grazing rotations. One compartment of the grazing scheme could be coppiced every year, and then left out of the grazing rotations for that growing season. During this time the coppice shoots would have had time to establish, after which they would be less vulnerable to damage from browsing. In well-wooded areas where there is no competition for grazing land, an intensive management area could be set out, which would be kept free from unplanned disturbance by humans and livestock.

ii) **Reduce the demand for wood products by local users**

Rural Zimbabweans are adverse to reducing their cattle herds for cultural and historical reasons, and therefore it is unlikely that there will be a reduction in the demand for browse from the woodland. Several initiatives could therefore be taken to reduce the demand for wood products from the communal woodlands, both in the communal and resettlement areas. These are:

a) to reduce fuel consumption by increasing wood-use efficiency. This is already practiced in deforested areas of Zimbabwe and includes the substitution of other types of fuel such as crop residues, dung, or paraffin. Alternatives to indigenous fuelwood may only be options for wealthy householders, however.

b) the preservation of construction poles with creosote or diesel so that they resist attack by borers, termites and fungi for longer.

c) the initiation of community woodlots to produce construction poles in short rotations.

d) the encouragement of 'farm forestry', where farmers plant various species of trees, both exotic and indigenous, on farm boundaries, on field contours, in home gardens and in any other available land, to provide private sources of poles and other produce.

e) the use of improved brick kilns and/or unburnt soil-stabilised bricks (made of a soil and cement mixture) (Grundy, 1990).

7.4.1.3. *Techniques to facilitate community management of the common property resource*

i) **Investigate the existing resource availability**

A successful management scheme requires a knowledge of the existing resource. An inventory of the communal woodlands should be carried out by forestry extension workers in collaboration with all the local people, so that every member of the village may participate in the decision-making process. Inventories in terms of numbers of poles or cords of firewood would be more beneficial than amounts in tonnes. In the past, schemes have often been devised where local headmen help in the planning stages, young school children help with the enumeration, and the community as a whole is only given token involvement in the decision-making.

ii) **Undertake a detailed socio-economic survey of the communities to be involved in the management scheme**

The success of a management scheme will depend on labour availability and perceived returns to labour investments in the scheme by local people. When forestry projects have been introduced in Zimbabwe in the past, it has often been the women who have

contributed their labour in the tree planting and tending process, but the men who have benefited from the sale of the products. These issues should be discussed in advance at all levels and by all parties concerned.

iii) **Determine the boundaries of the resource and the communities who have use rights**

The boundaries of the area to be managed must be agreed on by all involved, and clearly marked. The limits to the communities who are authorised to use the resource must be equally clearly defined, so that there can be no dispute as to who has access to the resource. In practice this is an extremely delicate issue, and requires an in-depth knowledge of the socio-economic dynamics of each community. As the value of the resources increases with scarcity, the greater will be the likelihood of conflict over their use.

iv) **Outline rules for resource use**

Clear rules for use of the resource must be developed by the community, aided by extension workers, through discussions, meetings, and workshops. Each community is unique, and must define its own set of rules for use, and the prevention of misuse, of the resource.

v) **Investigate need and possibilities for resource sharing**

Where the ownership of the resource is disputed, as in the case of resettlement areas, a resource-sharing scheme could be attempted. The objective of such a scheme would be a more even distribution of the resource among a larger number of people. Resettlement dwellers would have to accept a lower level of supply from the communal woodlands. In resettlement areas, the woodlands nearest the communal areas could be shared, while those nearer the resettlement villages could be managed more intensively to increase their productivity.

v) **Introduce an evaluation process**

This should be an iterative, participatory process which includes all community members, together with representatives of all institutions involved in the monitoring of the management scheme.

7.5. Closing remarks

The results reported in this thesis represent a first attempt to develop methodologies and conduct ecological studies aimed at improving the management of dry miombo woodland in resettlement areas in Zimbabwe. Some of the results have direct application for management, as detailed in the guidelines above, or for future studies of miombo, whereas others identify the need for further work to clarify the initial findings reported here (Appendix 4).

Faced with the limitations of inappropriate, disabling and antiquated forest policies, the challenge for future foresters, managers and communities is to develop appropriate methods of managing the woodland to the best effect and for the benefit of all. The increasing restriction of woodland to marginal areas and private land will require innovative management strategies. The study has highlighted the urgent need for further research on the ecology and appropriate management of this important woodland type.

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Appendix 1. Wood biomass estimation.

