DOCTOR OF PHILOSOPHY

Management of Vitellaria paradoxa in Guinea savanna rangelands in Ghana.

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MANAGEMENT OF *VITELLARIA PARADOXA* IN GUINEA SAVANNA RANGELANDS IN GHANA

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Abstract

From 1993-1994, a study of *Vitellaria paradoxa* was carried out. This study involved an in-depth review of biological and ecological information on *Vitellaria* throughout its range. Stand studies and an analysis of the climate in relation to fire risk. There were also experimental investigations of germination and pollination. All field studies were at the site of the Cocoa Research Institute outstation at Bole.

Stand characteristics of *Vitellaria* (>10 cm dbh) at the 68 km^2 plot of the Cocoa Research Institute's Sheanut Research Station, Bole were examined in two strata distinguished on the basis of distance from the nearest village: >3.0 km and <3.0 km. Regeneration (<10 cm dbh) was assessed and recorded for height, root collar diameter and mode of regeneration. Analysis of variance indicated higher stocking of individuals > 10 cm dbh further from villages but significantly more *Vitellaria* trees >10 m tall close to villages. Suckers accounted for > 86% of regenerating individuals, and more than 90% of regenerating plants were < 50 cm high. Analysis of climatic data indicated a mean drought index (1990-1994) of 514 ± 61 points. However, the fire danger index never reached an extreme value.

The germination response of depulped, cracked and intact seeds of *Vitellaria* sown under- and outside the canopy of mature *Vitellaria* trees (> 30 cm dbh), showed a significant association between germination and seed treatment: a higher proportion of depulped than intact seeds germinated. Open pollinated flowers, gave significantly lower fruit set than hand-pollinated flowers. There was no difference, however, in the amount of fruit set achieved with pollen from sources 50 m, 500 m and 1000 m away or from flowers of two different style lengths.

It is concluded that fires are adversely affecting the population structure and natural regeneration of stands at Bole, and that low fruit set in *Vitellaria* is due at least in part, to low vector activity. Suggestions are made for future research on the species.

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Chapter one

Introduction

INTRODUCTION

The shea butter tree, *Vitellaria paradoxa* C. F. GAERTN. (Syn. *Butyrospermum paradoxum*, (C. F. GAERTN.) HEPPER), known as karitè in francophone West Africa, is one of the most important trees of the Sudanian phytogeographical region. The economic importance of *Vitellaria* to the people of the region cannot be over-emphasised and is amply evidenced by the protection traditionally accorded the trees from the ravages of fire in the periphery of towns and villages. *Vitellaria* is greatly valued as a source of edible fat (shea butter), and much used in the cosmetic and pharmaceutical industries (FAO, 1993). It has long been important in international commerce (e.g. Holland, 1922 reports this at length), and is much appreciated for its high quality fat, which today is widely utilized in the formulation of cocoa butter substitutes (Purseglove, 1968). Extraction of the fat at household level is a very important cottage industry in rural areas and a major source of income for women (Abbiw, 1990; Anon, 1991). The nuts are the source of the fat and thus the main article of commerce. They are obtained from wild, unmanaged trees, and there are no traditions of planting because the species takes about 12 years to start bearing.

Many authors have identified a role for *Vitellaria* in combating soil degradation particularly in parklands (e.g. Pullan, 1974; El Hadji, 1984). Studies on *Vitellaria* in silvoarable systems in West Africa indicate improved soil fertility around the tree due to nutrient redistribution and enhanced plant-litter-soil recycling (Kessler, 1992; Kater et al. 1992).

Despite the importance of the tree in its socio-economic and enviromental role, its potential was not realised by the scientific community until the late

1970s. *Vitellaria* was included in the list of trees constituting Africa's forest genetic resource priorities at the fourth session of the FAO Panel of Experts on Forest Gene Resources (FAO, 1977), nine years after the inaugural session, although it had never appeared earlier. It was reported as being important for purposes other than wood production and justifying in-situ conservation action by the end of the 1980-84 quinquennium. Four years later the scope of recommended action was broadened (FAO, 1984) to include botanical and genecological exploration, a view reiterated at the panel's Sixth Session (FAO, 1988) with, in addition, an appeal for provenance trials to be implemented.

Vitellaria's range and resource role extend eastward well beyond West Africa, and shea butter has been a recognized non-timber forest product in Zaire, Uganda and Sudan for over 50 years. Nevertheless, only rarely have attempts been made to consider the species on a range-wide basis - briefly by Booth and Wickens (1988) and more comprehensively, in an unpublished dissertation, by Corbett (1989). It is interesting to note that at the Seventh Session of the FAO Panel of Experts on Forest Gene Resources (FAO, 1990) only Burkina Faso, Mali and Chad is it indicated that conservation action has started. However, Ghana's Cocoa Research Institute, has been establishing and monitoring stands for a decade and researchers have also been active in Nigeria. Clearly there has been little communication of knowledge of the tree among countries and any management initiatives continue to be on a national level. One aim of this thesis is to encourage greater awareness of the species as a resource of moist savanna north of the equator generally. This is attempted through an indepth review of its relations with environment over the whole range, since sustainable management of the species must be informed by genecological data.

Management in a savanna context is a neglected area where indigenous woody resources are concerned for a variety of reasons. When human populations were low, land use intensity had, at worst, only mild effects on savanna tree populations. Forestry services pursued other priorities - particularly timber exploitation from the closed forest zone - and no familiarity with woody species of the savanna developed. As plantation technology developed in the 1960s forestry involvement in the the savanna regions grew - but only in the context of planting exotic species. In-situ management of savanna trees is in its infancy and the services now asked to do it are finding the first need is to rebuild depleted populations by controlling the destructive agencies that prevent regeneration.

Intensifying use of savanna as a fuelwood resource supplying the expanding urban centres of the zone, increasing livestock impacts and more devastating fire regimes are all involved. Exotic species can be planted to ease pressure on savanna trees from exploitation for firewood. Livestock impacts can be addressed through a variety of management techniques in the moister savannas where *Vitellaria* occurs, since these are in the realm of the settled animal husbandman rather than the nomadic pastoralist. Reform in the manner in which livestock owners utilize their resource to cope with growing demand for fodder and grazing is a slow process. However, there is steady progress. Measures such as fodder banks and rotational grazing are being introduced and technical livestock professionals are learning that indigenous approaches to regulating range use also exist and offer a foundation for joint management in the future.

Livestock owners responsible for herds control where they go: savanna users who employ fire in resource exploitation often do not. Fire management is the principal challenge for the next century in the context of sustaining woody plant resources of the savannas. Compared with fuelwood supply and livestock management policies, the development of fire control and desirable burning practices for the West African savanna region is generally neglected. It is not clear who should be responsible for promoting more careful use of this essential tool but, in practice, early improvements are more crucial to the forester/agroforester than other resource professionals. It has been firmly established elsewhere in the tropics and subtropics, and especially in Australia, that climate determines the risk and intensity of fires - through both seasonal and day-to-day variations. Characterising the fire climate thus becomes a vital part of devising fire management routines. Special consideration is given to this in a section of the thesis (Chapter 4), using the Cocoa Research Institute of Ghana's outstation for a plot analysis of year-round fire danger patterns, viewing this as one facet of the management environment of *Vitellaria.*

Successful management of tree resources requires understanding and, where necessary and feasible, control of critical environmental factors. Nevertheless, it is equally important to appreciate the life cycle and biology of the species of interest and to relate these to the status of their populations in the context of the influence of the environment. With savanna trees, seed dormancy often confers resilience at the dispersal-establishment phase of the regeneration cycle. *Vitellaria* has no dormancy and conditions prevailing at dispersal determine whether germination is likely to be followed by establishment. Management can influence conditions to some extent in range use strategies and seed germination has therefore been a subject of some experimental work during this study. A further aspect of the reproductive process, the breeding system, has also been considered - through a controlled pollination experiment and investigation of floral polymorphy.

In summary, the objectives of this research are:

- to produce a comprehensive review of existing knowledge of the biology and ecology of *Vitellaria paradoxa,* taking into account of the full geographical range, and unifying and reanalysing the information collated

- to examine the fire/climate relationships in a locality where *Vitellaria* stocking is high and formal management of stands is most likely to prove rewarding

- to characterise the population of well-stocked stands of *Vitellaria* at the Cocoa Research Institute of Ghana's Bole Outstation

- to examine germination success under conditions typifying those prevailing, or which could be imposed, where the species grows at Bole

- to investigate the occurrence of floral dimorphism and examine the effect of pollination within and between populations on fruit production in *Vitellaria.*

- to identify from the results of these studies, and the literature review, priorities for further research and the management of the species.

Chapter two

Literature review

Chapter two

Literature review

In this chapter, available information on taxonomy, biology and ecology of the species is assembled. It consists of three sections. The first section (2.1) covers the taxonomy, systematics and describtion of the species. The second (2.2) outlines the biology, with emphasis on the phenology and reproductive biology. The third (2.3) deals with the ecology of the species rangewide. All sections are subdivided as appropriate.

2.1 Taxonomy and systematics of the species

Vitellaria is currently considered a monotypic genus in the Sapotaceae (Keay, 1989). Its botanical history begins with reports by Mungo Park (1799) who correctly referred it to the Sapotae (Sapotaceae) in his journal. By the time Park's plant was formally named (Don, 1838) as *Bassia parkii,* however, a seed of what later proved to be the same species had been described by C. F. Gaertner (in 1807) as *Vitellaria paradoxa*. Sometime later, placement in *Bassia* was deemed unacceptable and the species was re-named *Butyrospermum parkii* (Kotschy, 1864), this name remaining in common use for nearly a century. This long standing name was discarded in 1983 (Henry et al., 1983) and *Vitellaria* is now the nomenclature in use (Hall and Hindle, 1995). *Vitellaria* is the name used in this thesis.

Within the Sapotaceae over the years placement, determining its perceived closest relatives, has varied widely (Arends, 1976; Bokdam, 1977; Pennington, 1991) because of different weights attached to various morphological features.

In the most recent revision of the family, Pennington (1991) recognises *Vitellaria* as belonging to sub-tribe Mimusopinae of the tribe Mimusopeae. This reflects attention to the classifications put forward by earlier workers, combined with the occurrence of simple phenolic compounds (flavonols, procyanidins, propelargonidin and gallic acid), and the pollen morphology in Sapotaceous genera.

There are two subspecies of *Vitellaria paradoxa* - subspecies *paradoxa* and subspecies *nilotica* which occupy different, although contiguous geographical ranges. The western subspecies (*paradoxa*) occupies the more extensive range of the two, occurring from Senegal to the Central African Republic. Subspecies *nilotica* grows mainly in Sudan and Uganda, and its range just reaches Ethiopia and Zaire. The two subspecies are morphologically separated on floral and foliage features. The large flower of subspecies *nilotica* is one way to distinguish it from subspecies *paradoxa:* the style length is 8.0-12 mm as opposed to 12-15 mm for *nilotica*.

2.1.1 Description

Seedling

Bokdam (1977) describes the seedling of *Vitellaria* as cryptocotylar with cryptogeal germination. The fleshy persistent cotyledon remains enclosed in the testa.

The hypocotyl is not developed but the embryo is well developed. The straight cylindrical epicotyl which emerges after germination is 3 to 4 cm long and puberulous, bearing stipulate cataphylls. The first leaves [of the lateral shoots] are alternate and coriaceous with linear stipules 3 to 5 mm long. The petiole is canaliculate, 5 - 7 mm long and pubescent. The lamina is elliptic to narrowly elliptic, 4 - 7 cm long and 2 - 2.5 cm wide: its base is cuneate and its apex is rounded. The venation is craspedodromous (primary vein running down the centre with secondary veins branching off it) with a prominent marginal vein; the primary vein is stout, straight and distinct below. Secondary veins diverge from the midrib at moderately to widely acute angles, being uniformly curved and terminating in a marginal vein. The secondary veins are confluent with the tertiary veins. The quaternary veins are reticulate and prominent on both sides of the lamina.

The taproot which develops from the ill-defined radicle during germination, becomes solid and woody with a cylindrical to angular appearance at the root crown. According to Bonkoungou (1987), at 6 months the taproot is 20 cm long and at 18 months 65 cm long.

Mature tree

Habit, size and form

The architecture of *Vitellaria* corresponds to Aubreville's model (Hallé et al., 1978). The trunk extends from a single apical meristem - monopodial, grows rhythmically with spiral arrangement of leaves (phyllotaxis) in terminal cluster. The branches similarly grow rhythmically in horizontal complexes in which more peripheral shoots repeatedly outgrow the shoot from which they origiate. Since inflorescence is lateral growth continues indefinitely.

Delolme (1947) provides information on the structure of *Vitellaria* at the Agriculture Research Station, Ferkessedougou (3°36'N 5°12'W), Ivory Coast. He describes three distinct patterns of growth for the stem and branches. The first is apical growth, restricted to young shoots. The second is rapid elongation of the tissues of the stipulated buds on the terminal shoots. This growth occurs from 5-6 years with production of auxillary branches which can extend 15-20 cm in a year. Except in very vigorous individuals, such growth occurs only once in a year. The third growth is much slower and occurs in mature trees by terminal elongation forming two characteristic barrel-shaped nodules. The first nodule forms just after leaf fall as the tip of the branch swells, this bears the flowers and leaves of the subsequent season. The second is produced during vegetative growth, after flowering. This growth pattern is very slow. Observations made for 22 years showed branch elongation of 45 cm and 1-2 cm diameter growth (Delolme, 1947).

Vitellaria is usually 10-15 m high, the top highly branched and ramified (Bonkoungou, 1987). It has a characteristic square scales of deeply fissured bark of great thickness (Lely, 1925) about 1.5 to 2.0 cm deep in mature (15 years) trees. Hopkins (1962) reports bark thickness of 22 mm for subspecies *paradoxa* of height 11 m and dbh 34 cm in the Olokemeji Forest Reserve, Nigeria. Eggeling and Dale (1951) indicate a size of 4-6 cm for the square scales of subspecies *nilotica*.

According to Ruyssen (1957) the Bambara people distinguish three crown shapes: the first is ball (boule) shape, which has upright main branches but horizontal secondary branches giving the crown a compact sphere-like appearance. The bark has cracks of medium depth. The second is umbrella (parasol), the secondary branches grow upwards in a V-shape. The peripheral branches almost reach the top of the crown. The proximal branches are shorter, and the crown spreads out in an umbrella-shape form. The tree more or less lacks leaves at the base of the crown but is leafy near the top. It has an upright habit. The bark is fine with superficial cracks. The third is intermediate between the two described above, but more or less similar to the ball-type but with the crown more spread out. The main branches are near horizontal. The bole is clear and the bark thick with deep cracks.

Ruyssen (1957) considers 4-5 m height as normal for mature trees to commence fruiting in Ferkessedougou, Ivory Coast. Delolme (1947) recorded heights of 2-3.5 m and dbh 6.4-9.8 cm for 15 years old trees at the same station. In protected environments, subspecies *paradoxa* usually grows to heights of 15 to 20 m and sometimes 25 m with dbh 30-60 cm (Chevalier, 1943).

Bonkoungou (1987) reports vigorous initial downward root growth, but that the tap root does not penetrate deeply - usually only 0.75-1.0 m. According to Breman and Kessler (1995), the tap root reaches a maximum depth of about 2 m for subspecies *paradoxa*. The lateral roots are shallow. Hopkins (1962) considered lateral roots of trees, height 3 m, hardly penetrated deeper than 60 cm. At Ferkessedougou, Ivory Coast, a tree of dbh 48 cm had lateral roots extending more than 20 m within the top 10-20 cm soil (Delolme, 1947).

Foliage

Similar descriptions are given for the foliage of both subspecies *paradoxa* and *nilotica* (Eggeling and Dale, 1951; Hutchinson and Dalziel, 1963). The leaves are simple, entire, elongated (Bonkoungou, 1987) and spirally arranged in a dense terminal cluster at the shoot apex in the axils of scale leaves (Hemsley, 1968; Pennington, 1991). They vary considerably in size and shape. The leaf can be oblong, elliptic, oval or spathulate with petiole 3-16 cm long (Table 2.1). There are 20-30 pairs of conspicuous lateral nerves which spread almost at right angles. The leaf of the mature tree is glabrous in subspecies *paradoxa* but pubescent in subspecies *nilotica.* The leaves of subspecies *nilotica* are mostly wider than those of subspecies *paradoxa.*

Table 2.1 Leaf size reported for *Vitellaria paradoxa.*

subspecies	leaf length x width(cm)	location	reference
1	30 x 11	Ejura, Ghana	Chipp 756, K[1]
2	27x9.5	Sudan	Schweinfurth 2785, K
2	25x11	Uganda	Eggeling & Dale (1951)
2	25x10.5	Nioka, Zaire	Taton 222, P
1	23x7	Ghana	Coull (1927)
1	22x7	Bouloli, Mali	Vuillet 25, K
1	21x5	Longouassou, Ivory Coast	Chevalier 22154, P
1	20x6	Niokolo-Koba, Senegal	Berhaut 1473, P
2	18-22x7	Nakasiagola, Uganda	Langdale-Brown 2307, K
1	16x4	Koulikoro, Mali	Vuillet 571, K
1	15x7	Tanguieta, Benin	Chevalier 240097, P
1	15-20x6-7	Zaria, Nigeria	Lamb K
1	14x6	Dassa, Benin	chevalier 23639, P
1	14x5	Ouada Djole, CAR	Aubreville 428, P
1	11-16x3-4	Bukabuka, Ghana	Thomson 70, K
2	10-25x4.5-14	E/Africa	Hemsley (1968)
1	10-25x5-8	W/Africa	Hutchinson & Dalziel (1963)
1	10-25x4-12	Cameroun	Vivien (1990)
1	10-14x4-5	Bouake, Ivory Coast	Chevalier 22111, P
1	10-11x2-3.5	Pirada, Guinea	d'Orey 308, K
1	9-10x3-4	Bonfara, Ivory Coast	Leeuwenberg 4418, K
2	5-25x3-6	Uganda	Breitenbach (1963)

1 *paradoxa*; 2 *nilotica.*

Inflorescence and flowers

There are no consistent differences between subspecies in the number of floral parts but wide variations exist in the size of the floral parts within each subspecies (Table 2.2). The degree of pubescence distinguishes the two subspecies. The hermaphrodite flowers are arranged in dense umbels or corymbs at the extremities of the shoots, usually 30-40 flowers and

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[1] Throughout this thesis, voucher specimen are designated according to collector and number, separated by a space. A comma follows the number, separating this from the abbreviation for the herbarium which holds the specimen.

sometimes 80-100 in a single umbel (Eggeling and Dale, 1951; Ruyssen, 1957). The flower is 2-3 cm in diameter, white, nectar producing and sweet-scented.

Subspecies *paradoxa* has a sparsely pubescent pedicel up to 3.0 cm long (Ruyssen, 1957). The pedicel of subspecies *nilotica* is covered with a dense, long spreading ferruginous indumentum giving it a woolly appearance (Hemsley, 1961). Sepals are 8, rarely 10, in number, oblong-lanceolate shaped, and arranged in two rows. In subspecies *paradoxa*, the sepals are softly pubescent outside. The outer sepals of subspecies *nilotica* having dense, long, rust-coloured indumentum giving them a woolly appearance (Hemsley, 1961). The 8 (sometimes 6 or 10) apiculate staminodes are petaloid (Hutchinson and Dalziel, 1963). Delolme (1947) examined over 6900 flowers from 77 trees and found combinations of 8 petals and 8 stamens, of 9 petals and 9 stamens and of 7 petals and 7 stamens in 92%, 2.8% and 1.4% of the flowers respectively for subspecies *paradoxa*. The egg-shaped pubescent ovary is superior (Chevalier, 1943) and has between 8 and 10 locules, each containing a single ovule (Cobley, 1963; Hemsley, 1968).

The dimensions of flower parts for subspecies *nilotica* are larger than those of subspecies *paradoxa* - notably the sepals, filaments and styles (Table 2.2).

Table 2.2 Measurement (in mm) of parts of flowers of *Vitellaria paradoxa* *.

species	sepals length x width outer	 inner	corolla lobes l x w	corolla-tube length	filament length	anther length	style length	reference
2	14x6	14x4.5	11x6.5	4.0	11.5	4.5	15.0	Snowden 270, K
2	11x5	11x3.5	9.5x7.0	2.5	10.0	3.5	12.0	Speke & Grant 650, K
2	10.5x5.5	10x5.0	11.0x7.0	4.0	10.0	3.5	13.5	Brasnett 334, K
1	10x5.0	10x3.5	11.0x6.0	3.0	7.5	5.0	8.0	Kitson 899, K
1	10x4.5	9.5x4.0	9.0x6.0	3.0	7.0	4.0	9.5	Elliot 23, K
1	9.5x3.5	9.0x3.0	7.0x4.5	2.5	7.0	4.0	12.0	Carroll 1,K
1	9.0x4.3	9.0x4.0	9.0x6.0	3.0	8.0	3.5	11.0	Barter 1178, K
1	9.0x4.0	9.0x3.5	9.0x6.0	3.5	9.0	3.2	10.5	Ross 73, K
2	8.5x5.0	9.5x5.0	7.5x7.0	4.0	12.0	3.5	13.0	Schweinfurth 2785, K

1 *paradoxa*; 2 *nilotica*

* based on Hemsley (1961)

Fruits and nuts

Different shapes and sizes have been described for the fruits and nuts of both subspecies (Delolme, 1947; Eggeling and Dale, 1951; Booth and Wickens, 1988). The fruit of *Vitellaria* is a berry (Coull, 1928; Hemsley, 1968). The pericarp is 4-8 mm thick (Aubreville, 1950). The epicarp of the fruit is green. The immature fruit has a tough mesocarp which softens when mature. The endocarp is white and is fairly soft in the immature state but hardened when ripe (Greenwood, 1929).

The shape of the fruit has been variously described as subspherical and ellipsoid for both subspecies (Chevalier, 1943; Hutchinson and Dalziel, 1963; Hemsley, 1968). Greenwood (1929) recognizes two fruit shapes in Nigeria; round (round to ovoid) and long (oval to elliptical). Delolme (1947) indicates four different shapes in Ivory Coast; oblong, round, reverse-pear and fusiform, reflecting the degree of eccentricity from the main axis of symmetry.

The diameter of the fruit is never less than 50% of the length (Table 2.3). There is usually one (sometimes two, and rarely three) nuts per fruit. The shape of the nut varies, Ruyssen (1957) describes the nut of subspecies *paradoxa* as spherical, ovoid and fusiform, while that of subspecies *nilotica* is described as oval (Eggeling and Dale, 1951). The nut shape mirrors that of the fruit. Individual nuts are up to 4.5 cm long (Booth and Wickens, 1988) and on average weigh (fresh) 9-10 g (Delome, 1947). The fresh nut contains 48-60% by weight of moisture and is dark brown in colour. The fat content varies widely between individual trees, within and between populations and between years. Normally it falls between 40% and 60% of dry nut weight (Bourlet, 1950; Breitenbach, 1963; Godin and Spensely, 1971).

Table 2.3 The size/weight of fruit reported for *Vitellaria paradoxa*

Species	location	weight (g)	size (cm) length x width	reference
1	Shika, Nigeria	56.8	5.8 x 4.2	Greenwood (1929)
1	Iponrin, Nigeria	34.6	4.6 x 3.6	Greenwood (1929)
1	Iponrin, Nigeria	30.7	4.9 x 3.3	Greenwood (1929)
1	Saria, Ivory Coast	26.4	3.5 x 2.5	Aubreville (1950)
1	Cameroun	26	5-8 x 3-4	Vivien (1990)
1	Fekessedougou, Ivory Coast	21		Delolme (1947)
2	Sudan	10-45		Ruyssen (1957)
2	E/Africa		6.5 x 4.5	Hemsley (1968)
1	W/Africa		5-8 x 3-4	Maydell (1986)
2	Ethiopia		5-6 x 4-5	Breitenbach (1963)
2	Uganda		5-6 x 4-4.5	Eggeling & Dale (1951)
1	Nigeria		5 x 2.5	Lely (1925)

1 *paradoxa*
2 *nilotica*

2.2 BIOLOGY

2.2.1 Chromosome number

There are two reports of the chromosome number of *Vitellaria* (Table 2.4). Both are for subspecies *paradoxa* and both indicate 2n=24. Arends (1976) regards *Vitellaria* with 2n = 24 as evolutionarily advanced in the Sapotaceae, where 2n = 28 is deemed primitive.

Table 2.4 Reported chromosome number for *Vitellaria paradoxa*

Subspecies	2n	Location	Author
paradoxa	24	Kwara (8°30'N 5°45'E), Nigeria	Pilz (1980)
paradoxa	24	Burkina Faso	Miege (1954)

2.2.2 Life cycle and phenology

Life cycle

The ripe fruits are dispersed from the trees by animals or fall at the onset of the rains. There is no period of dormancy and once dispersed germination is immediate (Jackson, 1968). In natural populations growth is retarded by droughts and frequent fires. The species may exist as a suffrutex for several years before becoming a typical tree sapling (Jackson, 1968). The relationship between age and the beginning of fruiting (mature trees), period of maximum fruit production and life span (longevity) of *Vitellaria* is summarized in Tables 2.5 and 2.6. *Vitellaria* takes 12 to 15 years to reaching bearing age and 30 years to mature (Dalziel, 1937). Ruyssen (1957) and

Delwaulle (1979) consider the tree starts bearing at 20 years and reaches full production at 50 years. Chevalier (1948) suggests that the first flowers that appear are often sterile, and that full production is attained at 80-100 years. Eggeling and Dale (1951) consider subspecies *nilotica* matures at 30 years.

Table 2.5 *Vitellaria paradoxa*: seedling growth and increment

Reference	Locality	Approximate age (months)	Height (m)	Remarks
1	6	6	0.08	nursery plants
2	5	108	4-6	sucker regrowth
3	4	36-48	1.7	sucker regrowth
1	6	18	0.16	nursery plants
4	2	102	5.5	rain-fed plant
5	3	192	2-3	natural conditions
6	1	24	0.06-0.11	direct field sown seed
2	5	24	0.1-0.15	forestry services planting
2	5	36	0.2-0.25	forestry services planting
2	5	120	2-3	forestry services planting

Source: 1 Salle et al. (1991); 2 Ruyssen (1957); 3 Bonkoungou (1987); 4 Jackson (1968); 5 Delolme (1947); 6 Chevalier (1948).

Localities: 1 Ferkessedougou (9°37'N 5°05'W); 2 Ibadan (7°26'N 3°54'E); 3 Korhogo (9°25'N 5°37'W); 4 Ouagadougou (12°21'N 1°31'W); 5 Bamako (12°38'N 8°01'W) ; 6 Niagoloko (10° 25'N 5°00'W).

Longevity is estimated by Delwaulle (1979) and Fleury (1981) at 200 years, Chevalier (1948) gives an estimate of 200-300 years and Busson (1965) suggests 300 years (Table 2.6).

Table 2.6 Reports on the relationship between age and maturity in *Vitellaria* in natural communities.

Subsp.	Age (years)	Comment	Author
1	12	mature tree	Irvine (1961)
2	12-15	mature tree	Eggeling & Dale (1951)
1	12-15	mature tree	Greenwood (1929)
1	15-20	mature tree	Leplaideur (1987)
1	15-20	mature tree	Chevalier (1948)
1	17-20	mature tree	Bonkoungou (1987)
1	20	mature tree	Ruyssen (1957)
1	20	mature tree	Fleury (1981)
1	20	mature tree	Delwaulle (1979)
1	20-25	maximum production	Greenwood (1929)
2	30	maximum production	Eggeling & Dale (1951)
1	40-45	maximum production	Ruyssen (1957)
1	45	maximum production	Fleury (1981)
1	50	maximum production	Delwaulle (1979)
1	80-100	maximum production	Chevalier (1948)
1	200	longevity	Fleury (1981)
1	200-300	longevity	Chevalier (1948)
1	300	longevity	Busson (1965)

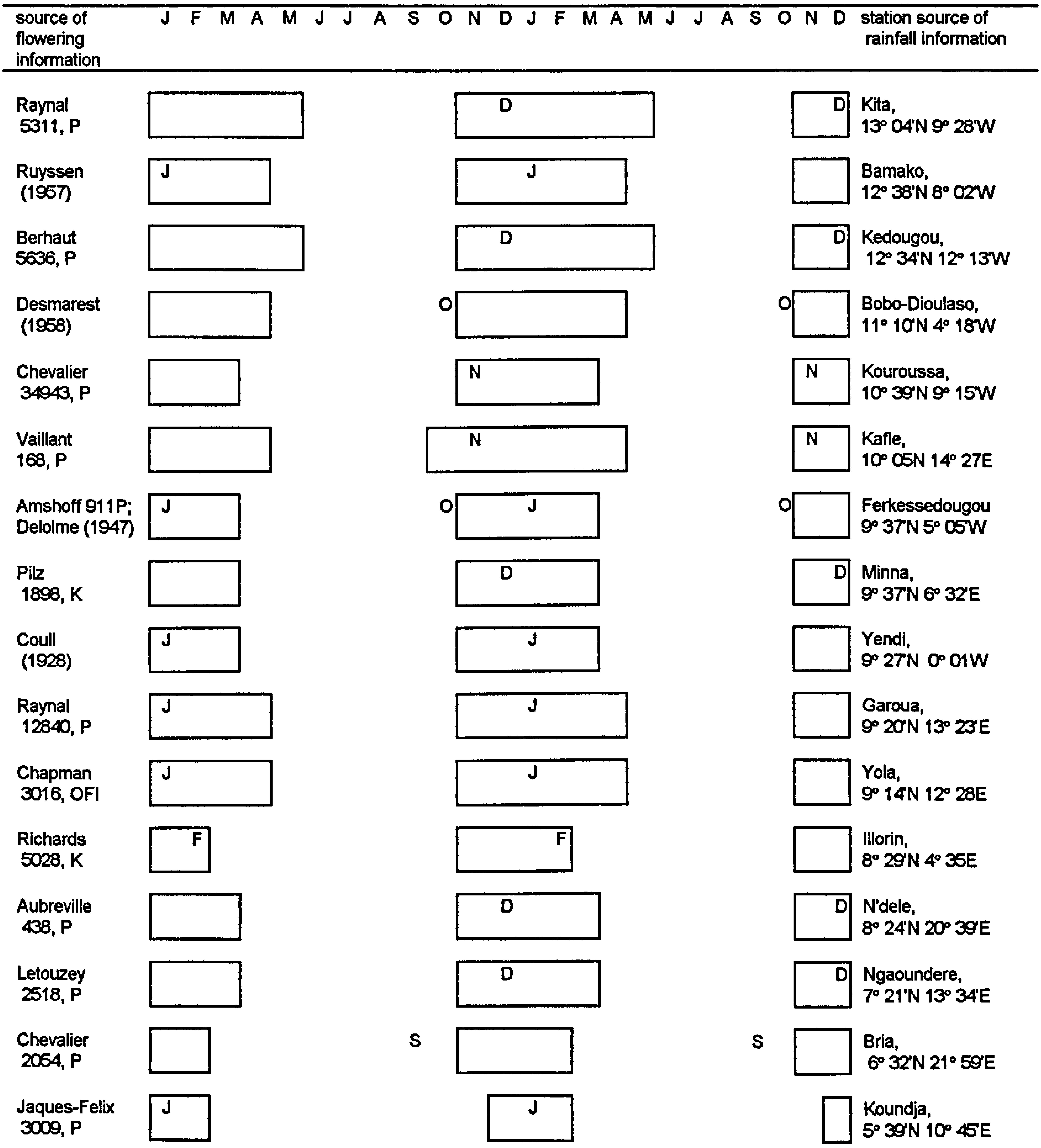
1 *paradoxa* 2 *nilotica*

Phenology

There are few location-specific reports on the phenology of *Vitellaria:* only reports by Coull (1928), Delolme (1947), Ruyssen (1957) and Desmarest (1958) are relevant. Collating information from herbarium specimens and collectors' notes and associating this with climatic data from nearby meteorological stations, however, enables a much more comprehensive picture of seasonality in flowering and fruiting for some localities (Figs 2.1

and 2.2). This has been done using information from collectors' notes accompanying herbarium specimens and specific phenological comments from the literature.

Fig 2.1 Flowering records of *Vitellaria paradoxa* subsp. *paradoxa* in its range



Flowering records of *Vitellaria paradoxa* subsp. *nilotica* in its range

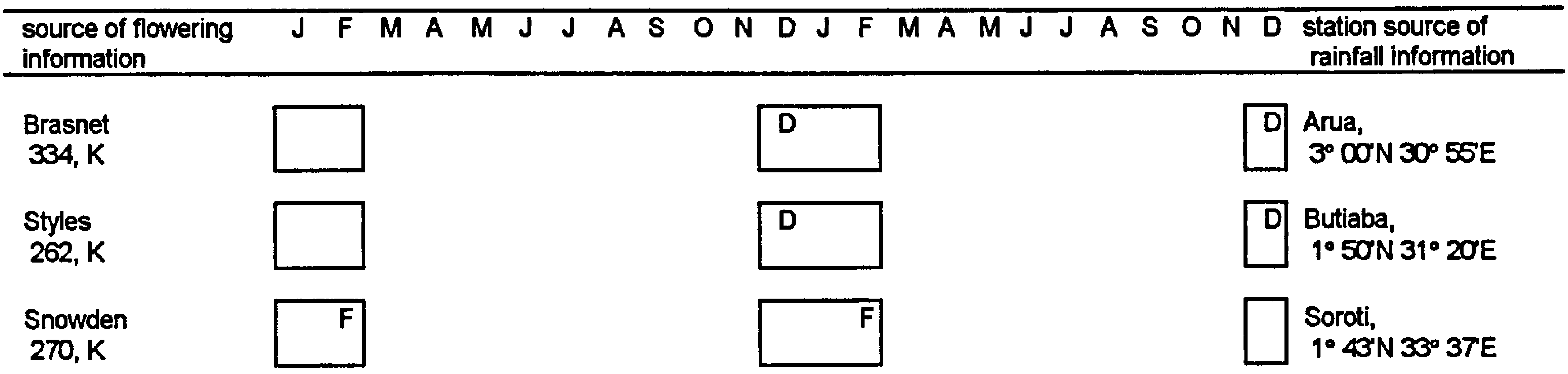
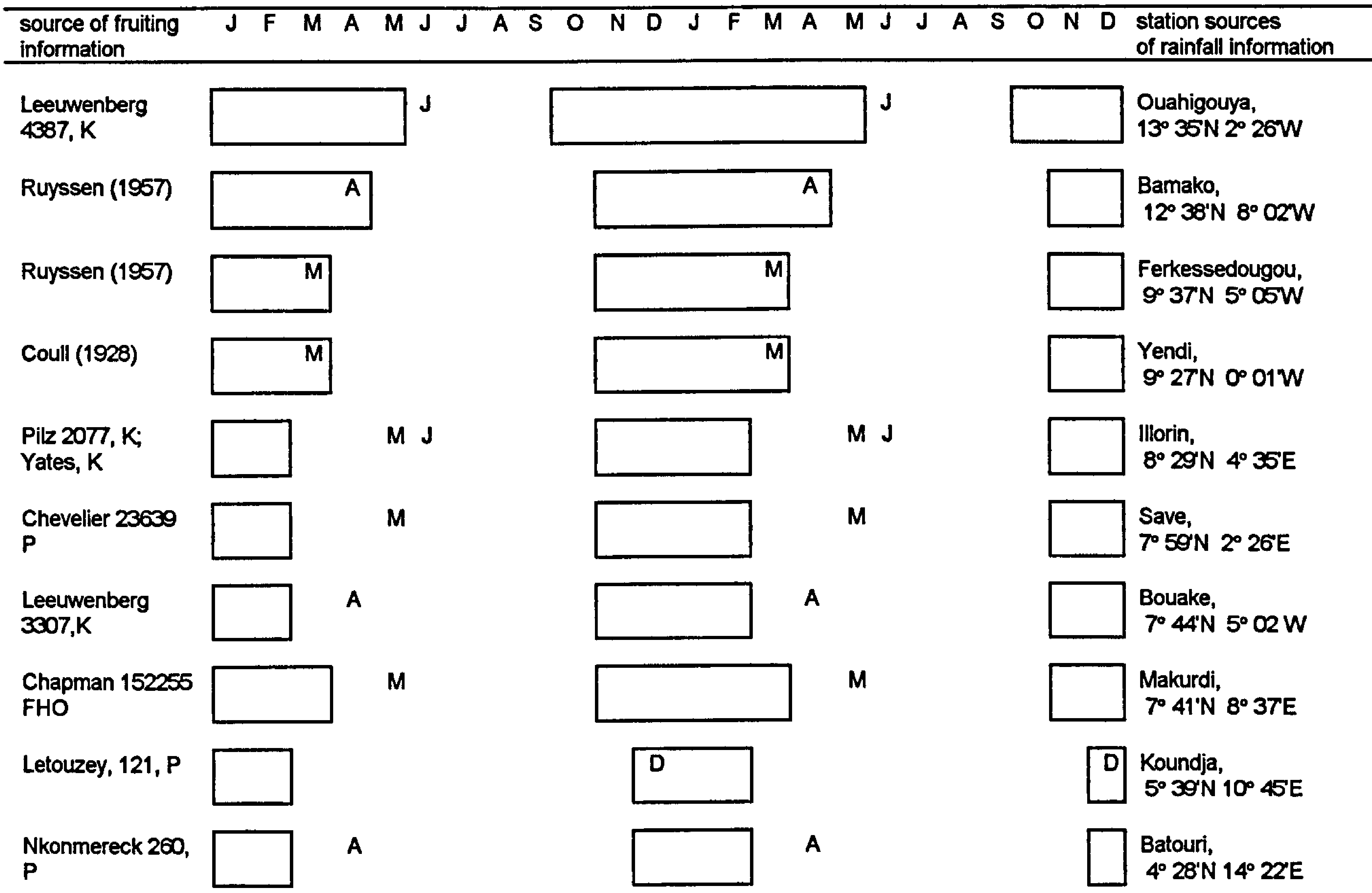
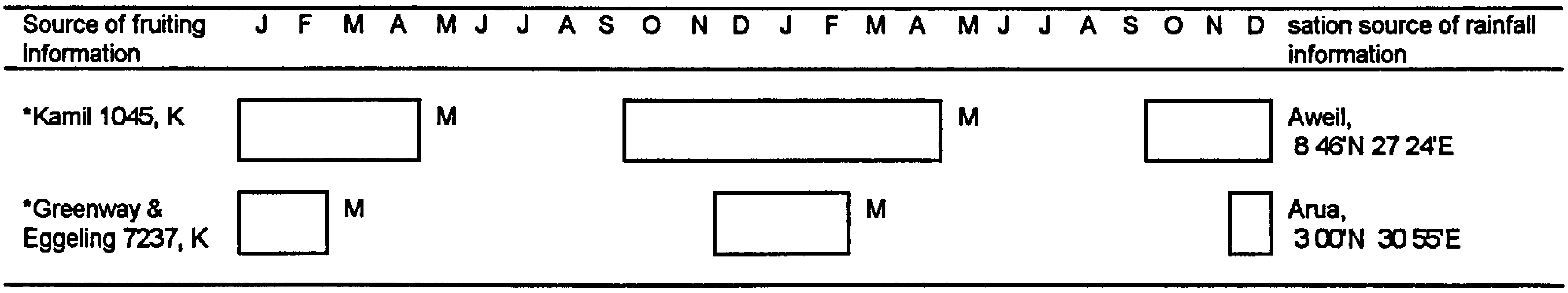


Fig 2.2 Fruiting records of *Vitellaria paradoxa* subsp. *paradoxa* in its range



Fruiting records of *Vitellaria paradoxa* subsp. *nilotica*



Source of fruiting information	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M	A	M	J	J	A	S	O	N	D	sation source of rainfall information
*Kamil 1045, K					M												M								Aweil, 8 46'N 27 24'E
*Greenway & Eggeling 7237, K			M												M										Arua, 3 00'N 30 55'E

Summary of information on flowering and fruiting in *Vitellaria* in relation to dry (mean rainfall <50 mm) months. Records are associated with meteorological station in the same area, sequence of dry months being enclosed by a frame. Entries of initial letters of the month indicate incidence of flowering/fruiting recorded for a single year in each case. A 24-month cycle is adopted to reveal climatic seasonality more clearly and meteorological stations are listed in north-south sequence.

