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African bamboos: an appraisal with special reference to Oxytenanthera abyssinica, the savanna bamboo

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African bamboos: an appraisal with special reference to *Oxytenanthera abyssinica*, the savanna bamboo

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Abstract

Oxytenanthera abyssinica, the African savanna bamboo, was studied in natural populations, and experimentally, in Malawi. In addition, the state-of-knowledge of the species was comprehensively reviewed. The field research addressed silvicultural and management aspects and was conducted in Malawi from October 2001 to October 2003.

Oxytenanthera clumps were characterised as management units and vegetative propagation procedures were tested. Seed propagation was also conducted - in open stands in Lilongwe, and in controlled conditions in Bangor. Clump characterisation was undertaken, in terms of culm numbers and ages, over two seasons after applying different culm harvesting intensities. Mapping and monitoring of the treated clumps were also carried out. Differences in clump characteristics between localities (Lilongwe, Nsawagi and Zomba) were observed. A harvesting intensity of 40% of young (7-12 months) and 40% of mature (>12 months) culms every two years was found to be suitable for clump management in a harvesting intensity experiment at Lilongwe. The survival of detached culm sections for vegetative propagation was affected by the position in the culm and source locality. No effect of culm age, hormone application or the number of internodes per cutting was observed. A soaking treatment before sowing was effective for seed propagation in the open. In a tetrazolium test, after three months stored at ambient temperatures, all seeds tested were viable. In a direct germination test, cumulative germination percentage was 53% under a 32/22°C (8h/16h) regime and 40% under a 36/26°C regime 13 days after sowing.

Silvicultural and management information is very limited. Most literature provides only descriptions of the plant or reports distribution records. To broaden the knowledge base, literature on the other five indigenous African bamboos was also reviewed - to underline contrasts and similarities of other species with *Oxytenanthera*. Herbarium information and ecological literature was used to draft distribution maps and a GIS exercise was then conducted to identify broad relations with environment.

It was concluded that with suitable clump management practices the resource can be sustainably managed. It is recommended that seed collection should be carried out whenever flowering provides the opportunity, and enables new propagation research with material raised from seed under controlled conditions. Studies on fertiliser application, which have been undertaken in managing other useful bamboos, should be carried out using permanent research plots.

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Acronyms

CITES	Convention on International Trade in Endangered Species of Wild Fauna and Flora
DRC	Democratic Republic of Congo (Former Zaire)
FAO	Food and Agriculture Organization of the United Nations
FR	Forest Reserve
FRIM	Forestry Research Institute of Malawi
GIS	Geographical Information System
GTZ	Deutsch Gesellschaft für Technische Zusammenarbeit
INBAR	International Network for Bamboo and Rattan
JICA	Japan International Cooperation Agency
LNS	Lilongwe Nature Sanctuary
PRC	People's Republic of China
SAFS	School of Agricultural and Forest Sciences, University of Wales, Bangor
STEP	Students Trees Education Project
WCMC	World Conservation Monitoring Centre

Chapter 1

Introduction

Bamboos occur in both tropical and temperate regions from 46°N to 47°S (Soderstrom and Calderon, 1979) and bamboo communities cover 14-16 million ha worldwide, 70% of this being in Asia (Uchimura, 1999). Estimates of the number of bamboo species in the world continue to vary, due to both the recognition of new species and taxonomic revisions. Recent literature, however, indicates there are from 77 genera and 1030 bamboo species (Dransfield and Widjaja, 1995) to 111 genera and 1575 species (Ohrnberger, 1999) recognised worldwide. Of these, 600-1000 species grow in tropical (300) and temperate (300-700) Asia and 400-500 species are found in tropical America. Continental Africa has only six species, one thought to be introduced, while Madagascar has around 37 species (Ohrnberger, 1999). No native species of bamboos grow in Europe (Clark *et al.*, 2000; Dransfield and Widjaja, 1995; Ohrnberger, 1999; Sharma, 1980).

For centuries, bamboos have played an important part in the daily life of the people in many tropical countries, particularly in Asia. A narrow strip of bamboos was already in use like paper 2500 years ago in China (Ueda, 1983). In the 12th century in China, bamboos were described as sources for food, roofing material, rafting boats, firewood, cloths, paper, shoes and floor by a certain poet, who concluded that no single day could pass without use of bamboos (Uchimura, 1999). About 1200 years ago, bamboo culms were used for frames of walls of the Horyu temple in Nara, Japan, which still stands and where the frames can be seen even today. In the same period, bamboos were used for water pipes (Ueda, 1983). Bamboos still play vital roles in daily life especially in the rural areas of developing countries where industrial products are expensive, unavailable or disfavoured among the people living there. They are widely used for scaffolding, houses, bridges, fodder, arrows, musical instruments, and food (Farrelly, 1996; Piper, 1992). Bamboos are put to hundreds of different uses. The list of bamboo products is endless.

Bamboos are the most important forest resource, in Bangladesh, Cambodia, China, India, Indonesia, Japan, Malaysia, Myanmar, Nepal, Philippines, Sri Lanka, Thailand and Vietnam (Farrelly, 1996; Piper, 1992; Sharma, 1980; Ueda, 1968). In the neotropics, they are much used in Central America which includes Colombia, Costa Rica and Ecuador (Uchimura, 1999). Almost the entire population of east and south east Asia (around 3 billion) depends on bamboos.

Japan trades bamboo products in large quantities - her bamboo exports in 2001 were valued at US$ 21 million, while bamboo imports were worth US$ 204 million. Fishing rods were the major export product, while the major import product was bamboo shoots, mainly from China (PRC) (Bamboo Journal, 2003). China's (PRC) bamboo exports in 2000 were estimated as US$ 300 million and her bamboo imports at US$ 4.5 million (Lu, 2001).

Bamboos are distinctive resources and have the special ecological advantages of gregariousness and abundance. It is sometimes seen in Japan that culms used in walls have eventually rooted from nodes, and also that abandoned culms used for rafting boats have drifted, reached river banks and started growing there (Muroi, 1987). Some years ago, it was estimated that more than 10 million tonnes of bamboos were produced annually in the world (Sharma, 1980). Annual yield from bamboo stands varies with species and country. The annual yield of *Dendrocalamus strictus* (Roxb.) Nees in India is 0.17-1.95 tonnes per ha (Varmah and Bahadur, 1980). The yield of *Phyllostachys edulis* (Carrière) J. Houz. in China is 27 tonnes per ha (Quantai, 1980) and that of *Bambusa bambos* (L.) Voss in Thailand is 5-25 tonnes per ha (Smitinand and Ramyarangsi, 1980).

Bamboos have remarkable qualities as structural material. Because of their strength, flexibility and versatility, culms have been used since ancient times in housing and other construction purposes. Bamboo bridges are built throughout Asia. The largest bridge built entirely of bamboos is remarkably 230 m long and 3 m wide. Bamboo bridges were mentioned as early as A. D. 399 in Chinese literature by a Buddhist monk. It is remarkable that the communities displayed the skill to build sophisticated structure from bamboos in the early stage. Bamboo is also widely used for scaffolding of high building. In Hong Kong, a typhoon struck and broke scaffolding made of steel, but the one made of bamboo held firm for its bending capacity, and light but strong structure (Farrelly, 1996). Bamboos are easily erected, dismantled and transported for scaffolding and other construction (Piper, 1992). A house is often made only from bamboos in rural areas of south east Asia. Bamboo poles support a thatched roof. In the split condition bamboos constitute narrow planks and smooth surfaced floors (Piper, 1992; Uchimura, 1999). For pillars, bridges and scaffolding, culms with a large diameter with thick walls and relatively short internodes are used. For walls, floors and roofs, culms with medium diameter and with relatively thin walls are used (Dransfield and Widjaja, 1995; INBAR, 2004).

The young shoots of many bamboo species are edible (Dransfield and Widjaja, 1995). In Japan, Taiwan, China and Thailand, shoots of some species are an extremely important vegetable. Thus, in Japan, the young shoots of *Phyllostachys edulis* are much appreciated as food (Uchimura, 1999), while in China, bamboo shoots for food are produced by *Phyllostachys edulis, Dendrocalamus latiflorus* Munro and *Bambusa oldhamii* Munro (Dransfield and Widjaja, 1995). Bamboo shoots have at least the same content of protein, fat and carbohydrate values as onions and cabbages (Ueda, 1983).

Bamboos cannot be grown and managed like timber trees, because morphology is totally different and managers need to understand bamboo morphology. As well as aerial shoots, bamboos have rhizomes, which are underground stems. Bamboo rhizomes are of two basic growth types: pachymorph and leptomorph. Bamboos with pachymorph rhizomes occur primarily in tropical regions. A pachymorph rhizome is typically short, and solid and it is often thicker than the culms, which generate from rhizome tips and form a densely tufted clump. Many temperate bamboos have leptomorph rhizomes, which are slender and hollow and extend horizontally outwards for some distance. Clumps of leptomorph bamboos are more open with a greater distance between culms, which are produced from lateral buds on the rhizomes (Dransfield and Widjaja, 1995; Liese, 1985, McClure, 1966). On the aerial shoots, branches form at each node and arise on alternate sides of the culms. Leaves develop on these branches. Branches may develop while the culms still growing or after they reach their full height and the resulting branch system is often distinctive for a bamboo genus. In *Bambusa*, for example, a primary branch emerges from each node and remains distinctly dominant. In *Schizostachyum*, the branches at each node are many and equal or subequal in size (Dransfield and Widjaja, 1995; McClure, 1966).

The main vegetative organs are rhizomes, culms and culm branches. Rhizomes grow underground branching away from bamboo plant. Shoots emerge on nodes or top of rhizomes, grow vertically from the ground and become culms. The diameter of the bottom of the shoot will be the diameter of the culm. The culm does not increase in diameter and remains throughout its life. New branches and leaves are produced every year as old branches and leaves are gradually lost (Ueda, 1983).