1.1. Validation of regression equations using an independent subset of the data.

The mean square error of prediction (MSEP) was calculated using the following formula:

$$\frac{(n-1)\, s^2(\partial) + (\partial)^2}{n}$$

where n = sample number, $s^2(\partial)$ = variance of the predicted values, and (∂) = the mean error of prediction.

1.2. Simple linear regression analyses to determine the 'best fit' model.

1) Using M (length of longest stem, from apex to base) as the independent variable (Σd) (sum of all diameters in the coppice stool, measured at 30 cm).

Table 1.1. Regression of total dry woody biomass (Bm) against maximum stem length (M).

	df	SS	MS	r^2
Brachystegia		$\log_{10}$ Bm = -0.97 + 2.43 $\log_{10}$M		
Regression	1	75.32	75.32	0.66
Residual	130	37.67	0.29	
Total	131	112.99		
Julbernardia		$\log_{10}$ Bm = -1.87 + 4.19 $\log_{10}$M		
Regression	1	75.72	75.72	0.89
Residual	138	9.72	0.07	
Total	139	85.44		

Table 1.2. Regression of total dry woody biomass (Bm) against sums of diameters (Σd)

	df	SS	MS	r^2
Brachystegia		$\log_{10}$ Bm = 2.74 + 2.05 $\log_{10}(\Sigma d)$		
Regression	1	80.78	80.78	0.72
Residual	130	32.21	0.25	
Total	131	112.99		
Julbernardia		$\log_{10}$ Bm = 2.77 + 2.01 $\log_{10}(\Sigma d)$		
Regression	1	67.57	67.57	0.79
Residual	138	17.87	0.01	
Total	139	85.44		

1.3. **Simple linear regression analyses to determine the 'best fit' model.**

2) Using D, $\Sigma(d^2)$, $(\Sigma d^2)M$ and $\Sigma(d^2L)$ as the independent variable.

Table 1.3. Regression of total dry woody biomass (Bm) against diameter of largest stem in the coppice stool.

	df	SS	MS	r^2
Brachystegia		$\log_{10}$ Bm = 3.95 + 2.64 $\log_{10}$(D)		
Regression	1	105.95	105.95	0.94
Residual	130	7.04	0.05	
Total	131	112.99		
Julbernardia		$\log_{10}$ Bm = 4.00 + 2.62 $\log_{10}$(D)		
Regression	1	79.24	79.24	0.93
Residual	138	6.21	0.05	
Total	139	85.44		

Table 1.4. Regression of total dry woody biomass (Bm) against summed squared diameters (Σd^2)

	df	SS	MS	r^2
Brachystegia		$\log_{10}$ Bm = 3.79 + 1.35 $\log_{10}(\Sigma d^2)$		
Regression	1	104.10	104.10	
Residual	130	8.89	0.07	0.92
Total	131	112.99		
Julbernardia		$\log_{10}$ Bm = 3.76 + 1.32 $\log_{10}(\Sigma d^2)$		
Regression	1	82.95	82.95	
Residual	138	2.49	0.02	0.97
Total	139	85.44		

Table 1.5. Regression of total dry woody biomass (Bm) against sums of squared diameters x maximum stem length (Σd^2)M.

	df	SS	MS	r^2
Brachystegia		$\log_{10}$ Bm = 2.29 + 1.01 $\log_{10}(\Sigma d^2)$M		
Regression	1	108.75	108.75	0.96
Residual	130	4.24	0.03	
Total	131	112.99		
Julbernardia		$\log_{10}$ Bm = 2.46 + 1.03 $\log_{10}(\Sigma d^2)$M		
Regression	1	83.75	83.75	0.98
Residual	138	0.01	0.01	
Total	139	85.44		

Table 1.6. Regression of total dry woody biomass (Bm) against summed squared diameters x maximum stem length (Σd^2L)

	df	SS	MS	r^2
Brachystegia		$\log_{10}$ Bm = 2.44 + 1.06 $\log_{10}$ (Σd^2L)		
Regression	1	110.36	110.36	0.98
Residual	130	2.64	0.02	
Total	131	112.99		
Julbernardia		$\log_{10}$ Bm = 2.50 + 1.04 $\log_{10}$ (Σd^2L)		
Regression	1	84.08	84.08	0.98
Residual	138	1.36	0.01	
Total	139	85.44		

1.4. **Species differences**

1.4.1. *Regression analysis using the combined data set for both species*

Table 1.7. Simple linear regression analysis for both species combined.