Authors generally imply wide variation in phenological events in *Vitellaria* both within and between populations. Nevertheless, leaf shedding, flushing, flowering and fruiting emerge from the wider review made as part of the present study as essentially dry season events. Periods of 4 to 6 successive months of dryness is common in the range of occurrence. Leaf shedding occurs mostly at the beginning of the dry season.

Flowering occurs at the peak of the dry season. There are, however, a few anomalies. At Ferkessedougou (Delolme, 1947) and Bobo-Dioulasso (Desmarest, 1958), flowering is observed one month before the onset of the dry season. Dry conditions prevail for three months - December to February at Arua - (Brasnett 334, K), Butiaba - (Styles 262, K) and Soroti - (Snowden 270, K), East Africa. Trees can remain in flower for over two months (Chevalier, 1948). In Nigeria, Anon (1975) reports the occurrence of a second flowering in certain trees in July at Afaka (10°40'N 7°24'E), Nimbia (9°30'N 8° 34'E) and Miango (9°51'N 8°41'E) area, normally the period of fruit maturation. Ladipo and Kio (1987) although not specifying locations recognise the differences in flowering time in Nigeria - starting in December in the south but not until late January in the north.

Leaflessness is not essential for flowering to start. Trees in flower with foliage cover at varying densities have been described for *Vitellaria* populations. Greenwood (1929) observed flowers when trees were leafless in Zaria and Niger districts in Nigeria, whilst Ruyssen (1957) in Mali and Chevalier (1908) in Chad, found both events coincided in *Vitellaria*. Coull (1928) noted at Yendi, Ghana, that flowers were few if new leaves were produced before flowering. Continual cambial activity observed by Amobi (1973) in the savanna of Oyo (7°51'N 3°56'E), Nigeria, suggests the occurrence of evergreen conditions in subspecies *paradoxa* at the humid southern limits of the distribution range.

Fruit development - a 4 to 6 months process (Ladipo and Kio, 1987; Hyman, 1989) - commences in the dry season but extends into the ensuing rainy season. Reports combine, without distinction, young and older fruits, obscuring the clarity of relationships with seasonal climatic patterns, and limiting opportunities to consider them in more detail. The presence of ripe fruits inferred from reported harvest records is given in Table 2.7. At N'dali (9°50'N 2°46'E) Benin, self-dropped fruits are found mostly in May, June and July (Agbahungba and Depommier, 1989), At Shaki, Nigeria (8°40'N 3°30'E) from April to August (Ladipo and Kio, 1987). Ruyssen (1957) observed in Bamako, Mali (12°40'N 8°02'W), that fruiting lasted from June till September.

Table 2.7 Time of presence of ripe fruits (inferred from reported harvest records) for *Vitellaria* in its range

species	location	harvest month reported	reference
2	Uganda	April	Jameson (1940)
1	Ferkessodougou, Ivory Coast	April	Ruyssen (1957)
1	Shaki, Nigeria	April	Ladipo & Kio (1987)
1	Ndali, Benin	March	Agbahungba & Depommier (1989)
1	Burkina Faso	June	Salle et al (1991)
1	Mali	June	Fluery (1981)
1	Bamako, Mali	June	Ruyssen (1957)
1	Niger district, Nigeria	June	Greenwood (1929)

1 *paradoxa* 2 *nilotica*

2.2.3 Reproductive biology

Pollination

The pollen of subsp. *paradoxa* has been described (Sowunmi, 1973). The grains are subprolate and isopolar, radially symmetrical, with four pores and furrows - 4-colporate. The long (polar) axis measures 36.1 ± 1.9 μm and the equatorial diameter is 29.5 ± 1.8 μm. The outer wall of the pollen grain - exine, is a three-layered structure comprising the tectum (ca 0.5 ± 0.1 μm), baculate zone (ca 0.3 ± 0.1 μm) and foot layer (0.7 ± 0.1 μm) and is ca 1.5 μ m thick. The tectum almost forms a roof over the rod-like baculate zone - subtectate.

On each grain there are four furrows (colpi), each 29.0 ± 1.0 μm long and 1.1 ± 0.2 μm wide, with well-defined margins, 2.7 ± 0.5 μm thick in the equitorial region of the grain, but narrower towards the ends. The opening (ora) is transversely elongated, 4.4 ± 0.6 µm long and 7.0 ± 0.9 µm wide. The tectum is faintly and minutely reticuloid.

Breeding system

According to Millogo-Rasolodimby (1989) the flowers are protandrous favouring cross-pollination. However, observations made by Yidana (1991) suggest protogyny, the style being exserted prior to pollen maturation and dispersal - an alternative mechanism that favours cross-pollination.

Yidana (1991) describes flower development in the species and notes that the style is exserted from the unopened flower before the pollen grains are mature and that there is no contact between the anthers and the stigmatic surface, precluding autogamy. Hand-pollination of unopened flowers with exserted style produced fruits in five experimental trees. In cross-pollinated flowers, 39% of 144 flowers produced fruits but only 1% of self pollinated flowers (of a total of 183) formed fruits in one of five trees. Open pollinated flowers produced fruits from 6% of 619 flowers (Yidana, 1994).

Chevalier (1948) has reported polygamous heterostyly in subspecies *paradoxa* - dimorphic flowers existing within the same umbel; one type functionally male with a short style and the other hermaphrodite with a long style. The more numerous male flowers open first, to ensure cross-pollination. No further report has been seen in support of this. Most workers reckon the flower to be bisexual (Booth and Wickens, 1988; Pennington, 1991).

Pollination is attributed to insects. Many authors (Holland, 1922; Greenwood, 1929; Irvine, 1961) note a strong attraction to the flowers of bees, identified as *Apis mellifera* LINN. (Millogo-Rasolodimby, 1989). Few flowers produce fruits - about 20% (Millogo-Rasolodimby, 1989). Fruit production varies widely between harvests (Hyman, 1991). Delolme (1947) reports from observation of 9 trees over 10 years, an inconsistent bi-annual fruiting cycle in subspecies *paradoxa* at Ferkessedougou, Ivory Coast. He notes wide seasonal variation in fruit production within and between populations, and for individual trees.

Seed dispersal

It is widely claimed that *Vitellaria* is animal dispersed, the sugary pulp, which forms 50 to 80% of the fresh fruit, making it attractive to a wide range of animals and man (Irvine, 1961 ;Soladoye et al., 1989). Vivien (1990) reports dispersal by large mammals in Cameroun and Afoloyan (1976) reports utilization of fruit by elephants in the Kainji Lake National Park, Nigeria. In the natural environment, a large number of birds, ungulates, and primates are reported to feed on the pulp (Table 2.8), dispersing the seed as they move from the seed source (Soladoye et al., 1989).

Table 2.8 Dispersal animals reported for *Vitellaria*

animal	type of animal	reference
Guinea fowl	bird	Soladoye et al (1989)
Yellow-bellied fruit pegion	bird	Soladoye et al (1989)
Senegal parrot	bird	Soladoye et al (1989)
Garden bulbul	bird	Soladoye et al (1989)
Elephants	mammal	Afolayan 1976; Irvine (1961)
Bats	mammal	Ayensu 1974; Jaeger (1962)
Monkey	primate	Soladoye et al (1989)

Bat dissemination of the seeds (Ayensu, 1974) is of particular interest since fruits harvested from the tree may be deposited at some considerable distance, ultimately extending outcrossing distance. Jaeger (1962) reports bats flying through a park in Bamako with fruits in their mouth. The seeds are released from a height and normally crack on striking the ground. This cracking is thought to enhance germination (Jackson, 1968).

Germination

Germination and seedling morphology have been described by Jackson (1968) and Bokdam (1977). Jackson (1968) describes the germination as cryptogeal, fruits which fall on the ground normally have the scar area downwards which promotes moisture uptake. Growth of material of cotyledonary origin causes the testa to crack at the acute-angled end of the scar area. This material, pseudo-radicle, is positively geotropic and penetrates and grows into the soil. When it has penetrated to a depth of 7-8 cm, a swelling appears at 5 to 7 cm from the testa. Above the swelling a split appears from which emerges the shoot which pushes upwards to the soil surface. The pseudo-radicle in the soil continues to grow and becomes the tap root.

2.2.4 Physiological studies

Few physiological studies have been undertaken on *Vitellaria* but efforts have been made to use hormones to induce rooting in cuttings and promote growth of seedlings (Owusu-Aduomi et al., 1984; Frimpong et al., 1993).

Cuttings treated with indol-3-acetic acid (IAA) and indol-3-butyric acid (IBA) prepared from 5% absolute ethanol and diluted with distilled water at concentrations of 0.25%, 0.5% and 1.0% formed callus. Callus formation increased in quantity proportionately to the concentration of hormone. Roots developed in the 1.0% IBA and 0.5% IAA treated cuttings. In a second experiment with 1.0% and 1.5% solutions of the hormones, roots developed in the 1.5% solution of both IAA and IBA (Owusu-Aduomi et al., 1984). On the other hand, studies in Burkina Faso with a combination of the two hormones at 0.5% concentration produced no roots in cuttings (Bonkoungou, 1987).

In another experiment, Biozyme and Ergostim (vegetative growth stimulants) at concentrations in water of 1000 ppm were applied to one-year old seedlings. After six months, height recorded was higher for both treatments than the control (water application) plants (Frimpong et al., 1993).

Efforts have similarly been made to stimulate flowering in young subspecies *paradoxa* trees. In 4-year old plants, Cultar (vegetative growth retardant) was applied at 0. 250, 500 and 1000 ppm of water to induce flowering. One plant in the 1000 ppm treatment initiated flowers but formed no fruits (Frimpong et al., 1993).

2. 2. 5 Susceptibility to diseases

Association with insects, vertebrate herbivores and parasitic angiosperms are discussed in section 2.3.3. Attacks by fungal pathogens have been reported. Dakwa (1984) observed the prevalence of a leaf spot disease affecting over 90% of *Vitellaria* trees in the vicinity of Bole, Ghana. The disease was found in both young and adult trees with the most severe manifestation on leaves close to the ground. The causal organisms were identified as *Pestalotia* and *Botryodiplodia*.

Leaf galls have been reported (Corbett, 1989 - plate 15) in Bornu province, Nigeria but have not been regarded as a serious problem. In Burkina Faso, a nematode *Aphasmatylenchus straturatus* GERMANI is associated with the roots but has not been shown to cause any disease (Germani and Luc, 1982).

2.3 ECOLOGY OF *VITELLARIA*

2.3.1 Geographical distribution

Present Distribution

The monotypic character of *Vitellaria* causes little difference of opinion regarding its distribution. Distribution maps produced for the species have differed little as far as the range limits are concerned for many years (Esdorn and Nolde, 1943; Chevalier, 1945; Bonkoungou, 1987; Salle et al., 1991). *Vitellaria* occurs in 19 countries. The distribution of the two subspecies is clear-cut. Subspecies *paradoxa* occurs in Benin, Burkina Faso, Chad, Cameroun, Central African Republic, Ghana, Guinea, Guinea Bissau, Ivory Coast, Mali, Niger, Nigeria, Senegal, Sierra Leone, and Togo. The eastern subspecies, subsp. *nilotica,* occurs in Ethiopia, Sudan, Uganda, and Zaire.

In developing a sound basis for managing an in-situ resource, such as *Vitellaria*, overall range is, however, inadequate. Individual records of occurrences need to be accurately located so that population characteristics can be brought into a geographic perspective and ecological and behavioural patterns can be elucidated in detail. In the case of *Vitellaria*, there exists no definitive map published based on substantiated localities although Corbett's (1989) unpublished map shows over 200 locations. A distribution map (Figure 2.3) was therefore prepared from the locations of voucher specimens from Kew Gardens, Natural History Museum, Oxford Forestry Institute and the Laboratoire de Phanerogamie, Paris. Information from the literature was also included. Using the IDRISI GIS, coordinates of sites were plotted.

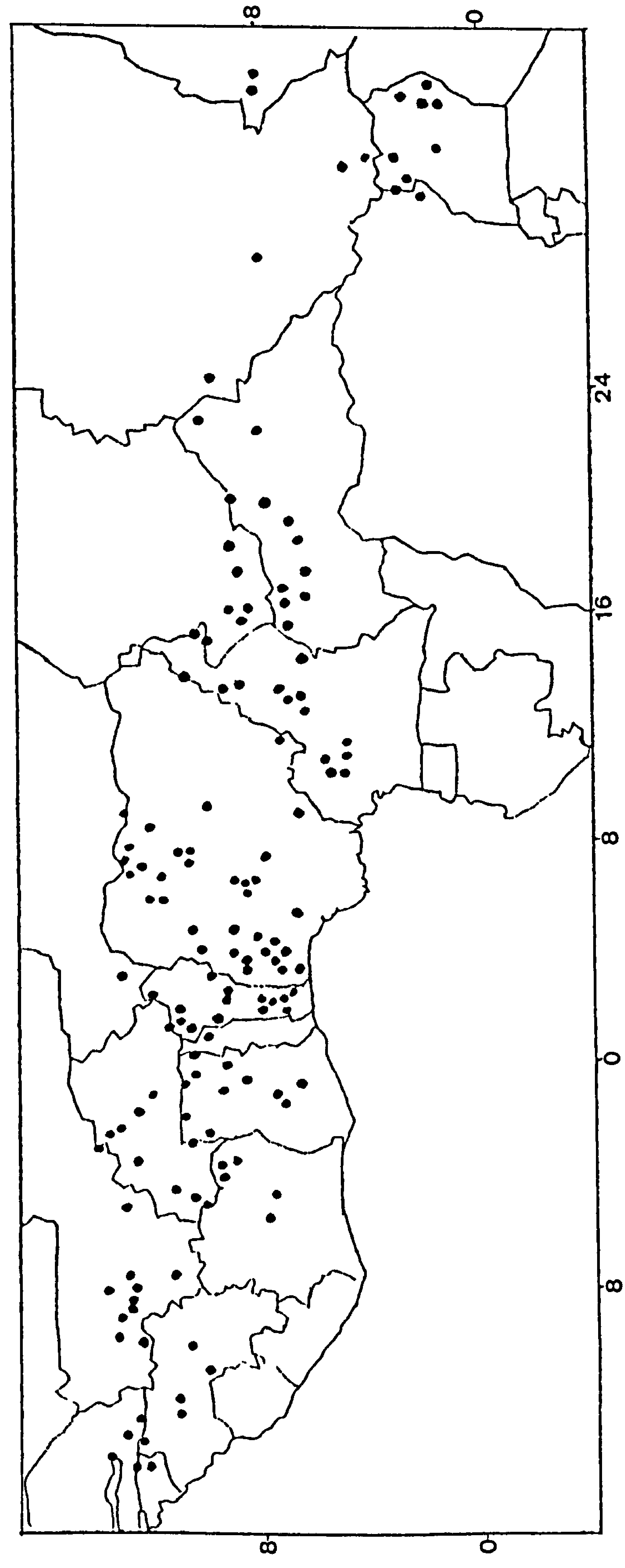


Figure 2.3 Point distribution map of *Vitellaria paradoxa*

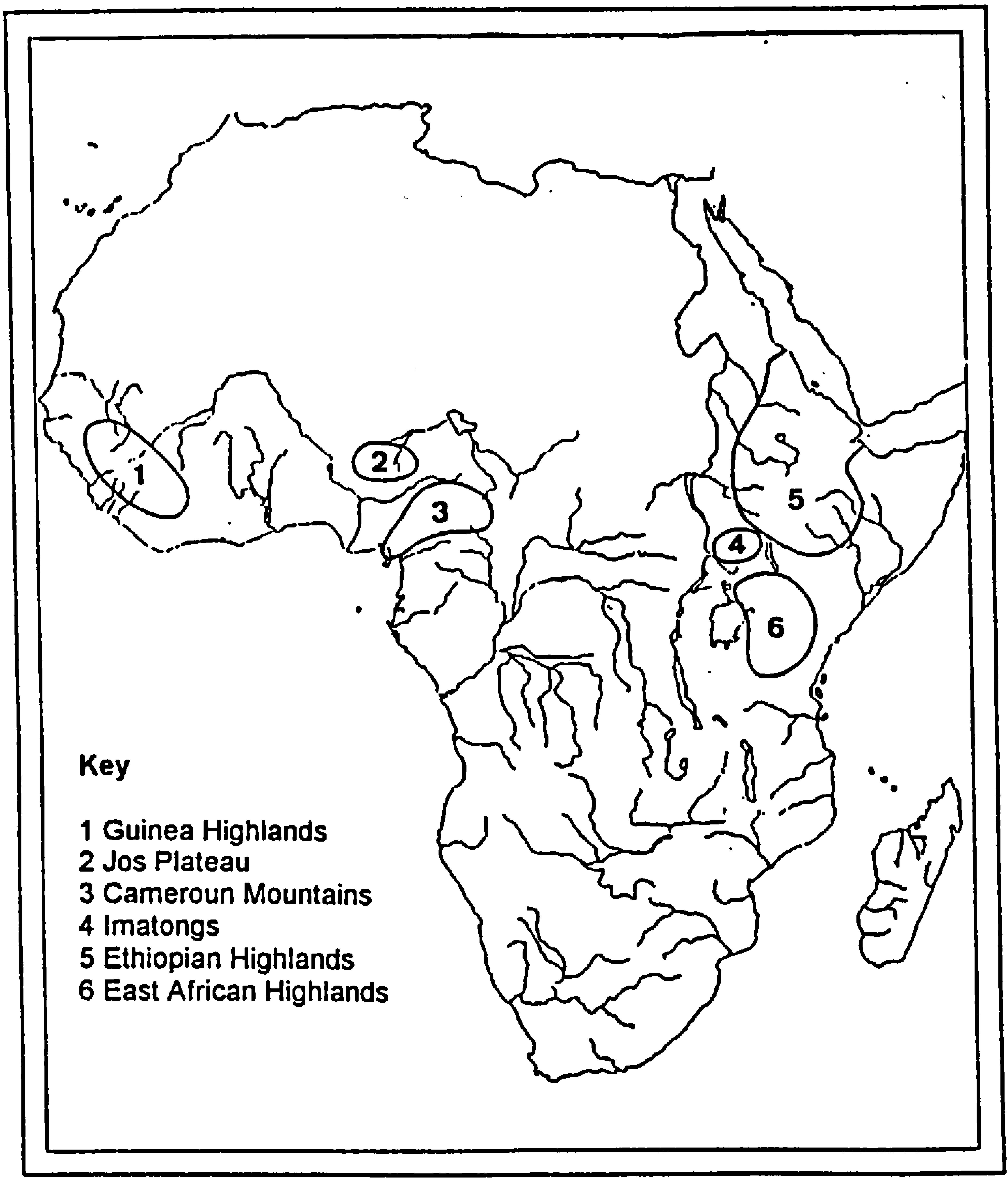
Range

The entire range of *Vitellaria* is within the Sudanian zone of White (1983). Bonkoungou (1987) estimates a latitudinal range of 500-750 km (7°N-15°N in the west and 3°N - 8°N in the east). The longitudinal limits are approximately 15°W and 35°E. The northern limit of subsp. *paradoxa* is represented by scattered trees near Bandiagora (14°25'N 3°37'W), Mali (Ruyssen, 1957) and its southern limit is in Cameroun (5°31'N 10°25'E, Bouffousam - Jacques-Felix 2957, P). Subsp. *paradoxa* occurs west of 24°E. Extending between longitudes 24°E and 35°E, the range of subspecies *nilotica* is contiguous to subspecies *paradoxa*, reaching 9°42'N 24°19'E at Hofrat en Nahas, Sudan (Kamil 1045, K), and 1°50'N 34°40'E at Moruita, Karamoja District, Uganda (Anon. 2319, K), at its southernmost.

2.3.2 Environmental factors in distribution

Elevation

The altitudinal range differs with subspecies (Fig 2.4). In the west, the range of subspecies *paradoxa*, there are occurrences at elevations above 500 m only locally reported on the Guinea highlands, the Jos plateau and the Cameroun highlands (1300 m: Labe, Guinea - Chevalier 34943, P; 1300 m: 9 °52'N 8°54'E, Jos Plateau, Nigeria - Lely 143, K; 1200 m: 5°39'N 10°45'E, Koundja, Cameroun - Letouzey 121, P). Land is generally elevated, (1200-1700 m) further east, where subspecies *nilotica* occurs (Breitenbach, 1963), although in the Sudan some occurrences are in areas of elevation as low as about 500 m. Collectors' comments confirm occurrences at high altitudes (Table 2.9). The altitudinal limits are higher than for subspecies *paradoxa* (e.g. 1600 m: 1°50'N 34°40'E Moruita, Karamoja, Uganda - Anon 2319, K).



Adapted from Wickens (1976)

Figure 2·4 Map showing distribution of mountain systems in the range of *Vitellaria paradoxa*

Table 2.9 Altitude of occurrence reported for *Vitellaria paradoxa*

Subspecies	location	altitude (m)	reference
2	Moruita, Uganda	1600	Anon 2319, K
2	Arua, Uganda	1400	Brasnett 334, K
2	Payida, Uganda	1300	Greenway & Eggeling 7237, K
1	Labe, Guinea	1300	Chevalier 34943, P
1	Bamoun, Cameroun	1300	Letouzey 121, P
1	Kounang, Cameroun	1300	Aubreville (1950)
1	Jos Plateau, Nigeria	1300	Lely 143, K
1	Adamaoua Plateau, Cameroun	1200	Aubreville (1950)
2	Nioka, Zaire	1200	Taton 222, P
1	Baleng, Cameroun	1200	Jacques-Felix (1946)
2	Kumi, Uganda	1100	Snowden 270, K
1	Meiganga, Cameroun	1027	Letouzey (1968)
1	Tibati, Cameroun	874	Letouzey (1968)
2	Gambela, Ethiopia	650	Friis & Vollesen (1984)
1	Bossangoa,CAR	600	Fay 5166, K
1	Yendi, Ghana	600	Coull (1927)
1	Koutiala, Mali	350	Kater et al. (1992)
1	Gbenou, Ivory Coast	300	Leeuwenberg 3307, P
1	Garoua, Cameroun	250	Letouzey (1968)
1	Ibadan, Nigeria	230	Jackson (1968)
1	Gashka, Nigeria	230	Chapman 152255, FHO
1	Bolgatanga, Ghana	200	Brookman-Amissah et al. (1980)
1	Olokemeji, Nigeria	100	Hopkins (1962)

1 *paradoxa*; 2 *nilotica*

Climate

In relation to climate, occurrences of *Vitellaria* are considered in terms of rainfall and temperature. Records of site locations of herbarium specimen and from the literature were linked with climatic data from meteorological stations (FAO, 1984) and Meteorological Office (1983) to develop a more comprehensive view than one based merely on comparing rainfall and species distribution maps.

Rainfall

Direct rainfall is important for the species. *Vitellaria* is intolerant of seasonal inundation and avoids areas of impeded drainage. *Vitellaria* is subject to between 500 and 1500 mm mean annual rainfall (Fig 2.5), combined with a dry season lasting 4-8 months (dry months are months with < 50 mm mean rainfall). Trees are few and scattered at the drier northern limit of the range of subspecies *paradoxa* (13°47'N 8°59'E, Zurmi, 700 mm yr^{-1}, 7 dry months - Keay, 1949; 13°00'N 7°41'E, Katsina, Nigeria, 737 mm yr^{-1}, 7 dry months- Fairbairn, 1939). At the southern limit in Cameroun, with ≤ 3 dry months and high mean annual rainfall (>1800 mm) it establishes only on slopes with good drainage (Jacques-Felix, 1946).

In the eastern part of the range, subspecies *nilotica* is associated with a more variable rainfall regime. At Hofrat en Nahas there are seven dry months but the rainy season is progressively longer towards the south. From Arua to the southern limit near Masindi there are ≤ 3 dry months.

Temperature

The mean annual temperature over the range is 24-30°C. Values commonly exceed 25°C in the western part of the species' range. However, there are marked exceptions on the highlands: e.g. 21°C at Koundja, Cameroun (Jacques - Felix 13009, P) and at Jos, Nigeria. The higher elevations in East Africa similarly influence mean annual temperature, subspecies *nilotica* occurs at <25°C (e.g. 24°C: 1°43'N 33°37'E Soroti, Uganda - Snowden 270, K; 18°C: 2°09'N 30°39E, Nioka-Drusi, Zaire - Taton 222, P). In Sudan, however,

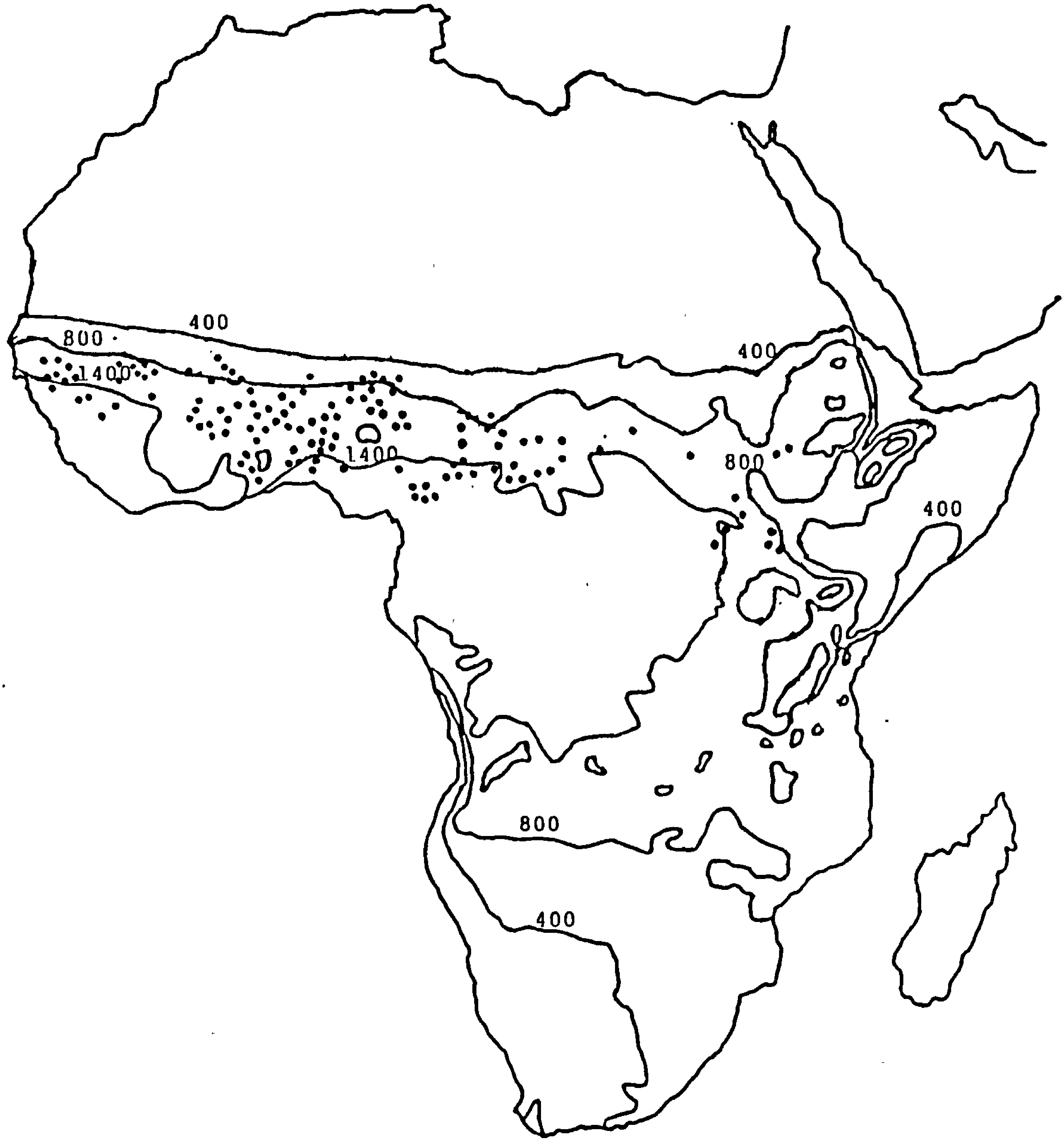


Fig. 2.5 *Vitellaria paradoxa*; distribution in relation to mean annual rainfall. The 400, 800 and 1400 mm isohyets are shown.

subspecies *nilotica* is exposed to mean annual temperatures >25°C (e.g. 28° C: 7°42'N 28°00'E, Wau - Morison et al., 1948).

For most of the range, monthly mean values of daily temperature maxima generally vary from low rainy season figures of 28-31°C to high late dry season figures (35-40°C). Corresponding minima drop to 15-20°C at the transition to the rainy season. Diurnal fluctations are least, often only 8-10°C, in the rainy season and highest (often *ca* 20°C) in the mid-dry season. Seasons correspond in time: peak rainfall is during some or most of the June-September period.

In Uganda and Zaire (and probably the extreme south of Sudan), the southern part of the range of subsp. *nilotica*, however, a different climate prevails. This has an equatorial character with appreciable rainfall throughout the year and much more uniform temperatures. Diurnal fluctuations, as reflected in differences between monthly values of mean daily minima and maxima, are < 15°C. Compared with the parts of the range further north and west, monthly means of daily maximum temperatures are low (25-33°C).

The species tolerates high absolute maximum temperatures (>35°C). Subspecies *paradoxa* is exposed to higher absolute maxima in the northern limits of the range (48°C: 13°04'N 9°23'W, Kita in Mali - Raynal 5311, P; 48° C: 13° 48'N 9°00'E, Zinder in Niger- Dundas, 1938) than in the southern limits (e.g. 40°C: 7°44'N 5°04'W, Bouake, Ivory Coast - Chevalier 22111, P). The higher altitude in Cameroun influences absolute maxima and subspecies *paradoxa* occurs where values are < 40°C (36°C: 7°21'N 13°34'E, Ngaoundere- Letouzey 2518, P; 33°C: 5°37'N 10°45'E, Koundja - Jacques-Felix 3009, P). Lower absolute maxima are associated with subspecies *nilotica* in the eastern range where altitude is also high (e.g. 37°C: 1°41'N 31°

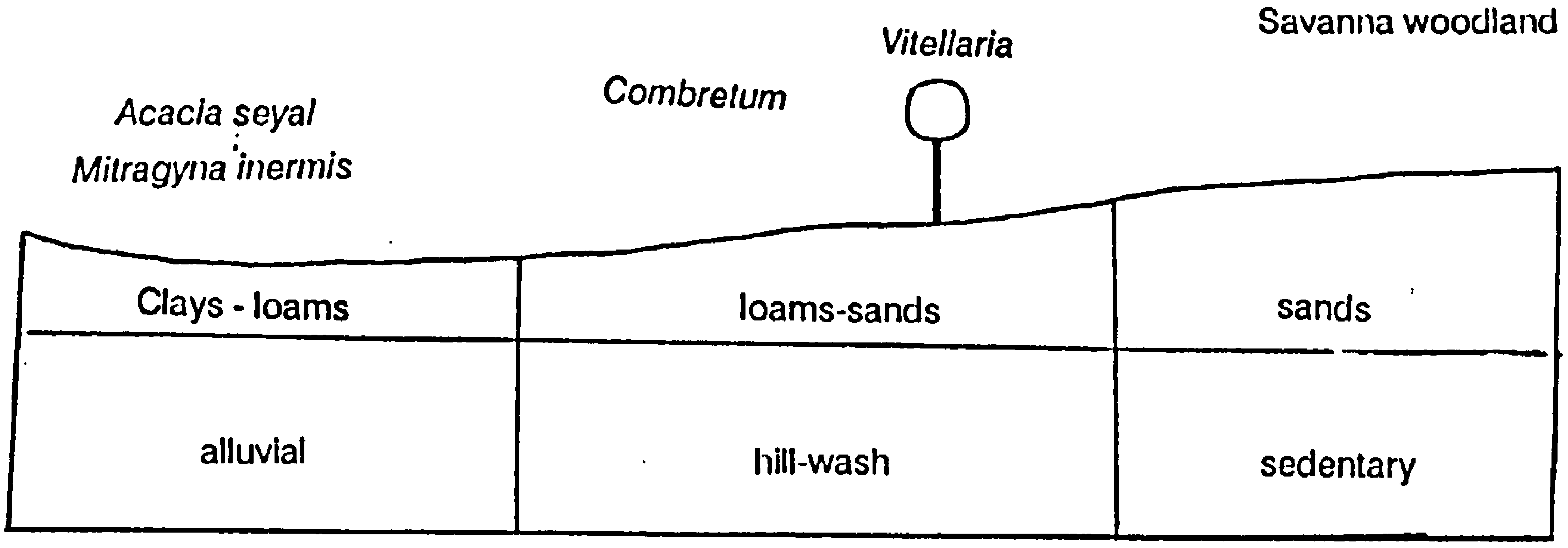
43E, Masindi - Langdale-Brown 2307, K; 38°C: 3°00'N 30°55'E, Arua - Brasnett 334, K). Subspecies *nilotica* is however, exposed to higher absolute maxima (>40°C) in Sudan (e.g. 43°C: 4°51'N 31°37'E, Juba - Simpson 7591, K; 43°C: 7°42'N 28°01'E, Wau - Morison et al., 1948).

Nowhere in the range is *Vitellaria* exposed to frost. Absolute minimum temperature is between 3°C and 14°C. At the northern limits, subspecies *paradoxa* is found in areas with values of absolute minima <5°C (3°C: 11° 42'N 11°02'E, Potiskum, Nigeria - Ramsay and Leeuw, 1964; 5°C: 12°23'N 5° 28'W, Koutiala, Mali - Bourlet, 1950). In Cameroun, on high ground at the southern limit, subspecies *paradoxa* is similarly exposed to < 5°C (3°C: Ngaoundere - Letouzey 2518, P; 11°C: Koundja - Jacque-Felix 3009, P). On the Jos Plateau, Nigeria, subspecies *paradoxa* is associated with an absolute minimum of 4°C. For subspecies *nilotica*, although the altitudinal range is higher, values are consistently > 10°C in Uganda (e.g. 11°C: Arua - Brasnett 334, K) but <10°C in Sudan at relatively low altitude (e.g. 9°C: Wau - Morison et al., 1948).

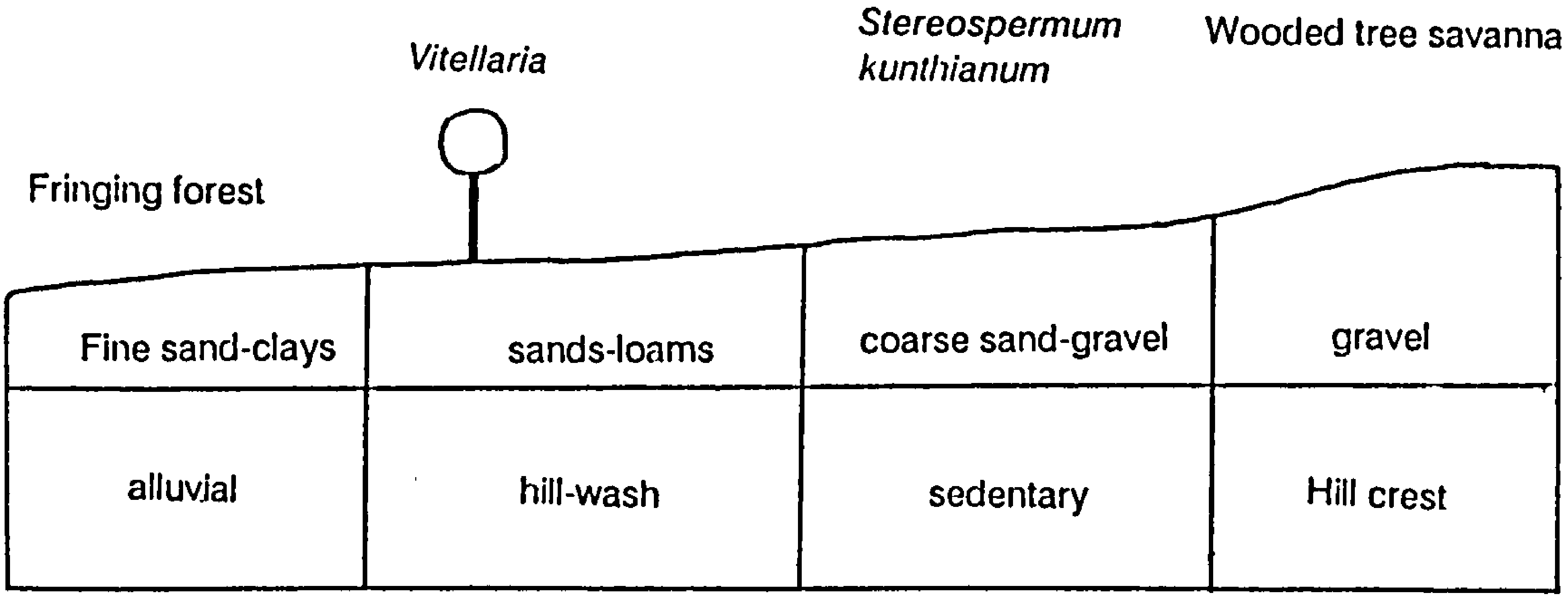
Toposequence position

For subspecies *nilotica* Morison et al. (1948) and for subspecies *paradoxa* Keay (1960) and Fagbami and Fayemi (1975) describe the positions of *Vitellaria* in catenas/toposequences (Fig 2.6).