Rapid growth and prolific vegetative regeneration sustains supplies. Young shoots and mature culms may be harvested for various purposes anytime. In the rainy season following harvest, new shoots grow from the rhizomes. Annual production may be 5-20 culms per clump for vigorous arborescent species, while 50-100 culms per clump may be produced for shrubby species (Troup, 1921). In favourable conditions, shoots grow rapidly, reaching their full length in 2-3 months. The average elongation is 10-30 cm per day (Dransfield and Widjaja, 1995). As the case of the most rapid growth, 121 cm elongation per day was recorded for *Phyllostachys bambusoides* Siebold & Zucc. in Kyoto, Japan (Ueda, 1960).

In most cases, bamboos flower only once in their life and die soon after flowering (Liese, 1985). The flowering cycle of such bamboos varies with species. Some species flower annually and some only flower after more than 60 years (Dransfield and Widjaja, 1995; Liese, 1985; Shibata, 1999). After flowering, culms may die together with the rhizomes that produce them. In some species, however, such as species of *Arundinaria* and *Phyllostachys*, while culms die after flowering the rhizomes do not (Liese, 1985). The flowering phenomenon in bamboos still remains poorly understood (INBAR, 2004).

Culms do not grow higher or thicker after the first season (Ueda, 1983). New shoots are produced every rainy season from rhizomes as described before. Therefore, the annual yield depends on the number of new culms produced every year (Liese, 1985). Emphasis in management must be on continually encouraging the appearance of new shoots rather than accelerating growth of one persisting shoot - as in growing timber trees. In sustainable management terms, the number of new shoots produced per season can be seen as approximating to the number of culms to be felled in an annual harvest (Ueda and Numata, 1961). New culm production relative to numbers of old culms varies with species, but is not known for African bamboos, including *Oxytenanthera abyssinica* (A. Rich.) Munro (Kigomo and Kamiri, 1985).

Temperate bamboos have received attention in China and Japan for centuries, and a number of significant studies of bamboos were carried out in China in the last century by McClure (1966) and many Chinese scientists. Formal scientific study on bamboos in Japan effectively began at the beginning of the last century (e.g. Makino and Shibata,

1901) and many studies are still carried out every year. In tropical forestry bamboos have mostly been neglected although there have been some important past studies, particularly in India. Troup (1921) provided details of what was then known about Indian bamboo species, especially *Bambusa polymorpha* Munro, *Bambusa bambos* and *Dendrocalamus strictus*. *Dendrocalamus strictus* was later the subject of a silvicultural monograph (Deogun, 1937), which was the first such document for any bamboo - and one of the first for any tropical forest resource. More recently, there has been extensive bamboo research by Malaysian foresters, including studies of *Gigantochloa scortechinii* Gamble (Azmy, 1996), *Bambusa* sp. (Wong, 1993) and Peninsula Malaysian bamboos in general (Wong, 1995b). Neotropical bamboos have been given relatively little forestry attention but taxonomic work has been appearing (Kelchner and Clark, 1997 - *Chusquea*; Soderstrom and Zuloaga, 1989 - *Olyra*).

It is tempting to apply information from past reports about Asiatic bamboos to African bamboos. However, major uncertainties about the relationships of African bamboos to bamboos in other parts of the world still remain. This limits the application of research and management experience from outside the African continent. Africa has only six true bamboo species, as currently defined, which are definitely or possibly native. Resource value is only attached to some of these but in the case of *Yushania alpina* (K. Schum.) W. C. Lin and *Oxytenanthera abyssinica* there is growing forestry interest and knowledge bases to support management are needed. In general, published work on African bamboos is very scattered and usually narrowly focused. Recent work by Embaye (2003) adopts a more substantial approach but attention is concentrated on Ethiopia. Ohrnberger (1999) summarised taxonomic information but excludes comments on other aspects. The need remains for approaches to Africa's major bamboo resources on a continental scale. For all Africa's bamboos, there is only limited ecological information. Assembling state-of-knowledge reports for these bamboos will be a first step to generate guidelines for their management.

African vegetation has been reported consistently by many people over many years, culminating with White (1983). The continental approach encourages collective action by the continental's foresters and researchers, following a well-established tradition. Setting up a continental framework first makes work as more local scales more effective. Computer based GIS mapping techniques offer an efficient means of generating series of maps, summarising where species occur and various ecological conditions. Mapping the coincidence of the particular environments with areas which each species occurs in

Africa indicates suitable growing conditions, and areas with potential for a species outside its present range.

In this thesis, work is thus reported which primarily concerns *Oxytenanthera abyssinica*, the African savanna bamboo, and combines archival and field-collected information. The opportunity has been taken to collate and interpret information on other African bamboos while acquiring knowledge about *Oxytenanthera*. These results are presented as an aspect of the general ecological context for *Oxytenanthera*.

The Forest Research Institute of Malawi (FRIM) has recognised the importance of the bamboos in the rural economy and generously facilitated the author's earlier field research on the utilization of *Oxytenanthera abyssinica* (Inada, 2000). FRIM has also noted the lack of information on management and silviculture of *Oxytenanthera abyssinica* as obstacle to bringing about sustainable production on a significant scale. Need for research on all levels with *Oxytenanthera abyssinica* is recognised, and this study contributes to this by aiming to:

- quantify the relations between clump size, number of culms per clump, and new culm production (*Oxytenanthera abyssinica*)
- monitor the growth of new shoots under various felling intensities of culms to determine an optimal number of culms for retention (*Oxytenanthera abyssinica*)
- identify suitable nursery techniques for propagation (*Oxytenanthera abyssinica*)
- review information on the state of knowledge of the other five indigenous African bamboos as well as *Oxytenanthera abyssinica*, and produce and interpret a distribution map for each one

Chapter 2

Oxytenanthera abyssinica: review of literature

The first section of this chapter reviews existing information about *Oxytenanthera abyssinica.* Information is assembled under five major headings: Taxonomy and description (2.1), Biology (2.2), Ecology (2.3), Silviculture (2.4), and Resource roles (2.5).

2.1 Taxonomy and description

2.1.1 Taxonomy

Of the 1575 bamboo species recognised world wide, around 1000 species grow in Asia. The continental Africa has only six indigenous species of which *Oxytenanthera abyssinica* is most widely spread (Ohrnberger, 1999). *Oxytenanthera* is a member of the family Poaceae (Gramineae), subfamily Bambusoideae, in the tribe of Bambuseae and subtribe Bambusinae. *Oxytenanthera abyssinica* is the sole representative of genus *Oxytenanthera.* Holttum (1956) considered that Asian species previously assigned to *Oxytenanthera* should be transferred to *Dendrocalamus* or *Gigantochloa* because the ovary structure of Asiatic plants previously referred to *Oxytenanthera* seemed similar to *Dendrocalamus* or *Gigantochloa* and different from the hollow structure of the ovary of the African type species of genus *Oxytenanthera.* Later, Holttum (1972), however, pointed out that reanalysis of this genus was necessary, considering his earlier assessment of the ovary structure of *Oxytenanthera abyssinica* incorrect. Grosser and Liese (1973) suggested some so-called *Oxytenanthera* species from Asia, *Oxytenanthera albociliata* Munro (current name *Pseudoxytenanthera albociliata* (Munro) T. Q. Nguyen) and *Oxytenanthera hosseusii* Pilg. (current name *Pseudoxytenanthera hosseusii* (Pilg.) T. Q. Nguyen), exhibited distinct differences from *Dendrocalamus* and *Gigantochloa* in terms of an anatomical structure of vascular bundles but a seemingly close relation to *Oxytenanthera abyssinica.* Comparing *Oxytenanthera monadelpha* (Thwaites) Alston with other bamboos in Sri Lanka, Soderstrom and Ellis (1988) transferred this species to a new genus *Pseudoxytenanthera* due to its distinctive branching pattern. According to Soderstrom and Ellis (1988), *Pseudoxytenanthera* is monotypic, and the branching pattern is not found in any other bamboos. Given that there are some species sharing characteristics with *Oxytenanthera abyssinica*, notably in anatomical structure (Grosser and Liese, 1973), Sharma (1996) concluded that Asiatic species should be kept under *Oxytenanthera* until more information was available. Nevertheless, Ohrnberger (1999) records that *Oxytenanthera* as monotypic and native to Africa. He refers the Asian species previously assigned to *Oxytenanthera, Dendrocalamus, Gigantochloa* or *Pseudoxytenanthera.* The currently accepted name of the African species is *Oxytenanthera abyssinica* (A. Rich.) Munro.

Chronology of *Oxytenanthera abyssinica*

Ohrnberger (1999) lists 31 species combinations under *Oxytenanthera.* These refer to 25 taxa recognised as different species today. All except *Oxytenanthera abyssinica* (and its synonyms *O. braunii, O. borzii* and *O. macrothyrsus*) are referred by Ohrnberger to other genera. One name (*Oxytenanthera ruwensoroënsis*) was applied to an African species and has been reduced to synonymy under *Yushania alpina.* The remaining species (all Asian/Pacific) are referred to *Cephalostachyum* (1 species), *Gigantochloa* (7 names; 6 species), *Pseudoxytenanthera* (13 names; 12 species) and *Schizostachyum* (3 species).