	df	SS	MS	r^2
Model		$\log_{10}$ Bm = 2.46 + 1.04 $\log_{10}$ (Σd^2L)		
Regression	1	194.03	194.031	
Residual	270	4.62	0.02	0.98
Total	271	198.65		
Model		$\log_{10}$ Bm = 3.97 + 2.63 $\log_{10}$ D		
Regression	1	185.06	185.06	
Residual	270	13.58	0.05	0.93
Total	271	198.65		

1.4.2. *Comparison of regressions for both species separately and both species combined.*

The following calculation was used to test whether the regression lines of the two species analysed separately were significantly different from the line obtained when the whole data set was analysed together:

	s.s	d.f.	m.s.
Residual variation for *B. spiciformis*	RSS_1	n_1-2	
Residual variation for *J. globiflora*	RSS_2	n_2-2	
Sum of residual variations	$RSS_1 + RSS_2$	n_1+n_2-4	s^2
Residual variation about a single line	RSS	(n_1+n_2)-2	
Difference	$RSS - (RSS_1+RSS_2)$	2	

$$F = \frac{\text{difference m.s.}}{s^2} = \frac{(RSS-(RSS_1+RSS_2))/2}{s^2}$$

F was compared with the F-distribution on 2 and (n_1+n_2-4) d.f. to test the hypothesis that there is no difference between the two regression lines.

From this calculation, $F_1 = 0.048$ $F_2 = 3.0$; df = 2, 268; p = 0.001.

$F_1 < F_2$ therefore the regression lines for the two species are not significantly different and the whole data set can be analysed together.

Appendix 2. Site assessment.

2. 1. Ground flora found at the nine miombo study sites.
Sites: 1 - 3 = Mazowe; 4 = Beatrice; 5 = Mafungautsi; 6 = Chatsworth;
7 = Burma Valley; 8 & 9 = Shurugwi. * = exotic species.

Site	Species	Authority	Family
7	*Acalypha allenii*	Hutchinson	*Euphorbiaceae*
1, 7, 8	*Acalypha villicaulis*	Hochst. ex A. Rich	*Euphorbiaceae*
1	*Adenia gummifera*	(Harv.) Harms.	*Passifloraceae*
1, 2, 7	*Agathisanthemum bojeri*	Klotzsch	*Rubiaceae*
8	*Aloe sp*		*Aloeaceae*
3	*Alysicarpus zeyheri*	Harv.	*Leguminoseae*
5, 6	*Andropogon sp*		*Gramineae*
5	*Andropogon gayanus*	Kunth.	*Gramineae*
6	*Aristida sp*		*Gramineae*
4, 7	*Aristida adscensionis*	Sw.	*Gramineae*
5, 7, 6, 9	*Aristida congesta*	Roem. & Schult.	*Gramineae*
6	*Aristida junciformis*	Trin. & Rupr	*Gramineae*
5	*Aristida sp (large)*		*Gramineae*
1, 2	*Aristolochia heppii*	Merxm.	*Aristolochiaceae*
4	*Asparagus africanus*	Lam.	*Liliaceae*
1	*Asparagus aspergillus*	Jessop	*Liliaceae*
5	*Asparagus sp*		*Liliaceae*
1,2,3,5	*Aspilia pluriseta*	Schweinf. ex Engl.	*Compositae*
5	*Bauhinia tomentosa*	Wall.	*Leguminosae*
3	*Becium grandiflorum*	(Lam.) Pichi-Sermolli	*Labiatae*
7, 9	*Becium grandiflorum*		*Labiatae*
2	*Berlinianche aethiopica*	(Welw.) de Vattimo	*Rafflesiaceae*
1	*Bidens biternata*	Lour. Merr & S	*Compositae*
1, 9	*Bidens pilosa*	Linn.	*Compositae*
4, 5	*Bidens sp*		*Compositae*
4	*Biophytum petersianum*	Klotzsch,	*Oxalidaceae*
2	*Blepharis glumacea*	S. Moore,	*Acanthaceae*
4, 5	*Blepharis maderaspatensis*	Juss.	*Acanthaceae*
1, 2, 4	*Blumea crispa*	(Vahl) H. Merxmuller	*Compositeae*
1	*Brachiaria brizantha*	Stapf,	*Gramineae*
8	*Brachiaria nigropedata*	Stapf.	*Gramineae*
5	*Bulbostylis burchellii*	C. B. Clarke,	*Euphorbiaceae*
4	*Celosia trigyna*	Willd. ex Wall.	*Amaranthaceae*
4	*Chamaecrista absus*	(L.) H. S. Irwin & R. C. Barneby	*Leguminosae*
4, 9	*Chamaecrista mimosoides*	Greene,	*Leguminosae*
1, 3	*Chamaecrista stricta*	E. Mey.	*Leguminosae*
1, 3, 8	*Chlorophytum sp*		*Liliaceae*
7	*Cissampelos mucronata*	A. Rich.	*Menispermaceae*
1	*Clematis welwitschii*	Hiern ex O. Kuntze,	*Ranunculaceae*
1	*Clematopsis villosa subsp kirkii*	Hutchinson	*Ranunculaceae*
5	*Clerodendrum glabrum*	E. Meyer	*Verbenaceae*
1	*Clerodendrum ternatum*	Moldenke	*Verbenaceae*
2, 6	*Combretum platypetalum*	Weld. ex Laws	*Combretaceae*