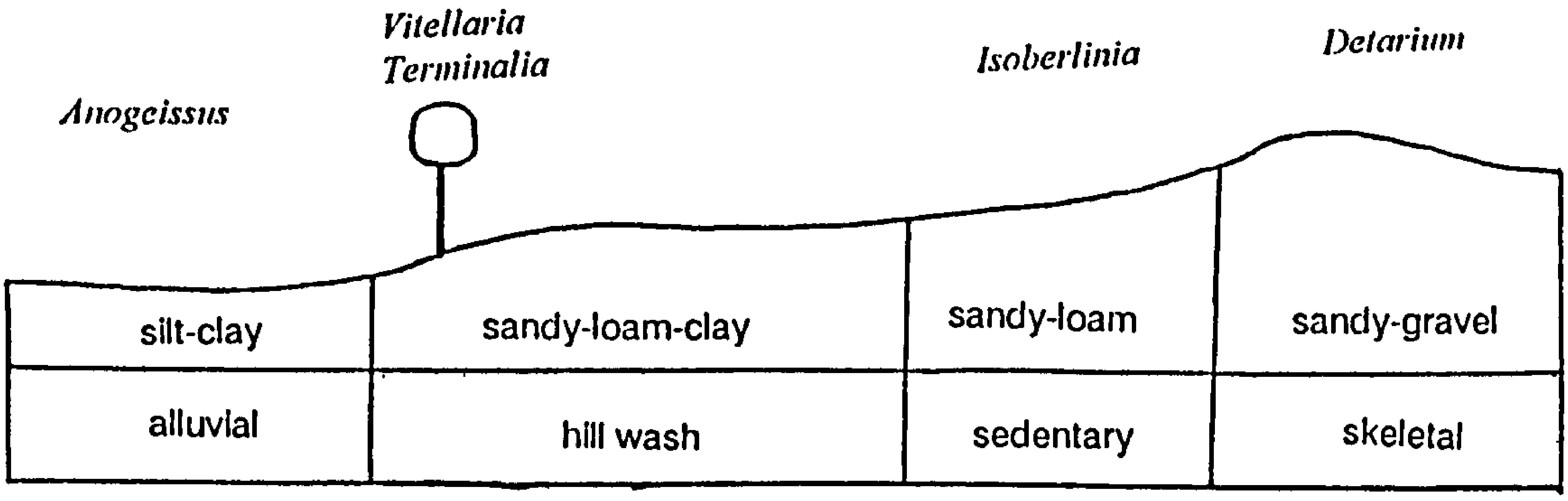
Morison et al. (1948) show an extensive colluvial slope where materials derived from erosion at the edge of the eluvial complex are deposited on being washed down the slope. Zones within the colluvial complex, determined by texture (reflecting particle size) of material deposited are recognized. Subspecies *nilotica* is characteristic of the upper zone sandy soil. Where the colluvial phase is fine re-sorted colluvial material, subsp.*nilotica* does not establish and *Combretum* spp. dominate the vegetation. At the colluvial-illuvial transition, deposits of finer material of sandy loam texture support *Parkia biglobosa, Entada africana*, *Borassus aethiopum* and *Maytenus senegalensis* to the exclusion of *Vitellaria*. On the seasonally flooded loam and clay soils within the alluvial complex *Acacia seyal* DELILE is the most prominent species: these soils do not support *Vitellaria.* Lawson et al. (1968) describe a sequence under similar rainfall on quartz sandstones in Ghana's Mole Game Reserve (9°30'N 2°00'W), where subspecies *paradoxa* grows in the corresponding zone of a colluvial complex, where soils are sandy loam.



Morison et al (1948), Sudan (9°N 27°E). Mean annual rainfall 1000 mm, quaterenary deposits.



Fagbami and Fayemi (1975), Nigeria (8°N 4°E), Mean annual rainfall 1200 mm, crystelline rocks of Basement complex.



Keay (1960),Nigeria (11°N 8°E) annual rainfall 1200 mm, precambrian basement complex.

Figure 2·6 *Vitellaria* in a catenary context. Positions of *V. paradoxa* within the catena, as indicated by original authors, are shown.

An extensive series of soil profiles from the Lower Ofiki Basin, Nigeria (7° 58'N 3°40'E) is described by Fagbami and Fayemi (1975), allowing a comprehensive overview of variation in occurrence in the landscape of this area. Subspecies *paradoxa* extends through a wide range of soil conditions in the toposequences. On hill crests, with slight convexity (slope >3-14%) or flatness, and thin soil derived in-situ, *Vitellaria* occurs. It is absent however, from bolder relief with rock outcrops. Elsewhere, occurrence is predominantly on the transported deeper sands and loamy sands of the middle-slope colluvial complex. Lower in the toposequence, on 4.5-12% slopes of illuvial complexes, *Vitellaria* grows on loamy sand subject to seasonal inundation but it is absent from more or less flat topography over deposits of clay. From further north in Nigeria, Keay (1960) describes a toposequence on the ironstone plateau of the Anara Forest Reserve (10°40'N 7°45'E). Here, on the eluvial complex, *Detarium* and *Combretum* dwarf savanna vegetation occurs while subspecies *paradoxa* is dominant and well-grown (up to 15 m in height) on the loose black sandy loams of the colluvial complex. In fringing forest, slightly raised above the flood plain on more sandy soil at this locality, subspecies *paradoxa* is associated with *Khaya senegalensis* A. JUSS.

Site

Vitellaria shows a well-defined association with sloping positions and soil with a substantial sand content, although not with pure sands or very porous soils. Absence from floodplains subject to flooding and from poorly-drained heavy soils have been reported for both subspecies (*paradoxa* - Keay, 1949 and Taylor, 1960: *nilotica* - Eggeling and Dale, 1951)

Adaptation to fairly fertile soil is indicated by the prevalence of occurrences on luvisols (Table 2.10), where there is generally high base saturation. Nitosols and regosols which cover areas in Cameroun (Jacques-Felix 2957, P) and Nigeria (Klinkenberg and Hildebrand, 1964) are also fertile soils.

Soils with good stands of either subspecies are normally weakly acidic, pH between 6.3 and 6.7 in the top soil (Morison et al., 1948; Hopkins, 1962; Lawson et al., 1968; Siderius, 1974; Appiah et al., 1988).

In most sites where *Vitellaria* grows, soil fertility is higher. Appiah et al. (1988) report higher levels of organic matter, exchangeable bases and total and available phosphorus in dense stands than in sparse stands at Bole, Ghana. In Burkina Faso, Kater et al. (1992) report significantly higher levels of carbon, available magnesium and potassium under the canopy of *Vitellaria* than beyond, due to the sequesteration of scarce nutrients by the trees.

Table 2.10 Distribution of *Vitellaria* in relation to the major soil groups over its range.

Acrisols

Ferkessedougou (9 37N 5 05W) - Delolme (1947)
Bouake (7 44'N 5 10'W) - Chevalier 2211, P
Bouna (9 N 3 30'W) - Leeuwnberg & Wilde 3499, K
Korhogo (9 22'N 5 31'W) - Chevalier (1948)
N'Gaoundre (7 20'N 13 35'E) - Letouzey (1968)

Arenosols

Koro (14 00'N 2 57'W) - Chevalier (1943)
Dasso (13 00'N 3 10'E) - White 14, K
Ouada-Djole (8 09'N 22 20'E) - Aubreville 438, P
Ndele (8 25'N 20 38'E) - Sillans (1958)
Zinder (13 48N 9 00'E) - Dundas (1938)
Zurmi (12 49'N 6 47'E) - Keay (1949)

Cambisols

Moruita (1 50'N 34 40'E) - Anon 2319, K
Gambela (8 15'N 34 35'E) - Friis & Vollensen (1984)
Sikasso (11 18'N 5 38'W) - Bourlet (1950)
Gaoua (10 18'N 3 12'W) - Bourlet (1950)

Ferralsols

Fort Crampel (5 59'N 9 11'E) - 2054, P
Bamoun (5 40'N 10 50'E) - Letouzey 121, P
Nioka (2 10'N 30 40'E) - Taton 222, P
Kumi (1 30'N 34 00'E) - Snowden 270, K
Paoua (7 09'N 16 20'E) - Ellenberger 234, K
Arua (3 05'N 30 55'E) - Brasnett 334,K
Bossangoa (6 25'N 17 28'E) - Fay 5166, FHO
Bria (6 32'N 21 54'E) - Sillans (1958)
Lira (2 15'N 32 55'E) - Anon 73184, FHO
Masindi (1 41'N 32 35'E) - Langdale-Brown 2307, K

Fluvisols

Fort Achambault (9 08'N 18 22'E) -Aubreville (1950)
Payida (2 30'N 31 00'E) Greenway & Eggeling 7237, K

Gleysols

Fiaga (9 57'N 15 03'E) - Lebrum P
Katikwe (1 55'N 34 00'E) - Lieberiberg 268, K

Lithosols

Wawa (10 00'N 4 15'E) - Siderius (1974)
Tibati (6 43'N 13 02'E) - Mbella Assom , P
Koulikro (12 55'N 7 31'W) - Vuillet 571, P
Tonkountoma (10 30'N 1 23'E) - Chevalier 24097,P
Bamako (12 40'N 7 59'W) - Bamps 2476, K
Gashka (7 20'N 11 30'E) - Latilo & Daramola 34413, K
Jos Plateau (9 52'N 8 54'E) - Lely 143, P

Luvisols

Posto de pirada (12 40'N 14 00'W) d'Orey 308, K
Koutiala (12 20'N 5 23'W) - Bourlet (1950)
Toumosseni (10 30'N 5 00'W) - Renes (1991)
Ketou (7 16'N 2 21'E) - Chevalier 23008,K
Koloubau (8 00'N 2 00'E) - Vuillet 570, P
Jebba (9 09'N 4 48'E) - Barter 987,K
Zaria (11 00'N 7 40'E) - Lamb K
Bonfara (10 30'N 4 40'W) - Leeuwenberg 4418
Dogonkaddi (8 40'N 0 30'W) - Kitson 899, K
Ejura (7 20'N 1 20'W) - Chipp 756, K
Wa (10 00'N 2 30'W) - Anon K
Atebubu (7 47'N 1 00'W) - Chipp (1927)
Olokemeji (7 26'N 3 32'E) - Hopkins (1962)
Petit Samba (12 45'N 2 15'W) - Gijbers et al (1984)
Gambaga (10 31'N 0 22'W) - Taylor (1960)
Bole (9 03'N 2 23'W) - Adomako (1985)
Lomoudan (8 56'N 13 28'E) - Raynal 12840, P
Langouassou (7 48'N 4 52'W) - Chevalier 22154, P
Tehini (9 36N 3 40'W) - Amshoff 911, K
Yendi (9 30'N 0 05'W- Coull (1927)
Kan Gimi (10 45'N 7 35'E) - Keay (1960)
Eruwa (7 33'N 3 40'E) - Pilz 1835, K
Parakou (9 21'N 2 37'E) - Agbahungba & Depom. (1989)
Igbeti (8 45'N 4 09'E) - Glendhill 717, K
Zuarungu (10 48'N 0 48'W) - Brookman-Amissah (1980)
Juba (4 52'N 31 36'E) - Douglas-Simpson 7591,K
Oyo (7 40'N 4 20'E) - Pilz 1852, K
Mole (9 30'N 2 00'W) - Lawson et al (1968)
Anara (10 40'N 7 45'E) - Onochie (1961)
Gonse (12 25'N 1 20'W) - Bonkoungou& Fromond(1988)

Nitosols

Bobo-Dioulaso (11 11'N 4 42'W) - Bourlet (1950)
Bussa (9 57'N 4 26'E) - Klinkenberg & Hildebrand(1964
Bida (9 05'N 6 00'E) - Pilz 1901, K
Badeggi (9 01'N 6 08'E) - Jones (1963)
Baro (8 36'N 6 25'E) - Yates
Bafoussam (5 13'N 10 25'E) - Jacques-Felix 2957, P
Bafia (4 55'N 11 00'E) - Letouzey 9649, P
Jalingo (10 53'N 11 18'E) - Chapman 3016, FHO
Nupe (7 56'N 7 26'E) - Barter 721, K

Regosols

Boulouli (13 17'N 9 39'W) - Vuillet 25, K
Ouahiagouya (13 31'N 2 20'W) - Bourlet (1950)
Ziga (13 19'N 2 20W'E) - Leeuwenberg 4387
Fada-N'Gourma (12 15'N 0 28'E) - Bourlet (1950)
Kiri (13 59'N 2 56'W) - Chevalier (1943)
Katsina (13 00'N 7 32'E) - Clayton (1964)
Hofrat en Nahas (9 45'N 24 19'E) - Kamil 1045, K
Wau (7 40'N 28 04'E) - Morison et al (1948)
Aweil (8 42'N 27 20'E) - Morison et al (1948)
Bandiagara (14 25'N 3 37'W) - Ruyssen (1957)

2.3.3 *Vitellaria* as a vegetation component

Population levels

There are a number of published reports on the local abundance of *Vitellaria* but all refer to subspecies *paradoxa* (Table 2.11) Among the reports there is little consistency in the size considered, or separation of size-classes to summarize population structure. The parameters of measurement vary. Emphasis has been on small sample areas, often assumed representative of the vegetation of the study area and not always extensively replicated. The numbers of actual observations made vary widely: from < 5 to exceptionally > 100.

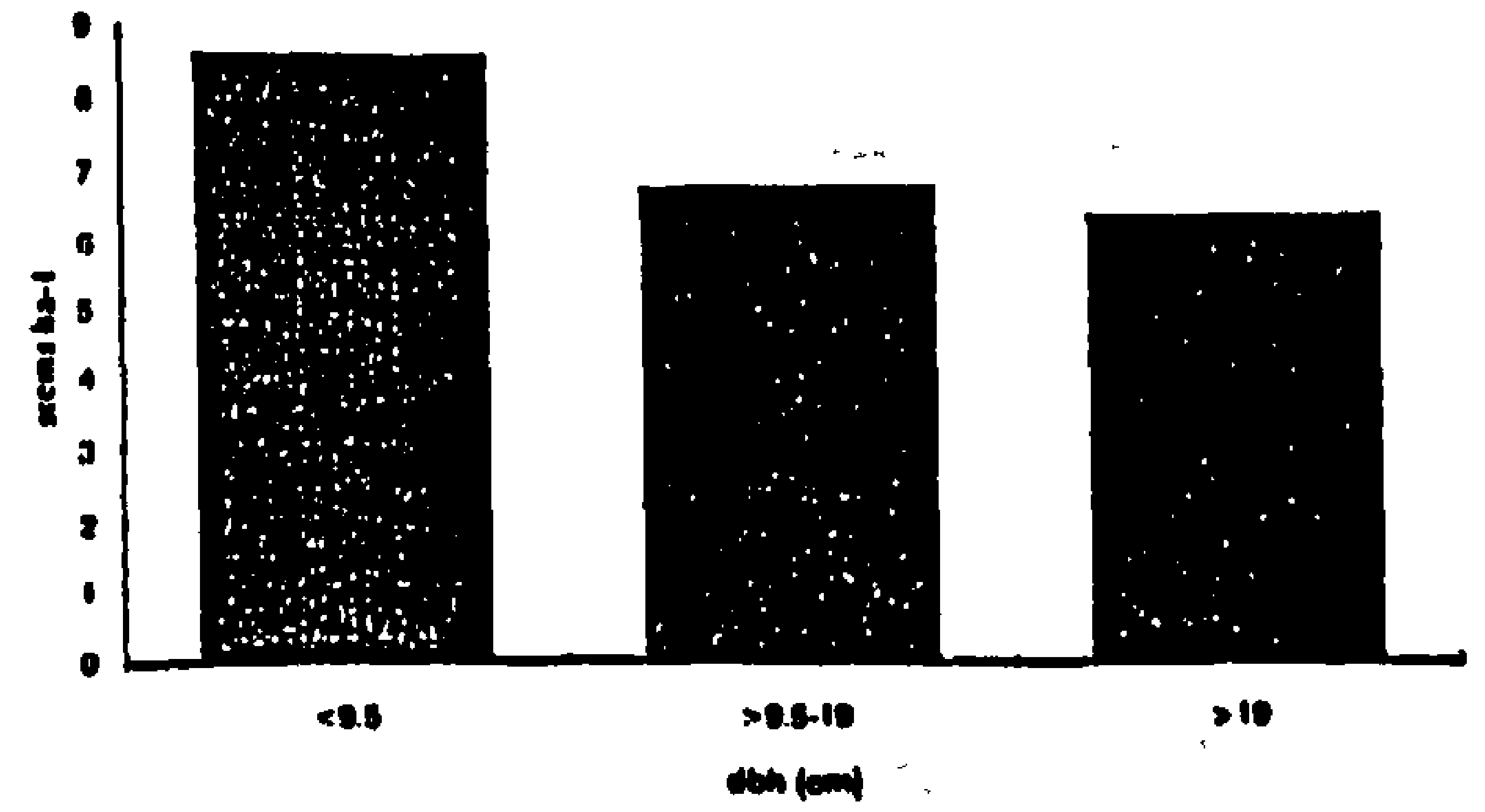
Stocking of 80 trees ha^{-1} (dbh >3.2 cm) in the Kainji Lake National Park, Nigeria and of 82 stems ha^{-1} (dbh >9.5 cm) in Bolgatanga, Ghana are reported by Afolayan (1974) and Brookman-Amissah et al. (1980) respectively. A lower stocking of 15 trees ha^{-1} is reported by Vigne (1936) for trees of dbh > 9.5 cm in northern Ghana. Hopkins (1962) considers individual trees > 2 m high and reports stocking of 16 and 21 individuals ha^{-1}, summarised into 3 classes (≥ 10 m, 5 - <10 m, and 2 - <5 m high). Hopkin's stocking levels can be compared with those of Vigne (Fig 2.7). In natural communities, fires suppress the growth of the species with extreme concentration of individuals in the lower size classes.

Table 2.11 Estimates of stocking of *Vitellaria paradoxa* subsp. *paradoxa* in Natural communities.

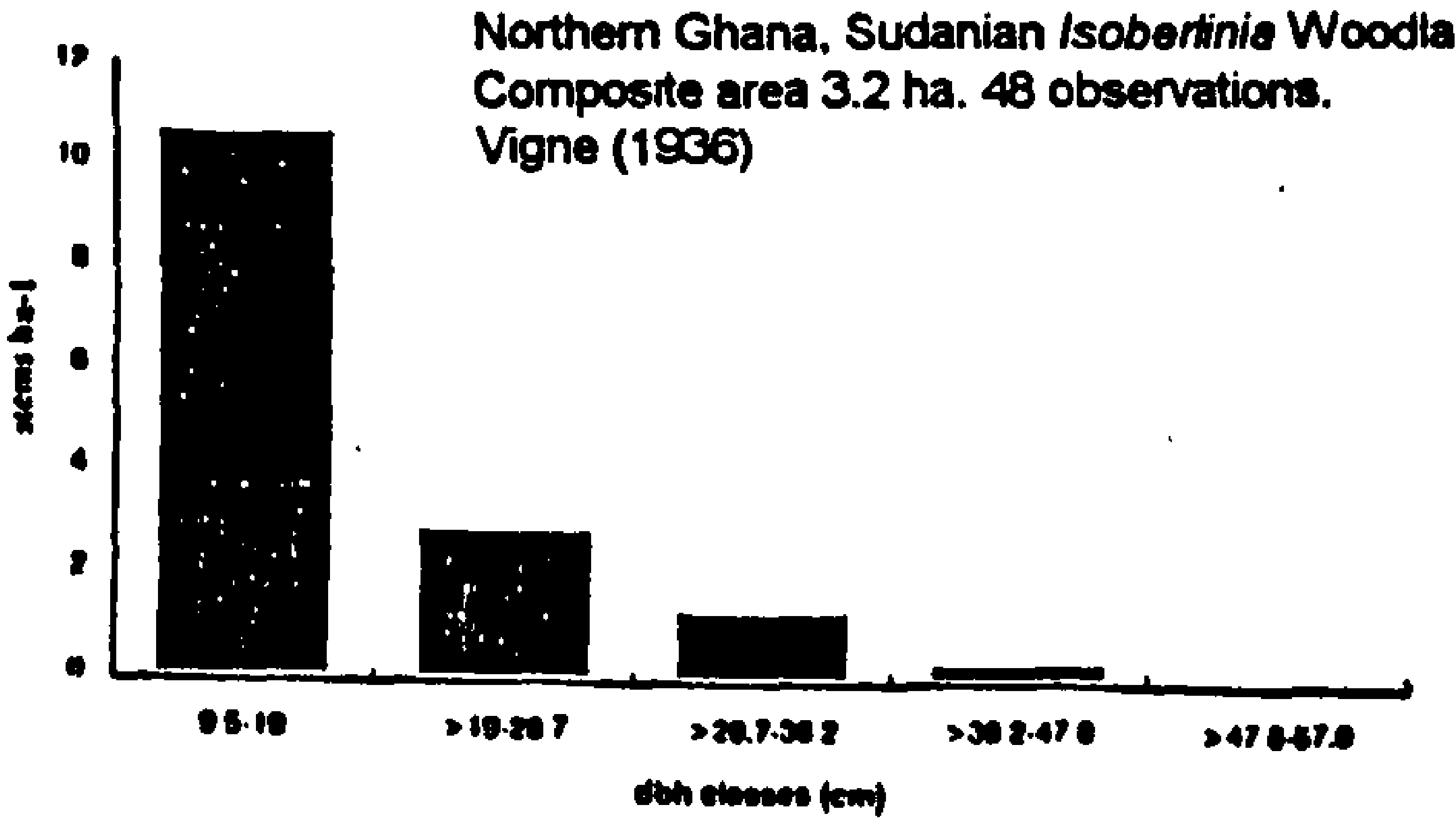
Stocking level ha-1 (representation)	Attribute	Min. value for inclusion	Location	Basis	Source
277-479	'trees'	not specified	Yendi (Ghana) 9° 30'N 0° 00'	305-585 observations on five individual plots of 1.02-1.29 ha	Coull (1928)
89-500+	all stems	not stated	Nazinga region Burkina Faso	not specified	Bonkoungou (1987)
85 (20.3%)	'stems'	not specified	Badeggi (Nigeria) 9° 01'N 6° 08E	32 observations on 0.4 ha plot	Jones (1963)
83	farmland trees	not stated	Ejura-Atebobo (Ghana) 7° 30'N 1° 15'W	32 observations on 0.46 ha	Chipp (1927)
79 (18.1%)	'trees'(root collar diameter)	5 cm	Toumossenni (Burkina Faso) 10° 30'N 5° 00' W	436 total stems including *Vitellaria*	Renes (1991)
65 (7.7%)	'trees' dbh	*ca* 3.2 cm dbh	Mole(Ghana) 9° 30'N 2° 00'W	26 obsevations on of 0.4 ha	Sobey (1978)
50-100	trees	' fruiting age'	general, Burkina Faso	not specified	Bonkoungou (1987)
40-88 (3-10%)	individuals	1m height	Mole(Ghana) 9° 30'N 2° 00'W	10-22 observations on each of three 1 ha. plots	Lawson et al. (1968)
21 (15.1%)	individuals (height)	2 m	Olokemeji (Nigeria) 7° 25'N 3° 33'E	21 observations on 0.25 ha	Hopkins (1962; 1965)
16 (15.7)	individuals (basal area)	*ca* 2.8 cm dbh	Olokemeji (Nigeria) 7° 25' 3° 33'E	16 observations on 0.25 ha	Hopkins (1962; 1965)
15 (6.3)	'trees' (dbh)	*ca* 9.5 cm	Northern Ghana	48 observations on composite area 3.2 ha	Vigne (1936)
15 (1.7%)	stems	not stated	Gonse Burkina Faso 12° 25'N 1° 20'W	15 stems on 1 ha assessed	Bonkoungou & Framond (1988)
12.8	'plants' dbh	10 cm	Petit Samba (Burkina Faso) 12° 45'N 2° 15'W	1.2 ha (30 plots each of 0.04 ha) ca 18 observations (pers comm).	Gijsbers et al. (1994)
12.5 (13%)	individuals	not specified but > breast height	Olokemeji (Nigeria) 7° 25' N 3° 33'E	72 individuals (73 stems) on 5.76ha.	Greig-Smith (1991)
9.7 (7.2%)	individuals (dbh)	> ca 9.7 cm	Gambaga scarp (Ghana) 10° 32'N 0° 25'W	1743 observations on 180 ha	Taylor (1960)
7.6-16 (22.5-34.7%)	stems (dbh)	*ca* 9.7 cm dbh	Zuarungu (Ghana) 10° 52'N 0° 37'N	31-67 observations on 3 plots each of 4 ha.	Ramsay & Rose Innes, (1963)

Stocking level ha-1 (representation)	Attribute	Min. value for inclusion	Location	Basis	Source
5-82 (6-10%)	stems (dbh)	*ca* 9.5 cm	Bolgatanga (Ghana) 10° 50'N 0° 35'W	5-82 observations on each of three 1 ha plots	Brookman-Amissah et al. (1980)
2.5 (1.5%)	individuals (dbh)	*ca* 1.6 cm	Zurmi (Nigeria) 12° 50'N 6° 50'E	1 observation 0.4 ha	Keay (1949)
0-80 (0-18.4%)	'trees' (dbh)	*ca* 3.2 cm	Kainji lake National park (Nigeria)	0-7 observations on each of a series of twelve 0.1 ha plots(total of 27 observations)	Afolayan (1974)
0-40 (0-9.6%)	individuals (dbh)	*ca* 3.2 cm	Anara Forest Reserve (Nigeria) 10° 40'N 7° 45'E	0-8 observations on each of a series of fifteen 0.2 ha plots (total of 52 observations)	Onochie (1961)
0-20 (0-11.8%)	'trees' (dbh)	*ca* 15.9 cm	Kainji Lake National Park (Nigeria)	0-2 observations on a series of twelve 0.1 ha plots in Isoberlinia woodland (total of 3 observations)	Afoloyan (1974)
0-8.4	individuals (dbh)	*ca* 9.7 cm dbh	Ejura-Atebobo (Ghana)7° 30'N 1° 15'W	0-9 observations on 4 areas each of 0.8 ha	Chipp (1927)

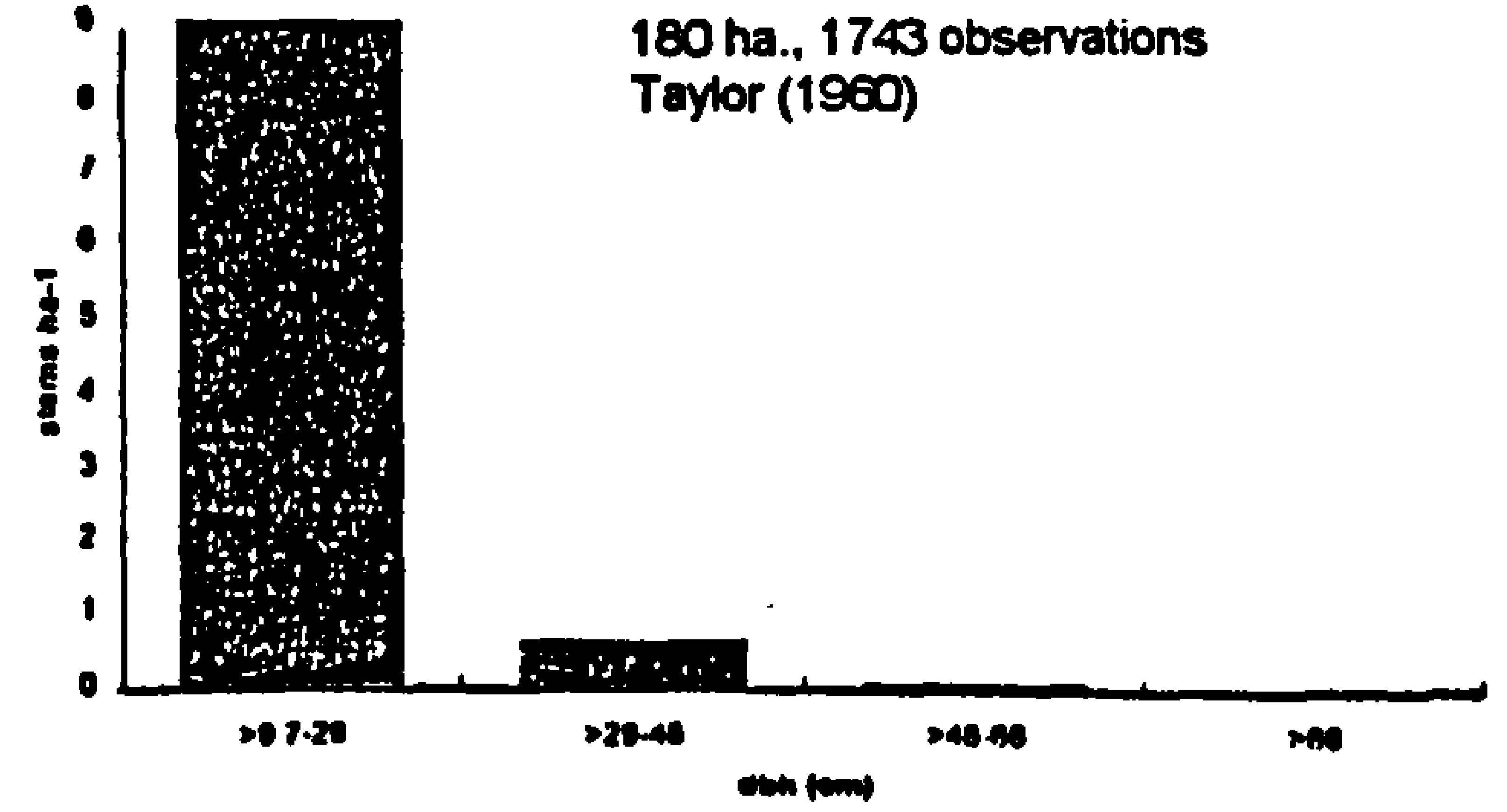
Ghana, Zuarungu (10 52'N 0 37'W),
12 ha., 261 observations.
Sudanian Undifferentiated Woodland.
Ramsay and Rose-Innes (1963).



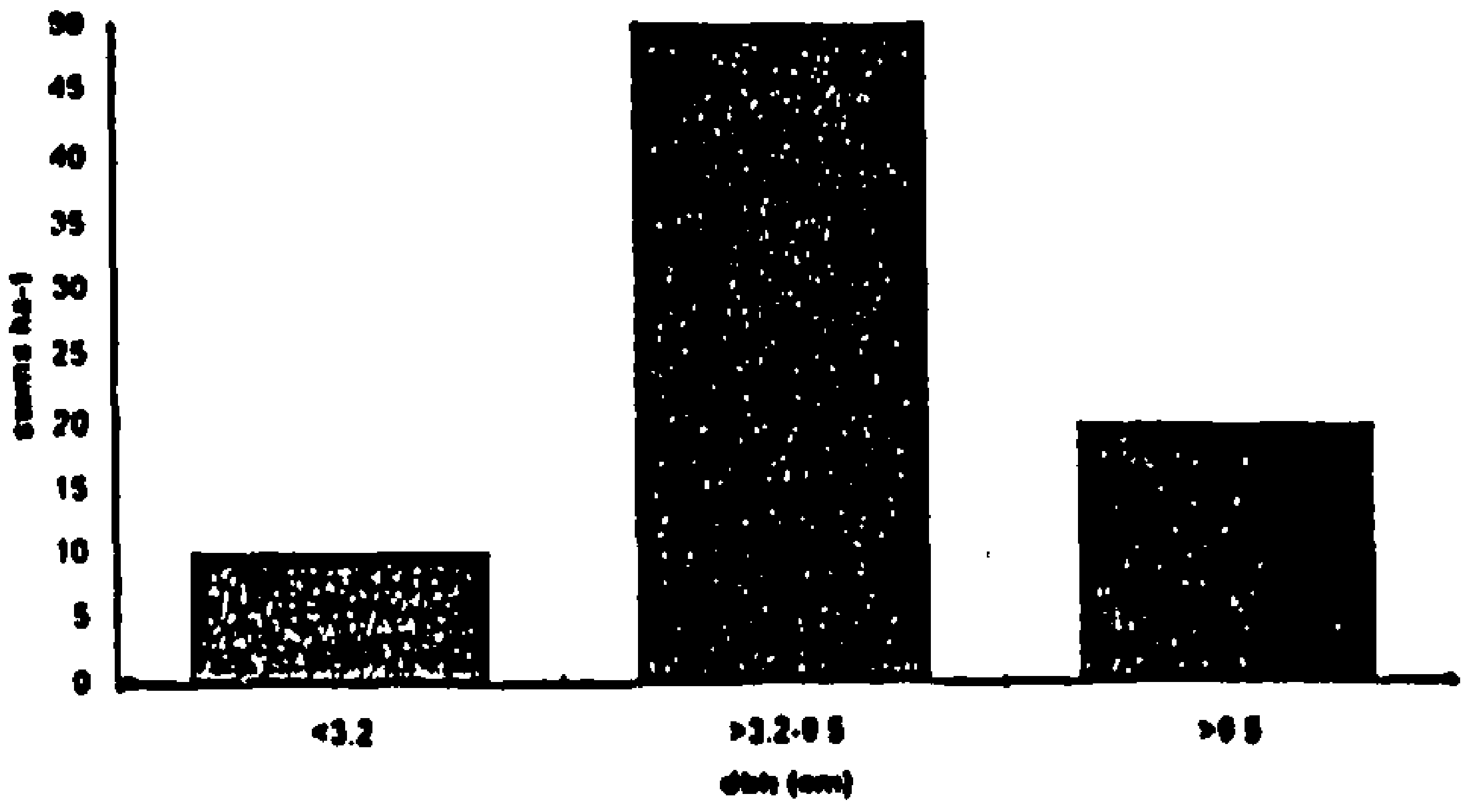
Northern Ghana, Sudanian *Isoberlinia* Woodland.
Composite area 3.2 ha. 48 observations.
Vigne (1936)



Ghana, Gambaga Scarp Forest Reserve.
Guinea Savanna woodland
180 ha., 1743 observations
Taylor (1960)



Nigeria, Kainji Lake National Park.
0.1 ha., 8 observations
Burkea/Detarium woodland
Afolayan (1974)



Nigeria, Olokemeji (7° 03'N 3° 23'E).
0.25 ha., 21 observations.
Guineo-Congolian/Sudanian transition woodland
Hopkins (1962)

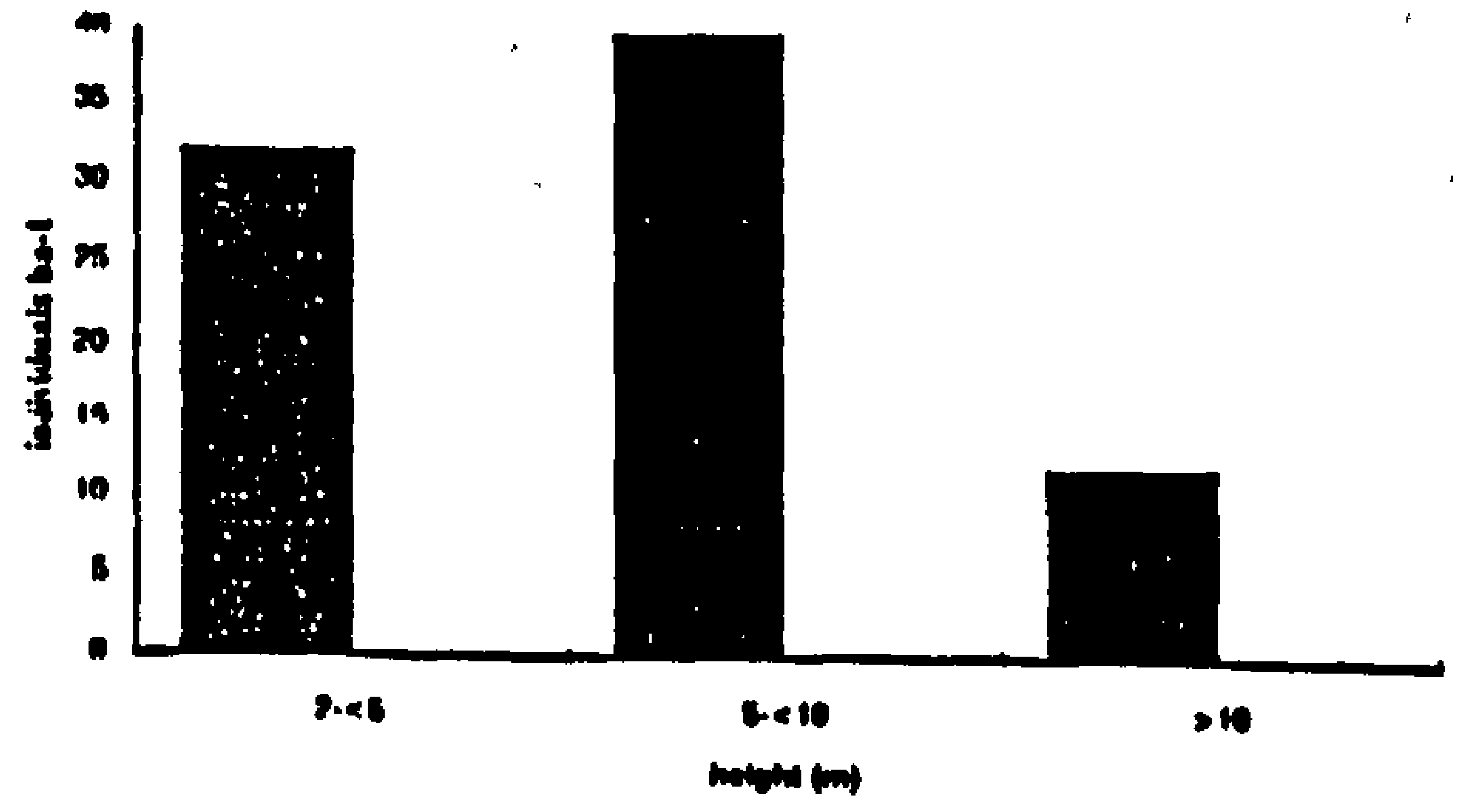


Fig. 2.7 *Vitellaria paradoxa* subsp. *paradoxa* size class distribution within populations

Keay (1949) in the Zamfara Forest Reserve (12°49'N 6°47'E), near the northern-most limits of *Vitellaria*, reports the stocking of individuals ≥ 1.6 cm dbh on nine plots - mostly of 0.4 ha area. Individuals were refered to eight classes but *Vitellaria* was represented by only a solitary tree (in the 9.5 -14 cm dbh class) on one plot. Similar rarity is indicated by Onochie (1964). Both Keay and Onochie were working at the limit of the range.