The current consensus is that *Oxytenanthera* is a monospecific genus endemic to continental Africa. Most of the names now regarded as synonyms were disregarded in taxonomic texts after 1965 (Napper, 1965), as continent-wide revisions of grass genera were undertaken in the preparation of accounts for the Flora of Tropical East Africa (Clayton, 1970) and Flora Zambesiaca (Launert, 1971). Some names now reduced to synonymy seem to have been used little, and usually only briefly, or not at all, following their publication: *Bambusa schimperiana, Houzeaubambos borzii, Oxytenanthera ruwensoroënsis.* Retention of *Oxytenanthera borzii* as an Eritrean endemic (Cufodontis, 1970) and reference to *O. braunii* and *O. macrothyrsus* (Knapp, 1973) probably reflect completion of writing before Clayton's treatment of the East African grasses became available, rather than any alternative interpretation. The reference to *Oxytenanthera* as a genus with two species by Wielgorskaya (1995) appears to be erroneous. A context for the synonymy of *Oxytenanthera abyssinica* is given in Table 2.1.

Table 2.1: *Oxytenanthera abyssinica* chronology of nomenclature and synonymy

Year	Name and remarks
1838	The oldest botanical specimens collected in Ethiopia. Richard Quartin Dillon and Antoine Petit collected a specimen from Aderbati (Quartin Dillon & Petit *sine numero (s.n.)*, P) and Quartin Dillon collected another from beside the Tacazze River (Quartin Dillon *s.n.*, P). A further specimen was collected at Djeladjeranne by Wilhelm Georg Schimper (Schimper 501, P). One or a combination of these is regarded as the type material of the species.
1841	The first West African material was collected by Theodor Vogel (Vogel *s.n.*, K). A locality of Accra has been attributed to this specimen (Irvine, 1961), but this is at variance with the current understanding (Innes, 1977) of the Ghana distribution of the species. It is also of interest that the specimen does not appear to have been cited by Hooker (1849) for the Niger Flora.
1850	**Name: *Bambusa abyssinica* A. Rich.** Achille Richard (Richard, 1850) formally described the species, referring it to *Bambusa*, which had been scientifically described in 1789 by Johann Schreber, as a new species: *Bambusa abyssinica* A. Richard. However, Richard did express reservations about whether referral to *Bambusa*, rather than a new genus, was appropriate.
1852	von Breitenbach (1963) implies that in 1852 Christian Ferdinand Hochstetter transferred Achille Richard's species from *Bambusa* to *Schizostachyum*, which had been scientifically described by Christian Nees von Esenbeck in 1829, as *Schizostachyum abyssinicum* Hochst. No other reference to this binomial has been seen.
1854	**Name: *Bambusa schimperiana* Steud.** Ernst Gottlieb von Steudel (Steudel, 1854) published the name *Bambusa schimperiana* Steud., presumably based on a duplicate of Schimper's specimen from Djeladjeranne.
1868	**Name: *Oxytenanthera abyssinica* (A. Rich.) Munro** William Munro, in the process of a general monographic revision of the bamboos (Munro, 1868), recognised a need to re-classify the genus *Bambusa*. As a result, *Bambusa abyssinica* was renamed and adopted as the type species of a new genus, *Oxytenanthera*, as *Oxytenanthera abyssinica* (A. Rich.) Munro. He apparently coined the generic epithet *Oxytenanthera* to indicate the plant's very long, sharp points of the anthers. At the same time, Munro also transferred an Asian species from *Bambusa* to *Oxytenanthera* and described three new species (all Asian) which he referred to his new genus. The species which were put into the new genus shared the presence of a staminal tube and a convex upper palea in the fertile flower. Munro was the first to recognise the wide distribution of the species across Africa, when he examined early specimens from West Africa (Vogel's specimen; Barter 805, K - collected in 1857 in Nigeria), from north east Africa (the Ethiopian specimens; Schweinfurth 2511, K - collected in 1865 in the Sudan/Ethiopia border area) and an Angolan gathering (Welwitsch 1134, K – collected in the period 1853-61). At the same time, Munro relegated Steudel's species to synonymy under *Oxytenanthera abyssinica*.
1889-94	In Tanzania, Franz Stuhlmann collected specimens of *Oxytenanthera* from Kasi (Stuhlmann 6177) and Kiserawe (Stuhlmann 6228), believed destroyed in Berlin in 1944, which were thought distinct from *O. abyssinica*.
1895	**Name: *Oxytenanthera macrothyrsus* K. Schum.** Stuhlmann's plants described as a new species, *Oxytenanthera macrothyrsus*, by Karl Schumann (Schumann, 1895).
1905-7	In Tanzania, Karl Braun collected specimens of *Oxytenanthera* from Ukinga (Herb. Amani 1347, B, EA, K) which were thought distinct from *O. abyssinica*.
1906	A bamboo was collected from the Ruwenzori Mountains, Uganda, during the Duke of Abruzzi's expedition (Duke of Abruzzi *s.n.*, TO) thought to be a species new to science. In due course this was described by Emilio Chiovenda (Chiovenda, 1907) as a new species of *Oxytenanthera*: *Oxytenanthera ruwensoroënsis* Chiov.
1907	**Name: *Oxytenanthera braunii* Pilg.** Karl Braun's material from Ukinga was used as the type material for formal description by Robert Pilger (Pilger, 1907) of the new species *Oxytenanthera braunii* Pilg.
1905-7	Lorenzo Senni collected a specimen of *Oxytenanthera* from Mount Anfalo, Eritrea (Senni 792, PAL), thought distinct from *O. abyssinica*.

Year	Name and remarks
1909-10	**Name: *Oxytenanthera borzii* Mattei; *Houzeaubambus borzii* (Mattei) Mattei** Giovanni Mattei formally described (Mattei, 1909) Lorenzo Senni's specimen as a new species of *Oxytenanthera*: *Oxytenanthera borzii* Mattei, apparently distinguishing the two on the basis of inflorescence position (von Breitenbach, 1963). In the following year, the status was amended and Senni's plant was re-described (Mattei, 1910) as type material for the new, monospecific, genus *Houzeaubambos*: as *Houzeaubambus borzii* (Mattei) Mattei.
1956	Richard Eric Holttum (Holttum, 1956) was the first to set *Oxytenanthera* apart as an exclusively African genus, regarding the hollow tapering, hairy, distal extension of the ovary as especially distinctive because the internal cavity was not continuous with a lower cavity containing the ovule. Other species that Munro (1868) had referred to *Oxytenanthera* were transferred to either *Gigantochloa* or *Dendrocalamus*, depending on spikelet organisation and floret characters.
1963	Friedrich von Breitenbach (von Breitenbach, 1963) reduces *Schizostachyum abyssinicum* to synonymy under *Oxytenanthera abyssinica*. In addition, von Breitenbach (1963) reduces *Houzeaubambos borzii* to synonymy under *Oxytenanthera borzii*, with the consequence that, at generic level, *Houzeaubambos* becomes a synonym of *Oxytenanthera*.
1970	For the treatment of the grasses in the Flora of Tropical East Africa, Derek Clayton reduced *O. macrothyrsus*, *O. braunii* and *O. borzii* to synonymy under *O. abyssinica* and reduced *O. ruwensoroënsis* to synonymy under *Arundinaria alpina* (the current name of which is widely accepted as *Yushania alpina*) (Clayton, 1970).

Vernacular names

In Chi-chewa, common language in Malawi, *Oxytenanthera abyssinica* is called Nsungwi, distinguishing it from exotic bamboos (Inada, 2000). As would be expected given the wide range, there are many vernacular names for the species (Appendix I).

2.1.2 Description

The *Oxytenanthera* clump

Oxytenanthera abyssinica is a clumped bamboo sometimes occurring in extensive stands of many clumps. Clumps are generally well separated (e.g. in Gambia - Rosevear, 1937). The reported distance between clumps in Zimbabwe was over 10 m (FAO, 2001b). The interval between culm bases within a clump varies - from contiguous to 5-15 cm apart (Fanshawe, 1972). Typically, a clump is 0.3-6.1 m in diameter, consisting of 3-80 culms, but occasionally clumps are as large as 8 m in diameter, with 100-200 culms. Culms lean outwards. New shoots appear on the edge of the clump (Fanshawe, 1972; FAO, 2001b; Istas and Raekelboom, 1962; Letouzey, 1968; Mooney, 1959).

Below ground, the clump is represented by a pachymorph rhizome system. The pachymorph rhizomes are thick (Andrews, 1956), 5-7 cm in diameter (occasionally 10 cm) (author's direct research 2001), and very short (Giffard, 1974). Sometimes rhizomes appear at the ground surface (Fanshawe, 1972).

The true roots of a clump are borne both on the rhizomes and, above ground, the basal regions of the culms. Roots are 3-5 mm in diameter, pale cream and smooth and glossy (above ground) or densely white woolly (underground), according to Fanshawe (1972).

Culms, culm sheaths and branches

Culms are solid when young, becoming hollow but with thick walls, as they mature (Clayton, 1970; Fanshawe, 1972; Launert, 1971). Sometimes, however, even mature culms are described as solid (Phillips, 1995). The usual length is 5-10 m, but they occasionally reach 15 m. The diameter is 5-10 cm (Table 2.2). They are many noded, individual internodes being 15-30 cm long, when young densely covered with appressed hairs, although glabrous later. A fresh culm (without leaves and branches) weight of 8.4 kg and a dry weight of 2.9 kg was reported for a culm 11.5 m tall and 8.6 cm in diameter in Zimbabwe (FAO, 2001b). The air-dry weight of *Oxytenanthera abyssinica* estimated two weeks after harvest in Malawi (Inada *et al.*, 2003) was: culm 2.9 kg (76%), branches 0.52 kg (14%) and leaves 0.39 kg (10%) per culm (8.3 m length, 2.9 cm dbh, two culms observed). The weight per air-dried wall volume of culm becomes 850 kg/m^3 (= 2.9 kg/0.0034 m^3 per culm). The weight per oven-dry volume (solid volume) of culm estimated in Ethiopia is 607 kg/m^3 (LUSO CONSULT, 1997a).

The culm sheaths are about generally 20 cm long and 4-10 cm broad (INBAR, 2001), covered with stiff dark brown hairs (Launert, 1971).