Site	Species	Authority	Family
1, 4,	*Commelina africana*	Linn.	*Commelinaceae*
4, 6	*Commelina aspera*	G. Don, ex Benth.	*Commelinaceae*
7	*Commelina benghalensis*	Wall.	*Commelinaceae*
2	*Conyza aegyptiaca*	Hook. f. & Thoms.	*Compositeae*
2	*Crassocephalum rubens*	S. Moore,	*Compositeae*
1	*Crassocephalum sarcobasis*	S. Moore,	*Compositeae*
1, 5	*Crotolaria sp*		*Leguminoseae*
7, 8	*Cryptolepis apiculata*	K. Schum. ex Engl.	*Asclepiadaceae*
1, 2	*Cryptolepis oblongifolia*	Schlechter	*Asclepiadaceae*
4	*Cynodon sp*		*Gramineae*
4	*Cyperus amabilis*	Vahl,	*Cyperaceae*
3	*Cyperus angolensis*	Boeck.	*Cyperaceae*
4	*Cyphostemma sp*		*Vitaceae*
1	*Cyphostemma gigantophyllum*	(Gilg. & Brandt) Descoings ex Wild & R.B. Drumm.	*Vitaceae*
1, 2	*Cyphostemma junceum*	(Webb) Descoings ex Wild & R.B. Drumm.	*Vitaceae*
3,4, 5, 8	*Desmodium barbatum*	Benth. & Oerst.	*Leguminoseae*
1	*Desmodium uncinatum* *	DC.	*Leguminoseae*
5	*Dichapetalum rhodesicum*	Sprague & Hutchinson	*Dichapetalaceae*
1, 4, 8,	*Dicoma anomala*	Sond.	*Compositae*
4, 7	*Dicoma schinzii*	O. Hoffm.	*Compositae*
6	*Digitaria (creeping)*		*Gramineae*
5, 6,	*Digitaria eriantha*	Steud.	*Gramineae*
7	*Digitaria milanjiana*	Stapf,	*Gramineae*
6	*Digitaria pentzii*	Stent	*Gramineae*
3	*Digitaria sp*		*Gramineae*
1	*Dioscorea dumetorum*	Pax,	*Dioscoreaceae*
1	*Diplolophium zambesianum*	Hiern,	*Umbelliferae*
1, 4	*Dolichos kilimandscharicus*	Taub.	*Leguminosae*
7	*Dyschoriste sp*		*Acanthaceae*
4, 5	*Emilia discifolia*	(Oliv.) C. Jeffrey	*Compositae*
6	*Eragrostis chapelieri*	Peters,	*Gramineae*
6	*Eragrostis curvula*	Nees,	*Gramineae*
2, 5, 6	*Eragrostis racemosa*	Steud.	*Gramineae*
6	*Eragrostis rigidior*	Pilger	*Gramineae*
4, 5	*Eragrostis sp (large)*		*Gramineae*
4	*Eragrostis viscosa*	Trin.	*Gramineae*
1, 2	*Eriosema englerianum*	Harms	*Leguminoseae*
12	*Eriosema nutans*	Schinz	*Leguminoseae*
7	*Erythrocephalum zambesianum*	Benth.	*Compositae*
5	*Evolvulus sp*		*Convolvulaceae*
1, 2, 5	*Fadogia ancylantha*	Schweinf	*Rubiaceae*
5	*Fadogia stenophylla*	Welw. ex Hiern,	*Rubiaceae*
4	*Felicia muricata*	Cass.	*Compositae*
2, 4, 5, 6, 7	*Fimbristylis macra*	Ridl.	*Cyperaceae*
4	*Gamphrena celosioides*	?	*Rubiaceae*
2	*Geigeria schinzii*	O. Hoffm.	*Compositeae*
1	*Gerbera viridifolia*	Sch. Bip.	*Compositeae*
1	*Glycine wightii*	(Grah. ex Wight & Arn.) Verdc.	*Leguminoseae*
5, 7, 9	*Helichrysum kraussii*	Vaill. ex Linn.	*Compositae*
7	*Helichrysum nudifolium*	Less.	*Compositae*
7	*Hemizygia bracteosa*	Briq.	*Labiatae*
1, 2, 3, 6, 7,	*Heteropogon contortus*	Beauv. ex Roem. & Schult.	*Gramineae*
7	*Heteropogon melanocarpus*	Pers.	*Gramineae*