Representation

In parklands, the population structure and dynamics are under anthropogenic influence and while the tree becomes dominant (Pullan, 1974), density is often low,. Representation is normally high in farmlands, 60% of trees 20-80 cm dbh are reported to be *Vitellaria* in Southern Mali (Ohler, 1985).

The high population density reported by Coull (1928) from Yendi, Ghana, suggest more or less pure stands, but he does not report on associates. Other reports sometimes allow calculation of the proportion of individuals referable to *Vitellaria.* In the Gambaga Scarp Forest Reserve, also in Ghana (10°32'N 0°25'W), *Vitellaria* formed 7.2% of individuals > 9.7 cm dbh but this pooled information from 180 ha in open woodland formation and is not accurate at the level of the stand. There are, however, some relevant reports. Renes (1991) reports a higher representation of 18.1% of individuals with root collar diameter ≥ 5 cm over 1.8 ha in Toumousseni Forest Reserve, Burkina Faso. A similar representation of 18.4% for trees > 3.2 cm dbh over 1.2 ha at the Kainji Lake National Park has been reported (Afoloyan, 1974). This indicates the prominence of the species in protected forest reserves and parks. The representation of *Vitellaria* (> 1 m high) on a 0.25 ha plot in natural woodlands at Olokemeji Forest Reserve (Hopkins, 1962) and of > 2 m high over 1 ha in the Mole Game Reserve Ghana (Lawson et al., 1968) were both less than 20%. Representation of 34.7% (>9.7 cm dbh) on a 4 ha plot in the Red Volta fire experiment, Ghana is extreme (Ramsay and Rose-Innes, 1963).

Relations with natural fauna

There are different categories of relationship with animals in natural vegetation. Associations with vertebrates arise predominantly from use of the fruits as food (Section 2.2.3) Browsing effects, however, also occur and are reported below. Flowers, fruits, leaves and stem of *Vitellaria* are important to several arthropods. Owusu-Manu and Kumah (1987) provide a list of insects knocked down from *Vitellaria* trees at Bole, but do not indicate their roles. Wills (1962), Forsyth (1966) and Salle et al. (1991) have listed major pests of *Vitellaria* (Table 2.12).

Different forms of associations are reported. *Curinosphena senegalensis* adults bore into growing shoots of the tree where they lay eggs. *Mussidia nigrivenella* breeds in the fruits (Salle et al., 1991). In Nigeria, the saturniid moth, *Cirina butyrospermi* oviposits on the tree in the rainy season (June): the eggs hatch at the peak of the rains (August), and larvae, feed on the leaves thereafter. There can be subsequent reduction in fruit yield (Golding, 1929). There are also insects which attack unhealthy trees of various tree species including *Vitellaria,* e.g. *Xyloctonus scotoides* and *Mussidia nigrivenella.* (Wagner et al., 1991).

There are reports of ruminant browsing of young *Vitellaria* plants in West Africa (Baumer, 1994). In the Kainji Lake National Park, Nigeria, Afoloyan

(1976) reports that of 903 adult *Vitellaria* trees (mean height 6.2 m, mean dbh 17 cm) 22% were either defoliated, pushed over or broken by elephants. He observed higher utilization during the dry season (November - April). Jachman and Croes (1991) reported that in areas of high elephant density (2.5-1.0 elephants km^{-1}) in the Nazinga Game Reserve, Burkina Faso, there was an increase in representation of *Vitellaria* because it was not of exceptional palatability.

Table 2.12 Arthropods associated with *Vitellaria* in natural vegetation

name	location	reference	remarks
Coleoptera			
Tenebrionidae			
Curinosphena senegalensis HAAG	Burkina Faso;	Salle et al. (1991)	Bores into shoots and young plants
Doliopygus dialumi ROBERTS	Ghana; Nigeria	Forsyth (1966)	Attacks felled trees
Elateridae			
Cardiophorus quadriplagiatus ER.	Burkina Faso; Ghana	Wills (1962); Salle et al. (1991)	Feeds on leaves
Scolytidea			
Xyloctonus scolytoides EICHHOFF	Burkina Faso; Ghana.	Wagner et al. (1991)	Secondary insect, attacks unhealty trees
Metahylesinus togonus EGGERS	Burkina Faso; Ghana.	Wills (1962)	Attacks dead branches
Cerambycidae			
Philematium festivum F.	Togo	Salle et al. (1991)	Attacks dead branches
Pachydissus spp	Burkina Faso		Also attacks dead branches
Hemiptera			
Penatomidae			
Glypsus conspicuus WESTW.	Burkina Faso, Ghana	Salle et al. (1991); Forsyth (1966); Lee (1971)	Destroy shoots and foliage of *Vitellaria* and also of coffea
Diptera			
Typetidae			
Ceratitis silvestri BEGZI		Salle et al. (1991)	Destroy flowers and fruits
Lepidoptera			
Saturniidae			
Cirina butyrospermi VUILLET	Mali; Burkina Faso; Nigeria	Salle et al. (1991); Wills (1962); Golding (1929).	Larva feeds on leaves; apparently specific to *V.paradoxa*
Pyralidae			
Bostra glaucalis HAMPSON	Mali;Nigeria; Burkina Faso.	Salle et al. (1991)	Destroys leaves
Mussidia nigrivenella ROGONOT	Ghana; Nigeria; Mali.	Wills (1962)	Breeds in fruits.
Mussidia pectinicornella HAMPSON	Ghana, Burkina Faso.	Wagner et al. (1991)	Larva attacks germinating seeds.
Nephopteryx orphnanthes MEYRICK	Burkina Faso; Nigeria.	Salle et al. (1991)	Destroy fruits of all age
Orthoptera			
Acrididae			
Anacridium melanorhodon WALKER	Mali; Burkina Faso.	Salle et al. (1991)	Both feed on
Pachytilus migatoroides REICHE	Mali.	Salle et al. (1991)	leaves and flowers.

Relations with man - including fire

Vitellaria is preserved on farms and forms a characteristic landscape in cultivated and fallow lands - *Vitellaria* parklands (Pullan, 1974). The protection received in the parklands results in good growth of the species where it can attain 15 m height (Keay, 1960). However, fallow periods have shortened and the species is reported to be disappearing gradually (Baumer, 1994) although recent reports underline its persisting significance as a much respected farm tree within its range (Kessler, 1992 - Burkina Faso; Gakou et al., 1994 - Mali).

The persistence of *Vitellaria* in the Sudanian zone is ascribed to its resilience to frequent burning, a constant feature of the zone (Hopkins, 1963). Indeed fire has been considered a fundamental influence in the evolutionary development of the species (Jackson, 1974).

Adomako (1985) observed at Bole, Ghana, that seasonal fires remove litter and clear undergrowth in *Vitellaria* stands. This is considered essential since fallen seeds come into direct contact with the soil and are more likely to germinate successfully. Direct heat treatment of subsp. *nilotica* seeds (method and temperature unspecified) prevented germination (Jameson, 1940).

Vitellaria exhibits vigorous suckering and coppicing, Hopkins (1963) notes that fires stimulate the former behaviour, which normally begins before the onset of the rains. Brookman-Amissah et al. (1980) demonstrate the vulnerability of *Vitellaria* to regular burning in Northern Ghana. Burning clear-felled plots early (November) and late in the dry season (April), over a 26-year period reduced the density of *Vitellaria* compared with a successfully protected plot that had been free of fires through this period. The late burn regime was particularly repressive for the species. In coppiced and pollarded plots subjected to similar burning regimes in the Anara Forest Reserve, Nigeria, Onochie (1961) reports poor coppicing ability in protected plots, however, in plots burned annually in late dry season (March), trees pollarded at 1.3 m high showed good regeneration. In the Olokemeji Forest Reserve, Hopkins (1962) showed that woody plants more than 75 cm high normally sprout after burning and those less high grow by new suckers. A positive correlation exists between postfire survival and plant height and basal area (Hopkins, 1965).

In an experiment to investigate the preference for browse species of ruminant livestock in Shika, Nigeria, Leeuw (1979) noted that subspecies *paradoxa* was readily consumed by stock. Similar observations have been made in the parkland at Petit Samba, Burkina Faso (Gijbers et al., 1994). In contrast at Bole, Ghana, Adomako (1985) reports that mature trees are not debarked or damaged by cattle. It seems that the species is likely to be browsed only in areas with poor and/or unpalatable grass cover since it is not known to be of exceptional palatability (Jachman and Croes, 1991).

Vegetation types

Both subspecies of *Vitellaria* occur in the same vegetation formation, the Sudanian zone (sensu White, 1983). As the species avoids areas with seasonal inundation (section 2.3.2), incident rain is important. In natural vegetations where it is numerically well-represented, it defines communities and associations. It defines anthropic landscapes in the zone (Table 2.13).

Table 2.13 Designations used for vegetation within which *Vitellaria paradoxa* is a typical constituent

Country	Community	Reference
Nigeria	*Vitellaria-Monotes* open savanna woodland	Keay (1947)
Sudan	*Vitellaria* woody vegetation	Morison et al. (1948)
Nigeria	*Terminalia-Vitellaria* farmed savanna	Keay (1960)
Uganda	*Vitellaria* savanna, subdivided into; *Vitellaria-Hyperrhenia rufa* savanna *Vitellaria- Hyperrhenia dissoluta* savanna *Vitellaria-Daniellia-Hyperrhenia* savanna.	Langdale-Brown et al (1964)
West Africa	*Vitellaria* parklands	Pullan (1974)
Central Africa Republic	Sub-Soudanien a *Vitellaria*	Boulvert (1980)

The vegetation types where *Vitellaria* occurs, in terms of White's (1983) classification, are the Guineo-Congolian/Sudanian transition woodlands (Sector 1) and Sudanian woodlands with abundant *Isoberlinia doka* (Sector 2) and Undifferentiated woodlands (Sector 3) (Fig 2.8). The species is reported as a component of the Mandara Plateau mosaic (Sector 4) (Letouzey, 1968). Reports of vegetation surveys which cover limited areas of *Vitellaria*'s range, sometimes provide information on overall stocking (ha^{-1}) of woody vegetation but several mention the species only as a component of vegetation associations, particularly reports from the range of subsp. *nilotica* (e.g. Langdale-Brown, 1960). Community descriptions provided along with comments relating to *Vitellaria* indicate it is a species or survivor of well-developed woody vegetation which in an undegraded state is 6 m or more tall.

Key

1 Guineo-Congolian/Sudanian transition zone
2 Sudanian *Isoberlinia* woodland
3 Sudanian Undifferentiated woodland
4 Mandara Plateau mosaic

Figure 2.8 *Vitellaria paradoxa* distribution in relation to the main phytochoria of White (1983)

In the transition woodlands, subspecies *paradoxa* sometimes coexists with forest species (Jones, 1963). Hopkins (1962) reports 520 individuals ha^{-1} (all species, > 2 m tall, highest 14 m), receiving 1200 mm mean annual rainfall in the Olokemeji Forest Reserve, Nigeria. In woodland with abundant *Isoberlinia*, Morison et al. (1948) report subsp. *nilotica* to be locally dominant in vegetation 4.5-11 m tall under 1000 mm yr^{-1} rainfall at Halima, Sudan. In Uganda, subsp. *nilotica* grows in open woodlands, in the 1000-1200 mm rainfall zone. Where it dominates the vegetation, it is normally associated with *Combretum* spp. Langdale-Brown (1960) describes *Vitellaria* dominated fire climax deciduous woodland 5-14 m under 1200-1400 mm yr^{-1} rainfall in West Nile, Acholi and Lango districts. In the Sudanian Undifferentiated woodland stocking of 1470 individuals of woody species ha^{-1} (all species, all sizes, tallest 8 m) over sandstone receiving 850-1000 mm mean rainfall yr^{-1} in the Gongola Valley, Nigeria has been reported (Ramsay and Leeuw, 1964). A sparse stocking of 3-14 trees ha^{-1} (all species, all sizes, tallest 15 m high) in an anthropic parkland under 850 mm yr^{-1} rainfall at Kolakani, Mali reflects the destruction of woody vegetation by farmers (Ohler, 1985) and the survival of *Vitellaria* trees as locally valued relics.

Associated species

About 200 woody species are reported as associates of subspecies *paradoxa* over its range. To identify species justifying inclusion in this list, special attention has been paid to inventoried plots over restricted areas (eg. Onochie, 1961; Hopkins, 1962; Lawson et al., 1968) to focus on close rather than merely regional or zonal associates. The species listed are those repeatedly reported and/or quantitatively adundant in at least one plot with *Vitellaria* prominent.

The list is of 50 woody species associated with subspecies *paradoxa* in 20 sample plots (individually 0.1-4.0 ha) over its range (Table 2.14).

Vitellaria grows within a wide latitudinal band (500 to 700 km wide) through the Sudanian zone (White 1983). The northern part of this band receives less rainfall than the south and *Isoberlinia* is not dominant (Undifferentiated zone) except on rocky hills. Associates with the listed species restricted to this zone are *Combretum molle, C. binderianum* and *Lannea microcarpa.* None of the associated species, however, is limited to the southern Sudanian *Isoberlinia* woodland. The Guineo-Congolian/Sudanian transition woodland forms a band between the forest in the south and woodland in the north. Five associated species of the *Isoberlinia* dominant zone are also important in this transition. Although the Mandara Plateau is high enough for its distinctive vegetation to be mapped separately *Vitellaria* occurs there and 21 of its associates on the Plateau are also listed for other parts of the range. Five associates occur in all four zones: *Hymenocardia acida*, *Terminalia laxiflora*, *Stereospermum kunthianum, Anogeissus leiocarpus* and *Annona senegalensis.*

As associates the Leguminosae are widespread (14 species listed) and the family is represented in all sections of the range of subsp. *paradoxa*. The Combretaceae (7 listed) are similarly widespread through the range. Woody species of farm regrowth vegetation are restricted to those of economic importance to farmers (e.g. *Tamarindus indica*).

There is less satisfactory information on the species associated with subsp. *nilotica.* Morison et al. (1948), Langdale-Brown et al. (1964), and Friis and Vollesen (1984) provide a list of associates of subsp. *nilotica* in Sudan, Uganda and Ethiopia respectively. Kriek (1967) also provides a list of associated species in Uganda. The associated species in Sudan occur in Sudanian *Isoberlinia* woodland, and those of Uganda and Ethiopia in what is referable to Sudanian Undifferentiated woodland. Several associates occur only within subsp. *nilotica* range (e.g. *Uvaria bukobensis, Xylopia rubescens* and *Pappea capensis).* Fifteen species (Tables 2.14 and 2.15) are associated with both subspecies.

Table 2.14 Erect woody species associated with subsp. *paradoxa* in natural communities

Species	1	2	3	4
Amblygonocarpus andongensis (WELW. & OLIVER) EXELL.	1	2		
Afzelia africana SMITH	1	2		
Diospyros mespiliformis HOCHST.	1	2		
Parinari curatellifolia PLANCHON ex BENTH.	1	2		
Parinari polyandra BENTH.	1	2		
Bridelia ferruginea BENTH.	1	2	3	
Combretum ghasalense ENGL. & DIELS	1	2	3	
Crossopteryx febrifuga (AFZEL. ex G. DON) BENTH.	1	2	3	
Detarium microcarpum GUILL. & PERR.	1	2	3	
Pseudocedrela kotschyi (SCHWEINF.) HARMS	1	2	3	
Terminalia glaucescens PLANCH.	1	2	3	
Lannea kerstingii ENGL. & K. KRAUSE	1		3	
Acacia dudgeonii CRAIB ex HOLL.	1		3	
Burkea africana HOOK	1	2	3	
Daniellia oliveri HUTCH. & DALZ.	1	2	3	
Monotes kerstingii GILG.	1	2	3	
Pericopsis laxiflora (BENTH. ex BAK.) V. MEEUWEN.	1	2	3	
Prosopis africana TAUB.	1	2	3	
Terminalia avicennioides GUILL. & PERR.	1	2	3	
Lophira lanceolata VAN TIEGH. ex KEAY	1	2		
Annona senegalensis PERS.	1	2	3	4
Anogeissus leiocarpus (DC.) GUILL. & PERR.	1	2	3	4
Hymenocardia acida TUL.	1	2	3	4
Stereospermum kunthianum CHAM.	1	2	3	4
Terminalia laxiflora ENGL.	1	2	3	4
Combretum glutinosum PERR. ex DC.	1		3	

Species	1	2	3	4
Entada africana GUILL. & PERR.	1	2	3	4
Khaya senegalensis A. JUSS.	1	2	3	4
Maytenus senegalensis (LAM) EXELL.	1	2	3	4
Nauclea latifolia SMITH	1	2	3	4
Parkia biglobosa (JACQ.) BENTHAM	1	2	3	4
Piliostigma thonningii (SCHUM) MILN-REDH.	1	2	3	4
Pterocarpus erinaceus POIR	1	2	3	4
Vitex doniana SWEET	1	2	3	4
Malacantha alnifolia (BAKER) PIERRE	1			4
Allophylus africanus P. BEAUV.	1			4
Acacia hockii DE WILD		2	3	
Lannea acida A. RICH.		2	3	
Strychnos innocua var. innocua DEL.		2	3	
Swartzia madagascariensis DESV.		2	3	
Ximenia americana L.		2	3	
Strychnos spinosa LAM		2	3	4
Boswellia dalzielii HUTCH.		2	3	4
Bridelia scleroneura MUELL. ARG.		2	3	4
Tamarindus indica LINN.		2	3	4
Grewia mollis JUSS.		2		4
Isoberlinia doka CRAIB & STAPF.		2		4
Sterculia setigera DEL.			3	
Combretum binderianum KOTSCHY			3	
Combretum molle R.BR. ex G. DON			3	
Lannea microcarpa ENGL. & K KRAUSE			3	

1 Guineo-Congolian transition
2 Sudanian with abundant *Isoberlinia*.
3 Sudanian undifferentiated woodland
4 Mandara Plateau mosaic

Table 2.15. Erect woody species associated with subsp. *nilotica* in natural communities

Species	2	3	3a	3b
Oxytenanthera abyssinica (A. RICH.) MUNRO	2			
Pterocarpus abyssinica HOCHST. ex A. RICH.	2			
Gymnosporia senegalensis (LAM.) LOES	2			
Combretum undulatum ENGL. & DIELS.	2			
**Hymenocardia acida* TUL	2		3a	3b
**Acacia hockii* DE WILD	2		3a	3b
Entada sudanica SCHWEINF.	2	3		
Lonchocarpus laxiflorus GUILL. & PERR.		3	3a	
**Combretum ghasalense* ENGL. & DIELS	2		3a	3b
Chlorophytum micranthum BAK.		3		
Pterocarpus lucens LEPR. ex GUILL. & PERR.		3		
Terminalia mollis LAWS		3	3a	
Combretum fragrans F. HOFFM.		3	3a	
**Combretum molle* R.BR. ex G. DON			3a	
Lophira lanceolata VAN TIEGH ex KEAY			3a	
**Terminalia glaucescens* PLANCH.			3a	
Erythrinia tomentosa R. BR. ex A. RICH.			3a	
**Annona senegalensis* PERS.			3a	
Strychnos innocua var. innocua DEL.			3a	
Dombeya rotundifolia (HOCHST.) PLANCH.			3a	
**Lannea kerstingii* ENGL. & K. KRAUSE			3a	
**Burkea africana* HOOK			3a	
**Daniellia oliveri* HUTCH. & DALZ.			3a	
Kigelia aethiopica DECNE			3a	
Lannea humilis (OLIV.) ENGL.			3a	
Uvaria bukobensis ENGL.			3a	

Species	2	3	3a	3b
Xylopia rubescens OLIV.			3a	
Pappea capensis BAK. f			3a	
Commiphora africana (A. RICH.) ENGL.			3a	
Albizia coriaria WELW ex OLIV.			3a	
Lannea schimperi HOCHST. ex A. RICH.			3a	
Terminalia mollis LAWS			3a	
Acacia polycantha subsp. campylacantha HOCHST. ex A. RICH.			3a	
Albizia zygia (DC.) MACBRIDE			3a	
Acacia macrothyrsa HARMS			3a	
Boscia salicifolia OLIV.			3a	
Acacia gerrardii BENTH.			3a	
Sclerocarya birrea (A. RICH.) HOCHST.			3a	
Albizia amara subsp. sericocephala (BENTH.) BRENEN			3a	
**Tamarindus indica* LINN.			3a	
**Bridelia scleroneura* MUELL. ARG.			3a	3b
**Combretum binderanum* KOTSCHY			3a	3b
Piliostigma thonningii (SCHUMACH.) MILNE-REDH.			3a	3b
Terminalia macroptera GUILL. & PERR.				3b
**Afzelia africana SMITH*				3b
**Khaya senegalensis A. JUSS.*				3b
**Grewia mollis* JUSS.				3b
Ziziphus mauritiana LAM.				3b

* listed as associates of subsp. *paradoxa*

2 Sudan - Morison et al. (1948)
3 Ethiopia - Friis ans Vollesen (1984)
3a Uganda - Langdale-Brown et al. (1964)
3b Uganda - Kreik (1967)

Vascular plant parasites associated with *Vitellaria*

Vascular plant parasites of the Loranthaceae have been known to attack *Vitellaria* for many years (Anon., 1912; Ruyssen, 1957). Bonkoungou (1987) noted that *Tapinanthus* parasitized subsp. *paradoxa* (Table 2.16). Later a detailed survey of Loranthaceae on *Vitellaria* was carried out in Burkina Faso (Boussim et al., 1993). Four species of *Tapinanthus* are involved. Boussim et al. (1993) identified *T. dodoneifolius*, *T. globiferus* and *T. ophioides* as attacking *Vitellaria* in Burkina Faso. Salle et al. (1991) observed a fourth species *T. pentagonia* parasitizing *Vitellaria* in both Burkina Faso and Mali. The commonest and most widespread was *T. dodoneifolius,* especially in the more humid part of the range (Boussim et al., 1993). In Burkina Faso, 95% of *Vitellaria* trees were parasitized. Frequently two or more Loranthaceous species attacked one tree. Infestation is reported to affect tree vigour and fruit production (Bonkoungou, 1987). Under the combined effects of drought and parasitism, Boussim et al. (1993) reported 26% of 16027 parasitized trees died.

Table 2.16 Vascular plant parasites (*Tapinanthus*) associated with *Vitellaria paradoxa* subsp. *paradoxa* in West Africa

Species	location	severity	author
T.dodoneifolius (DC.) DENSER	Mali, Burkina Faso	very common	Salle et al. (1991); Boussim et al. (1993)
T. globiferus (A. RICH.) DENSER	Mali, Burkina Faso	less frequent	Boussin et al. (1993)
T. pentagonia (DC.) VAN TIEGHEM	Burkina Faso	less frequent	Boussim et al. (1993)
T. ophioides (SPRAGUE) DENSER	Burkina Faso	least spread	Boussim et al. (1993)

Chapter three

Study site, materials and procedures

CHAPTER THREE

Study site, materials and procedures

This chapter provides a description of the study site (3.1), and explains the materials and procedures adopted in this study. The derivation of drought and fire danger regimes are outlined in Section 3.2, and the investigation of population structure and natural regeneration in Section 3.3. The methodology of germination and seedling survival evaluation is reported in Section 3.4. In the last section, 3.5, flowering and pollination study approaches are summarized. Sections are subdivided as appropriate.

3.1 Study site

The study was undertaken at the Cocoa Research Institute of Ghana (CRIG) sub-station at Bole (9°02'N; 2°29'W; 301 m) in Sudanian *Isoberlinia* woodland (sensu White, 1983). The vegetation has been subject to centuries of disturbance by farming, grazing and fire and the current vegetation does not represent the climax, which is considered to be savanna woodland (Lawson et al., 1968). The vegetation is dominated by fire-tolerant tussock grasses which form a continous herbaceous layer over the land surface. The station is subject to a dry period from November to April when north-easterly harmattan winds coupled with high temperatures predispose the near-dormant vegetation to bush fires. Bole enjoys a mean annual rainfall of 1087 mm and mean temperature of 26.1 °C (Fig. 3.1). The soils of the 68 km^2 station are mainly ferric luvisols, but smaller areas of eutric regosols and lithosols are also present (FAO-Unesco, 1977). The topography is level to gently undulating.

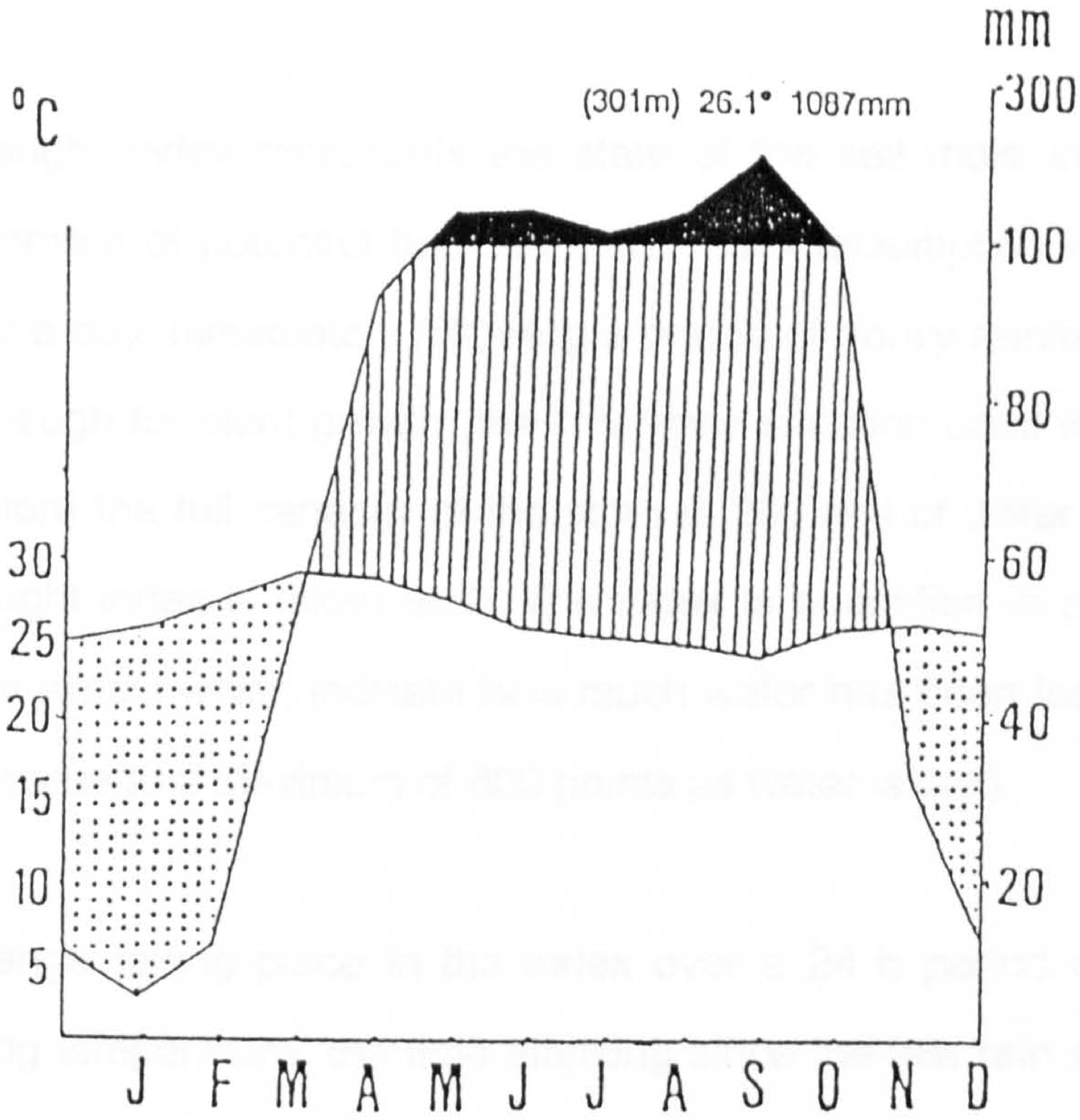


Figure 3.1 Climatic diagram for Bole, Ghana. (30 years mean).

3.2 Derivation of drought indices and fire risk indices.

3.2.1 Drought index

The drought index represents the state of the soil moisture store and the water content of potential fuel. An initial index assumption is made of a full store for a day immediately following a period of heavy rainfall. Where soil is deep enough for plant growth (the reference situation used for drought index calculation) the full capacity of the store is 200 mm of water. At full capacity the drought index is taken as 0. The index is quantified in points (1 point = 0.25 mm water) which indicate how much water has been lost (i.e. the index rises in value to a maximum of 800 points as water is lost).

The change taking place in the index over a 24 h period depends on the prevailing temperature, the time elapsing since the last rain and the quantity of rain which fell on that day and information on these is extracted from station climatic records. It also depends on the mean annual rainfall of the site and the state of the soil moisture store and potential fuel when the last rain fell: these extra influences are taken into account by reference to standard drought factor tables for four mean annual rainfall categories: 500-725 mm, 750-975 mm, 1000-1475 mm, ≥1500 mm. For this study the table for 1000-1475 mm mean annual rainfall was used.

Daily records of rainfall and maximum temperature for the period 1990-1994 were extracted from the Bole station records. An assumption of full soil moisture store was made for 11 October 1989 and drought indices determined forward day-by-day, as explained by Keetch and Byram (1968) and Hall and Gwalema (1985). From the daily rainfall, net rainfall was determined. Net rainfall is 5 mm less than the daily rainfall when the latter is ≥

5 mm, and taken as 0 mm whenever the daily rainfall is < 5 mm. Each day's initial drought index is calculated by increasing the previous day's index by the tabulated drought factor. The factor used depends on the current day's maximum temperature and the previous day's drought index, adjusted if necessary. An adjustment is made to the previous day's drought index if net rainfall is >0 mm for that day. The index is lowered by 1 point for every 1 mm of net rainfall.

3.2.2 Fire danger index

Using the drought index as a starting point its interactions with recent rainfall and ambient temperature, humidity and wind conditions were used to determine the fire danger index on monthly basis (Hall and Gwalema, 1985). A McArthur Forest Fire Danger Meter (McArthur, 1973, 1976) was employed for this. Procedure for using the meter followed the instructions printed on it (Appendix 1). Monthly fire danger conditions were expressed as the maximum fire danger likely, assuming the most recent fall of rain in one day to be 12.5 mm 10 days previously. Fire danger indices are indicated by McArthur's meter on a scale of 0 to 100. Values < 5 are considered indications of low danger; values >50 are considered indications of extreme danger.

3.3 Population and natural regeneration studies

3.3.1 Population structure of *Vitellaria* at Bole

In the Bole area, the influence of human activities (e.g. farming and livestock grazing) have resulted in variable vegetation composition, density and structure around villages. Two sampling strata were therefore distinguished in the study area (Fig 3.2) - areas > 3 km from a village (Stratum 1) and within 3 km of a village (Stratum 2).

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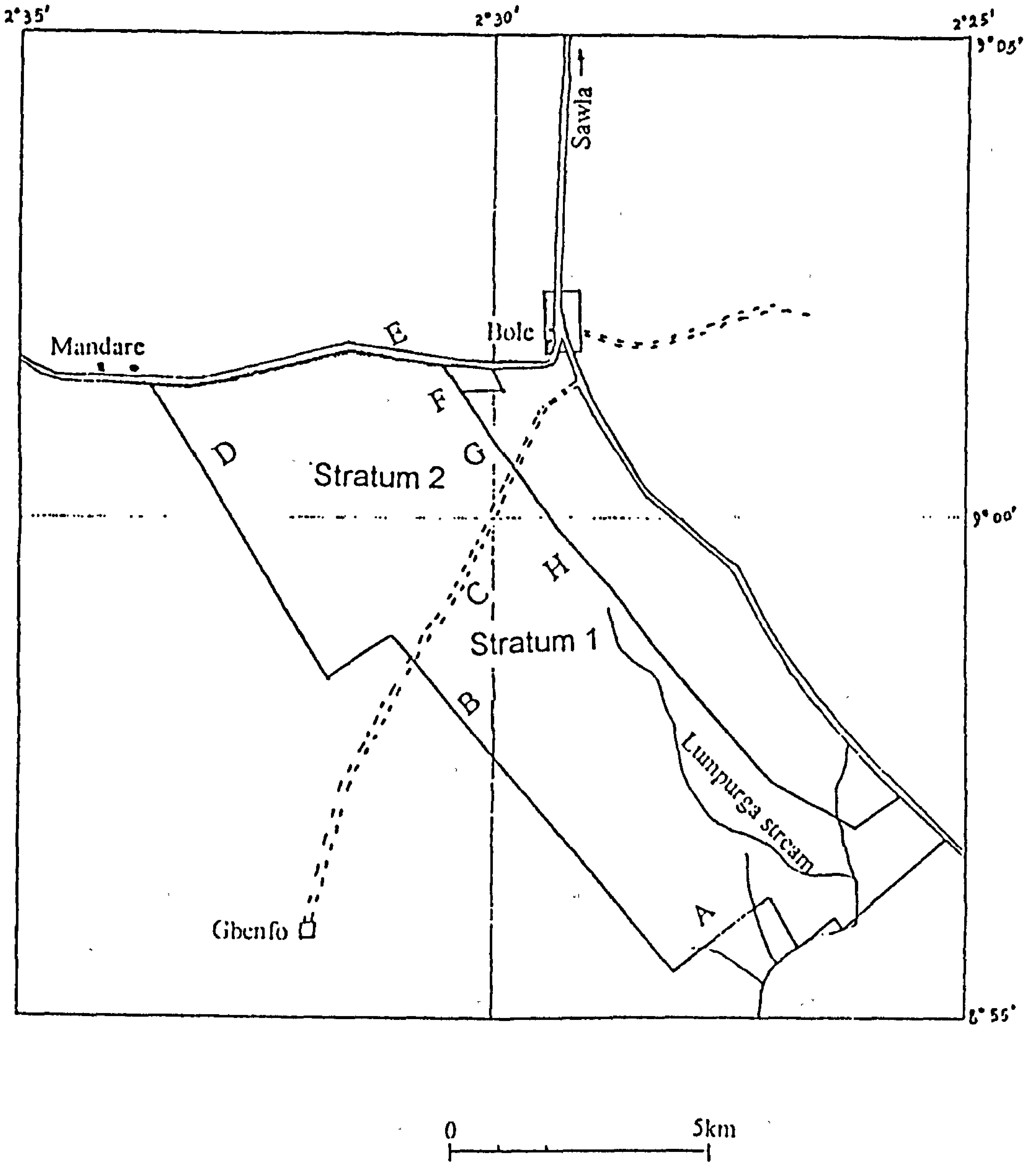


Figure 3.2 Map of Bole station showing the location of the stands, A-H.

From experience gained in the activities of the CRIG *Vitellaria* programme, shea trees ≥10 cm diameter at breast height (dbh) were considered mature (potentially able to fruit). For present purposes, a tree is therefore defined as any individual with at least one stem ≥10 cm dbh. This is broadly in agreement with other reports of dbh of *Vitellaria* trees commencing fruiting (e.g. Delolme, 1947). Fourteen stands of mature individuals favoured for fruit collection by the local population and Institute staff were located through a reconnaissance exercise and four within each stratum, each composed of an estimated 100 or more mature trees, were investigated. The four sampled stands were the most accessible (within 30 minutes of the nearest vehicle access), given an interval of at least 500 m between one of these stands and any other.

Within each stand a reference point was marked with a ranging pole. From this point, working progressively outwards, positions of all mature *Vitellaria* individuals were mapped until at least 100 trees had been recorded, or no additional mature *Vitellaria* trees could be found within 50 m of any *Vitellaria* previously mapped. Mapped *Vitellaria* individuals were labelled with aluminium embossing tape. Individuals of other species ≥ 10 cm dbh were tallied as the sample was assessed but were not mapped. For summary and description purposes individual trees were assigned to diameter classes of >10≤20 cm >20≤30 cm, >30≤40 cm and >40 cm according to the dbh (to the nearest cm) of the main (largest) stem.

Stand density for *Vitellaria* was determined with the computer programme of Ward (1991). Polygonal tessellations and the associated Delaunay triangles were generated with the FORTRAN programme - MUSHROOM (Green and Sibson, 1978 - Appendix 2). In each stand, triangles were then randomly sampled from the triangulations and fed into Ward's programme (until the output value of per hectare stocking stabilized). Stocking per hectare was also determined directly from number of trees and area involved.

3.3.2 Regeneration sampling

Maps of the mature *Vitellaria* individuals (>10 cm dbh) in each stand were plotted and subdivided into triangular sections, using the mature individuals as nodes. Triangles were demarcated to approach an equilateral shape as far as possible and, additionally, so that no mature *Vitellaria* trees occurred within them. When subdivision was completed the areas of the largest and smallest triangles were calculated. The range of the area values was divided into three parts representing triangles small, medium and large in area. From each stand six triangles from each area category were sampled at random and in each of these regeneration was sampled.