Table 2.2: Reported heights and maximum diameters of *Oxytenanthera abyssinica* culms

Country	Culm diam. (cm)	Culm length (m)	Internode length (cm)	Source
Cameroon	5.0-8.0	5.0-6.0	n. r.	Letouzey (1968)
Cameroon	5.0-10.0	3.0-10.0	n. r.	Van der Zon (1992b)
Central African Republic	n. r.	10.0	n. r.	Sillans (1958)
Congo (DRC)	1.4-4.5	8.0-9.0	18.0-30.0	Istas and Raekelboom (1962)
Congo (DRC)	n. r.	15.0	40.0	Istas and Raekelboom (1962)
East Africa	5.0-10.0	3.0-10.0	n. r.	Clayton (1970)
East Africa	n. r.	4.0-9.0	n. r.	Lind and Morrison (1974)
Ethiopia	10.00	>7.0	n. r.	Bekele *et al.* (1993)
Ethiopia	4.6	6.8	n. r.	LUSO CONSULT (1997a)
Ethiopia	4.0-7.0	8.0-12.0	n. r.	Mooney (1959)
Ethiopia	4.0-6.0	6.0-8.0	n. r.	von Breitenbach (1961, 1963)
Ethiopia	n. r.	10.0-12.0	n. r.	von Breitenbach (1961, 1963)
Ethiopia and Eritrea	5.0-10.0	3.0-13.0	n. r.	Phillips (1995)
Gambia	5.0	6.0	n. r.	Rosevear (1937)
Ghana	6.0-10.0	6.0-10.0	20.0	INBAR (2001)
Ghana	n. r.	6.0	n. r.	Innes (1977)
Ghana	10.0	12.2	n. r.	Irvine (1961)
Ghana	n. r.	15.0	n. r.	Knapp (1973)
Malawi	3.3	8.8	37.0	Inada *et al.* (2003)
Malawi	n. r.	12.2-15.2	n. r.	Chapman (1962)
Malawi	n. r.	9.0-15.0	n. r.	Williamson (1975)
Nigeria	5.0	10.0	n. r.	Stanfield (1970a)
Senegal	2.0-4.0	5.0-8.0	n. r.	Berhaut (1967)
Senegal	3.0-5.0	5.0 - 10.0	n. r.	Giffard (1974)
South Central Africa	5.0-10.0	13.0	n. r.	Launert (1971)
Southern Africa	5.0-10.0	10.0	n. r.	Gibbs Russel *et al.* (1990)
Sudan	3.8-7.6	7.6-15.2	n. r.	Andrews (1956)
Sudan	6.0	n. r.	n. r.	Chipp (1929)
Sudan	8.0-16.0	n. r.	n. r.	El Amin (1990)
Sudan	5.0	3.0-9.0	n. r.	Morison *et al.* (1948)
Sudan	n. r.	8.0	n. r.	Sommerlatte and Sommerlatte (1990)
Sudan	6.0-16.0	n. r.	n. r.	Vogt (1995)
Tanzania	10.0	7.0	n. r.	Mbuya *et al.* (1994)
Uganda	5.0-6.0	10.0-20.0	n. r.	Snowden (1953)
Uganda	n. r.	7.6-10.7	n. r.	Langdale-Brown *et al.* (1964)
West Africa	8.0-10.0	10.0-15.0	n. r.	Burkill (1994)
West Africa	5.0	6.0	n. r.	Hutchinson and Dalziel (1972)
Zambia & Malawi	n. r.	6.0	n. r.	White (1962)
Zambia	n. r.	9.0	15.0-30.0	Fanshawe (1972)
Zambia	1.2-8.0	3.0-16.0	n. r.	Fanshawe (1972)
Zimbabwe	1.0-6.0	3.0-10.0	n. r.	Pardy (1954)
Zimbabwe	6.4-7.6	10.7-12.2	n. r.	Henkel (1927)
Zimbabwe	9.0	10.0	n. r.	FAO (2001b)
Zimbabwe	n. r.	7.0	n. r.	Palgrave *et al.* (1993)
General	5.0	10.0	n. r.	Doat (1967)
General	10.0	3.0-13.0	n. r.	Watson and Dallwitz (1992 onwards)
General	7.0-15.0	7.0-15.0	n. r.	Ohrnberger (1999)

n. r.: not reported

Branches are in clusters at alternate nodes. Within each cluster, a single primary branch from the main axis is distinctly dominant at each node; the subsidiary branches at each culm node are equal or subequal in size. The primary branch of cluster is 0.9-2.4 m long but the subsidiary branches are shorter, 0.6-0.9 m long. Usually the lower 6-8 nodes from the ground level produce a few primary and subsidiary branch complements so that stems in the lower part of a clump look clean. The subsidiary branches are usually 4-5 internodes. The two most proximal nodes of the subsidiary branches do not produce a leaf, but the next 1-2 nodes produce one leaf at each node (Fanshawe, 1972; Pardy, 1954).

Leaf buds, leaves and sheaths

Leaf buds arise at culm nodes, primary branch nodes and subsidiary branch nodes (Fanshawe, 1972). Leaves are alternately arranged with laminae 5-25 cm long and 1-3 cm wide. In shape, the lamina is linear-lanceolate to lanceolate, rounded at the base and tapering at the apex to a fine tip. The appearance is glaucous with inconspicuous transverse veins (Clayton, 1970; Fanshawe, 1972; Hutchinson and Dalziel, 1972; INBAR, 2001; Launert, 1971). The sheaths of branch leaves bear a few deciduous setae 2-5 mm long at the shoulders, and there are no auricles (Clayton, 1970; Fanshawe, 1972; Launert, 1971).

Inflorescences, fruits and seeds

The inflorescence is a globose spikelet cluster 4-8 cm diameter and greenish to straw-coloured. Adjacent clusters are sometimes confluent or condensed into a capitulum at the branch tip. Individual spikelets are sessile, very narrowly lanceolate, 1.5-4 cm long, and 1-4 flowered, with hermaphrodite florets at the spikelet apex and usually two or three sterile florets below (Clayton, 1970; Fanshawe, 1971; Launert, 1971). Many spikelets may be sterile (Watson and Dallwitz, 1992 onwards).

The glumes, (usually 2, rarely 3), are 17-30 nerved, with transverse veinlets, and are ovate to oblong in shape with the apex obtuse to acute, usually with a sparse scattered indumentum of stiff hairs. The lower glumes are 5-8 mm long and the upper 8-10 mm long. The lemmas are 26-32-nerved, narrowly lanceolate in shape, dorsally hispidulous and with transverse veinlets. The lower part is 1.2-2 cm long and the uppermost almost as long as the spikelet, tapering to a rigid spine up to 7 mm long. The paleas are 16-19 nerved, slightly shorter than the lemmas and narrowly lanceolate (Clayton, 1970; Launert, 1971). There are no lodicules. Six stamens are present, the filaments being united. There are three stigmas (Clayton and Renvoize, 1986). The caryopsis is hard and cylindrical with a sulcate brown side. It is 12-15 mm long and 2-3 mm in diameter (Fanshawe, 1972).

2.2 Biology

2.2.1 Chromosome complement

Chromosome numbers are 2n = 72, hexaploid (Reeder and Singh, 1967).

2.2.2 Life cycle

2.2.2.1 Development from seed to maturity

According to Fanshawe (1972) and Henkel (1927), seeds germinate in the rainy season following the dry season of flowering. Seedlings are 9-10 cm tall seven weeks after germination, and up to 22 cm tall after six months and 1 m after 8-12 months. Culms become 1.2 cm in diameter and 1.8-3.0 m in height in a few years (Fanshawe, 1972). In a planted experimental stand in Kenya, after 23 years of observation since the seeds had germinated under 50-70% (mature culm) thinning intensities, culms were 6.5 m tall and 9 cm in diameter at breast height. Shoots were reaching 3.1 m in height one year after 0.5 m seedlings were transplanted. Higher maximum height occurred in clumps with lower number of culms (Kigomo and Kamiri, 1985). The upright growth of shoots was suppressed by the dense older culms.

Five culms had developed from one seed two years after germination in Zambia (Henkel, 1927). In a plantation at Kagelu, Sudan, there were two to three mature culms per clump seven years after planting (Vidal-Hall, 1952). Seedlings generally grow on the site of mother clumps which die back after flowering (Knapp, 1973). It was reported by Henkel (1927) that seedlings grew well in the clumps where mature culms were dying after flowering in Zambia, probably because they were protected from browsing animals as Irvine (1961) noted in Ghana. Seedlings reach maximum length and diameter after 7-8 years in Congo (Kinshasa) (Fanshawe, 1972) and after 4-5 years in Ethiopia (von Breitenbach, 1961). Culms become woody in the third year after germination in Malawi and in Zambia (Adlard, 1964; Henkel, 1927).

Inflorescences can be dispersed by clinging to animals' fur due to their spiny structure (Irvine, 1961). Henkel (1927) suggested water and roaming animals assisted seed distribution. Otherwise, seeds fall and germinate by the mother clumps. Seedlings were abundant adjacent to old bamboo clumps except under the dense shade of closed forest in Malawi (Adlard, 1964).

2.2.2.2 Growth processes

New shoots appear mostly during the rainy season but some earlier (Fanshawe, 1972; Pardy, 1954). Shoots cease to grow after 2-4 months in Malawi (Anon., 1944) and after 2-3 months at Muguga in Kenya (Kigomo and Kamiri, 1985). The time when shoots cease growth in length is apparently related to when the rains stop. Lateral branches appear in the fifth week. The increment rate peaked in 3-4 weeks and declined rapidly subsequently (Kigomo and Kamiri, 1985). Anon. (1962a) reported that culms became mature in three years. In Malawi, culms described by local people as mature are brownish with many brown leaf sheaths. By the end of five year's, 53% of culms were still alive (Kigomo and Kamiri, 1985). There may be many branches on mature culms, and also second or third order branches (Inada, 2000). Rhizomes had extended 30 cm below ground three years after flowering in Malawi (Adlard, 1964).