Site	Species	Authority	Family
2	*Hibiscus rhodanthus*	Guerke, ex Schinz	*Malvaceae*
4, 8	*Hirpicium gracile*	(O. Hoffm.) Roessler,	*Compositae*
5	*Huernia sp*		*Asclepiadaceae*
1, 4, 5, 8	*Hyparrhenia filipendula*	Stapf,	*Gramineae*
2	*Hyparrhenia rufa*	Stapf.	*Gramineae*
3	*Hyparrhenia sp*		*Gramineae*
5	*Hypericophyllum compositarum*	Steetz,	*Compositae*
7	*Hyperthelia dissoluta*	(Nees ex Steud.) W. D. Clayt.	*Gramineae*
4, 5	*Hypoestes forskalei*	R. Br.	*Acanthaceae*
2	*Indigofera antunesiana*	Harms,	*Leguminosae*
2, 4, 8	*Indigofera setiflora*	Baker,	*Leguminosae*
4, 5, 9	*Indigofera sp*		*Leguminosae*
2	*Indigofera vicioides*	Taub. & Spach,	*Leguminosae*
7	*Indigofera wildiana*	J. B. Gillett	*Leguminoseae*
1	*Indigophera rhyncocarpa*	Linn.	*Leguminoseae*
1	*Inula glomerata*	Oliver & Hiern,	*Compositeae*
2	*Ipomeoa blepharophylla*	Hallier f. ex Engl.	*Convolvulaceae*
1	*Ipomoea obscura*	Hassk.	*Convolvulaceae*
1	*Justicia betonica*	Linn.	*Acanthaceae*
2	*Justicia elegantula*	S. Moore,	*Acanthaceae*
5	*Justicia sp*		*Acanthaceae*
7	*Justicia striata*	(Klotzsch) Bullock	*Acanthaceae*
4	*Kalanchoe lanceolata*	Pers.	*Crassulaceae*
4	*Kyphocarpa angustifolia*	?	*?*
1, 2, 3, 4, 5,	*Lannea edulis*	Engl.	*Anarcardiaceae*
1, 2, 5, 7	*Lantana camara* *	Linn.	*Verbenaceae*
1, 2, 3	*Launaea sp.*		*Compositeae*
1	*Ledebouria sp*		*Liliaceae*
6	*Leptactina benguelensis*	(Welw. ex Benth. & Hook. f.) Good	*Rubiaceae*
7	*Leucas milanjiana*	Guerke,	*Labiatae*
6	*Lopholaena coriifolia*	D. C.	*Compositae*
6	*Loudetia flavida*	(Stapf) C. E. Hubbard	*Gramineae*
6	*Loudetia simplex*	(Nees) C. E. Hubbard	*Graminae*
6	*Macrotyloma sp*		*Leguminosae*
3, 7	*Margaritaria discoidea*	(Baill.) Webster	*Euphorbiaceae*
5	*Melinis ambigua*	Hack.	*Gramineae*
7	*Melinis kallimorpha*	(W. D. Clayton) G. Zizka,	*Gramineae*
7	*Melinis nerviglumis*	Beauv.	*Gramineae*
1, 4, 5, 6, 7	*Melinis repens*	(Willdenow) G.Zizka,	*Gramineae*
1	*Mondia whiteii*	Skeels	*Ascplepiadaceae*
5	*Monechma debile*	Nees,	*Acanthaceae*
5	*Oldenlandia herbacea*	P. Br.	*Rubiaceae*
7	*Opilia celtidifolia*	Engl. ex Walp.	*Opiliaceae*
1	*Orthosiphon rubicundus*	Benth.	*Labiateae*
4	*Ossimum swavi / urtifolium*	?	*?*
5	*Oxygonum dregeanum*	Meissn.	*Polygonaceae*
2	*Pachystigma pygmaeum*	Robyns,	*Rubiaceae*
5	*Pandiaka sp*		*Amaranthaceae*
1, 9	*Panicum maximum*	Hochst. ex A. Rich.	*Gramineae*
7	*Panicum sp*		*Gramineae*
6	*Parinari (creeping)*		*Chrysobalanaceae*
5	*Paropsia brazzaeana*	(Stapf) Engl.	*Passifloraceae*
2	*Paspalum scrobiculatum*	Linn.	*Gramineae*
4	*Pavetta schumaniana*	F. Hoffm. ex K. Schum.	*Rubiaceae*