In each sampled triangle a careful search for regeneration was carried out. Regeneration, individuals of *Vitellaria* with shoots < 10 cm dbh, was tallied in the field for each sample triangle in August 1993 and again in August 1994. The height, root collar diameter and mode of regeneration of each regenerating individual tallied was recorded. The diameter at breast height of regenerating individuals ≥ 1.5 m high and < 10 cm dbh were recorded: these were categorized as saplings. In stand F, height increment in regeneration over the period (1993-1994) was calculated by difference.

The mode of regeneration was classified as suckers, coppice or seedlings. Suckers were shoots sprouting from below the soil surface or the root collar of dead shoots (suckers were mostly multiple shoots, in which case the tallest was measured). Coppice plants were shoots sprouting from above the soil surface up to a height of <15 cm off partly dead shoots or stumps. Seedlings were germinated seeds or shoots unaffected by fire. A few longer-established individuals with no indication of an old root system within 6 cm of the surface were included here.

3.4 Germination and seedling survival in *Vitellaria*

3.4.1 Seed treatment and canopy influence on germination

Objective

The combined effects of seed treatment and canopy influences on seed germination in *Vitellaria* were investigated in an experiment.

Basic design:

The trial was a factorial combination of three seed treatments (depulped, cracked, intact) and two locations (under and outside tree canopy). A replicate of the experiment was installed around each of three reproductively mature trees (dbh > 30 cm) isolated from other trees to ensure that neighbouring trees do not influence germination outside canopy. The basic unit for the experiment was a seed sown in a soil-filled polybag. Nursery soil was thoroughly mixed in bulk and all polybags filled from it afterwards to ensure uniformity of medium. This was to eliminate possible site differences in soil between trees and with distance outwards from the tree base. Treated seeds were randomly distributed under and outside the canopy of mature trees (Fig 3.3). Under canopy seeds were distributed from tree trunk to canopy edge and outside canopy seeds from canopy edge to 8 m beyond. Watering was undertaken when there was more than three successive days without rain.

Seed treatment procedure

Depulped seeds were obtained by removing pulp from fresh fruits, and cracked seeds by exerting slight pressure on depulped seeds to make ruptures 10-12 mm long in the shell-like testa.

Location:

CRIG Substation, Bole.

Extent/Scale

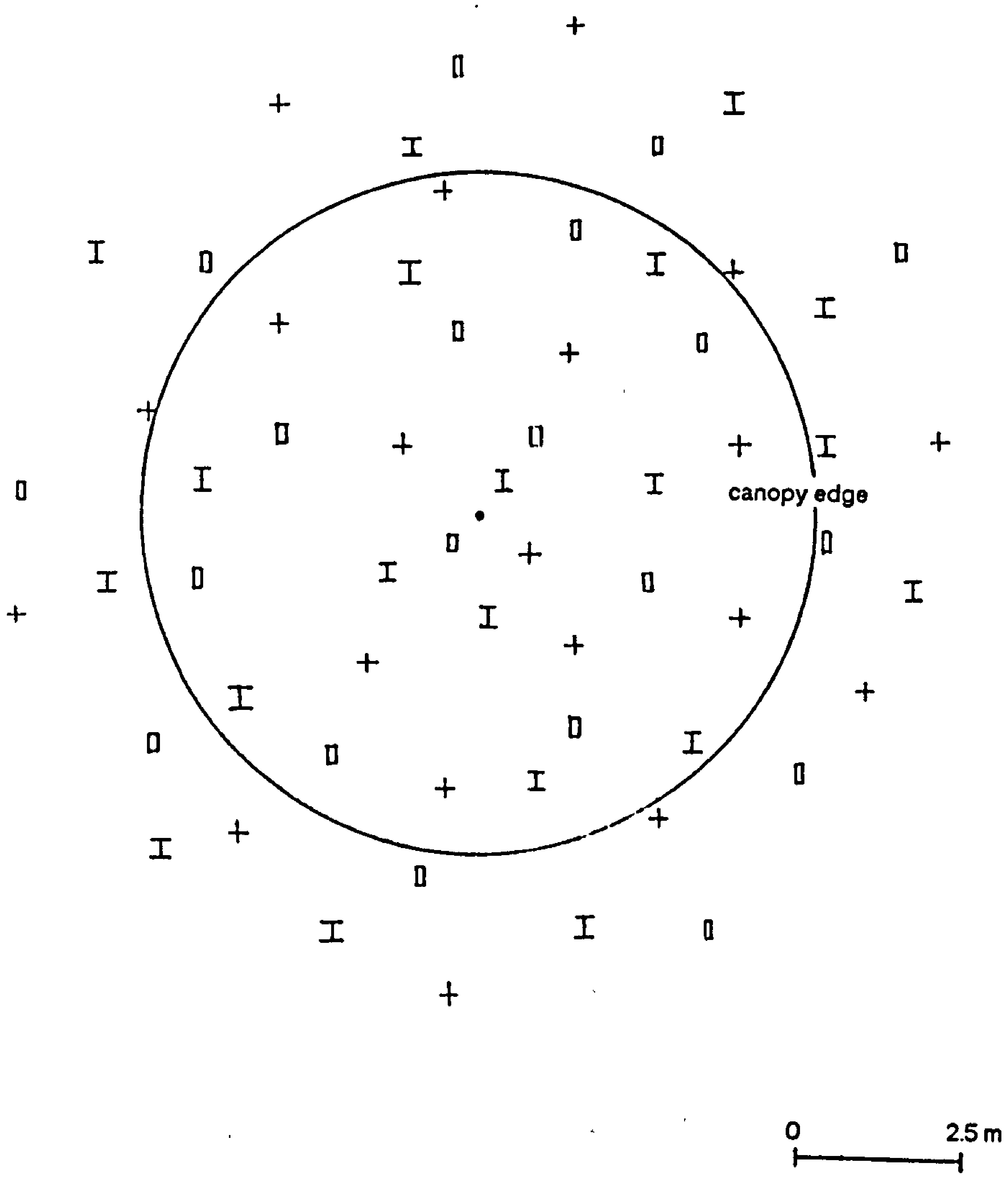
A total of 180 seeds were used in the experiment: 60 for each of the three seed treatments.

Species

Vitellaria paradoxa

Treatments

- Intact seeds under canopy.
- Intact seeds outside canopy.
- Depulped seeds under canopy.
- Depulped seeds outside canopy.
- Depulped, cracked seeds under canopy.
- Depulped, cracked seeds outside canopy.



Key

undepulped ▯
depulped I
cracked +

Fig. 3.3: Layout of seed germination experiment

Date of sowing

16 August 1994.

Duration

Observation continued for 20 weeks

Assessment

Parameter	Dates			
	7/10/94	15/11	27/12	20/1/95
Germination	+	+	+	+
Height				+
Root collar diameter				+

3.5 Flowering and pollination studies

3.5.1 Studies on flower development and floral dimorphism

Objective:

Following the report by Chevalier (1948), of the occurrence of floral dimorphism due to different style lengths in the flowers of *Vitellaria,* this study

[*] was undertaken to evaluate variations in flower style length in five *Vitellaria* stands of > 40 mature trees (minimum dbh >20 cm) at Bole.

Five stands were used, separated from each other by a minimum distance of 500 m. Initially, flowers from 10 tagged umbels from a minimum of two and maximum of five trees per stand were collected after anthesis for measurement of style length *. Style lengths in flowers were measured to the nearest mm with the aid of 1 x 1 mm graph paper after the calyx, petals, staminodes and filaments were removed with forceps. In total 64 umbels were sampled at least two from each tree. There were generally 25-50 flowers which could be examined in each umbel.

3.5.2 Fruit production and abscission in *Vitellaria* in relation to tree size and pollen source distance

Objective:

The possibility that pollen from more distant sources would differ in effectiveness of fruit set from pollen in the immediate vicinity was examined in relation to the size of the recipient tree.

The experiment consisted of recipient trees ≥10-20 cm, >20-30 cm and > 30 cm dbh in factorial combination with pollen from distances <50 m, >500-1000 m and > 1000 m. Each combination was replicated three times. All nine recipient trees (3 in each size class) were contained in an area of 50 x 50 m.

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[*] Later, two trees noted to have long styles were added to the trees sampled.

Procedure

12 Umbels on lower branches of recipient trees, on each of 3 trees >20-30 cm dbh and >30 cm dbh, and 9 umbels on trees >10-20 cm dbh covered with protective nets to exclude insects served as pollination units. Protected buds were hand-pollinated once the style protruded from the distal end. Buds serving as pollen sources were taken when the style was exserted and the inner sepals had appeared between the outer ones. Pollen for pollination was obtained from 3 trees in each donor population by carefully removing sepals and petals with forceps and applying pollen borne on the exposed anthers to the target style. On application to a receptive stigma, pollen became translucent. To take into account differential bud development within an umbel, pollination was undertaken two to five times until > 20 buds per umbel were pollinated. Unenclosed umbels with a number of well-developed buds recorded and undeveloped buds (i.e. still sessile) removed served as controls. Four weeks after pollination, nets were removed from protected umbels. Pollination success was assessed at this time and again 15 weeks after pollination. Fruits formed on unenclosed umbels were similarly assessed.

Location

CRIG substation, Bole.

Extent/Scale

A total of 2156 flowers in 99 umbels were pollinated.

Species

Vitellaria paradoxa

Treatments

- unenclosed umbels in trees ≥10-20 cm dbh.
- protected umbels on recipient trees ≥10-20 cm dbh pollinated with pollen from sources < 50 m
- protected umbels on recipient trees ≥10-20 cm dbh pollinated with pollen from sources > 500 m.
- protected umbels on recipient trees ≥10-20 cm dbh pollinated with pollen from sources > 1000 m.
- unenclosed umbels in trees > 20-30 cm dbh.
- protected umbels on recipient trees >20-30 cm dbh pollinated with pollen from sources < 50 m.
- protected umbels on recipient trees >20-30 cm dbh pollinated with pollen from sources > 500 m.
- protected umbels on recipient trees >20-30 cm dbh pollinated with pollen from sources >1000 m.
- unenclosed umbels in trees > 30 cm dbh.
- protected umbels on recipient trees >30 cm dbh pollinated with pollen from sources < 50 m.
- protected umbels on recipient trees >30 cm dbh pollinated with pollen from sources > 500m.
- protected umbels on recipient trees >30 cm dbh pollinated with pollen from sources > 1000m.

Date of commencement*

13 December 1994

Duration

Hand-pollination continued daily for 25 days. Observation of pollinated and control umbels continued for 15 weeks after pollination.

Assessment

Parameter	Date			
	2/2/95	3/2	4/2	20/4/95
Fruit initial (4 weeks)*	+	+	+	
Mature fruits (15 weeks)				+
Aborted fruits (15 weeks)				+

3.5.3 Source and style length of pollen donor and fruit production in *Vitellaria*

Objective:

Whether pollen from source flowers with styles of differing lengths, influenced fruit production and interacted with distance from the recipient tree was investigated experimentally using hand pollination.

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* period after pollination when pollination success was assessed

Basic design

Pollen from buds of two different style lengths at distances of <500 m and >500 m was used to pollinate recipient trees 10-20 cm, >20-30 cm and >30 cm dbh. Each combination was replicated three times. Four umbels on each recipient tree were pollinated. A different umbel was pollinated with pollen from each of the following sources ;

- source < 500 m away, style short
- source < 500 m away, style long
- source > 500 m away, style short
- source > 500 m away, style long

Procedure

Recipient pollination units were umbels protected with nets to exclude insects. Protected buds were hand-pollinated once the style protruded from the distal end. Buds for pollination were taken when the style was exserted and the inner sepals appeared between the outer ones.. The length of style protruding outside the buds was measured, (after keeping in sunshine and shade for 2 hours, to ensure the process of elongation was complete) to distinguish between long and short style buds. The length of style exserted at the distal end of buds from the same tree varied in length but was usually 2-4 mm. Pollen borne on the source anthers was carefully applied to the target style after removal of sepals and petals from the donor buds. Pollination was undertaken 3 to 5 times until > 25 buds were pollinated on each umbel. Unprotected umbels served as controls. Twenty days after pollination nets were removed from umbels and pollination success assessed. Reassessment was undertaken 14 weeks after pollination.

Location

CRIG Substation, Bole.

Extent/Scale

Four umbels on each of 9 trees, (3 trees from each of 3 diameter classes) were pollinated in this experiment. In all 1116 buds were pollinated.

Species

Vitellaria paradoxa

Treatments

- one unprotected umbel on trees ≥10-20 cm.
- one protected umbel on trees ≥10-20 cm dbh pollinated with long style from source < 500 m.
- one protected umbel on trees ≥10-20 cm dbh pollinated with short style from source < 500 m.
- one protected umbel on trees ≥10-20 cm dbh pollinated with long style from source > 500 m.
- one protected umbel on trees ≥10-20 cm dbh pollinated with short style from source > 500 m.
- one unprotected umbel on trees >20-30 cm dbh.
- one protected umbel on trees > 20-30 cm dbh pollinated with long style from source < 500 m.

- one protected umbel on trees > 20-30 cm dbh pollinated with short style from source < 500 m.
- one protected umbel on trees > 20-30 cm dbh pollinated with long style from source > 500 m.
- one protected umbel on trees > 20-30 cm dbh pollinated with short style from source > 500 m.
- one unprotected umbel on trees > 30 cm dbh.
- one protected umbel on trees > 30 cm dbh pollinated with long style from source < 500 m.
- one protected umbel on trees > 30 cm dbh pollinated with short style from source < 500 m.
- one protected umbel on trees > 30 cm dbh pollinated with long style from source > 500 m.
- one protected umbel on trees > 30 cm dbh pollinated with short style from source > 500 m.

Date of commencement

4 January 1995

Duration

Hand-pollination continued for 10 days and observation of pollinated and control umbels for 14 weeks after pollination.

Assessment

Parameter	Date		
	4/2/95	5/2/95	20/4/2
Fruit initials (3 weeks)	+	+	
Mature fruits (14 weeks)			+
Aborted fruits (14 weeks)			+

3.6 Data handling and statistical analysis

Drought index values were depicted graphically and fire risk indices in tables.

Tree population density was summarized by dbh and height classes in tables for each stratum. For regeneration, tables of numbers tallied by height and root collar diameter were prepared in aggregate for each stratum and also on a per hectare basis. Differences in parameters between and within the two strata considered in this study were explored through analyses of variance.

The log-linear model of the SPSS statistical package was used to test three-way interactions between canopy, seed treatment and germination interdependence. Two-way analysis of variance was used to test the effect of seed treatment and tree canopy on seedling growth.

Percentage data from the pollination experiments were angular transformed following the procedure of Snedecor and Cochran (1967) prior to analysis of variance. Tukey's multiple comparison test was employed to separate means which were significantly different. Where missing data were observed, the general linear model was used in the analysis of variance and the Tukey-Kramer unequal sample size comparison test was employed to seek significant differences between means.

Chapter four

Results

Chapter four

RESULTS

Results of research undertaken are presented in this chapter. Drought and fire danger indices are reported in Section 4.1 and population structures and levels of natural regeneration in Section 4.2. Findings of experimental work, germination and seedling survival are presented in Section 4.3 and those of flowering and pollination studies in Section 4.4.

4.1 Drought and fire danger indices

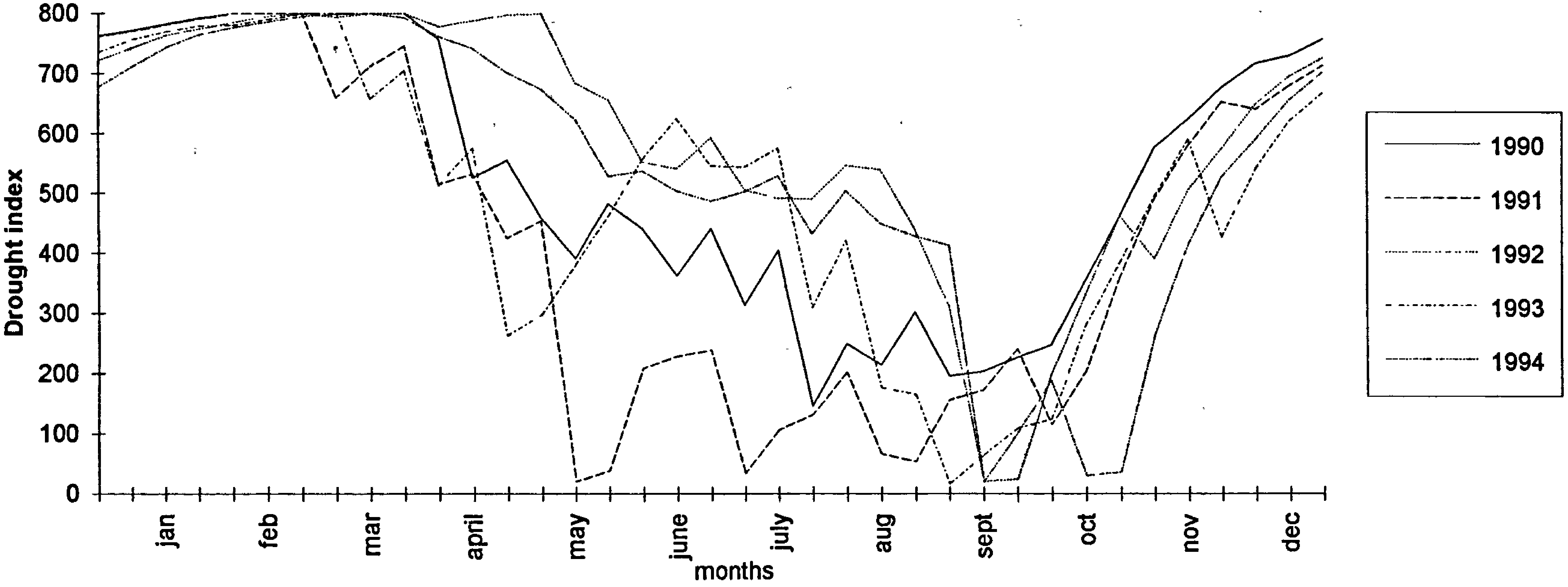
4.1.1 Drought indices

The drought index calculation process commenced in October 1989, after a 9-day period which brought 158 mm of rain. The assumption of zero drought index (no drought effect) was made for 11 October 1989 following a fall of 20 mm rainfall on the 10 October, the last day of the 9-day period.

Drought index values obtained for Bole over the five years period (1990-1994) were high (Fig 4.1). The mean annual index (± standard deviation) was 514 ± 61 points.

More than 50% of the days in each year had index values > 400 points, a total of 213, 189, 310, 256 and 298 days for 1990, 1991, 1992, 1993 and 1994 respectively. Drought index values of > 600 points persisted during the dry season from November into the early months of the following year, with peak values of 800 points in February and March.

Fig 4.1 **Drought index by 10-day intervals for Bole, 1990-1994**



Periods when drought indices were < 100 points were brief and in single uninterrupted periods each year - lasting 4, 49, 15, 29 and 26 days in 1990, 1991, 1992, 1993 and 1994 respectively. The onset of the rains in May is reflected in the start of a fall in index values. In every year, < 250 points prevailed from mid-September to mid-October.

In May 1990, the fall in index values was initially gradual, culminating in a rapid fall to < 50 points in July. The rains peaked in September but were not heavy: index values remained at > 200 points for most of September.

In May 1991, there was a rapid fall to < 50 points as a result of successive heavy rains. Thereafter, moderate rains maintained the values at < 250 points until the end of the rains in October.

Drought index values for 1992 remained > 400 points until the peak rains when values fell to <50 points (in September). Index values rose to > 500 points in November.

In 1993 early rains, in April, resulted in a decline of index values from 800 points to < 250 points in May but a serious break in the rains caused index values to rise to > 600 points in June. Successive heavy rains in August caused a rapid fall in drought index to < 50 points and it remained at this level for most of September. Values increased to > 600 points in December.

The drought index reached 800 points in March, 1994, but fell only gradually to September (400 points). During September there was a rapid fall to < 50 points due to two successive days with combined rainfall of 104 mm. Index values rose to > 200 points in November and reached > 600 points before the year ended.

4.1.2 Fire danger indices

Monthly fire danger indices interpreted from the fire danger categories shown on the meter are listed in Table 4.1. The derived fire danger indices are shown in Fig 4.2.

Table 4.1 McArthur Forest Fire Danger Meter: fire index categories

Index	Interpretation
<5	low danger
5 - 12	moderate danger
12 - 24	high danger
24 - 50	very high danger
50 - 100	extreme danger

Generally, a period of high danger commenced from December with values > 12. Monthly fire danger did not reach very high and extreme values. The grass becomes fully cured (i.e. dried) and fire hazard prevails from December until the onset of the rains in May when the dry north-easterly harmattan winds blow over the country.

Fig 4.2 Monthly fire danger severity at Bole, Ghana

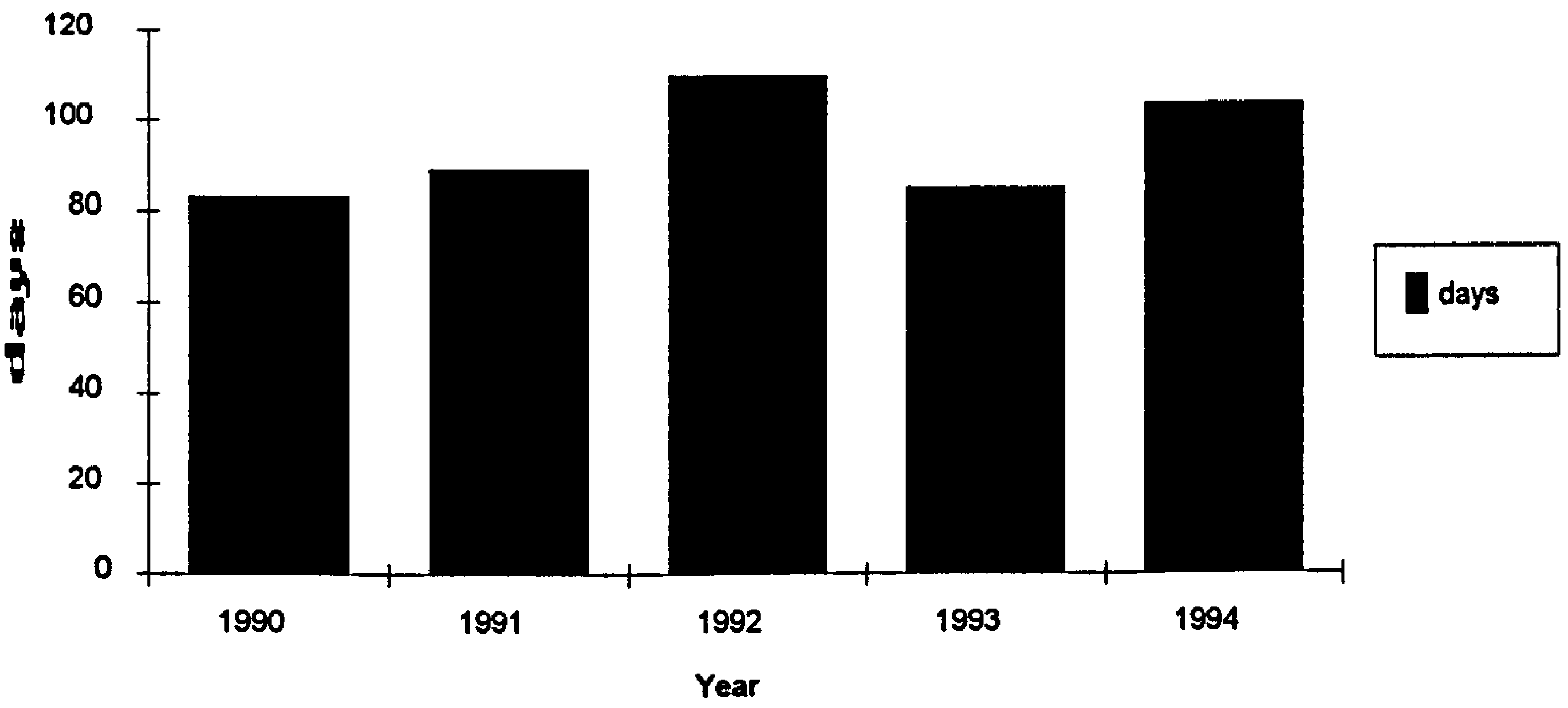
Month	1990	1991	1992	1993	1994
Jan	***	***	***	***	***
Feb	***	***	***	***	***
Mar	***	**	**	**	***
Apr	**	**	**	**	**
May	**	*	**	*	**
Jun	*	*	*	*	*
Jul	*	*	*	*	*
Aug	*	*	*	*	*
Sep	*	*	*	*	*
Oct	*	*	*	*	*
Nov	**	**	**	**	**
Dec	**	***	***	***	***

* , low danger; ** , moderate danger; *** , high danger

Low danger levels prevailed for 5 months (June to October) in 1990, 6 months (May to October) in 1991, for 5 months (June to October) 1992, for 6 months (May to October) in 1993 and for 5 months (June to October) in 1994. During this period the rains enhance biomass build-up of grass and fire does not occur in the Guinea savanna.

Fires normally break out or are set in the Guinea savanna from December onwards into the dry season. From the beginning of the ensuing year, January, to the beginning of the rains in May, fires become increasingly intense and destructive. This period is characterised by high drought indices (> 600 points) and relative humidities < 40 %, creating severe fire weather. Fig. 4.3 shows the number of days in the years when severe fire weather prevailed.

Fig 4.3 Number of days with drought index >600 points and Relative humidity < 40%, 1990-1994



In every year there were more than 80 days of severe fire weather causing pronounced drying of herbaceous vegetation, and woody vegetation entering into a period of dormancy. The shortest severe fire weather, a period of 83 days was for 1990, followed by 1993 and 1991 with 85 and 89 days respectively. 1992 had 110 severe fire weather days and 1994 had 104 days.

4.2 The *Vitellaria* population at Bole

4.2.1 Individuals ≥ 10 cm dbh

Vitellaria accounted for most of the large (> 30 cm dbh) trees in all the stands except A, and dominated all diameter classes in stands E, F, G and H (Table 4.2).

Table 4.2 Numbers enumerated by size class and by stand of *Vitellaria*, *Parkia* and other tree species at Bole

		Stratum one				Stratum two			
dbh (cm)	species	A	B	C	H	D	E	F	G
	area (ha)	2.5	1.5	4.9	1.5	4.6	2.5	2.9	3.3
10-20	*Vitellaria*	85	75	33	78	35	50	20	36
>20-30	*Vitellaria*	19	19	33	12	32	24	47	35
>30-40	*Vitellaria*	1	7	25	7	22	23	27	23
>40	*Vitellaria*	0	0	9	0	4	9	9	10
10-20	*Parkia*	0	2	3	2	1	0	0	0
>20-30	*Parkia*	0	2	1	3	0	2	1	1
>30-40	*Parkia*	0	0	2	2	0	2	0	0
>40	*Parkia*	0	0	0	0	0	2	0	3
10-20	other species	190	79	277	20	99	5	13	26
>20-30	other species	37	14	59	4	21	3	8	6
>30-40	other species	7	2	14	0	7	0	4	3
>40	other species	4	3	1	0	1	2	4	4

Parkia biglobosa, widely recognized as a species associated with *Vitellaria*, was much less well represented, a contrast partly explained by generally low per hectare stocking of this extremely wide-crowned species (Kater et al.

1992). In most stands the numbers of individuals enumerated increased as diameter class was reduced: the main exception to this trend was stand F.

There was higher stocking ≥10 cm dbh in Stratum One than in Stratum Two (Table 4.3). Ward's method of estimating stocking ≥ 10 cm dbh gave higher values than direct assessment from the stand maps. There was no significant difference in *Vitellaria* stocking (≥10 cm dbh) between strata, but All Species stocking ≥10 cm dbh was significantly higher ($P< 0.01$) in Stratum One. Basal area for *Vitellaria* (≥10 cm dbh) was not significantly different.

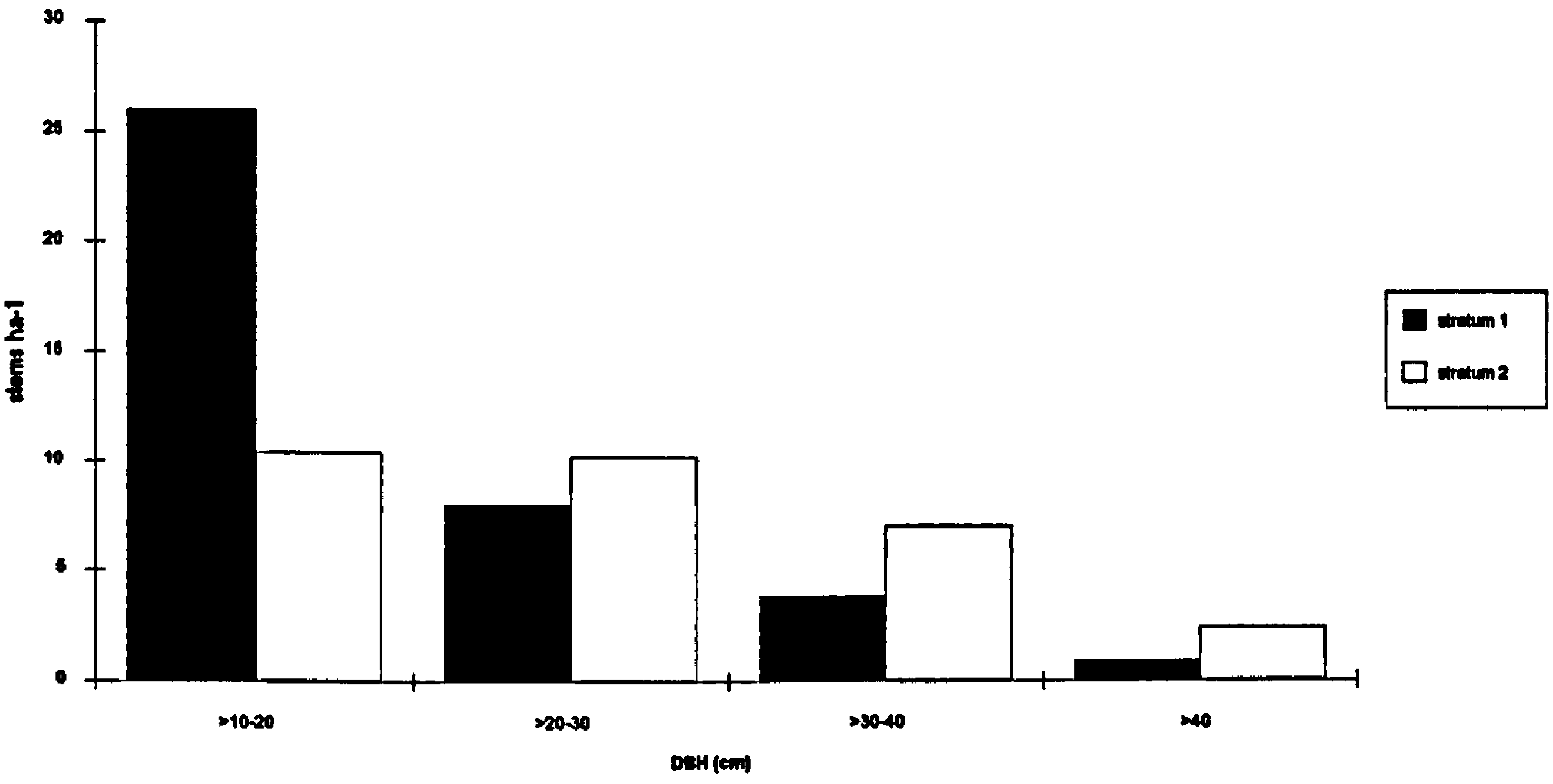
Table 4.3 Basal area and stand density of trees(>10cm dbh) determined by Direct and by Ward's method for the stands at Bole, Ghana

		Stratum 1		
Stand	*Vitellaria* Direct method basal area (m^2 ha^{-1})	*Vitellaria* Direct method Stocking ha^{-1}	*Vitellaria* Ward's method Stocking ha^{-1}	All Species Direct method Stocking ha^{-1}
A	0.9	43	72	139
B	2.2	67	79	138
C	1.3	20	37	92
H	1.7	65	93	85
mean ± s. e	1.5 ± 0.3^a	49.0 ± 11.3^a	70.2 ± 11.9^a	113 ± 14.5^a
		Stratum 2		
D	1.1	20	43	48
E	2.3	43	48	49
F	2.3	36	54	45
G	1.9	31	50	44
mean ± s. e	1.9 ± 0.3^a	32.5 ± 4.8^a	48 ± 2.3^a	$46.5+1.2^b$

Means in the same column with different superscripts are significantly different ($P<0.01$)

Comparison of the size class distribution of *Vitellaria* (direct method), between strata shows a higher stocking for Stratum One in the 10-20 cm dbh class (Fig 4.4). Stratum Two shows higher stocking for the larger dbh classes.

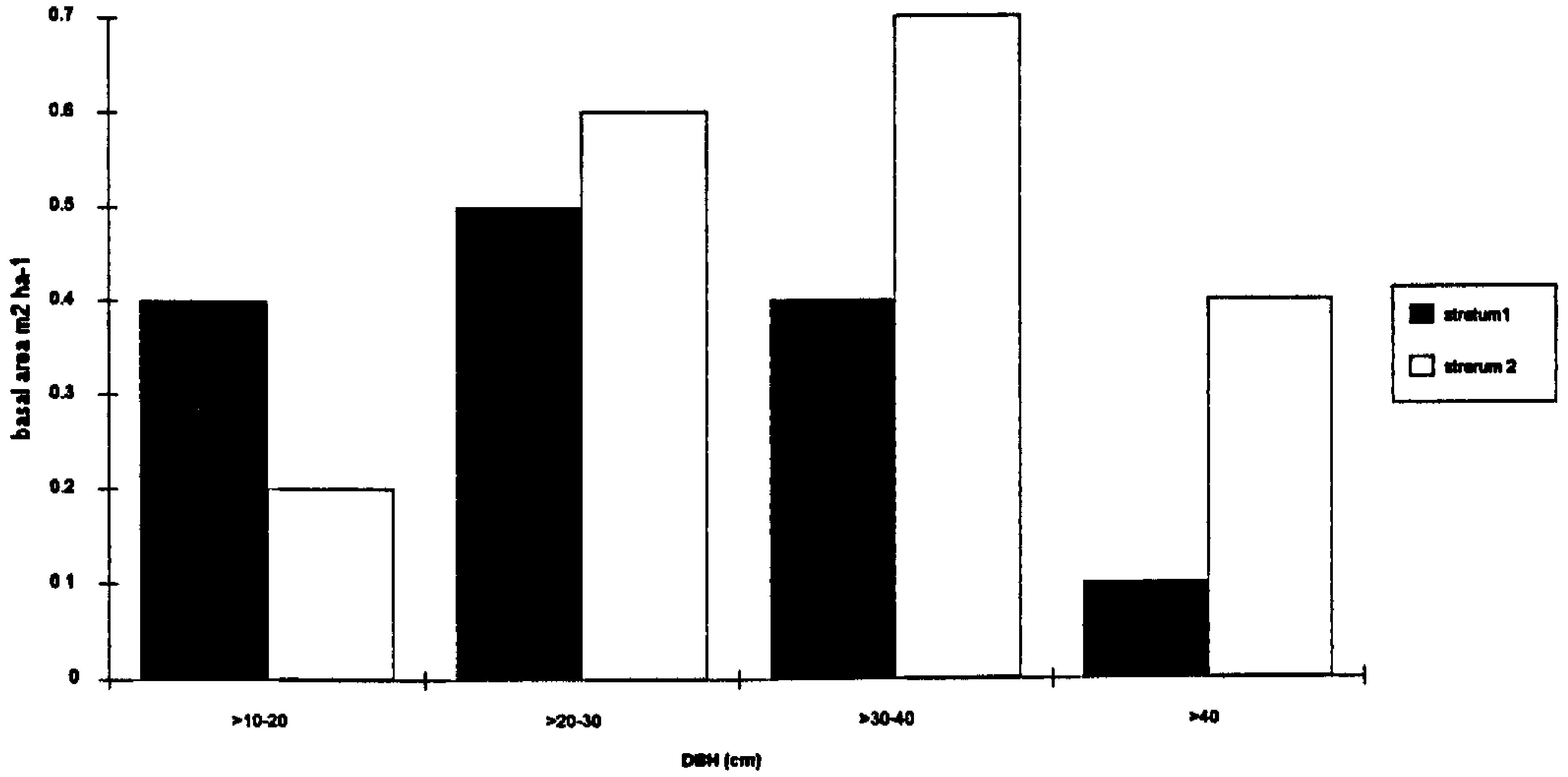
Fig 4.4 Size class distribution of *Vitellaria* in the two strata at Bole



The 10-20 cm diameter class contributed most (42.0%) to the total basal area of All Species (including *Vitellaria*) in Stratum One. Trees <30 cm dbh added more than 70% to the total basal area in this stratum. *Vitellaria* formed 42.4% of the basal area of All Species in Stratum One (Fig 4.5).