Clumps reach maturity 5-8 years after germination and start producing harvestable mature large culms (Fanshawe, 1972). The average number of culms produced annually in a clump of *Oxytenanthera abyssinica* was 17-20% of the pre-existing number of culms in Zambia (Henkel, 1927) and 50% of this number in Ethiopia (LUSO CONSULT, 1997a). New shoots are normally produced at the perimeter of the clump. However, on termite mounds, new shoots tend to appear on the higher side (Fanshawe, 1972).

2.2.2.3 Phenology

Flowering takes place from May - September (dry season) and fruiting six months later from February to March (rainy season) in Zambia. Fruits persist on the culms for a few months before falling (Fanshawe, 1972).

Pardy (1954) indicates that *Oxytenanthera abyssinica* is deciduous or semi-deciduous in areas of shallow soils or where frost occurs in Zimbabwe. In Lilongwe Nature Sanctuary, Malawi, most leaves fall in the dry season but some persist throughout the year (direct observation, 2002). The number of dry months (less than 50 mm rainfall) in Lilongwe is seven (from April to October). Leaves fall in the late dry season (Malawi: September to October). Moisture retained in the soil may delay leaf fall. In Zambia, leaves fall in the late dry season (May-July) after turning pale yellow in March-May. New leaves appear in September-October when the rainy season starts (Fanshawe, 1972).

2.2.2.4 Flowering cycle

Oxytenanthera abyssinica is a bisexual plant, hermaphrodite florets being present in the spikelets (Watson and Dallwitz, 1992 onwards). It is assumed that flowers are pollinated by wind as they are in most other members of the Poaceae.

Williamson (1975) describes the flowering of *Oxytenanthera abyssinica* as periodic and spasmodic. Eggeling and Dale (1951) deduced the flowering cycle in Uganda to be seven years and others have followed this view. Eggeling and Dale (1951) do not, however, mention the location or the year of flowering. Istas and Raekelboom (1962) report much longer intervals, with flowering every 25-40 years (in Democratic Republic of Congo) and there are several localised records which indicate that periods of flowering occurred over large areas (Table 2.3). Fanshawe (1972) reports that the flowering interval in Malawi might be 20-21years because several reports (Anon., 1944; Anon., 1945; Anon., 1953a; Anon., 1954a; Henkel, 1927) indicated there was gregarious flowering in 1924-28 and 1944-48, but, infrequently, sporadic flowering events may occur (Innes, 1977 - Ghana) or there may be successions of flowering years (Khan, 1966 - Sudan). Flowering of *Oxytenanthera abyssinica* is apparently noted less often in West Africa (Irvine, 1961) and southern Africa (Gibbs-Russell *et al.*, 1990).

Table 2.3: Reports of gregarious flowering of *Oxytenanthera abyssinica* in Africa

Country	Period	Location	Coordinates	Reference
Malawi	1923-24	south	—	Henkel (1927)
Malawi	1924-28	unknown (a)	—	Anon. (1944)
Malawi	1924-28 and 1944-48	unknown	—	Fanshawe (1972)
Malawi	late 1920's	Cholo and Dedza District	16°04'S, 35°02'E and 14°20'S, 34°20'E	Anon. (1954a)
Malawi	1928-30	unknown	—	Adlard (1964)
Malawi	1943-47	Dowa	13°39'S, 35°56'E	Anon. (1954a)
Malawi	1944	Central Province	—	Anon. (1945)
Malawi	1944-46	unknown	—	Adlard (1964)
Malawi	1944-48	unknown (a)	—	Fanshawe (1972)
Malawi	1951	all over the country	—	Anon. (1953a)
Malawi	1960	Mua Livulezi forest	14°09'-14°16'S, 34°28'-34°30'E	Adlard (1964)
Senegal	1899	Thie's Forest	14°49'N, 16°52'W	Giffard (1974)
Senegal	1940	M'bour	14°22'N, 16°54'W	Giffard (1974)
Zambia	1935-36	north west (b)	—	Fanshawe (1972)
Zambia	1949-50	north west (b)	—	Fanshawe (1972)
Zambia	1950-51	Copperbelt	12°37'-13°12'S, 27°82'-28°64'E	Pardy (1954)
Zambia/Congo	1947-49	north Zambia/Shaba	—	Schmitz (1963)
Zimbabwe	1918-24	north	—	Henkel (1927)
Zimbabwe	1920-24	Bindura, Mazoe valley	17°20'S, 31°21'E	Anon. (1944)

Keys: (a): the same area in Malawi but location unknown; (b): the same area in the north west of Zambia but location unknown

Anon. (1953a) reports *Oxytenanthera abyssinica* flowered and died throughout Malawi in 1951. All culms and rhizomes in clumps die after flowering, according to Grondard (1964) - referring to Chad and Schmitz (1963) - referring to the Democratic Republic of Congo. However, Bekele-Tesemma *et al.* (1993 - Ethiopia) and Eggeling and Dale (1951 - Uganda) noted that culms died after flowering but rhizomes remained alive, producing new shoots in the following season. In such cases, the life spans of clumps are longer than flowering cycles.

Anon. (1949) suggested flowering might be triggered by a drastic change of climate, or stimulated by a congested clump condition or by over-exploitation. Vidal-Hall (1952) also associated *Oxytenanthera abyssinica* flowering with clump congestion in Sudan.

Henkel (1927) reports that seedlings in Zimbabwe were germinating in the ash resulting from culm destruction by fire in the previous winter (May to August). From these comments, it was inferred by Fanshawe (1972) that disturbances to growth, such a fire or over-exploitation, stimulated flowering.

2.3 Distribution and ecology

Oxytenanthera abyssinica occurs in 28 tropical African countries (Appendix II), outside the humid forest zone, from Senegal to Ethiopia and Eritrea, and south to Angola and Mozambique. It is also reported from the Northern Province of South Africa (Gibbs Russell *et al.*, 1990) although with reservations, as confirmatory flowering material is still awaited. It has been introduced to Maryland, USA (specimen records F. A. McClure Pl-279656, 2795A, 2795, K).

2.3.1 Relations with environmental factors

The species is found from sea level to 2000 m (Anon.1962a; Doat 1967; Ohrnberger, 1999). In East Africa, the highest *Oxytenanthera abyssinica* occurrences reliably reported are at 1600-1800 m and the lowest at altitudes below 500 m (Bégué, 1958; Bekele-Tesemma *et al.*, 1993; Fanshawe, 1972; Mooney, 1959; Mbuya *et al.*, 1994; Phillips, 1995). In Malawi, *Oxytenanthera abyssinica* is found from 530 m at Chikwawa, in the south, to 1460 m at Dedza (central). In Cameroon, *Oxytenanthera abyssinica* has been reported from elevations consistently less than 1300 m (Letouzey, 1969, 1985; van der Zon, 1992a). Higher ranges of occurrences are reported by Phillips (1995) in Ethiopia (1200-1800 m), and by Sommerlatte and Sommerlatte (1990) in Sudan (1200-1400 m).

Oxytenanthera abyssinica is typically associated with good drainage. It generally grows on the lower parts of wooded hillsides (Badi *et al.*, 1989; Jackson, 1956; Launert, 1971; Letouzey, 1968) both exposed to the sun (Kigomo, 1990; Schmitz, 1963) and in ravines (Ohrnberger, 1999). It is often abundant on stream banks (Doat, 1967; Fanshawe, 1972; Launert, 1971; Ohrnberger, 1999). It occurs in foothill forests under moist conditions while under drier conditions, it tends to be associated with termite mounds (Williamson, 1975 - Malawi).

In terms of soil parent materials, *Oxytenanthera abyssinica* grows on rhyolites, granite (Letouzey, 1969 - Cameroon; Wickens, 1976 - Jebel Marra, Sudan), and alluval soils (Werger and Coetzee, 1978 - Democratic Republic of Congo). Grondard (1964) reports *Oxytenanthera abyssinica* to be associated with laterite and also grey and beige soils in Chad. The fact that *Oxytenanthera abyssinica* can thrive on diverse types of soil suggests a potential invasive character (Letouzey, 1968).

Various reports indicate the general texture of the soils where *Oxytenanthera abyssinica* grows. It widely occurs on well drained sandy and/or rocky soils (FAO, 2001a; Langdale-Brown *et al.*, 1964; Letouzey, 1968; Mgeni, 1983; Sillans, 1958; Vidal-Hall, 1952; Vogt, 1995; von Breitenbach, 1963). *Oxytenanthera abyssinica* grows even in dry and superficial soils, but salty and heavy clay soils are not suitable (Anon., 1962a; Doat, 1967; FAO, 1974; Giffard, 1974). In Sudan, *Oxytenanthera abyssinica* occurs on loamy soils (Anon., 1957). The species grows well on sandy river margin soils in Lilongwe, Malawi.

In Zambia, *Oxytenanthera abyssinica* commonly grows on termite mounds which are slightly acid to neutral and rich in humus and nutrients, but more generally on sandy soils with poor nutrients status (Fanshawe, 1971, 1972). It occurs even among rocks in Karamoja, Uganda (Thomas, 1943). However, on poor dry soils, this bamboo produces weak culms (Anon., 1962a). The height, diameter and density of culms are related to fertility and depth of soils in Senegal, according to Giffard (1974).