Site	Species	Authority	Family
1	*Pentas angustifolia*	(A.Rich. ex DC.) Verdcourt	*Rubiaceae*
6, 7	*Perotis patens*	Gandoger,	*Gramineae*
6	*Phyllanthus angolensis*	Muell. Arg.	*Euphorbiaceae*
9	*Phyllanthus nummulariifolius*	Poir.	*Euphorbiaceae*
2	*Pimpinella huillensis*	Welw. ex Engl.	*Umbellifereae*
1, 2, 4	*Plectranthus esculentus*	N. E. Br.	*Labiateae*
1, 4, 5, 6, 7,	*Pogonarthria squarrosa*	Stapf, ex Rendle,	*Gramineae*
4, 5	*Polycarpaea corymbosa*	Lam.	*Caryophyllaceae*
5	*Portulaca kermesina*	N. E. Brown	*Portulacaceae*
4	*Psychotria kirkii*	Hiern.	*Rubiaceae*
4	*Psydrax livida*	(Hiern(D.M. Bridson	*Rubiaceae*
1	*Rhoicissus tridentata*	(L. f.) Wild & Drumm.	*Vitaceae*
1	*Rhynchosia insignis*	(O. Hoffm.) R. F. Fries	*Leguminosae*
4	*Rhynchosia monophylla*	Schlechter,	*Leguminosae*
4	*Richardia scabra*	Linn.	*Rubiaceae*
1	*Ruellia cordata*	Thunb.	*Acanthaceae*
1	*Scadoxus multiflorus*	Rafin.	*Liliaceae*
6	*Schizachyrium jeffreysii*	Stapf	*Gramineae*
5, 6	*Schizachyrium sanguineum*	(Retz.) Alston	*Gramineae*
6	*Schizochyrium sp*		*Gramineae*
4	*Selaginella dregeii*	Linn.	*Selaginellaceae*
1	*Senecio venosus*	Harv.	*Compositeae*
4	*Setaria homonema*	Beauv.	*Gramineae*
4	*Setaria pimula*	Beauv.	*Gramineae*
1	*Setaria sphacelata*	Stapf & C. E. Hubbard ex Chipp	*Gramineae*
2	*Sida alba* *	Cav.	*Malvaceae*
4	*Sida cordifolia*	Forsk.	*Malvaceae*
4	*Spermacoce arvensis*	(Hiern) Good	*Rubiaceae*
1, 2	*Spermacoce dibrachiata*	Oliver,	*Rubiaceae*
5	*Spermacoce pusilla*	Wall.	*Rubiaceae*
1	*Spermacoce senensis*	Hiern,	*Rubiaceae*
4	*Spermacoce sp*		*Rubiaceae*
2, 3	*Spermacoce subvulgata*	(K. Schum.) Garcia	*Rubiaceae*
1	*Sphenostylis marginata subsp ere*	E. Mey.	*Leguminoseae*
4	*Sporobolis sp*		*Gramineae*
8	*Sporobolus africanus*	(Poir.) Robyns & Tournay	*Gramineae*
1, 3, 4	*Sporobolus pyramidalis*	Beauv.	*Gramineae*
6	*Sporobolus stapfianus*	Gandoger	*Gramineae*
3	*Steganotaenia araliacea*	Hochst.	*Umbellifereae*
4, 7	*Stereochlaena cameronii*	(Stapf) Pilger	*Gramineae*
2	*Stomatanthes africanus*	(Oliv. & Hiern) R. M. King & H. Robinson,	*Compositeae*
2, 3	*Stylosanthes fruticosa*	(Retz.) Alston	*Leguminoseae*
5	*Tephrosia cephalantha var decun*	Welw. ex Baker,	*Leguminosae*
1, 2, 4, 8, 9	*Tephrosia purpurea*	Pers.	*Leguminosae*
7, 9	*Tephrosia uniflora subsp uniflor*	C. B. Clarke	*Leguminosae*
1, 7	*Themeda triandra*	Forsk.	*Gramineae*
2	*Thesium goetzeanum*	Engl.	*Santalaceae*
8	*Thunbergia huillensis*	S. Moore,	*Acanthaceae*
1, 2	*Thunbergia lancifolia*	T. Anders	*Acanthaceae*
1	*Trachypogon spicatus*	Kuntze,	*Gramineae*
8	*Tricliceras longipedunculatum*	(Mast.) R. B. Fernandes	*Turneraceae*
1, 5, 6, 9	*Triraphis schinzii*	Hack. ex Schinz.	*Gramineae*
8	*Tristachya lualabaensis*	Nees,	*Gramineae*
5, 7	*Triumfetta annua*	Linn.	*Tiliaceae*