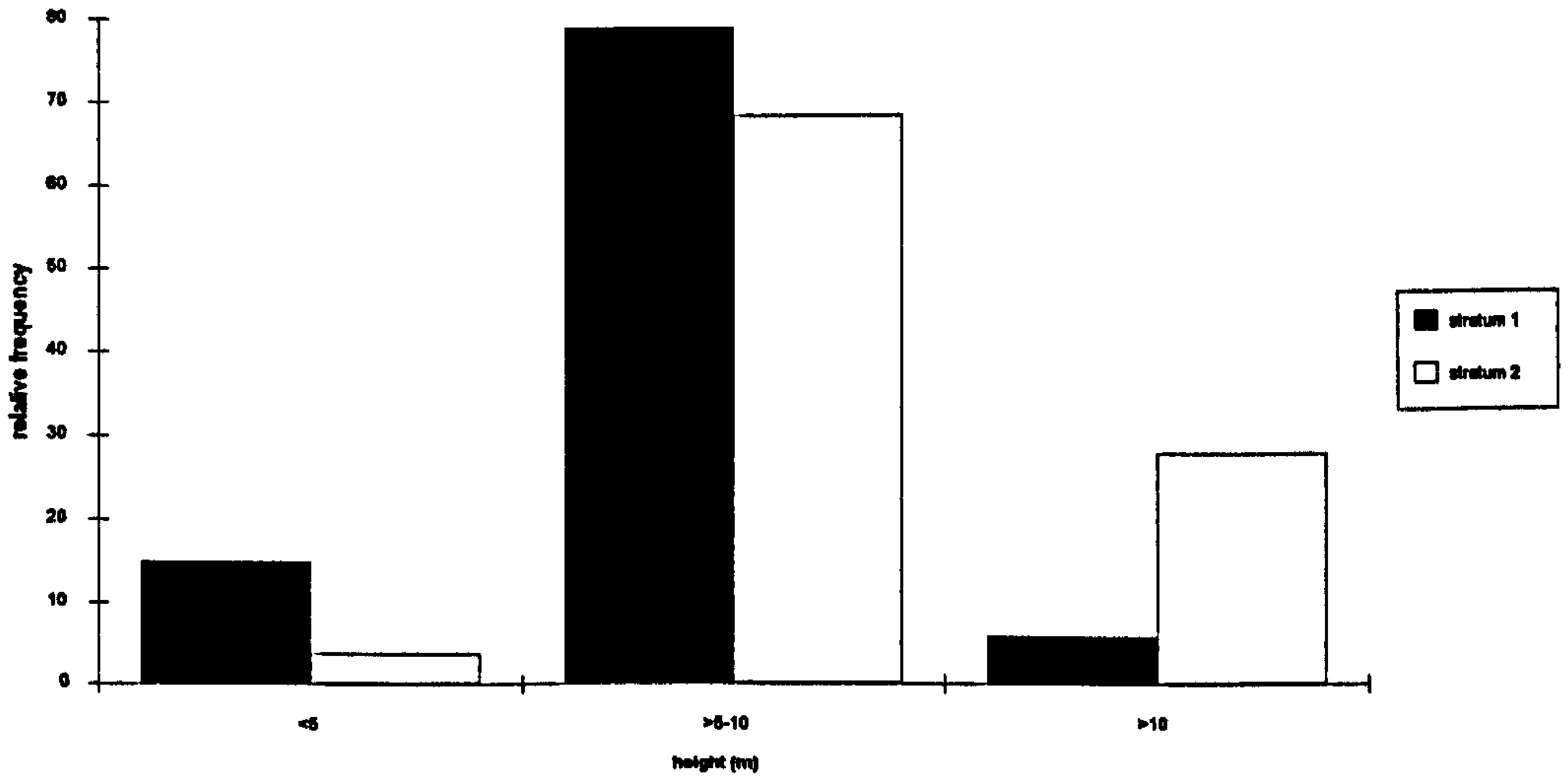
In Stratum Two, the >30-40 cm diameter class contributed 37% and 31% of basal area for *Vitellaria* and All Species respectively. *Vitellaria* formed 73.0% of the total stand basal area in this stratum, higher than in Stratum One. *Vitellaria* stocking per hectare was related to basal area by regression analysis for the 8 stands. Stand stocking (direct method) positively correlated with stand basal area but the relationship was not significant (n=8; $r^2 = 0.17$; $P > 0.310$).

Fig 4.5 Distribution of basal area by size class for *Vitellaria* in the two strata at Bole, Ghana



The height of *Vitellaria* distributed over three classes; >10 m, >5 - 10 m, and <5m high but > 10 cm dbh (Fig 4.6), shows a higher proportion of trees in Stratum Two (28%) growing above > 10 m than in Stratum One (5.9%).

Fig. 4.6 Height class frequency distribution of *Vitellaria* (>10 cm dbh) in the two strata at Bole, Ghana



Mean stocking of *Vitellaria* by height class for the two strata was examined by analysis of variance to determine differences in the stocking of the different height classes in the two strata. The two-way interaction between strata and height class was significant (Table 4.4).

Table 4.4 Analysis of variance: stocking of *Vitellaria* by height class and stratum at Bole, Ghana

Source of variation	df	ms	Significance
Strata	1	182.6	ns
Height class	2	1720.9	**
Height class x Strata	2	292.1	*
Error	18	67.1	
Total	23		

ns, not significant; * $P< 0.05$; ** $P< 0.01$

Breakdown one-way analysis of variance of the three individual height classes for the two strata indicated significantly higher ($P< 0.01$) stocking of trees ≤5 m high in Stratum One (Table 4.5). There was no significant difference between strata in stocking of *Vitellaria* trees >5-10 m high but stocking of trees >10 m was significantly higher ($P<0.01$) in Stratum Two.

Table 4.5 Mean stocking (ha^{-1} ± standard error) of *Vitellaria* by height class and stratum at Bole, Ghana

	Height class(m)		
Strata	≤5	>5-10	>10
Stratum One	7.7 ± 2.0^a	39.0 ± 9.2^a	2.0 ± 0.6^a
Stratum Two	1.3 ± 0.6^b	21.8 ± 2.9^a	9.0 ± 1.7^b

Means in the same column with different superscripts are significantly different ($P<0.01$).

4.2.3 Studies on natural regeneration of *Vitellaria*

Natural regeneration was assessed in proportions of the 8 stands ranging from 14% to 23% (Table 4.6).

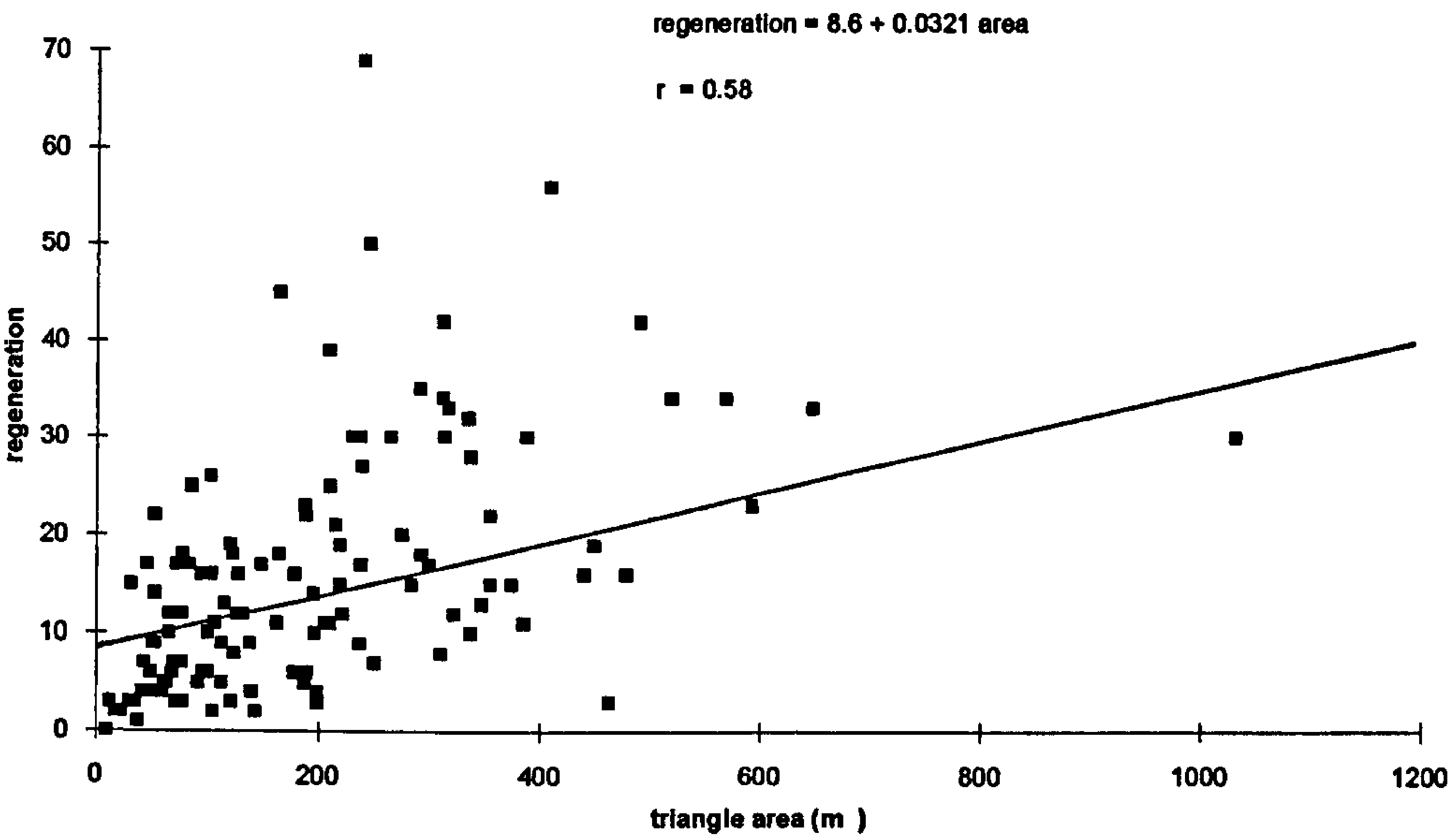
Table 4.6 The percentage of each stand sampled for seedlings

Stand	Stand area (ha)	Triangles area (ha)	% stand sampled
A	2.5	0.49	19.9
B	1.5	0.34	23.1
C	4.9	0.82	16.6
H	1.5	0.25	16.6
D	4.6	0.70	15.1
E	2.5	0.41	16.6
F	2.9	0.42	14.5
G	3.3	0.47	14.2

In a total area of 3.9 ha scanned for natural regeneration, 2495 regenerating individuals (640 ha^{-1}) and 4700 (1205 ha^{-1}) were encountered in 1993 and 1994 respectively.

The 144 triangle areas assessed for regeneration (<10 cm dbh) ranged from 9 m^2 to 1799 $m^{2.}$ The number of regeneration in 1993 was related to the triangle area in which they were assessed. The number of regenerating individuals was positively correlated (Fig 4.7) with area of triangle ($n=144$; $r^2=0.34$; $P<0.01$).

Fig. 4.7 The relationship between number of regenerating individuals and area assessed within 8 stands at Bole, Ghana



Nb. each area is a triangle defined by three *Vitellaria* individuals ≥ 10 cm diameter at breast height and lacking additional *Vitellaria* trees within.

Suckers were the most common mode of regeneration (Table 4.7), accounting for 86.5% and 94.0% of the total number of regenerating individuals assessed in the stands for 1993 and 1994 respectively. Coppice regeneration was least common, 3.0% and 1.6 % of the total for 1993 and 1994.

Table 4.7 Summary of regeneration by height class, assessment year and mode of regeneration at Bole, Ghana

Mode of regeneration
1993

Ht. class(cm)	Suckers	Coppice	Seedling	Total	% of total
<50	1975	69	122	2166	89.2
>50-100	147	3	27	177	4.8
>100-150	26	2	35	63	2.3
>150	10	0	79	89	3.6
total	2158(86.5)*	74(3.0)	263(10.5)	2495	100
		1994			
<50	4148	67	77	4292	91.3
>50-100	187	9	5	201	4.3
>100-150	64	1	19	84	1.8
>150	21	0	192	123	2.6
total	4420(94.0)*	77(1.6)	203(4.3)	4700	100

* Figures in parentheses are percentages of total regenerating individuals in each year.

Regeneration in the < 50 cm height class dominated (ca 90%). The relative rarity of larger regeneration suggests most is destroyed or burned back to the soil surface during the seasonal burning of vegetation. There was no coppice regeneration >150 cm.

Broken down by root collar diameter class, the data set showed a trend similar to that for height (Table 4.8) with over 80% of regenerating individuals in the <10 mm class. In 1993, 3.3% of regenerating individuals had root collar diameters greater than 50 mm but in 1994 only half this proportion (1.7%).

Table 4.8 Summary of regeneration by root collar diameter class, assessment year and mode of regeneration at Bole, Ghana

Mode of regeneration

Root collar diameter (mm)	Suckers	Coppice	Seedling	Total	% of total
			1993		
<10	1847	45	114	2006	80.4
>10-20	219	20	6	245	9.8
>20-30	64	6	14	84	3.4
>30-40	14	2	36	52	2.1
>40-50	4	1	20	25	1.0
>50	10	0	73	83	3.3
total	2158	74	263	2495	100
			1994		
<10	3956	51	77	4084	86.9
>10-20	296	16	4	316	6.7
>20-30	88	6	5	99	2.1
>30-40	54	2	22	78	1.7
>40-50	19		23	42	0.9
>50	7	2	72	81	1.7
total	4420	77	203	4700	100

On a per hectare basis, the stocking of regeneration (mean ± standard error) was higher in 1994 in both strata (Table 4.9). Stratum Two similarly had higher stocking than Stratum One. Analysis of stocking data of Table 4.9 indicated no significant difference between strata (Table 4.10). The stocking for 1994 was significantly higher ($P<0.01$) than for 1993. Interaction between years and strata was not significant.

Table 4.9 Summary of stocking per hectare of regeneration in areas <3 km and ≥3 km from villages and by year of assessment at Bole, Ghana

	year		
Strata	1993	1994	Stratum mean ± s.e.
Stratum One	533	755	
	386	1409	
	469	1157	
	676	1832	902 ± 181.7
Stratum Two	614	730	
	621	885	
	864	1960	
	1057	1560	1036 ± 181.7
Year mean ± s.e.	652 ± 76.8	1286 ± 169.6	

Table 4.10 Analysis of variance: stocking of regeneration in areas < 3 km (Stratum 2) and ≥ 3 km (Stratum 1) from villages in 1993 and 1994 at Bole, Ghana

Source of variation	df	ms	Significance
strata	1	72092	n.s.
year	1	1605289	**
strata x year	1	77006	n. s.
error	12	149366	
total	15		

** P<0.01; n. s., not significant

Saplings (>1.5 m tall and <10 cm dbh) were also measured for dbh. Stocking per hectare of saplings in Stratum One was higher than in Stratum Two (Table 4.11). There was little difference in stocking between the assessment years.

Table 4.11 Summary of stocking per hectare of saplings in areas < 3km and ≥3 km from villages and assessment year at Bole, Ghana

	year		
Strata	1993	1994	Stratum mean ± s.e
Stratum One	14	14	
	74	79	
	13	16	
	12	16	29.7 ± 10.2
Stratum Two	4	10	
	27	29	
	12	14	
	23	34	19.0 ± 3.7
Year mean ± s.e	22.4 ± 7.8	26.5 ± 3.7	

Two-way analysis of variance of Table 4.11 showed no significant difference between strata (Table 4.12) nor between years. Interaction between strata and years was not significant.

Table 4.12 Analysis of variance: stocking of natural regeneration saplings (>1.5m tall, <10cm dbh) assessed in areas < 3km and ≥ 3km from villages at Bole, Ghana

Source of variation	df	ms	Significance
strata	1	451.6	n. s.
year	1	68.1	n. s.
strata x year	1	5.1	n. s.
error	12	547.1	
total	15		

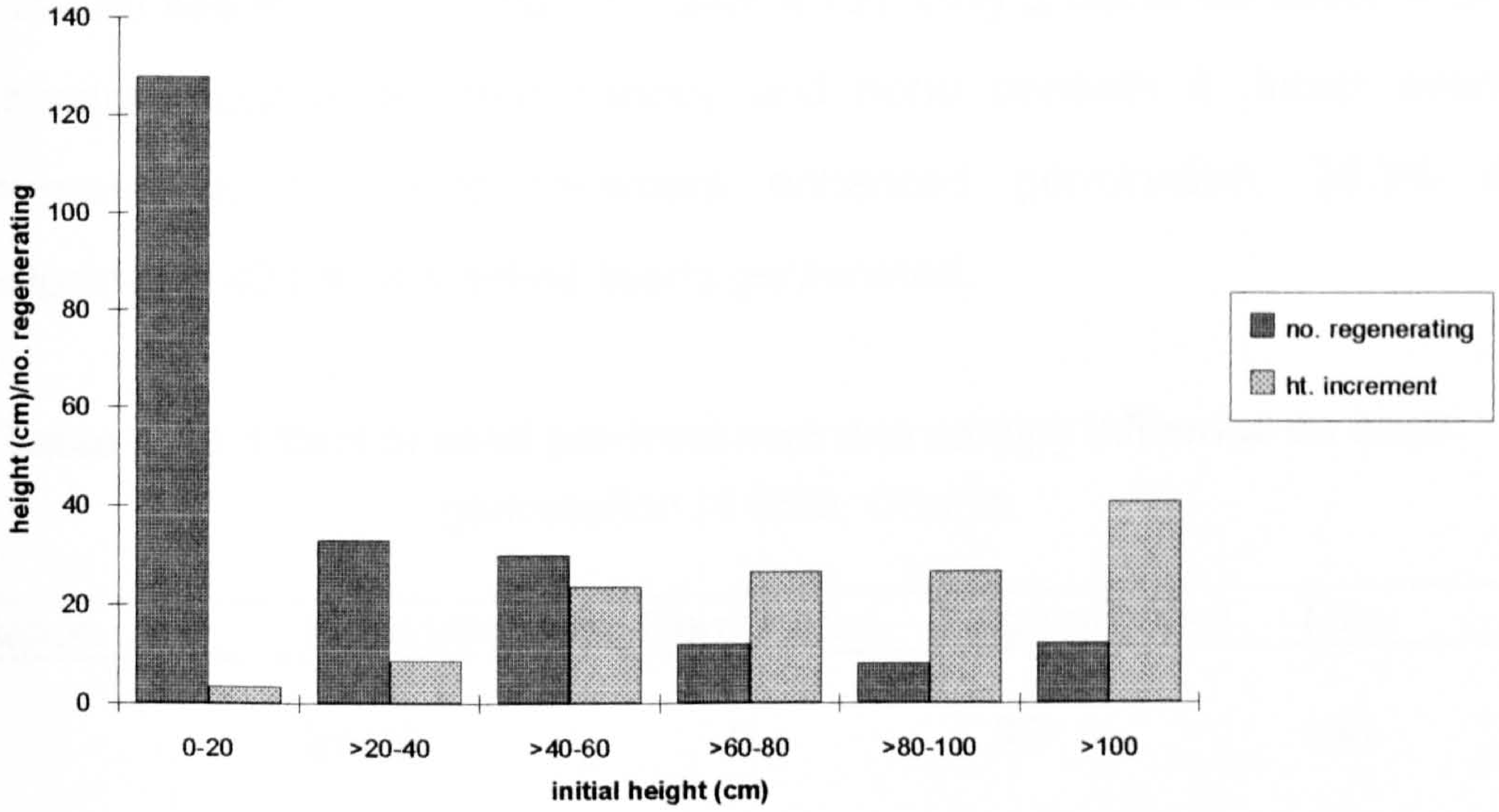
n.s., not significant

Height increment in natural regeneration seedlings

After tagging, the heights of natural regeneration in Stand F, were recorded in 1993 and in 1994 and height increment calculated by difference for the one-year period for all tagged regenerating individuals (223) identified in the second season.

Mean height increment over the one-year period was higher for individuals with high initial height (Fig 4.8). There were few regenerating individuals 60-100 cm tall.

Fig 4.8 Number of individuals and mean height increment in natural regeneration in Stand F, Bole, Ghana



4.3 Germination and seedling survival

4.3.1 Seed treatment and canopy influence on germination.

Out of 180 seeds, 49 germinated (Table 4.13). Only 2 out of 60 intact seeds germinated outside the tree canopy and none beneath it. Intact seeds germinated poorly. Seed treatment enhanced germination, 38.3% of depulped and 40.0% of cracked seeds germinated.

Table 4.13 Effect of seed pre-treatment and canopy influence on seed germination at Bole, Ghana.

Situation	Seed treatment	Germinated	Ungerminated	Total
	Intact	0	30	30
Under canopy	Depulped	12	18	30
	Cracked	6	24	30
		18	72	90
	Intact	2	28	30
Outside canopy	Depulped	11(1*)	19	30
	Cracked	18(3*)	12	30
		31	59	90
		49**	131	180

* mortalities: germinated but died within 20 weeks; ** Including mortalities

There was a significant three-way association between seed pre-treatment, canopy and germination (G = 29.016, 2 d.f.). Since the degree of association between seed pre-treatment and germination differed for canopy situation, the data sets for response to seed pre-treatment under canopy and outside the canopy were considered separately (Table 4.14). Germination was significantly associated with seed pre-treatment both under- and outside the canopy, being more marked outside the canopy.

Table 4.14 Effects of seed pre-treatment and canopy influence on seed germination at Bole, Ghana.

Situation	Effects	df	G	$G_{adj.}$
Under canopy				
	seed pre-treatment x germination	2	19.66	18.931**
	[partitioning of G:			
	intact seed x pre-treated seed	1	16.76	16.22**
	depulped x cracked	1	2.90	2.81]
Outside canopy				
	seed pre-treatment x germination	2	28.55	27.89 **
	[partitioning of G:			
	intact x pre-treated seed	1	23.01	22.54**
	depulped x cracked	1	5.54	5.49]

** $P< 0.01$

The mean height and root collar diameter (± s.e.) of seedlings surviving at 20 weeks (Table 4.15) were subjected to statistical analysis to consider whether seed pre-treatment and tree canopy influenced post-germination growth. The intact seeds (control) which germinated poorly (2 out of 60) were excluded and analysis of variance restricted to depulped and cracked seeds, to allow the interaction of the two treatment factors (seed pre-treatment and canopy influence) to be examined.

Table 4.15 Mean seedling height (cm) of *Vitellaria* at 20 weeks outside and under canopy of mature trees in relation to seed pre-treatment at Bole, Ghana.

		Seed pre-treatment		
Situation	Location	Depulped	Cracked	Canopy mean ± s.e
	tree 1	2.4	2.9	
Outside canopy	tree 2	3.2	3.0	
	tree 3	3.1	2.9	2.9 ± 0.11
		(n 10*)	(n 15)	
	tree 1	1.7	1.0	
Under canopy	tree 2	2.4	2.1	
	tree 3	2.4	2.6	2.0 ± 0.24
		(n 12)	(n 6)	
Seed treatment mean ± s.e		2.5 ± 0.2	2.4 ± 0.3	

* Figures in parentheses are number of seedlings in each treatment combination.

Height reached after 20 weeks was significantly influenced by tree canopy (Table 4.16): seedlings outside the canopy were significantly taller. No effect of seed pre-treatment was reflected in seedling increment and there was no interaction between treatment and canopy situation.

Table 4.16 Analysis of variance: effect of seed pre-treatment and canopy situation on seedling height at 20 weeks at Bole, Ghana

Source	df	ms	Significance
canopy influence	1	2.340	*
seed pre-treatment	1	0.040	ns
canopy x seed treatment	1	0.067	ns
error	8	0.256	
total	11		

*, $P < 0.05$; ns, not significant.

Root collar diameter (Table 4.17) for seedlings at 20 weeks after sowing was not influenced by seed pre-treatment or canopy situation (Table 4.18). The interaction between seed pre-treatment and canopy was not significant.

Table 4.17 Mean root collar diameter (mm) of *Vitellaria* at 20 weeks outside and under canopy of mature trees in relation to seed pre-treatment at Bole, Ghana

		Seed treatment		
Situation	Location	Depulped	Cracked	Canopy mean ± s. e
Outside canopy	tree 1	1.5	1.5	
	tree 2	2.0	1.4	
	tree 3	1.9	2.0	1.7 ± 0.11
Under canopy	tree 1	1.9	1.1	
	tree 2	1.9	1.8	
	tree 3	1.8	1.4	1.6 ± 0.13
Seed pre-treatment mean ± s. e.		1.8 ± 0.07	1.5 ± 0.13	

Table 4.18 Analysis of variance: effect of seed pre-treatment and canopy on root collar diameter at 20 weeks at Bole, Ghana.

Source of variation	df	ms	Significance.
canopy	1	0.013	ns
seed treatment	1	0.270	ns
canopy x seed treatment	1	0.053	ns
error	8	0.075	
total	11		

ns, not significant.

4.4 Flowering and pollination studies

4.4.1 Studies on flower development and floral dimorphism

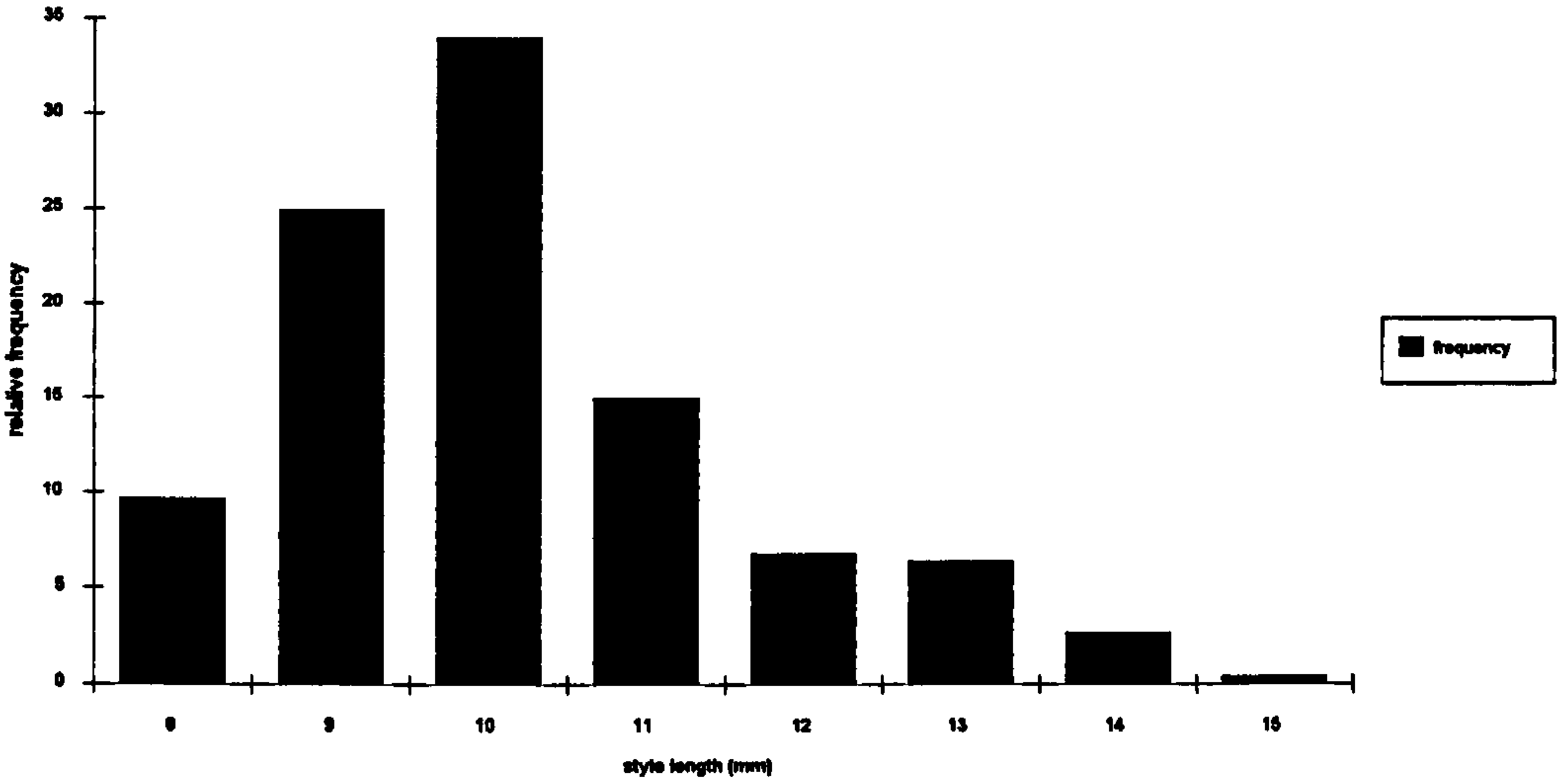
Style length in 1932 flowers evaluated in the five *Vitellaria* populations ranged from 8 mm to 15 mm (Table 4.19).

Table 4.19 Frequency distribution (observed numbers of flowers in category) of style length in five *Vitellaria* populations at Bole, Ghana

		style length to nearest mm							
Popn	Tree	8	9	10	11	12	13	14	15
1	A1	25	84	37	1				
	A2	1	29	30	2				
2	B1		5	11	36	6			
	B2		21	78	31	1			
	B3			9	35	7			
	B4				9	27	21	9	
3	C1	4	33	108	17	1			
	C2		13	56	55	17			
4	D1	7	80	64	2				
	D2			2	28	31	36	6	
5	E1	3	31	54	5				
	E2	2	26	63	11				
	E3		49	59	2				
	E4		29	83	9				
	E5	146	83						
	E6			3	46	42	10		
	E7						57	37	7
total (all populations)		188	483	657	289	132	124	52	7

Mean, modal and median style length values were 10.2 mm, 10 mm and 10.3 mm respectively (Fig 4.9).

Fig. 4.9 Relative frequency distribution of style length in five *Vitellaria* populations at Bole.



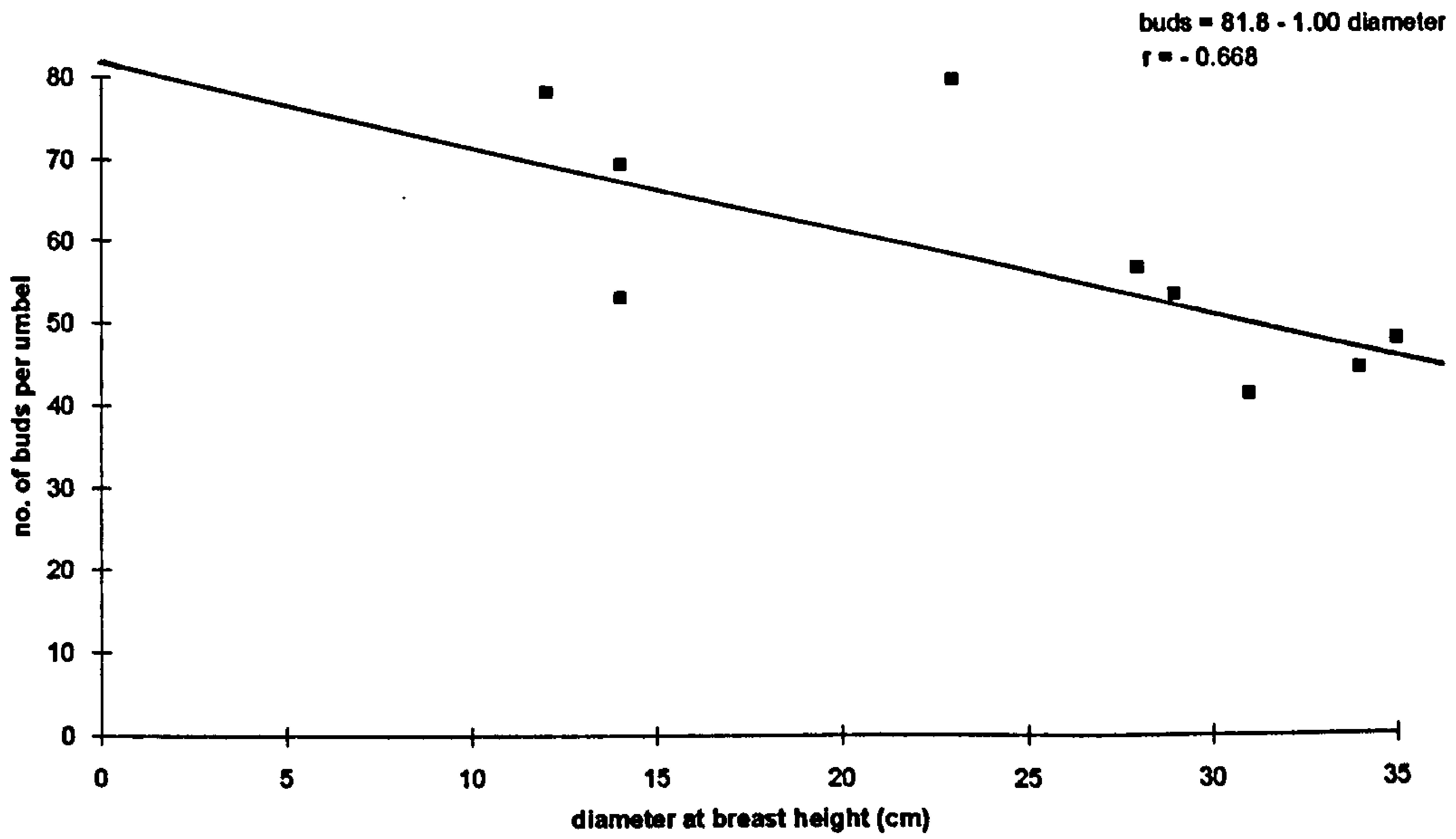
4.4.2 Bud and flower development

On each tree studied at least 84% of the buds present at the start of the observation period (all umbels combined) developed into flowers. Bud development was unexpectedly higher in the lower diameter (presumed younger) trees (Table 4.20). The relationship between tree size and mean number of buds per umbel was therefore examined further by checking whether number of buds per umbel correlated with tree dbh (Fig 4.10). There was no correlation (n=9, r = - 0.66, P>0.054).

Table 4.20 The relationship between tree size and flower development in *Vitellaria* at Bole Ghana

Tree dbh (cm)	No. of umbels	Mean No. of buds ± s.e.	% Flowers
12	9	78.2 ± 8.6	93.5
14	9	69.4 ± 5.3	92.0
14'	9	53.1 ± 6.2	89.7
23	12	79.3 ± 6.5	88.2
28	9	56.3 ± 4.8	84.2
29	10	53.0 ± 5.4	86.2
31	12	41.1 ± 2.9	95.7
34	11	44.1 ± 2.1	95.9
35	12	47.6 ± 4.2	84.2

Fig. 4.10 The relationship between tree size and number of buds per umbel in the experimental trees at Bole, Ghana



4.4.3 Effect of tree size and pollen source on fruit production and abscission in *Vitellaria*

A higher percentage of pollinated umbels developed into fruits compared with open-pollinated ones (Table 4.21).

Table 4.21 Influence of pollen source and tree size on the percentage of fruit set in *Vitellaria* 4 weeks after hand-pollination at Bole, Ghana

	Pollen source (m)			
Diameter at breast height (cm)	<50 m	>500 m	>1000 m	open
12	24.4	19.1	24.4	8.4
14	20.0	29.7	27.9	7.3
14*	50.6	34.2	22.3	10.4
23	40.8	58.8	43.6	2.3
28	13.8	24.5	24.5	2.6
29	36.0	44.6	38.9	10.1
31	68.7	40.7	45.4	7.2
34	66.7	64.1	64.2	8.0
35	36.0	55.4	48.9	7.1

The two-way analysis of variance (Table 4.22) of the angular transformed data indicated that fruit production in open (control) pollinated umbels was significantly lower ($P < 0.01$) than in hand-pollinated umbels (Table 4.23). Pollen source distance did not influence the numbers of fruit set.

Table 4.22 Analysis of variance: source of pollen and tree size on fruit set in hand-pollinated buds 4 weeks after pollination at Bole, Ghana

Source of variation	df	ms	significance
tree size	2	538.38	**
pollen source	3	1320.79	**
tree size x pollen source	6	81.78	n.s.
error	24	42.01	
total	35		

** $P<0.01$; n.s., not significant

Table 4.23 Mean number of fruits set, by source of pollen, 4 weeks after hand-pollination at Bole, Ghana

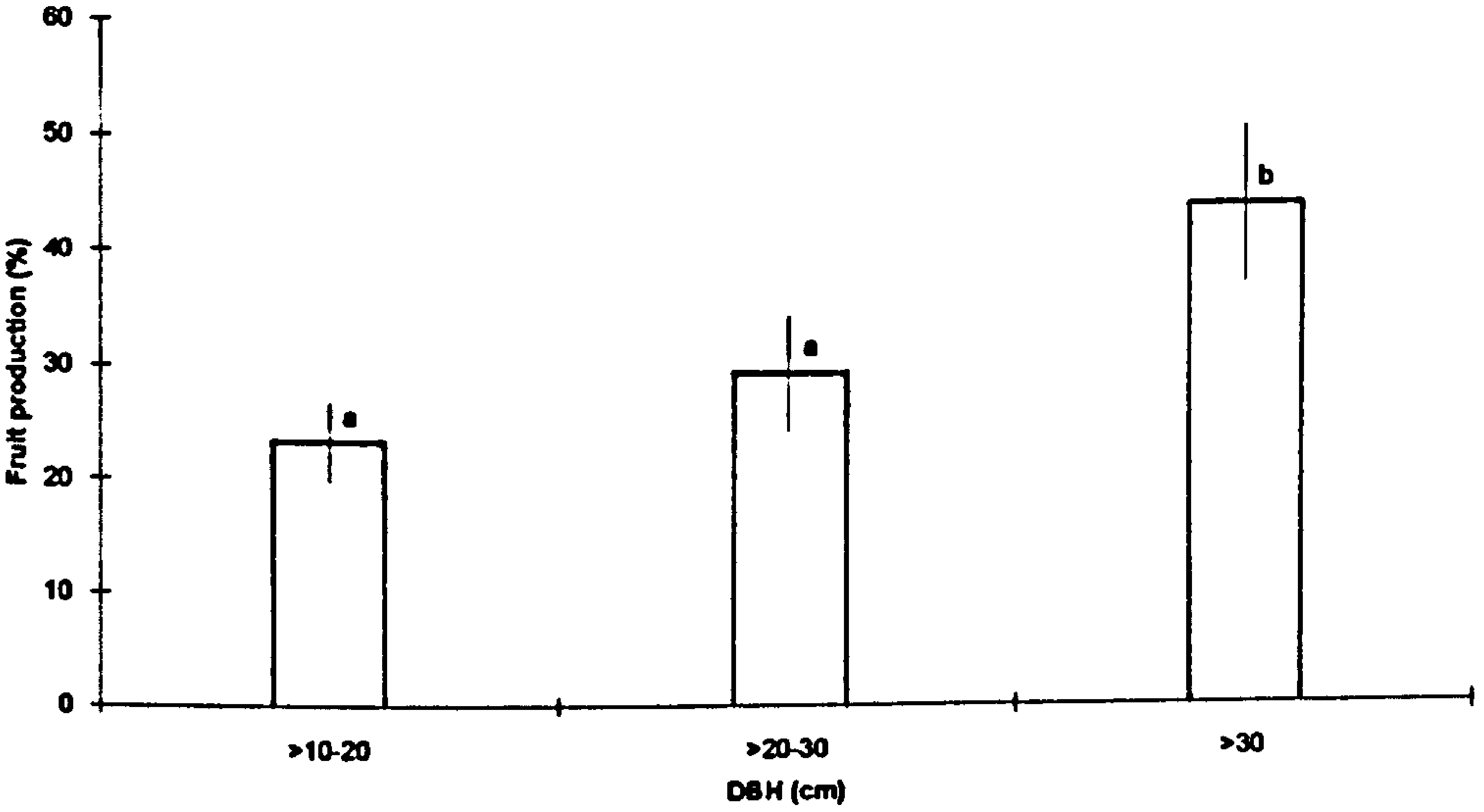
Pollen source	mean ± s.e.
<50 m	$40.7^{*} \pm 6.5^{a}$
>500 m	41.2 ± 5.2^{a}
>1000 m	37.8 ± 4.7^{a}
Open (control)	7.0 ± 0.9^{b}

Mean with different superscripts are significantly different ($P<0.01$)

* Means presented untransformed; significance test based on data after angular transformation.