Rainfall is a limiting environmental factor for *Oxytenanthera abyssinica* (Mgeni, 1983). Although Vogt (1995) mentioned that 400 mm of annual rainfall or more is suitable for *Oxytenanthera abyssinica* in Sudan, this is a low estimate and for productive stands mean annual rainfall at least 800 mm is necessary (Badi *et al.*, 1989 - Sudan; Schnell, 1977 - Senegal). *Oxytenanthera abyssinica*'s absence from Kenya (Kigomo and Kamiri, 1985) where most of the land area (72%) receives less than 500 mm mean annual rainfall and there are more than 7 months <50 mm mean rainfall (Griffiths, 1969), is consistent with this. Further, *Oxytenanthera abyssinica* is present in the countries bordering Kenya where mean annual rainfall is commonly more than 800 mm. Anon. (1962a) and Doat (1967) report that *Oxytenanthera abyssinica* is associated with 700-2000 mm annual rainfall and 3-7 months with <50 mm mean rainfall. In the northernmost parts of Mozambique where rainfall is of the monsoon type with 1000 mm of mean annual rainfall, many clumps of *Oxytenanthera abyssinica* occur locally

(Werger and Coetzee, 1978). Fanshawe (1972) noted *Oxytenanthera abyssinica* was frost hardy. Nevertheless, exceptional frosts in 1947 and 1968 scorched leaves at Ndola, Zambia.

2.3.2 Ecosystems

2.3.2.1 Vegetation types

White (1983) divides the continent into 20 biogeographical regions (phytochoria) according to floristic features. *Oxytenanthera abyssinica* extends to seven phytochoria but typically occurs in the vast Sudanian and Zambezian regional centres of endemism and in the western part of the Guinea-Congolia/Sudania regional transition zone. In the Somalia-Masai regional centre, it occurs in the region surrounding the Ethiopian system of the Afromontane regional centre of endemism to the north and in northern Tanzania to the south. It is widely distributed in the Zanzibar-Inhambane regional mosaic. It is rare in the Guineo-Congolian region but occurs in Sierra Leone and Ivory Coast adjoining the Guinea-Congolia/Sudania regional transition zone. It is not characteristic of the Afromontane regional centre of endemism, but is present in some places near its lower limit (Likubula, Mt Mulanje - Malawi; Upangwa, Kipenger range - Tanzania; Bulugenyi, Mt Elgon - Uganda).

In the Zambezian regional centre of endemism, *Oxytenanthera abyssinica* occurs in both wetter (mean annual rainfall >1000 mm) and drier (mean annual rainfall <1000 mm) Zambezian miombo woodland which is dominated by the species of *Brachystegia*, alone or with *Julbernardia* or *Isoberlinia*, and is generally related to vegetation change resulting from local disturbance (Werger and Coetzee, 1978). In the Sudanian regional centre of endemism, it appears in Sudanian woodland with abundant *Isoberlinia* (Burkina Faso, Central African Republic, central Nigeria, Togo) and undifferentiated Sudanian woodland (northern Nigeria, Senegal). *Oxytenanthera abyssinica* generally occurs along rivers in these woodlands.

2.3.2.2 Interactions with fauna and disturbance

Young *Oxytenanthera abyssinica* leaves are browsed by cattle when there is a shortage of grass (Fanshawe, 1972). Wild boars eat young shoots in Malawi. Up to 80% of plantations in Gezair, Sudan, failed because pigs dug out roots to eat. Also in Sudan, plantations of *Oxytenanthera abyssinica* have been reported to suffer damage from squirrels and goats (Anon., 1952, 1954b). Anon. (1946) mentioned that seeds were eaten by baboons whilst still on the culms and/or by rodents after falling to the ground. Inflorescences are adherent to the fur of mammals and carried long distances (Henkel, 1927).

In southern Africa, spontaneous or intentional fires may kill the above ground parts but rarely kill rhizomes. Plants subsequently regenerate from these rhizomes (Fanshawe, 1972). Thick-walled mature stems of *Oxytenanthera abyssinica* may resist fire (Bekele-Tesemma *et al.*, 1993), but young culms are fire sensitive and rejuvenation may eventually be prevented (Snowden, 1953), an increasing tendency as rising population pressures lead to high frequencies of burning (Werger and Coetzee, 1978). When culms have been harvested, increased fuel loads may be created by branch debris left on site, intensifying the risk of a later damaging fire. Fire is claimed, however, to also have a positive effect by stimulating flowering (Henkel, 1927) and bamboo thickets dominated by *Oxytenanthera abyssinica* may be one form of secondary vegetation replacing miombo forest destroyed by fire (World Conservation Monitoring Centre, 2001).

2.4 Silviculture

The need for silvicultural knowledge of *Oxytenanthera abyssinica* is underlined by the high value accorded by the communities who use it (2.5) and its quantitative importance, especially in eastern Africa. The extent of bamboo forest in eastern Africa is 1.5 million ha (Jiping, 1987; Kigomo, 1988), of which 86% is found in Ethiopia. Of the two bamboo species accounting for this 86%, the major part is attributed to *Oxytenanthera abyssinica* (700,000-850,000 ha), with *Yushania alpina* contributing 130,000 ha (LUSO CONSULT, 1997a). Within Ethiopia, *Oxytenanthera abyssinica* covers 544,000 ha in western Wollega and 130,000 ha in western Gojjam (Persson, 1975). In Tanzania, bamboo forest is less extensive, but still covers 128,000 ha, of which *Oxytenanthera abyssinica* accounts for 44,450 ha (Chihongo, *et al.* 2000). Further south in Africa, *Pterocarpus* - *Oxytenanthera abyssinica* woodland covers 15-20% of the steep escarpments by the rift valley, Malawi (Persson, 1975), *Oxytenanthera abyssinica* accounting for 10,000 ha, (2.8% of the total national forest cover - Crafter *et al.*, 1997).

Persson's (1975) estimate of the area of *Oxytenanthera abyssinica* communities in Senegal is 20,000 ha. Probably these estimations refer to the areas of plant communities where *Oxytenanthera abyssinica* is one of the prominent woody species.

2.4.1 Nursery technology

Cuttings

The most systematic study reported of the propagation of *Oxytenanthera abyssinica* was carried out by Khan (1966) who compared 1-3 noded cuttings from different culm regions (lower 1/3, middle 1/3 and upper 1/3) as planting material in Sudan. A small percentage (28.6%) of two-noded cuttings from the lower one-third of culms planted in the mixture of silt and sand survived for 92 days after planting but none survived beyond 252 days in Sudan. Khan (1966) observed that new rhizomes were produced from the thickened base of an existing branch. It was noted that there should be a node of the cutting above the ground, because it is from this point that new branches and the leaves essential for photosynthetic activity from an early stage will arise. Khan (1966) acknowledged that his own experiments were generally unsuccessful but gives several suggestions of way to improve propagation:

- an adequate branch base to be retained at each node for further development of rhizomes and culms
- placing cuttings vertically in the soil with at least one node above ground
- irrigation during the non-rainy season (in the dry season of his study, irrigation water was not sufficiently available imposing a serious drawback for tending activities)
- providing light shade over the propagation beds.

In what is now the Democratic Republic of Congo, Abeels (1961) also tried vegetative propagation of *Oxytenanthera abyssinica* using culm cuttings, planted in four types of bed (soil, stagnant water over sand in tubs, floating beds and the sandy bed of a stream) but no success was achieved with any. Young leaves were produced five to six weeks after propagation in floating beds, but no roots and gradually the cuttings died. The cuttings used by Abeels were of three culm nodes and the ends were protected by plastic bags to reduce loss of water. With the other types of bed, neither leaves nor roots were produced. Kigomo and Kamiri (1987) also conducted culm cuttings in Kenya, but none of them survived beyond five months. According to Fanshawe (1972) *Oxytenanthera abyssinica* can be regenerated by culm cuttings but it is not reported how long it takes the sections to root.

Rhizome planting

Eggeling and Dale, (1951), Kigomo and Kamiri (1987) and von Breitenbach (1961) recommend rhizome planting for *Oxytenanthera abyssinica* propagation. In Malawi, propagation by rhizome planting was practised for *Oxytenanthera abyssinica* (Anon., 1944; Inada, 2000). In rhizome planting, a unit of a 45 cm long basal length of shoot or culm, with 30 cm of rhizomes attached, is detached from a clump, and all twigs and leaves except a few are removed. These units (culm + rhizome) are planted in their new locations at once, the soil around the rhizomes being firmly tamped (Anon., 1954a). Better results were obtained with rhizome connected to old culms than with rhizomes connected to young culms. In Tanzania, rhizome planting uses detached two years old rhizomes with culms at their necks (Mgeni, 1983). The author interviewed farmers in southern Malawi. Although one of those interviewed mentioned that he planted young shoots with rhizomes (Inada, 2000), young shoots generally seem not particularly suitable for this method, because they have higher nutrient and water contents (Tamolang *et al.*, 1980) making them vulnerable to insect attack. In seasonal terms, the best results are obtained when buds on culms are nearly bursting (Anon., 1944). The season recommended for rhizome planting by the Forestry Department, Malawi, is from December to January, when the soil is moist (Anon., 1954a). Anon. (1944), however, indicated that planting from January onwards failed and recommended planting a week before the rainy season was expected. Rhizome planting was conducted within the first month of the rainy season in Tanzania and planted culms produced new rhizomes in the second year (Mgeni, 1983).

Sandy soils are considered a suitable substrate for rhizome planting, leading Anon. (1954a) to recommend soils on riverbanks and termite mounds as appropriate places. Suitable sites for rhizome planting of *Oxytenanthera abyssinica* are beside old bamboo clumps, on old termite mounds, alongside rivers and on soils rich in organic matter overlying decomposing rocks (Anon., 1944).

Seeds

Seeds are larger than those of most grasses. The weight per 1000 seeds was recorded as 72 g in Sudan (Anon., 1959b). Seedlings for extensive plantations of *Oxytenanthera abyssinica* were raised in Sudan in the 1950's and 1960's (Anon., 1952-1966; FAO, 1974).