Site	Species	Authority	Family
2, 3, 4, 8	*Triumfetta dekindtiana*	Engl.	*Tiliaceae*
9	*Triumfetta rhomboidea*	Jacq.	*Tiliaceae*
5, 6	*Triumfetta sp*		*Tiliaceae*
2	*Triumfetta tomentosa*	Boj.	*Tiliaceae*
1, 2	*Triumfetta welwitschii*	Mast.	*Tiliaceae*
10	*Vernonia acuminatissima*	S. Moore	*Compositae*
1	*Vernonia adoensis*	Sch. Bip. ex Walp.	*Compositae*
1, 2	*Vernonia amygdalina*	Delile,	*Compositae*
3	*Vernonia filipendula*	Hiern.	*Compositae*
7	*Vernonia glaberrima*	Welw. ex O. Hoffm.	*Compositae*
1, 2, 3	*Vernonia glabra*	Vatke,	*Compositae*
2, 3	*Vernonia oligocephala*	Edgew.	*Compositae*
8	*Vernonia petersii*	Oliver & Hiern ex Oliver	*Compositae*
1, 5	*Vernonia poskeana*	Vatke & Hildeb.	*Compositae*
9	*Vernonia sp*		*Compositae*
1	*Vigna nuda*	N. E. Br.	*Leguminoseae*
1	*Vigna pygmaea*	R. E. Fries	*Leguminoseae*
2	*Wahlenbergia abyssinica*	(Hochst. ex A. Rich) Thulin	*Campanulaceae*
4, 5, 9	*Waltheria indica*	Linn.	*Sterculiaceae*
4	*Zornia glochidiata*	Moench,	*Leguminoseae*

Appendix 3. Coppice management

3.1. ANOVA tables.

The detailed analyses of the comparisons between treatments executed in chapter 5 are shown in Tables 3.1 to 3.14.

3.1.1. Coppice vs control

Table 3.1 Sample numbers used in the unbalanced comparison of coppice regrowth vs uncoppiced (control) regrowth.

	Plot				
Treatment	2	5	6	8	9
B. spiciformis					
Coppice	26	21	20	20	18
Control	44	18	19	20	18
J.globiflora					
Coppice	27	20	21	22	21
Control	27	19	17	21	15

Factor	Levels	Values
site	5	Sites 2, 5, 6, 8, 9
treatment	2	1 = coppice, 2 =control
species	2	1 = *B.spiciformis*, 2 = *J. globiflora*
size	2	1 = large stump (> 7cm), 2 = small stump (< 7 cm)

Table 3.2. ANOVA table for the balanced analysis of mean dry woody biomass of the largest stem of coppice stools in the protected coppice treatment, compared with those of thecontrol treatment.

Source	**DF**	**MS**	**F**	**p**
site (s)	4	11.16	0.44	0.782
treatment (t)	1	421.74	16.49	<0.001
species (sp)	1	3.53	0.14	0.711
size	1	294.70	11.52	0.001
s x t	4	14.76	0.58	0.680
s x sp	4	15.65	0.61	0.655
s x size	4	16.37	0.64	0.636
t x sp	1	6.40	0.25	0.618
t x size	1	220.08	8.61	0.004
sp x size	1	0.16	0.01	0.937
s x t x sp	4	11.03	0.43	0.786
s x t x size	4	17.13	0.67	0.615
s x sp x size	4	12.70	0.50	0.738
t x sp x size	1	0.65	0.03	0.874
site x t x sp x size	4	10.12	0.40	0.811
Error	80	25.57		
Total	119			

Table 3.3. ANOVA table for the unbalanced analysis of mean dry woody biomass of the largest stem of coppice stools in the protected coppice treatment, compared with those of thecontrol treatment.