Tree size also influenced fruit set (production) assessed after 4 weeks. Trees > 30 cm dbh set significantly more ($P < 0.01$) fruits than smaller trees (Fig 4.11). Between the two smaller dbh classes there was no significant difference. There was no interaction between tree size and pollen source.

Fig. 4.11 The effect of tree size on percentage fruit production at 4 weeks after hand-pollination at Bole, Ghana



Bars are percentage fruit set (production) by tree size. Letters on top of dbh columns differ for significantly different fruit production ($P<0.01$). Standard errors are represented by lines left of letters.

After 15 weeks fruits were in greater numbers (as percentages of the number of flowers pollinated per umbel) in hand-pollinated umbels than in open-pollinated umbels (Table 4.24)

Table 4.24 Influence of pollen source and tree size on the percentage of fruit set in *Vitellaria* 15 weeks after hand-pollination at Bole, Ghana

Dbh (cm)	<50 m	>500 m	>1000 m	open
12	22.0	11.2	19.7	5.2
14	6.1	23.4	4.4	1.5
14	18.2	21.0	11.8	8.3
23	6.1	12.1	5.1	2.3
28	6.9	5.7	10.2	1.3
29	8.1	25.0	15.3	3.8
31	48.7	27.6	38.6	7.2
34	4.7	7.5	1.5	0.0
35	18.7	14.8	9.4	2.8

Two-way analysis of variance (Table 4.25) of the angular transformed data indicated that fruit numbers in open pollinated umbels were significantly lower ($P<0.05$) than in hand-pollinated umbels. (Table 4.26) The numbers of fruits present were not affected by pollen source distance or by tree dbh, nor by interaction between them.

Table 4.25 Analysis of variance: source of pollen and tree size on percentage fruit set at 15 weeks in hand pollinated umbels at Bole, Ghana

Source of variation	df	ms	Significance
tree size	2	63.3	n.s.
pollen source	3	331.2	*
tree size x pollen source	6	25.9	n.s.
error	24	73.3	
total	35		

* $P<0.05$; n.s., not significant

Table 4.26 Mean numbers of fruits set by source of pollen 15 weeks after hand-pollination at Bole, Ghana

Pollen source	mean ± s.e.
<50 m	$15.5^{*} \pm 4.6^{a}$
>500 m	16.5 ± 2.7^{a}
>1000 m	12.8 ± 3.7^{a}
open (control)	3.6 ± 0.9^{b}

means with different superscripts are significantly different ($P<0.05$).

* Means presented untransformed; significance test based on data after angular transformation

Abscission of fruits between the assessments at week 4 and at week 15 was examined. The difference (loss) in the number of fruits over this period was expressed as a percentage of the fruits present in week 4 (Table 4.27). For analysis (Table 4.28) angular transformation was applied to these data.

Abscission percentages were high but no significant differences in the percentage lost were detected between pollen sources or tree sizes and there was no interaction between these factors.

Table 4.27 Influence of pollen source and tree size on the percentage fruit abscission in *Vitellaria* between 4 weeks and 15 weeks after hand-pollination at Bole, Ghana

Dbh (cm)	<50 m	>500 m	>1000 m	open
12	10.0	46.7	19.0	38.5
14	69.2	21.4	84.2	80.0
14	64.1	38.5	47.0	20.0
23	85.4	79.4	88.2	71.4
28	50.0	76.9	58.3	50.0
29	77.4	56.0	60.7	37.5
31	29.1	12.5	15.0	0.0
34	92.8	88.5	97.7	100.0
35	58.5	21.6	80.8	60.0

Table 4.28 Analysis of variance: pollen source and tree size on fruit abscission in hand-pollinated umbels between 4 weeks and 15 weeks after hand-pollination at Bole, Ghana

Source of variation	df	ms	significance
tree size	2	514.8	n.s.
pollen source	3	148.0	n.s.
tree size x pollen source	6	67.9	n.s.
error	24	483.6	
total	35		

n. s., not significant

4.4.4 Effect of source and style length of pollen donor on fruit production and abscission.

Three weeks after hand-pollination, there were higher percentages of flowers that had set fruit than in open pollinated umbels (Table 4.29).

Table 4.29 Influence of pollen source and tree size on the percentage fruit set in *Vitellaria* 3 weeks after hand-pollination at Bole, Ghana

Dbh (cm) recipient trees	.<500 m short style	<500 m long style	>500 m short style	>500 m long style	open
13	61.1	86.7	55.0	93.5	0.0
17	51.5	84.8	93.0	69.7	8.3
19	45.4	50.0	28.6	42.8	6.7
22	21.4	60.0	67.8	76.9	2.3
24	75.0	92.6	92.5	90.9	6.5
26	69.0	62.8	57.1	38.9	9.4
34	10.7	11.5	10.3	48.0	4.9
35	*	74.2	74.1	46.1	7.7
59	25.8	15.8	14.6	26.9	3.4

* missing data (flowers aborted after pollination)

Analysis of variance of angular transformed values using the general linear model confirmed a significantly ($P<0.01$) lower proportion of flowers developing into fruits in open pollinated umbels. The effect of pollen source on the proportion of flowers developing into fruits was not significant (Table 4.31). Mean percentage fruit set was slightly higher in pollen from long style flowers but was not significantly different from short style flowers. Recipient tree size influenced the proportion of flowers developed into fruits 3 weeks after pollination. The proportion was significantly higher on recipient trees > 20-30 cm dbh than in recipient trees > 30 cm dbh (Table 4.31). The interaction between tree size and pollen source was not significant.

Table 4.30 Analysis of variance: effects of pollen source and tree size on fruit set in hand-pollinated umbels 3 weeks after hand-pollination at Bole, Ghana

Source of variation	df	ms	Significance
tree size	2	1443.9	**
pollen source	4	2423.8	**
tree size x pollen source interaction	8	120.4	n.s.
error	29	212.7	
total	43		

** P<0.01; n.s., not significant.

Table 4.31 Mean percentages of fruits in hand-pollinated umbels, by source of pollen and tree size, 3 weeks after hand-pollination at Bole, Ghana

Pollen source	mean ± s. e	Recipient tree dbh (cm)	mean ± s.e.
<500m, short style	44.9* ± 8.3^{a}		
<500 m, long style	59.8 ± 9.8^{a}	10-20	51.8* ± 8.0^{ab}
>500 m, short style	54.8 ± 10.3^{a}	>20-30	54.8 ± 8.2^{a}
>500 m, long style	59.3 ± 8.0^{a}	>30	26.7 ± 6.7^{b}
open (control)	5.4 ± 1.0^{b}		

means in the same column with different superscripts are significantly different (P<0.01).

* Means presented untransformed; significance test based on data after angular transformation

Fourteen weeks after pollination there were still no differences in the proportion of flowers that had developed into fruits (Table 4.32) in relation to pollen source although in the open pollinated controls the proportion developing was again significantly lower (Table 4.33). The influence of the size of the recipient tree also remained unchanged (Table 4.34).

Table 4.32 Influence of pollen source and tree size on the percentage fruit set in *Vitellaria* 14 weeks after hand-pollination at Bole, Ghana

Dbh (cm) recipient trees	<500 m short style	<500 m long style	>500 m short style	>500 m long style	open
13	30.5	70.0	42.3	54.8	0.0
17	*	42.4	44.8	*	0.0
19	15.1	16.6	17.1	7.1	1.3
22	17.8	20.0	25.0	*	2.3
24	57.1	*	*	54.5	0.0
26	42.8	42.8	35.7	27.8	1.4
34	7.1	7.6	10.3	28.0	2.4
35	*	3.2	40.7	42.3	0.0
59	9.6	5.3	4.9	11.5	3.4

* Missing data (tags on trees lost)

Table 4.33 Analysis of variance: effects of pollen source and tree size on fruit set in hand-pollinated umbels 14 weeks after hand-pollination at Bole Ghana

Source of variation	df	ms	Significance
tree size	2	504.8	*
pollen source	4	1177.0	**
pollen source x tree size interaction	8	137.0	n. s.
error	24	109.6	
total	38		

*, $P<0.05$; **, $P<0.01$; n.s, not significant

Table 4.34 Mean percentages of fruits abscissed, by source of pollen and tree size, over the period 3 -14 weeks after hand-pollination at Bole, Ghana

Pollen source	mean ± s. e	Recipient tree dbh (cm)	mean ± s.e.
<500m, short style	25.7* ± 7.0^{a}		
<500 m, long style	25.9 ± 8.3^{a}	10-20	26.3* ± 6.3^{ab}
>500 m, short style	27.6 ± 5.5^{a}	>20-30	27.3 ± 5.7^{a}
>500 m, long style	32.3 ± 7.2^{a}	>30	12.6 ± 3.7^{b}
open (control)	51.2 ± 0.4^{b}		

Means in the same column with different superscripts are significantly different ($P<0.05$).

*Means presented untransformed; significance test based on data after angular transformation.

The effect of tree size and pollen source on fruit abscission was examined as in Section 4.4.3. The difference in fruit production between week 3 and week 14 assessments was expressed as a percentage of the number of fruits present in each umbel in week 3. Neither pollen source nor recipient tree size influenced abscission and there was no interaction between them (Table 4.35).

Table 4.35 Analysis of variance: effects of pollen source and tree size on abscission of fruit set in hand-pollinated umbels between 3 and 14 weeks after hand-pollination at Bole, Ghana

Source of variation	df	ms	Significance
tree size	2	130.6	n.s
pollen source	4	159.6	n.s
tree size x pollen source interaction	8	164.0	n.s.
error	24	730.6	
total	38		

n. s., not significant

Chapter five

Discussion

Chapter Five

Discussion

In recent years, there have been changes in the savanna environment that have influenced the vegetation characteristics of the zone. Breman and Kessler (1995) assert that mean annual rainfall in West Africa has persistently decreased in recent years, and drier years have become more frequent. Ohler (1982) notes that *Vitellaria* used to occur up to 500 mm rainfall zone (pre-1972 drought rainfall data), whereas it now occurs south of the 700 mm isohyet corresponding more or less to the 500 mm isohyet of the last 20 years. In addition, today woody vegetation is subject to more frequent and more severe fires.

Herders traditionaly use high intensity fires to prevent encroachment of grassland by woody species (Rose-Innes, 1977) and this practice, rooted in the management of livestock in the savanna, is also aimed at improving grass quality (Gillon, 1983). The late, high-intensity, fires release nitrogen and sulphur held in the herb layer into the atmosphere. Nye and Greenland (1960) estimated for a herb layer of 7710 kg ha^{-1} the release of 22 kg of nitrogen into the atmosphere at Ejura, Ghana. This depletes the soil reserves which adversely affect the productivity of savanna soils. The late fires coincide with flowering and early fruiting in *Vitellaria*, thereby destroying them.

Vitellaria is under threat but the preference for quick returns from low investment by the African farmer (Baumer, 1994) and the common property nature of land in northern Ghana (Norton, 1988) makes planting of *Vitellaria* an unattractive option. The slow growth rate and long gestation period (15 years) are considered further disincentives to planting and thus indirectly contribute to the decline in *Vitellaria* stocking in parklands (Baumer, 1994). As the major source of income to the women of areas of production (Abbiw, 1990; Anon, 1991) excessive exploitation of the fruits continues to be high around settlements, with few seeds left to germinate.

Kessler (1992) and Kater et al. (1992) have demonstrated that shading by *Vitellaria* canopies reduce crop yield and farmers destroy regeneration in the periphery of villages where farming is practiced to increase output from their crops. Stands of *Vitellaria* will eventually decline as farming expand into new areas.

Nevertheless, resource value persists. In a survey on the use of non-timber forest products in Mali, Gakou et al. (1994) reported that after *Parkia biglobosa*, *Vitellaria* was the next most valued tree resource: the two species were valued far above any others but fruits from *Vitellaria* were collected more from the natural woodlands than from the fallowlands and crop fields. The need to manage the *Vitellaria* woodland resource for sustained production for the rural communities is imperative to prevent erosion of the existing gene pool.

The present state of knowledge of *Vitellaria* is uneven and biased towards descriptive aspects of the characteristics making the species an economic resource. Attention to the status of the shea tree has been negligible in most of the countries where it grows, particularly those where subspecies *nilotica* occurs. In the long-term, a much fuller understanding of the biology and ecology of *Vitellaria* will be fundamental to its management. This understanding will also be essential as a basis for genecological studies. Implementing management, however, will also involve choosing routines compatible with today's savanna environment. These routines will have to include measures which prevent or minimise disruption of production and regeneration.

This study has involved an in-depth review of biological and ecological information on *Vitellaria* and has examined its status at Bole, a Ghana location long recognized as potentially very suitable for the species. Aspects of germination and reproductive biology have been investigated experimentally. Further, because fire is the greatest immediate threat to savanna tree populations, the fire climate of the experimental site at Bole has been evaluated as a case study which could be replicated elsewhere in the species' range.

The importance of *Vitellaria* as a fat producing tree drew much attention (Appendix 3) to its exploitation. Early work concentrated on the extraction and chemical characteristics of the fat, most of which was done outside the species' range (e.g. Andrè and Pradain, 1947). In the eastern range although it is used extensively, its resource role is a neglected subject. Information is available from Burkina Faso, Ghana and Nigeria on aspects of the germination (Jackson, 1968), phenology (Chachu, 1982) and pollen morphology (Sowunmi, 1973) but little has been reported on the reproductive biology of the species. Information on the breeding and improvement of the species is not available, but recently work on this aspect has started in Ghana (Yidana, 1994). The majority of references to *Vitellaria* throughout its range, are no more than ecological descriptions of the vegetation formation in which it is a component. These concern mainly the distribution, environmental factors, and population levels of the species, but these vary in nature and are not easily standardized to a consistent basis. Ecological information is replete with the effects of fire on the species.

Several characteristics of *Vitellaria* makes it peculiar in the savanna environment. It has no close relatives in its family - the nearest is believed to be *Teighemella*, a forest tree. It is possible that *Vitellaria* is a species which has moved into savanna habitats in the course of its evolution but retains forest characteristics. There are no other savanna trees in the Bole area with an equally large, single seeded, indehiscent fruit with flesh around the seed which attracts animals. There is no dormancy mechanism and viability is very short - atypical for a savanna species. Viability seems to be retained as long as the flesh remains on the outside of the seed in an unfermented state. Local people stimulate fermentation to prevent germination by killing the seed but there has been no formal study of this aspect.

The main way germination arises is after the flesh has been stripped from the seed by vertebrates - probably mainly small mammals. Without this stripping there is negligible germination as found in the experiment in this study. It is possible that the epicarp prevents water reaching and entering the seed. Jackson (1968) notes that the scar area of the seed coming to rest directly on the soil surface enables the vascular tissues to take up water via the helium into the seed. In the experiment described (Section 4.3), no difference in germination was found between depulped seeds and cracked seeds. The cracked seeds were also in a depulped state. It is evident that sufficient water was taken up for germination to proceed without cracking and cracking gave no extra advantage.

In its present state at Bole, *Vitellaria* is a very variable resource and examination of *Vitellaria* stands between and within the two strata considered revealed differences in stand density, basal area, height and natural regeneration patterns.

Sampling from the mapped Delaunay triangles and use of Ward's programme indicated stocking higher than that directly assessed. In a similar application of the method to estimate stocking of *Albizia zygia* in cocoa farms and fallow lands in Ghana, Anim-Kwapong (1994) also noted overestimation. Ward (1991) indicates that the programme gives good estimates of stocking irrespective of the distribution pattern. It seems it is not robust enough to handle variable distribution patterns at the scale of the stands studied here.

The mean stocking (individuals ≥10 cm dbh) of 32 ha^{-1} obtained for Stratum Two, (<3.0 km) is high for other Sudanian woodland areas in West Africa (Pullan, 1974; Ohler, 1985). The mean *Vitellaria* stocking of 49 stems ha^{-1} (>10 cm dbh) in Stratum One (>3.0 km) is even higher and compares favourably with the figure of 53 stems ha^{-1} reported by Brookman-Amissah et al. (1980) for trees >9.5 cm dbh.

At Bole, mean *Vitellaria* stocking around villages (Stratum Two) was lower than in deserted (>50 years regrowth, Stratum One) woodland. The destruction of young trees during land preparation for farming after the fallow periods in Stratum Two explains the lower stocking of *Vitellaria* in this stratum. There has been felling of uneconomic tree species in Stratum Two resulting in a significantly lower All Species stocking in this stratum (Table 4.3). The basal area contribution of *Vitellaria,* retained because of its resource value in Stratum Two, was 73% as against only 42% for Stratum One.

The balanced size class distributions of *Vitellaria* (>10 cm dbh) in the two strata (Fig 4.4) indicates stands of good regeneration with frequent reproduction (Knight, 1975). This pattern was also observed by Vigne (1936) and Ramsay and Rose-Innes (1963) in the Guinea savanna of Ghana (Fig 2.7). However, the balanced appearance of population may be misleading because the small stems may not be young stems. They may be stems from old rootstocks which have repeatedly lost aerial shoots in fires or the growth rate may have been reduced by fire damage even when they survive. This is an aspect deserving systematic study.

Regeneration (<10 cm dbh) is influenced by several forms of land use pressure and by shade and competition in the Bole area. In Stratum One, shading of regeneration by the higher stocking of mature trees will influence regeneration. In Stratum Two farming activities and fruit collection are more intense and these will influence regeneration. Regeneration stocking was significantly different between the two years of assessment of the present study. Comparison of the density of regeneration in the two strata offers some explanation. Higher stocking of regeneration was obtained for Stratum Two than Stratum One during the first year of field work, in 1993 - searching of fruits (more intense in Stratum Two) during the previous harvesting period (June-September 1992) resulted in exposure of the soil to direct sunlight, as the rains began stimulating sucker production. Similarly, the search for regeneration in 1993 was followed by a significant increase in regeneration in 1994.

The suppressive effect of herbaceous vegetation and of fires on regeneration in *Vitellaria* has been illustrated in this study - 90% of regenerating individuals were in the form of shoots < 50 cm tall. This is consistent with past observations. Ramsay and Rose-Innes (1963) reported poor initial growth of regeneration of *Vitellaria* in the first six years of fire protection in Bamako, Mali, where 98% of 463 regenerating individuals were < 50 cm high in a plot of 800 m^2. In a coppicing experiment in the higher rainfall zone (mean 1200 yr^{-1}) in Toumousseni, Burkina Faso, Renes (1991), over three years, observed poor initial regeneration due to high grass growth. Regeneration is destroyed in seasonal fires but resprout (Fatubarin, 1987), a reflection of adaptation to the fire environment (Lawson et al. 1968). In this study >80% of regeneration was of suckers. Other studies in the West Africa savanna zone indicate high numbers of suckers (Hopkins, 1962; Lawson et al., 1968; Fatubarin, 1987). Accumulation of litter and high grass growth suppress regenerating individuals and fuel the high intensity fires which exacerbate this effect

The stocking of regeneration (600-1200 - both strata combined) recorded in this study is higher than 320 individuals ha^{-1} (< 2 m high) reported by Hopkins (1962) in the Olokomeji Forest Reserve, Nigeria but well below the 4900 individuals ha^{-1} (≤100 cm high) reported for Bamako (Ramsay and Rose-Innes, 1963). However, this difference can be explained by the small sample area at Bamako and is not likely to be present over areas as large as the Bole sample. Relating size of the area assessed to number of regeneration in the present study exposed a positive correlation indicating that regeneration is not simply concentrated closely around parent trees. Hopkins (1962) in the Olokemeji Forest Reserve, although on a smaller scale, also observed uniform distribution of *Vitellaria* regeneration. The importance of dispersal animals can be deduced from this.

There have been attempts to relate the wide variability in fruit production in *Vitellaria* to environmental factors (e.g. Delolme, 1947). In general, it is accepted that large trees have a large root volume and higher nutrient levels in the trunk and are therefore expected to be more productive than smaller size trees (Sedgley and Griffin 1989). However at Bole, flower development was more frequent in lower diameter trees, which was unexpected.

Bees pollinate *Vitellaria* (Millogo-Rasolodimby, 1989) and their activity is affected by climatic conditions such as temperature (Goncalves and Stort, 1978) and smoke from fires which has a tranquilizing effect (Ikediobi et al., 1985), depressing bee activity. The presence of other flowering tree species (e.g. *Bombax costatum* and *Commiphora africana* in West Africa savanna*)* can divert bees from *Vitellaria.* In unprotected umbels, soot and ash from burning grass sometimes clogg stigmatic surfaces preventing the germination of pollen tubes on the stigma. Reduced attention from bees and savanna burning may contribute to low fruit set in the species. In the present research hand-pollination compared with open pollination gave consistently higher fruit production in *Vitellaria.* This indicated that fruit set is limited by pollination, confirming the conclusion reached at Bole by Yidana (1994). Further, flowering at Bole coincides with periods of bush burning. Additional factors apparently operate, too. Insect-pollinated flowers are mostly geitonogamous (Bawa, 1974) since insects spend more time within plants than between plants. Yidana (1994) demonstrated for *Vitellaria* at Bole, that with geitonogamous pollination only 1% of pollinated flowers bore fruits whilst cross-pollinated flowers gave 39% fruits. The low fruit set in open pollinated umbels could reflect bees being covered with pollen from the same tree. The number of pollen grains deposited on the stigma is known to be associated with fruit development and maturation (Stephenson, 1981). In hand-pollination, pollen was applied directly to the stigma. With the open pollinated situation it seems that few visits by bees to flowers are beneficial due to absence or low levels of *Vitellaria* pollen from many of the visitors.

It has been shown for some species that pollen source, in terms of its isolation from the recipient, determines whether or not a flower will produce fruit (Lee, 1988). In this study, pollen source did not significantly influence fruit set within- and between populations. The maximum distance of 1 km employed in this study is short, however, bees may forage over longer distances (Janzen, 1971). Including more distance pollen sources might have produced a different result and is a priority for further research.

Only a small proportion of flowers within any umbel ever produces fruit although flowering is high in the species (Plate 1). Ruyssen (1957) reported that an umbel with 50 or more flowers gives at most 12 fruits and mostly 2 or 3. This low fruit set was ascribed to heterostyly by Corbett (1989), a condition described in *Vitellaria* (Chevalier, 1948). Style lengths for the five populations fall within the range reported (Hemsley, 1961) for subspecies *paradoxa*, 8-12 mm (Table 2.2) but the frequency distribution of style length is unimodal. This continous variation may be why pollinations with pollen donated from styles of different lengths obtained from the same tree showed no significant difference between style length on fruit set. The situation is not one of sharply defined di- or tri-styly hence low fruit production cannot be associated with heterostyly in itself.

Fruit abscission was high in the manually pollinated trees. Several factors have been advanced for high fruit abscission in tree crops. Competition for nutrient resources between developing fruits and expanding leaves (Lee, 1988) and plant-growth regulators (Sedgley and Griffin, 1989) have been implicated.

Fruit production in *Vitellaria* occurs in the dry season when the soil moisture level is low, limiting the supply of water and other nutrients to the developing

Plate 1 A leafless *Vitellaria paradoxa* subsp. *paradoxa* (height 13.5 m, diameter at breast height 58 cm) in flower at Bole, Ghana

fruits. Stephenson, (1981) indicated that application of nutrients to tree crops shortly after flowering period significantly reduced fruit abscission. Lee (1988) also showed that experimental application of drought and defoliation treatment induced seed abortion in tree crops. Greater fruit abscission is expected from pollinations between genetically very similar or very dissimilar individuals (Lee, 1988). There was no significant difference in abscission between any of the treatment combinations employed in this study and within its limits (sources up to 1 km away), environmental factors therefore seem to overide any genetic effects. As with the comparison of pollen source effects, this is a matter needing more study bringing pollen from more distant sources.

In the experiment undertaken, abscission did not vary with tree size, it seems nutrient reserves in the larger trees were not adequate to support high fruit yields. In another member of this family, *Achras sapota* L., Minhas and Sandhu (1985), obtained no fruit production from pollinated umbels at Ludhiana, India when humidity was low (46.5%) but stimulated production of some fruits on the same trees when humidity was high (65.5%). Humidity during fruit development at Bole remained low (<40%) and the low fruit production can similarly be attributed to this environmental factor. Of course, fruit production at Bole coincides with flushing in *Vitellaria* (Chevalier, 1908; Greenwood, 1929; Ruyssen, 1957) and competition for nutrients between emerging leaves and developing fruits cannot be exempted from the possible causes of high fruit abscission in *Vitellaria*. The seed is large and "metabolically expensive" to maintain - it is tempting to speculate about a further legacy of closed forest ancestry.

Fire has been identified as a particularly critical environmental factor for savanna tree response management. It cannot be ignored because it is a factor which exerts its effects so swiftly and is not as readily contained by barriers (e.g. fences) as livestock. Nor can it be guided away from sensitive areas as easily as stock. Compared with fuel gathering its impact strikes regeneration as well as established trees, and more severly. Compared with soil degradation it is an instantanuous process rather than a progressive one which can be checked and gradually reversed to achieve site improvement. Fire management is relatively straightforward now that drought index and fire danger index assessments using climatic data is possible. In the last two or three decades these have been used in Africa situations (Cheney, 1970; Uganda Forest Department, 1970; Kimaryo, 1986).

The 5-year period used for fire danger evaluation in the present study is short considering the variability of the rainfall regime year-to-year in much of Africa (Breman and Kessler, 1995) but it does provide insight into trends in the Bole district and for the CRIG sheanut station in particular. At Bole, there is a rise in drought index values > 400 points at the end of the rainy season in October and further increase to a maximum of > 700 points in December. The highest index value attainable (800 points) is reached at the peak of the dry season in February and March of the subsequent year due to successive months of no or poor rains. Hall and Gwalema (1985) for lower (800 mm yr^{-1}) mean annual rainfall at Morogoro, Tanzania, observed a similar increase in index values following the end of the rainy season in June. Values at Morogoro rose above 700 points usually in November, the peak of the dry season. Also at Ndola, Zambia, with mean annual rainfall similar to that at Bole, Cheney (1970) recorded a drought index of > 700 points at the height of the dry season in October/November, similar to the trend observed at Bole, Ghana. In contrast, at Kugamba and Mafuga in Uganda in an equatorial climate, the drought index never rose above 600 points at the peak of dry season in September/October (Uganda Forestry Department, 1970).

The drought index at Bole falls from the high dry season levels when the rains start. Values of < 400 points occur in August and get to < 100 points at the peak of the rains for 8-29 consecutive days, in most cases falling below 50 points for 5-10 days in September or October. This trend is consistent with observations made by Hall and Gwalema (1985) in Morogoro where the high dry season values fall to < 100 points in the rainy season for periods of 20-30 consecutive days and at the height of the rainy season in April/May, indices get to < 50 points.

Even when the drought index (used to calculate fire danger indices) was high, fire danger index never rose >24 at Bole. The low fire danger values arise from the high relative humidity (> 30%) and low wind speed, < 3.0 km hr^{-1}, (0.8 m s^{-1}) in February and March when index values reach a peak (Fig. 4.1). High fire danger prevailed from December of one year to January/February of the subsequent year. A similar combination of high drought indices and relatively low fire danger indices was observed by Hall and Gwalema (1985) for Morogoro. At Ndola, Zambia, Cheney (1970) recorded fire danger indices > 30 in several days late in the dry season due to relatively lower relative humidity (<20%) and generally high wind speed.

During periods of low fire danger, high rainfall coupled with high levels of nutrients released from burned plant material cause a rapid growth of grass in the Guinea savanna (Rose-Innes, 1977). The grass biomass built up during this period serves as fuel in the dry season when it dries (Gillon, 1983). One part of management practice can therefore be to reduce fuel load within *Vitellaria* stands. Since cattle do not attack mature *Vitellaria* trees, Adomako (1985) advocates grazing cattle to reduce the incidence and severity of fires. Grazing reduces the available fuel and the associated trampling compacts the grass layer, further reducing flammability. Regulated grazing of cattle in good stands of mature *Vitellaria* in the Guinea savanna is a promising management tool.

Even though fire danger indices indicate that the fire climate at Bole never becomes as severe as in some parts of Africa, such as Ndola (Cheney, 1970), and very high fire danger levels as at Ukiriguru and Dodoma, Tanzania (Kimaryo, 1986), fire at Bole is a threat to regeneration, growth and production of the species (Plates 2 and 3). Effective management of fires is therefore important for sustained regeneration and production. Use of livestock will not always be feasible - in most areas controlled burning is a more realistic option.

There are conflicting views on the stage at which fires become intense and uncontrollable. At Bole the grass layer is usually fully cured in January, when drought index > 600 points and fire danger index is high, during this period fires become common and intense. In Uganda, with appreciable rainfall throughout the year, the Uganda Forestry Department (1970) reports that grass becomes fully cured when the drought index reaches 250 points. This difference is likely to be a reflection of the grass cover with dense tall (2-3 m) *Pennisetum* in Uganda and less robust *Andropogon* and *Hyperrhenia* at Bole. Cheney (1970) notes that accurate prediction of fire behaviour for a particular fuel type can be determined by carrying out fire behaviour experiments in that fuel type. In the Guinea savanna of Ghana, grass curing starts when drought index values are >400 points in November, the period when the grass layer is not fully cured and when less destructive early dry season burning is practiced (Ramsay and Rose-Innes, 1963).

Plate 2 Fire-damaged *Vitellaria* tree (diameter at breast height, 53 cm) in a plot at Bole, Ghana.

Plate 3 Fire-damaged regeneration and suckering response to fire by regeneration at Bole, Ghana

The implication is to carry out controlled burning in productive stands of *Vitellaria* when index values are < 400 points and relative humidity is 30-40% in November at Bole. Day-by-day drought index computation and humidity conditions should be considered in conducting controlled burning. Clearing of fire breaks and access routes should be done immediately after the rains before controlled burning commences. Hall and Gwalema (1985) suggest that, in years when the rainy season ends abnormally early, checks of when to carry out controlled burning should be initiated after any 10 successive days without rain.

Drawing up controlled burning schedules should take account of the phenology of the *Vitellaria* population of the area concerned. The pattern may not be identical to that at Bole. Undesirable side-effects, such as depressing bee activity and depositing smoke particles on stigmatic surfaces, could occur with controlled burning of early flowering populations. Options are to use the grazing animal approach if there is a valuable, productive, early flowering population or to focus active management on late flowering populations. Good access and trained staff are important in the control of fires during the dry season. There is also an obvious need to train staff in basic fire fighting techniques.

For Ghana, there has been a recent review of the causes of fires and management policies instituted by the government to prevent fires (Ampadu-Agyei 1988). This review followed the bushfire destruction of 1983 in Ghana, which led the government to establish the National Anti-Bushfire Committee which has trained local volunteers to serve as the first line of attack against bushfires. As at 1987, the figures available indicated 7 trained anti-bushfire volunteers per square kilometre for the whole country and for the Guinea savanna, 56 per square kilometre (Ampadu-Agyei, 1988).

Improving resource status by protection from fire would be a positive management measure but basically passive and relatively slow to generate significant benefits. Corbett (1989) has reviewed silvicultural experiences of a wide range of techniques including direct sowing, transplanting and forms of vegetative propagation. Combining protection with enrichment planting could accelerate stand improvement but rather slowly. In the case Corbett describes most fully and which seems most successful, (Delolme, 1947) transplanted nursery raised seedlings four and one half years old to fill gaps in understocked stands in Ivory Coast. The technique involved two pricking out operations to obtain a dense mat of root hairs around the tap root, which had to be completely enclosed in soil when transplanted. This ensured significant faster growth and development. Experience suggests, however, that until plants are 10 cm dbh moderate slashing of weeds is necessary for fast growth to be sustained. Controlled burning could be undertaken when the trees are larger.

With more collaboration between countries throughout the range an alternative strategy to improving stand quality whilst retaining the original genetic base would be to identify productive provenance x site combinations. Restriction of past attention to local usage means no basis for provenance selection has emerged. Casual comments reveal, however, that variation in both product quality and biology could be harnessed to advantage in multinational improvement programme. It is remarkable that so little interest in subsp. *nilotica* has been indicated in West Africa countries where subsp. *paradoxa* is a major national resource since ideas of tree selection and breeding are long established and have been applied to so many tree resource. It is 60 years since Anon. (1935) reported the superior quality and quantity of fruits of "lulu" (shea) in Sudan. What could germplasm from this part of the range offer West Africa with its more developed shea technology and emerging interest in breeding? Within West Africa attention has been drawn to variations in flowering time, with rainy season flowering trees identified in Nigeria (Anon., 1975). There is evidently a case for seeking provenances which flower at times convenient to management with, for example, freedom from excessive competition for pollinators and from the undesirable side effects of savanna burning. There are many prospects for interesting future research studies on *Vitellaria* but the most urgent single need is for them to be linked to studies of provenance and geographical variation.

Chapter six

Conclusions and recommendations

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This study has indicated the need to manage *Vitellaria* as a valuable resource in the Guinea savanna of Ghana.

Conclusions

Analysis of the Bole fire climate leads to identification of a high fire danger period during February and March. Evolutionary strategies developed by the species ensure its perpetuation within the savanna ecosystem in the face of frequent droughts and bushfires. The soil surface is devoid of litter and standing grass at the time seeds drop, coinciding with the rains. The contact with the soil surface promotes decay of the pulp around the seeds, favouring germination. Subsequent dry season burning of the vegetation destroys the aerial shoots but the adaptive suckering habit confers resilience of the species in the savanna environment. Nevertheless growth is held in check and under natural conditions one or more seasons without fire is then important for regenerating individuals to become typical tree saplings.

Vitellaria is a savanna tree with distinctive seed and germination characteristics and its management cannot be successfully achieved on the basis of experience with other savanna trees. Management routines for *Vitellaria* need to be developed from first principles. This work showed that seed pre-treatment in the form of depulping, for instance, is important for the germination of *Vitellaria* seeds.

Literature reports indicate that *Vitellaria* tends to occupy a well-defined topographic position: colluvial slopes where soil is of sandy-loam texture. It is not characteristic of low positions in the landscape where there is risk of soil occasionally or regularly becoming saturated. This has obvious relevance in the selection of sites for plantation establishment.

The review of literature provides ample evidence of genetic variation within and between populations in different geographic localities. The existence of trees with different crown shapes, important for selecting trees for different farming systems, are traits worth exploiting. Differences in the timing of phenological events between populations within the species range offers variation that could be exploited by selecting and breeding early flowering and fruiting cultivars in the fire-prone guinea savanna.

Subsp. *paradoxa* is not heterostylous. Style length varies continously and cannot be distinctly categorised into short and long style types. Style length in populations at Bole is normally distributed.

Controlled pollination gave higher fruit set than open pollination and neither the style length of the pollen donor nor the pollen source distance (up to 1 km) influenced fruit set. The population can be said to be genetically homogeneous within this limit. Abscission of fruits similarly was not influenced by source of pollen within 1 km nor by size of tree. Environmental and other factors (e.g. competition for nutrients between expanding leaves and developing fruits) seem to overide genetic factors in fruit abscission in *Vitellaria*,

At Bole, farming has reduced *Vitellaria* stocking in the periphery of villages, indicating destruction of regeneration by farmers. Expanding farming into new areas as human pressure on land increases will cause gradual erosion of the existing genepool and deterioration of the biological diversity of the area.

Recommendations

Recommendations are in terms of silviculture, management of mature stands and research.

Silviculture

Raising seedlings in the nursery for outplanting in the field requires depulping of fruits to ensure maximum germination of seeds. The technique developed in the Ivory Coast 50 years ago (Delolme, 1947) can be used to ensure faster growth and development of outplanted seedlings.

In newly established stands, herbicide use is recommended to control weeds, since at the stage when the shoots of young *Vitellaria* plants are susceptible to fires, control burning cannot be practised. Grazing of cattle increases seedling mortality due to trampling and cannot be employed in the management of establishing stands. Vegetative propagation techniques, can be used to raise rooted cuttings from promising trees for outplanting. Mulching is necessary after seedlings are transplanted to reduce soil temperature and soil moisture loss.

Management recommendations

Management recommendations designed to protect the *Vitellaria* resource for increased regeneration and production, should aim at integrating knowledge on the biology and ecology of the species from all parts of the species range into a comprehensive working management programme.

Stand structure, and natural regeneration after germination of seeds, are adversely affected by dry season fires. Fire exclusion or, better, management is needed to maintain fully productive *Vitellaria* stands. Taking account of the seasonal cycle in fire danger index values, if burning is to be used at Bole as a management tool in *Vitellaria* stands rather than excluded, it should be applied in November. Reducing or eliminating combustible material (grass) which fuels dry season fires can be achieved through regulated grazing of cattle in good (> 50 stems ha^{-1}) stands of mature (>10 cm dbh) *Vitellaria*. Enrichment planting should take account of the topographic position and soil characteristics of the site for high establishment since the species is intolerant of sites subject to flooding and soils with high clay content.

Flowering will usually coincide with fires carried out as part of management. Early dry season burning in productive stands is recommended for improved yield. Assessment of fire climate to determine suitable regimes for control burning is necessary. Management must aim to reduce fuel load and prevent more destructive late fires. At Bole it is therefore important that staff be trained in basic fire fighting techniques to assist in effective fire control operations.

Research recommendations

To manage the species in the fire-prone savanna environment, research on controlled burning should be undertaken in relation to drought index trends to confirm the most suitable time to carry out control burning. The growth stage (height and diameter) at which fire exerts little effect on young trees should be determined for effective fire management of established stands.

Identification of sources of high genetic diversity of the species within the geographic range is important for improvement of the species. Germplasm collection throughout this range and establishment of gene banks is recommended. Provenance trials should be initiated to identify types suitable for improvement. Vegetative propagation techniques need to be perfected for the species so that they can be used to multiply promising provenances and to raise plants of the most suitable quality for farmers. It may be possible to use fertilizers in the nursery to promote growth of seedlings, reducing the time taken to reach transplanting size. Research into this possibility is recommended.