Seed propagation is more successful than propagation by culm cuttings for *Oxytenanthera abyssinica* (FAO, 1974; Kigomo and Kamiri, 1987). Anon. (1954a) recommends storing seeds for some months before sowing but without details of the method. Cumulative emergence of seeds was 80% for lay flat orientation, 60% for embryo-end up and 65% for embryo-end down after being stored in a cold store for six months (Embaye, 2003). The warm season when, in tropical climates, water is more available, is suitable for seed planting (November in Malawi). It takes about 11 days for seeds to germinate when sown in November in Malawi. Seeds should be covered lightly in ordinary nursery beds, being watered and shaded until they are growing vigorously (Anon., 1954a).

There is significant variation in the germination rate of *Oxytenanthera abyssinica* seeds, depending on location and season (Fanshawe, 1972; Table 2.4). According to Anon. (1957), in Sudan, seeds from the southern Fung gave a much higher germination rate than seeds from Kordofan.

Table 2.4: Germination period of *Oxytenanthera abyssinica* seeds

Country	Stands	Season	Period	Germination rate
Malawi	open	rain	11 days	5-30%
Lunkwakwa, Zambia	open	rain	4 weeks	no information
Congo	open	rain	2 months	no information
Ichimpi, Zambia	open	cold dry	3-4 months	no information
Muguga, Kenya	open	no info.	2 months	70%
Sweden (source from Metekel, Ethiopia)	greenhouse	11-24℃	62 days	60-80%

Source: Embaye (2003), Fanshawe (1972), Kigomo and Kamiri (1987)

Transplantation from the seed beds can be done between the ages of eight months and one year, when the bamboo reaches one metre in height (Anon., 1962a). Peak rainfall and drought seasons should be avoided when transplanting, because of the risks of flood and drought damage (Anon., 1955b, 1959b).

2.4.2 Plantation technology

Extensive plantations of *Oxytenanthera abyssinica* were established in Sudan from 1952-1966 (Appendix III). In 1958, *Eucalyptus umbellata* Domin was interplanted with *Oxytenanthera abyssinica* at 6 m × 6 m spacing. More than 50% of the *Eucalyptus* were, however, killed by termites (Anon., 1958). *Cordia africana* Lam., *Eucalyptus microtheca* F. Muell. and *Khaya senegalensis* A. Juss. were often planted together with *Oxytenanthera abyssinica* in Sudan but the spacing of the plantations was not reported. These species are also associated with medium to low altitudes and mean annual rainfall (*Cordia africana* - 550-2600 m, 700-2000 mm; *Eucalyptus microtheca* 80-700 m, 200-1200 mm; *Khaya senegalensis* 0-1800 m, 400-1750 mm) and generally occur in moister areas along rivers (Duke, 1983; World Agroforestry Centre, 2004).

Little comment has been published about the attention that should be given to planted stands to maintain vigour and health. However, heavy shade over *Oxytenanthera abyssinica* clumps should be avoided: *Oxytenanthera abyssinica* can be suppressed by the shade of associated neem trees (*Azadirachta indica* A. Juss.). When neem trees were removed to admit more light to the *Oxytenanthera abyssinica*, this produced vigorous shoots (Anon., 1956).

Considerably more comment on harvesting has been published. Regular selective harvesting is necessary because clumps of *Oxytenanthera abyssinica* expand fast (Bein *et al.* 1996; Bekele-Tesemma *et al.*, 1993; Katende *et al.* 1995; Mbuya *et al.* 1994). Masamba and Bwanali (2000) recommend rotational cutting, weeding, and removal of dead bamboos to be carried out for the better growth of the young bamboo culms. Before rotational harvesting of culms is applied in the dense conditions of previously unexploited mature clumps, Anon. (1957) recommends clearing one quadrant of both young and mature culms each year. After four years of such treatment extending progressively round the clumps, these are expected to be in a condition that will allow convenient harvesting of mature culms of satisfactory quality anywhere within them.

Mooney (1959) also recommends a four year cutting cycle but for long term management, not simply to bring a clump to a good productive condition. Mooney's approach removes one quarter to one third of the culms in each clump (harvesting intensity 25-33% of culms >2 seasons old every year) but keeps at least six culms of more than two seasons growth evenly through the clump (Table 2.5) and he specifies that no young culms of less than two seasons growth should be felled. With Mooney's approach there should be no culms that become more than four years old. Anon. (1962a) also suggested selective cutting on a four years rotation, harvesting 25% of mature culms in each clump every year, but implies that young culms should not be felled.

Table 2.5: Felling intensity for *Oxytenanthera abyssinica* recommended by various references

	Congo	Ethiopia	unknown place
Intensity	25% of mature culms	25-33% of mature (>2 years) culms	50% of culms (no age mentioned)
Cycle	every year	every year	every year
References	Anon. (1962a)	Mooney (1959)	Fanshawe (1972)

There was no marked effect on annual production (14-28 t/ha/year) over five year monitoring of planted clumps subject to a thinning intensity of 50-70% of culms (probably >one year old)/clump being felled every year at Muguga, Kenya (Kigomo and Kamiri, 1985). New culm production per clump was reported, but Kigomo and Kamiri did recommend basing (harvesting measures) relative numbers of existing and recruited culms.

In formalising what should be harvested, Fanshawe (1972) emphasised leaving culms older than two years throughout the clump, but especially at its periphery, to promote production of young shoots. Culms become over-mature after six years (Doat, 1967). Such old culms should be removed whenever found according to Doat, and should be excluded from counts when harvesting intensity is being determined.

2.4.3 Reports of stand density and production

Stand density of culms/ha varies from 4000-30000. Culm density depends on whether the assessed community is a pure bamboo stand or a mixed forest containing bamboo. LUSO CONSULT (1997a) and Inada *et al.* (2003) drew up estimates for mixed forests. Mooney (1959) and von Breitenbach (1961) estimated 25000-30000 culms/ha were present in western Ethiopia and concluded that the *Oxytenanthera abyssinica* stands were a resource sufficient for 10000 t (Mooney, 1959) to 40000 t (von Breitenbach, 1961) paper production per annum. LUSO CONSULT (1997a) estimated a lower density of culms - 8100 culms/ha, of which 4100 culms are >1 year old and 4000 culms are ≤1 year old. This high figure for young culms <1 year might reflect fire impacts (LUSO CONSULT, 1997a). Young culms ≤1 year old (4000 culms/ha) become the annual production of culms. An estimate of the density of *Oxytenanthera abyssinica* in Lilongwe, Malawi, is 4000 culms/ha (Inada *et al.*, 2003).

Anon. (1959a) evaluated the weight of culms growing on a site in the Democratic Republic of Congo, which had not been harvested for 35 months. On this site, 875 culms were harvested from 37 clumps (mean value 24 culms/clump) and their total fresh weight was 1929 kg. The average diameter was 3.04 cm and the height 6.36 m. Twigs and leaves constituted 82.5% of fresh culm weight, 1591 kg. Kigomo and Kamiri (1985) report mean loss in weight of green culms on drying over three months was 48 ± 4% (48% moisture content). There is a linear relationship between air dry weight and the volume surrogate D^2L if both are expressed as $\log_{10}$ values (Inada *et al.*, 2003):

$$\log_{10} w = 0.868 \log_{10} D^2 L - 1.12$$

where:
w = air dry weight (kg) of culm; D = diameter at breast height (cm); L = culm length (m).

Potential annual production (air dried culms) ranges widely - from as little as 0.35 t/ha in eastern Senegal (Giffard, 1974) to 30 t/ha in Sudan (Khan, 1966). A major contributing factor is that for Sudan and Kenya estimates refer to plantations, while the others refer to natural stands. Fanshawe (1972) reported 12.4 dry tons/ha were produced at Muguga plantation in Kenya and this production was maintained for six years by removing 60-70% of the old culms each year. LUSO CONSULT (1997a) estimated an annual production of 10.1 oven dry tons/ha/year of *Oxytenanthera abyssinica* culms in Ethiopian natural bamboo stands. It is the former for woodland products that are of interest as indications of possible commercial potential. In Democratic Republic of Congo, eight tons of dry material per ha (4.4 ton of cellulose) were produced every four years (Anon., 1955a) and in Ethiopia a high value of 20 tons of cellulose/ha/year production were estimated (von Breitenbach, 1961). Kigomo and Kamiri (1985) suggest that annual production depends on rainfall in a previous year. It is also apparent that soil characters affect the production. Giffard (1974) reports solid volume production of *Oxytenanthera abyssinica* calculated on two different soils: the stands on alluval soil (12.5 - 37.4 m^3/ha, 10-33 t/ha wall volume and nodal plates only; his estimation on steres was reduced to culm volume ($\times$ 0.26) and then the hollows within culms were excluded ($\times$0.8)) were far more productive than those on laterite (production 0.4-2.1 m^3/ha, 0.35-1.8 t/ha).

Conservation

Oxytenanthera abyssinica is not threatened on international level but the resource is regionally declining. *Oxytenanthera abyssinica* is not among the plants listed in any appendix of the Convention on International Trade in Endangered Species (CITES, 2004) and it is not included in the Southern Africa Red Data lists (Golding, 2002) which covers Angola, Malawi, Mozambique, Zambia and Zimbabwe. The FAO Panel of Experts on Forest Gene Resources (2001) provides up-to-date information relevant to gene resources of forest trees and reports any recommendations that they should be subject to conservation action. However, the Panel's result appears not to have included any bamboos, so far (sessions 1-13 of the Panel) so that it has not expressed or (through omission) implied a view on *Oxytenanthera abyssinica*. However, FAO's newly opened REFORGEN resource, world-wide information system on forest genetic resources, lists *Oxytenanthera abyssinica* as one of the endangered species at species level and at population level in Guinea (FAO-REFORGEN, 2004). It is relevant to note reports - some dating back over 50 years (Anon., 1944; Inada, 2000 - Malawi; Embaye, 2003 - Ethiopia; FAO, 2001b - Zimbabwe; Vogt, 1995 - Sudan) indicating that intensive harvesting in populated areas has been causing progressively greater scarcity of *Oxytenanthera abyssinica*.