Source	**DF**	**MS**	**F**	**p**
site (s)	4	0.49	2.16	0.073
treatment (t)	1	40.69	180.97	<0.001
species (sp)	1	0.37	1.63	0.203
size	1	39.04	173.60	<0.001
s x t	4	0.54	2.42	0.048
s x sp	4	0.85	3.77	0.005
s x size	4	0.24	1.05	0.383
t x sp	1	0.002	0.01	0.926
t x size	1	4.17	18.57	<0.001
sp x size	1	0.21	0.95	0.330
s x t x sp	4	0.25	1.12	0.349
s x t x size	4	0.29	1.28	0.278
s x sp x size	4	0.17	0.76	0.553
t x sp x size	1	<0.001	<0.01	0.990
site x t x sp x size	4	0.09	0.41	0.805
Error	391	0.22		
Total	430			

3.1.2. Coppice vs coppice reduction

Table 3.4 Sample numbers used in the unbalanced comparison of coppice regrowth vs reduced coppice regrowth.

	Plot				
Treatment	2	5	6	8	9
B. spiciformis					
Coppice	26	21	20	20	18
Coppice reduction	21	21	20	21	22
J.globiflora					
Coppice	27	20	21	22	21
Coppice reduction	18	21	21	20	19

Factor	Levels	Values
site	5	Sites 2, 5, 6, 8, 9
treatment	2	1 = coppice, 2 = coppice reduction
species	2	1 = *B.spiciformis*, 2 = *J. globiflora*
size	2	1 = large stump (> 7cm), 2 = small stump (< 7 cm)

Appendix 4. Recommendations for future work

This study has identified a number of topics for subsequent work, with the aim of improving the knowledge base of the functioning of miombo woodland, and ultimately providing the information required for better management of this important resource.

1. ***Annual productivity rates***.

There is a lack of information on growth rates of miombo at present, and many forecasts of wood yields are based on unsubstantiated estimates of growth. The first and greatest need is for accurate assessments of the annual production rates of miombo in different areas, in order to develop sustainable management strategies.

2. ***The estimation of woody biomass from aerial photographs and satellite images***

Using the biomass equations developed in this work, including those using crown measurements, and some of the newly developed geographical information systems (GIS) computer packages, it should be possible to estimate biomass more accurately from aerial photographs and satellite images than in the past.

3. ***Growth rings in miombo trees***

Since one of the dominants of miombo, *B. spiciformis*, makes annual rings, it is likely that other species within this vegetation type do the same. Can species which make more reliable and obvious rings be found, and if so, can they be used to document the effects of past management practices on the growth of the woodland? Can growth rings be used to develop fire histories of woodland areas? Do the roots show annual growth rings? What effect do site changes have on wood anatomy, and can these changes be used to good effect in management?

4. ***The effects of resource availability on miombo functioning***

In this work it was not possible to determine the exact effects of nutrient and moisture availability on tree growth. How does the availability of these two resources on different soil types affect species composition and wood production? Which of the two resources is limiting and under what conditions?

5. ***Site indices***

a) Can the distribution of woody species within miombo woodland be used to indicate changes in soil fertility and moisture availability? This could be attempted using the relative proportions of *Brachystegia* species present.

b) Can the height of trees of a diameter of 25 cm be used to indicate site quality in miombo woodland?

6. ***Bud production after felling***

Large trees have been found to coppice well after felling, but it is possible that large trees on shallow sites may not coppice as readily as those on deeper soils. Is this so?. Is there a critical size of stem after which bud production slows down? How long will trees continue to produce coppice shoots? How does the size of the root stock influence bud production?

7. ***Genetic effects on tree growth and biomass production***

Are certain populations of miombo trees adapted to certain climatic conditions? Do genetic variations cause differences in crown area and tree height?

8. ***Water harvesting***

What are the effects on the root systems of *B. spiciformis* and *J. globiflora* of water catchments? If water is a limiting factor in these woodlands, can this technique be adapted so that it is useful in improving the woody growth of these species?

9. ***Resource sharing***

Resource sharing has been heralded as one of the most hopeful methods of conserving wild animals in small-scale farming areas of Zimbabwe. What are the prospects for introducing this type of management in the indigenous woodland of resettlement areas in Zimbabwe?