Taking account of the significant increase in regeneration between the two years of study, a deeper understanding of the effects of soil exposure in the rainy season on natural regeneration needs to be developed for application in the future improvement of stands. The relationship between root nutrient reserves and the effect of nutrients released during fires on sprouting and subsequent growth of regeneration merits detail study, to identify the factors and their interelationships which control suckering.

Inefficient pollination is considered a factor reducing fruit yield. Research should therefore be conducted into bee colony/pollination relationships. Since bees can forage over distances > 1 km, studies comparing the response to pollen from distant sources (up to 10 km) from the recipient population is recommended. The study of style length variation should be extended to populations throughout the range to support more detailed investigations of the breeding system and mechnisms regulating gene flow. Tree size (>20-30 cm dbh) influenced fruit set in this work: more work on trees size/age and fruit production relationships is therefore considered desirable.

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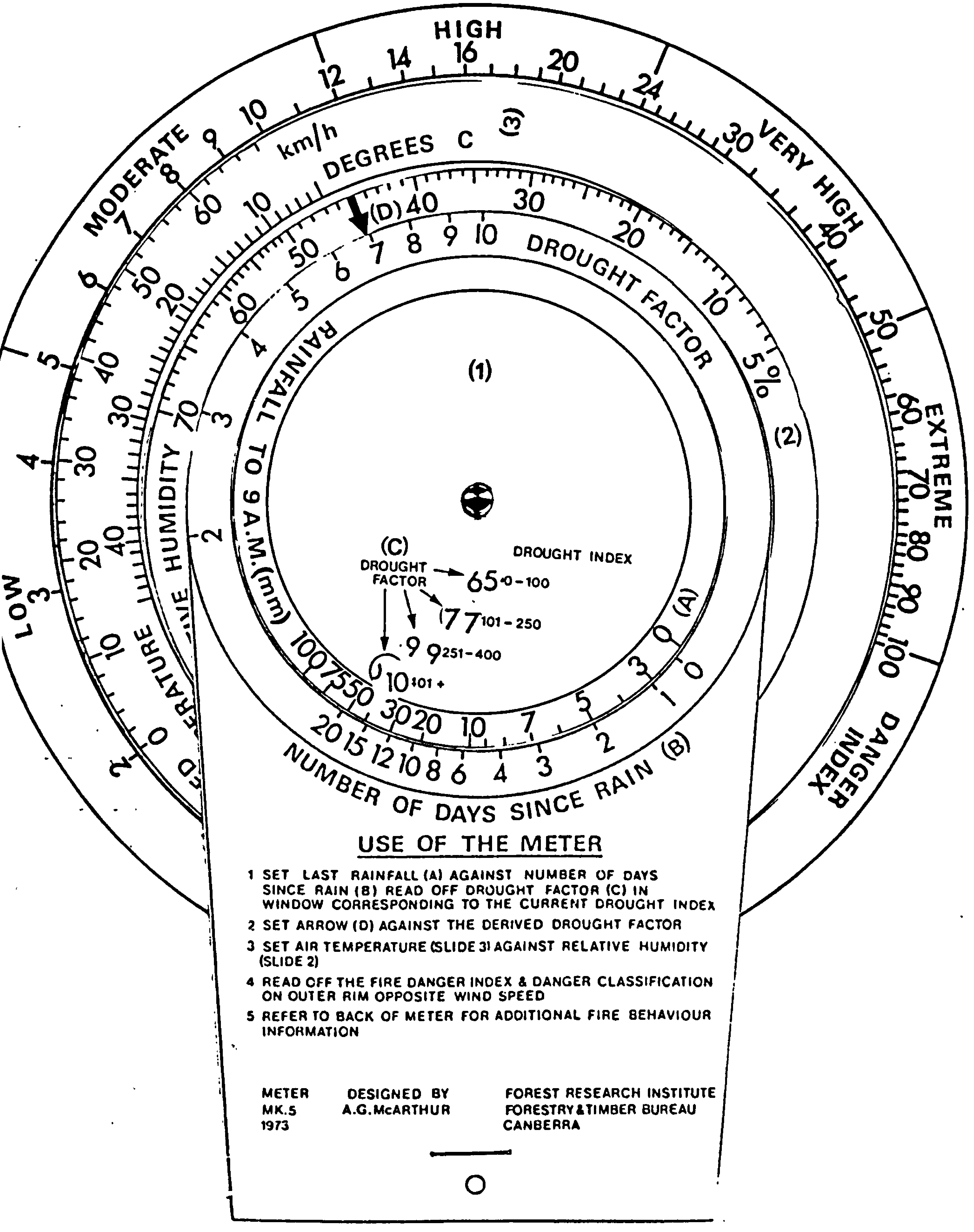
Appendix one

McArthur forest fire danger meter

FOREST FIRE DANGER METER



USE OF THE METER

1 SET LAST RAINFALL (A) AGAINST NUMBER OF DAYS SINCE RAIN (B) READ OFF DROUGHT FACTOR (C) IN WINDOW CORRESPONDING TO THE CURRENT DROUGHT INDEX

2 SET ARROW (D) AGAINST THE DERIVED DROUGHT FACTOR

3 SET AIR TEMPERATURE (SLIDE 3) AGAINST RELATIVE HUMIDITY (SLIDE 2)

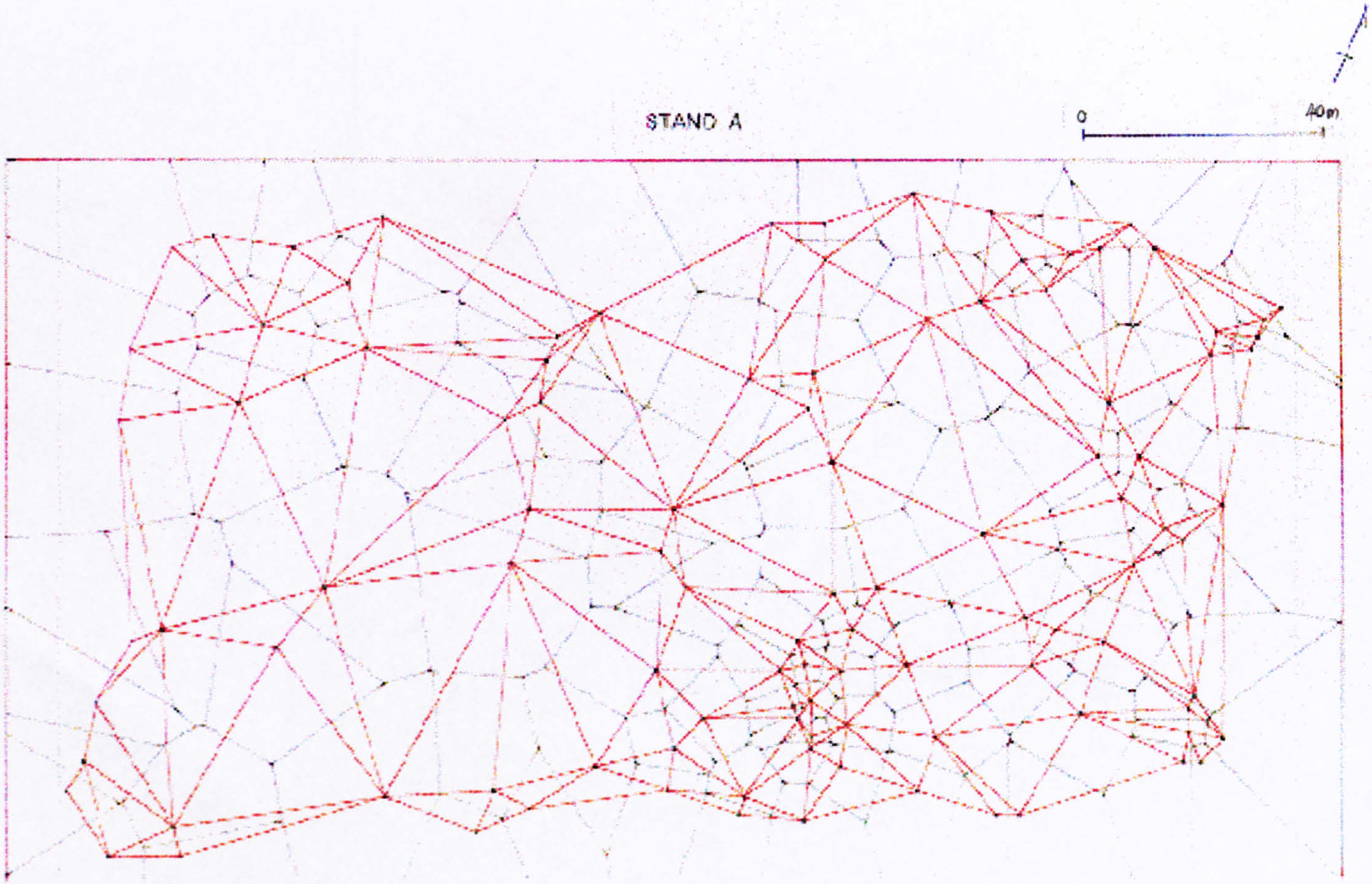
4 READ OFF THE FIRE DANGER INDEX & DANGER CLASSIFICATION ON OUTER RIM OPPOSITE WIND SPEED

5 REFER TO BACK OF METER FOR ADDITIONAL FIRE BEHAVIOUR INFORMATION

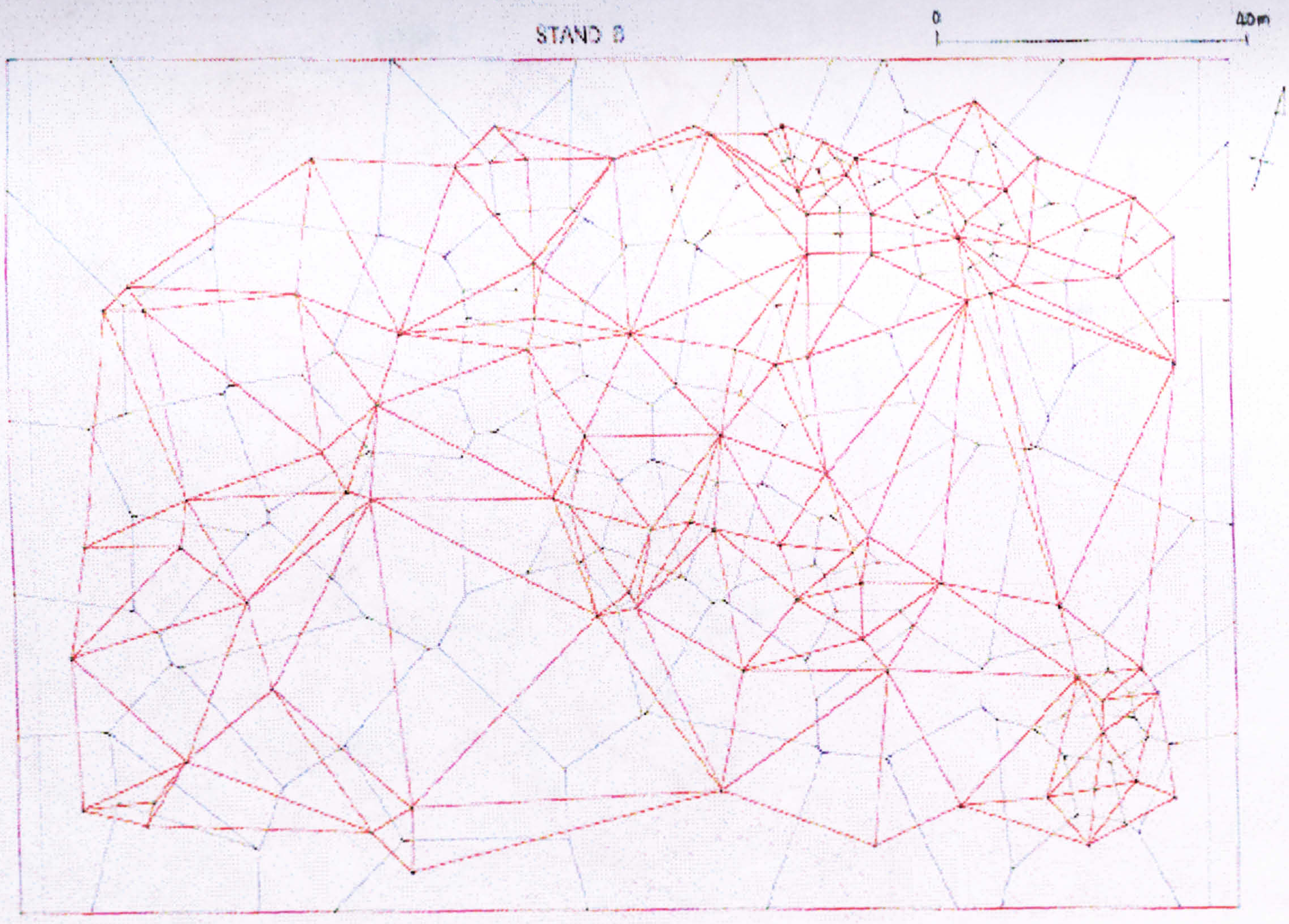
METER MK.5 1973	DESIGNED BY A.G.McARTHUR	FOREST RESEARCH INSTITUTE FORESTRY&TIMBER BUREAU CANBERRA

Appendix two

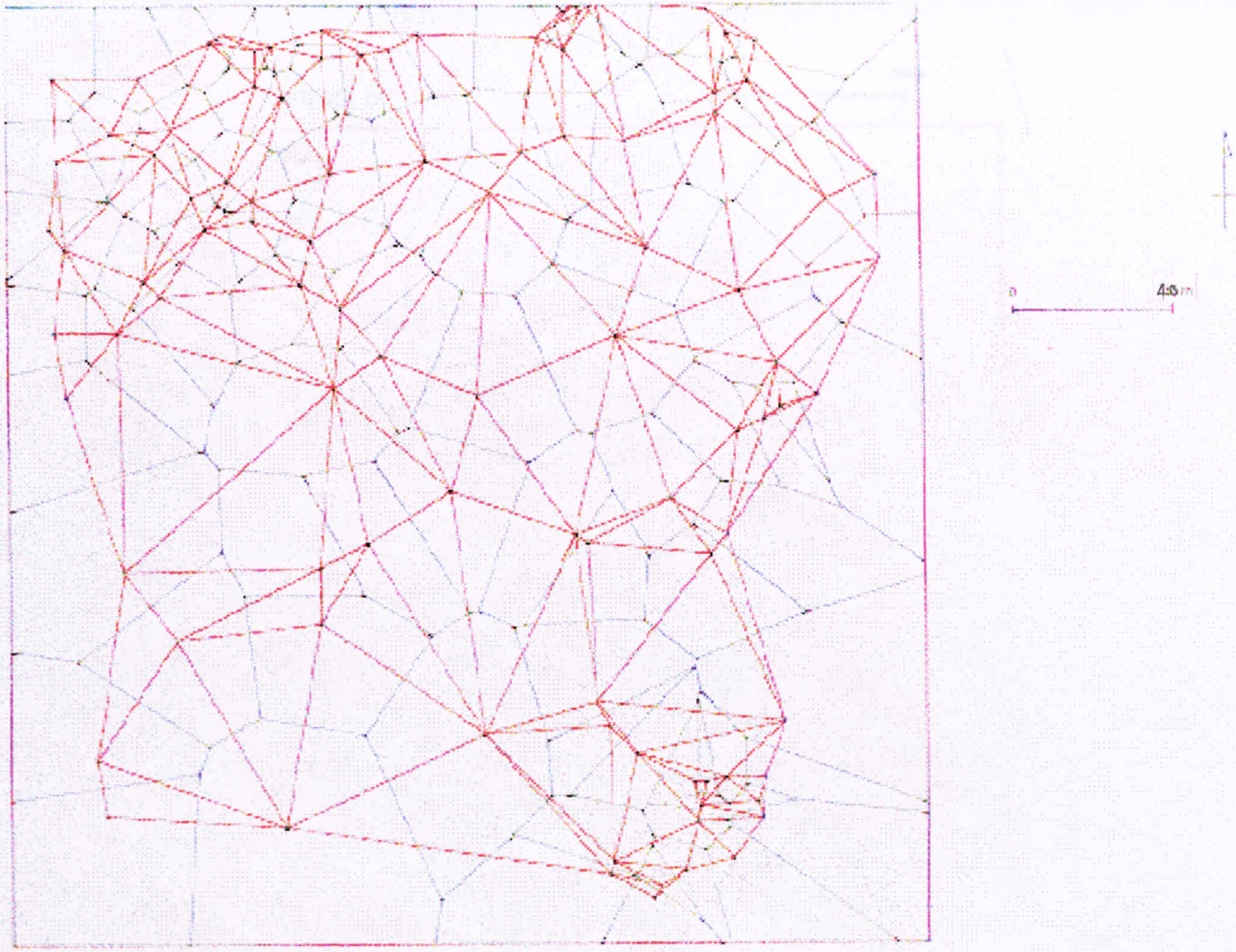
Polygonal (black) and triangular (red) tessellation map of stands

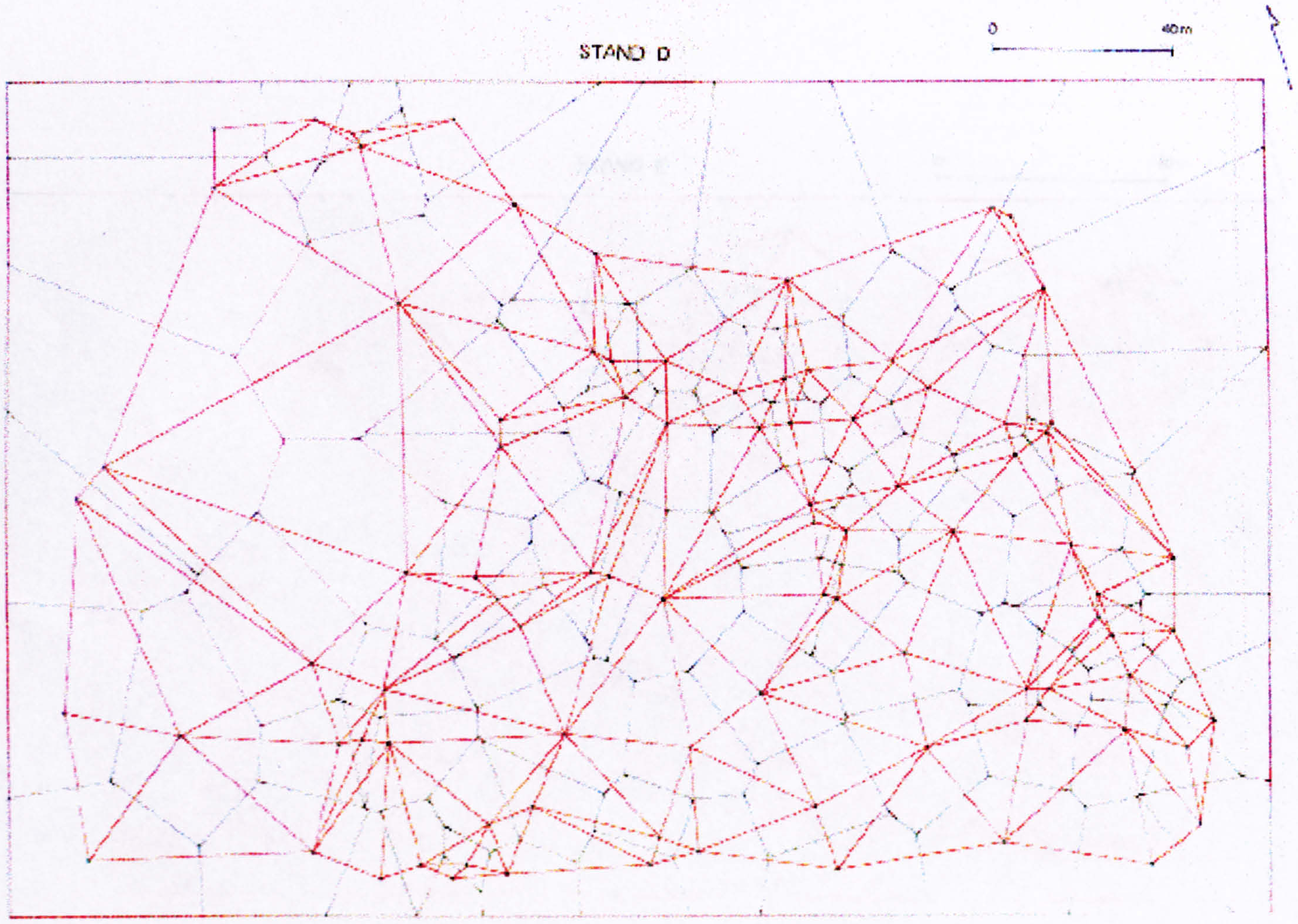

STAND A
0
10m

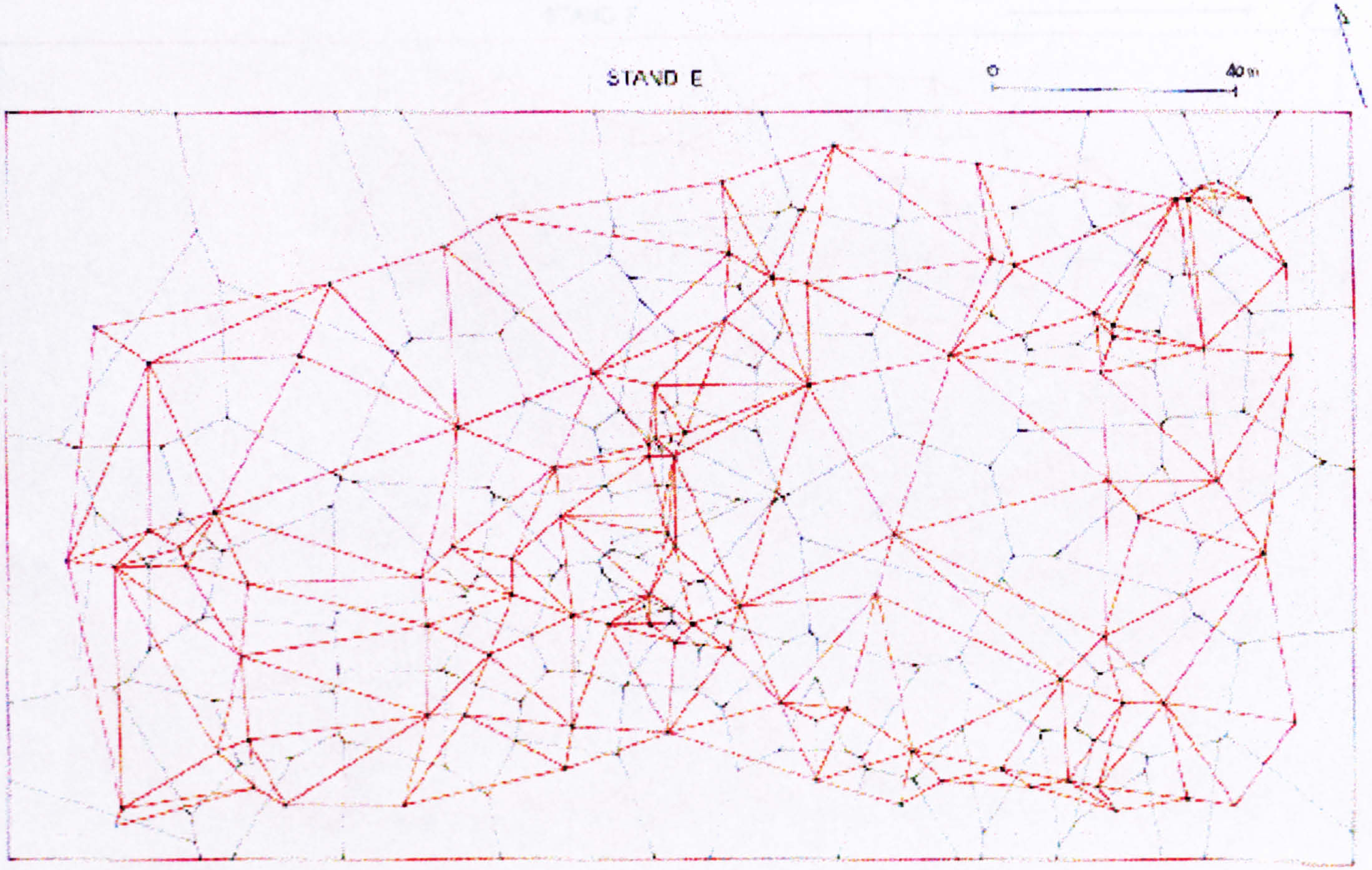
STAND B



STAND C




STAND D
0
40m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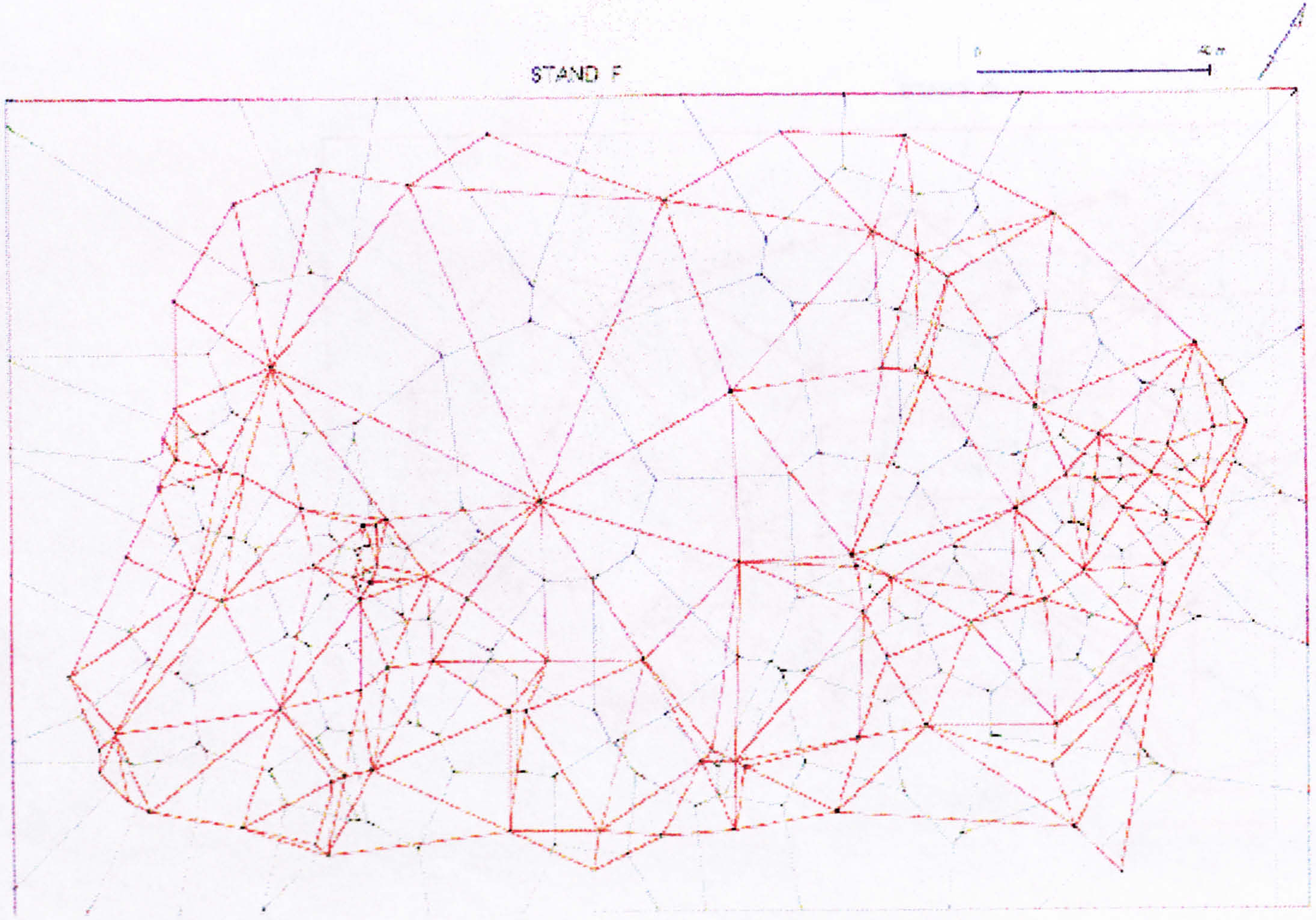
0
40m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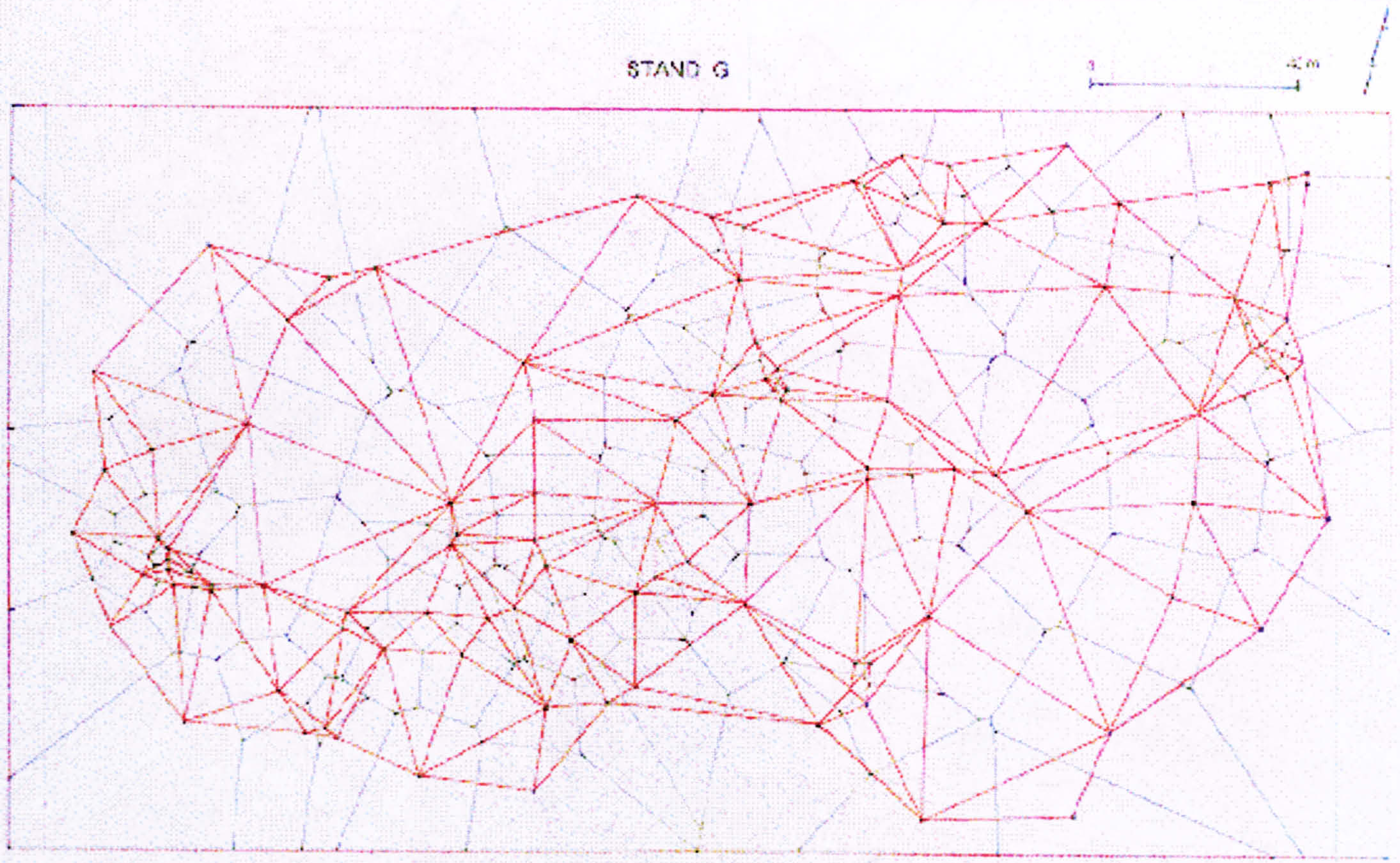
4 m


STAND G
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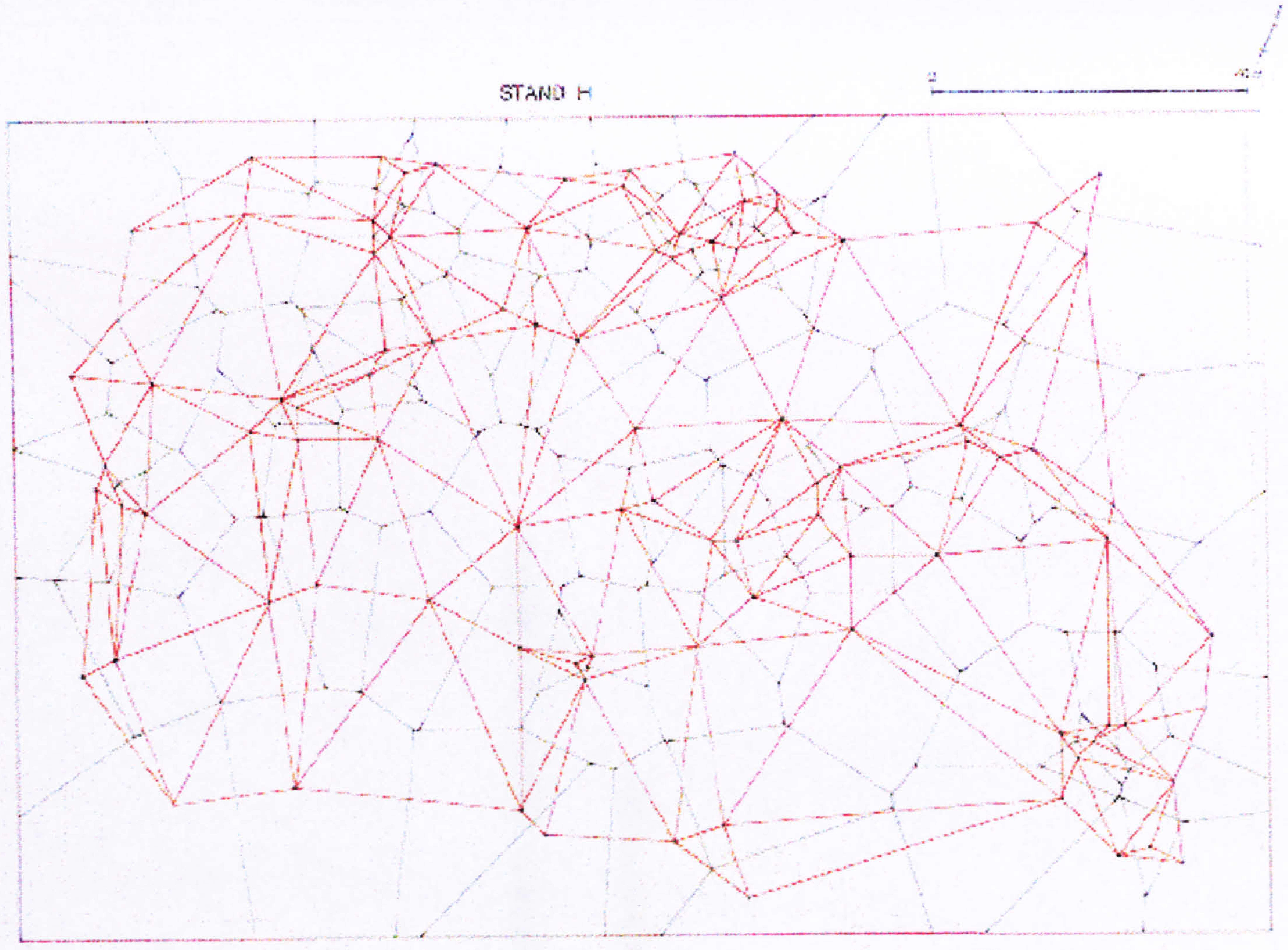
2 m


STAND H
0

Appendix three

Research on *Vitellaria* by country

Research on *Vitellaria* by country

	Burkina Faso	Benin	Cameroon	CAR	Cote d'Ivoire	Ghana
species						
taxonomy		110	86			93
description		110				93
biology						
phenology/life cycle						(194?);230
reproductive biology						
pests, parasites	101;102;322					99;109;219
artificial regen.						
ecology	315			32		331
geographical distribution	52;		34;86		179	84;213
environmental factors	52;				178	49;50
population levels	73;117				277?	50;51
vegetation type	52;		257	284	178	50;108;51;213;246;334
interaction with man, animals	56;57;					49;51
assoc. spp.	52;					49;50;51;108
husbandry and management	335	281				
role as a resource	358		346			163
apiculture	67;69;111	110			200	
agriculture, agroforestry, forestry	76	70	72		71;277?	85;160;236;263;289;325
socio-economics	88					74;80;87
tree improvement	104;					85;105;
sheabutter/oil						171
extraction, production	18;311	48				84;85;87;109;151;164;217;288
chem. composistion						24;25;84;218
utilisation	103;	48	86			87;93
seed meal						112;113
medicinal					344	
wood						83
general	185;186					

	Mali	Nigeria	Senegal	Sudan	Togo	Uganda
species						
taxonomy		15	35; 197	110;205	206	
description	201	238	197	205;269;271;304;326	206	224;323
biology						
phenology/life cycle		208				
reproductive biology		162;285;314				
pests, parasites	101	54	100			
artificial regen.			38			
ecology			35			
geographical distribution	31	29				
environmental factors	58;31	45;46;54;55;226				
population levels		30;40;314?				
vegetation type	31	29;30;44;133;214;215;216;239;247;248;249;290;329;351;376	297	295;352		118;255;332
interaction with man, animals		40;43;47;106;256			330	
assoc. spp.		30;44;46;54;59				
husbandry and management	281					
role as a resource		238;242;355				
apiculture		66		110	68	
agriculture; agroforestry, forestry	75;77	72;122;184		282		353
socio-economics		89;279				
tree improvement						134
sheabutter/oil						
extraction, production	18;26;27;135;196;301;311	2;3	35			
chem. composistion						
utilisation		90				
seed meal		21				
medicinal		260;338?	251			
wood		28;59;96;338?;340			97;114	161
general		237				

Guiena francaise (273) (369) `275 Niger 308;313;316 Zaire 310
Ethiopia? (231) Sierra Leone (343) 212 221/222? Chad (232) 254 264

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