Snowden (1953) drew attention to diminishing native bamboo resources in Uganda over 50 years ago. He suggests that *Oxytenanthera abyssinica* had been overexploited to the extent that near populated areas it was 'in danger of being exterminated'. Snowden associates the depletion of *Oxytenanthera abyssinica* shades by cutting with subsequent invasion of woodland species into the cleared areas, a process bringing with it a more severe fire regime which prevents *Oxytenanthera abyssinica* regeneration.

Currently, more attention is being given to *Oxytenanthera abyssinica* as a useful but hitherto neglected natural resource at national level (Boko, 2004 - Benin; Chihongo *et al.*, 2000 - Tanzania; Kelbessa *et al.*, 2000 - Ethiopia).

2.5 Resource roles

2.5.1 Quality

The chemical composition of *Oxytenanthera abyssinica* culms has been recorded: moisture 9%, ash 4%, cellulose 60%, pentosans 12%, lignin 15% (Khristova *et al.*, 1982). Khristova *et al.* (1982) concluded from the composition that the species could be used for paper production. Further, the fibres of *Oxytenanthera abyssinica* were significantly longer (1.98 mm) and wider (14.6 μ), and contained more cellulose, than those of about 60 monocotyledons examined (Nelson *et al.*, 1966). Nelson *et al.* (1966) also considered *Oxytenanthera abyssinica* a suitable raw material for paper.

2.5.2 Application

Diverse resource roles of *Oxytenanthera abyssinica* are summarised in Appendix IV. The broad product uses meriting comment are for structural and artificial use, for beverages and famine food and for medication. There are also miscellaneous uses. The woody culms are valued as building material for houses and granaries. House walls are built of a framework of the culms with mortar and cement (Giffard, 1974). Fences can be made of *Oxytenanthera abyssinica* but are susceptible to termite and borer degradation (Bein *et al.*, 1996; Bekele *et al.*, 1993; FAO, 2001a; Katende *et al.*, 1995; Mbuya *et al.*, 1994; Snowden, 1945). Even dried culms are damaged by borers (Masamba and Bwanali, 2000). After flowering, termites attack dead rhizomes first, then dead fallen culms (Irvine, 1961). The stems of *Oxytenanthera abyssinica* can also be split, for making baskets and panniers. Arrow shafts and fish traps are made from the culms (Burkill, 1994; Inada, 2000, 2001a, 2001b; Irvine, 1961; LUSO CONSULT, 1997a; Williamson, 1975), and walking sticks from culms with a piece of the basal rhizome (Burkill, 1994). Musical instruments (flutes) are made from the culms. Furniture is made by scorching and bending culms in Malawi.

Oxytenanthera abyssinica culms are used as fuel wood in Ethiopia and in Malawi (LUSO CONSULT, 1997a; Masamba and Bwanali, 2000). In Jebel Marra, Sudan, charcoal is made from the culms (Burkill, 1994), although, to make charcoal, the culms apparently need to be boiled (Irvine, 1961).

In the south of Tanzania, the top part of the young shoot is cut to allow collection of sap in the rainy season to make bamboo beer, an alcoholic beverage (Mgeni, 1983). One culm produces 40 litres of sap monthly (Takara Shuzo, 2001). Bamboo beer used to be commercially brewed in Iringa region, southern Tanzania, but this activity has been abandoned. The author found bamboo juice locally made from the sap of *Oxytenanthera abyssinica* in Songwe, northern Malawi, bordering on Tanzania, at the end of March 2002. Perhaps it is significant that this area receives highest mean annual rainfall in Malawi >1800 mm at 80% probability (National Atlas of Malawi, 1983). Young shoots are eaten in Uganda in time of famine (Burkill, 1994), while in Malawi the seed is eaten in time of famine (Williamson, 1975). The leaves are browsed by livestock and monkeys (Burkill, 1994). Monkeys and wild boars eat the pith of new shoots in Malawi.

In Ghana, leaves are used on house walls to keep away lice (Irvine, 1961). In Burkina Faso, the rhizomes are used in treatment for dysentery. A leaf decoction treats urinary problems, including lack of urine flow as well as too much urine (Burkill, 1994). *Oxytenanthera abyssinica* provides ornamental uses (Gibbs Russell *et al.*, 1990). For its rapid growth, *Oxytenanthera abyssinica* is used for soil erosion control in Tanzania (Mbuya *et al.*, 1994) and shelter-belts for crops and windbreaks are among uses in agroforestry in Sudan (Bayoumi, 1977; Vogt, 1995).

Chapter 3

The distribution of *Oxytenanthera abyssinica*: map generation and interpretation

In this chapter, suitable ecological conditions for *Oxytenanthera abyssinica* were explored, using an IDRISI (GIS facility), and complemented with information from the state-of-knowledge review. The chapter is in three major parts: background to the GIS approach (3.1), assembly and handling of data sets (3.2, 3.3, 3.4), and results and discussion (3.5).

3.1 Background: GIS approach in distribution mapping

For successful afforestation efforts, it is desirable to have information defining suitable environmental conditions for the species to be planted. The computer programmes of Geographical Information System (GIS) packages assist preliminary exploration of the match between the plant requirements and prevailing environments (Booth, 1998). This is a convenient and effective method to bring plant locations into an environmental perspective. In this context, GIS programmes have previously been used to combine continental scale distributions of native species in Africa and mapped environmental factors (Hall *et al.*, 2000; Hall *et al.*, 2002). Also, GIS was used to determine where, in Africa, the environmental conditions were suitable for the planting of Australian trees (Booth, 1998 - *Eucalyptus camaldulensis* Dehnh.; Booth and Jovanovic, 1988 - *Acacia mearnsii* De Wild.).

In the present study, where *Oxytenanthera abyssinica* is of interest, conditions of collection localities are considered suitable for the species. Data files existing in GIS-IDRISI contain information of climate that can be accessed for specified coordinate positions in Africa. *Oxytenanthera abyssinica* localities were overlaid on maps of climate and ecological conditions to indicate suitable growing conditions. Other areas with similar conditions but outside the present range could then be identified and localised as potential areas for the species - or where populations may yet become known.

3.2 Data sets

There are essentially three kinds of data being brought together:

- coordinate data for recorded locations of *Oxytenanthera abyssinica.*
- thematic interpolated pixel maps of environmental information for Africa in its entirety, accessed as files included in the GIS-IDRISI programmes.
- locality-related temperature data.

With the ultimate aim of mapping the distribution of the species, collection localities were noted in floras and ecological literature and from voucher specimens held in the herbaria at the Royal Botanic Gardens, Kew, and the National History Museum, London. There were 257 records assembled, of which 192 could be localised (in 22 countries) and used for mapping. A sequence of steps was followed to achieve this:

Initially, a range of African floristic documents was consulted and this enabled a listing of countries where the species occurs to be drawn up. For each country listed, reference was then made to White's (1983) geographic bibliography, which was used to identify key ecological papers. A check on the availability of the papers/books cited by White was made and those accessible were consulted for information on localities for the species. Interlibrary loans were used for documents thought to be especially important but not immediately to hand. Fortunately, because of the dominance of the accepted name in the literature, no complications from synonymy arose as literature information was extracted. Reported localities were listed, with coordinates if given, and note was taken of the references cited, so that further literature of reference was identified which could be obtained and consulted in efforts to further extend the list of localities for the species. Maps and gazetteers (Global Gazetteer, 2003), or equivalent sources (such as lists of where plant collectors worked), were then used to find geographic coordinates applicable to named localities. Coordinates acceptable for GIS were prepared (3.3.1.1).

Four environment data sets incorporated in the GIS-IDRISI programme were used to generate thematic environmental background maps on which *Oxytenanthera abyssinica* distribution could be superimposed:

- mean annual rainfall

- mean monthly rainfall - this was modified to be represented as the number of months with mean rainfall <50 mm
- elevation
- soil unit according to the FAO-UNESCO World Soil Map.

Original rainfall data for Africa were developed by Legates and Willmott (1992) who used the mean values for a certain period (mostly 1920-1980) at over 26000 meteorological stations worldwide. With mean monthly rainfall data, rainfall regimes can be characterised as the number of dry month <50 mm, using IDRISI to reclassify and overlay commands (see Subsection 3.3). Soil data in FAO-UNESCO (1977) separate the African continent into 22 major soil groups. These soil groups were simplified to two groups: suitable and unsuitable for each species, using the reclassify command of IDRISI.

Each pixel in an image file covers approximately 85 km^2 on the equator (5 minutes of latitude by 5 minutes of latitude). The area covered by each pixel varies with distance from the equator, since the length of 5 minutes of longitude is different at various latitudes. The covered area by a pixel becomes smaller than 85 km^2 as latitude increases. Because of the coarse resolution of the data, local variations are obscured, but broad areas are defined as suitable or not suitable.

FAO (1984) presents the mean values of various agroclimatological parameters for each African country in the form of monthly and yearly tables. About one thousand African meteorological stations are included in all. Meteorological stations less than 50 km away from *Oxytenanthera abyssinica* localities were considered representative for the localities. From climate data in FAO (1984), following parameters were extracted:

- Mean annual temperatures (℃) per annum: mean daily temperature for the period (usually 30 years), expressed in degrees Celsius and tenths
- Highest monthly mean of the daily maximum temperature
- Lowest monthly mean of the daily minimum temperature

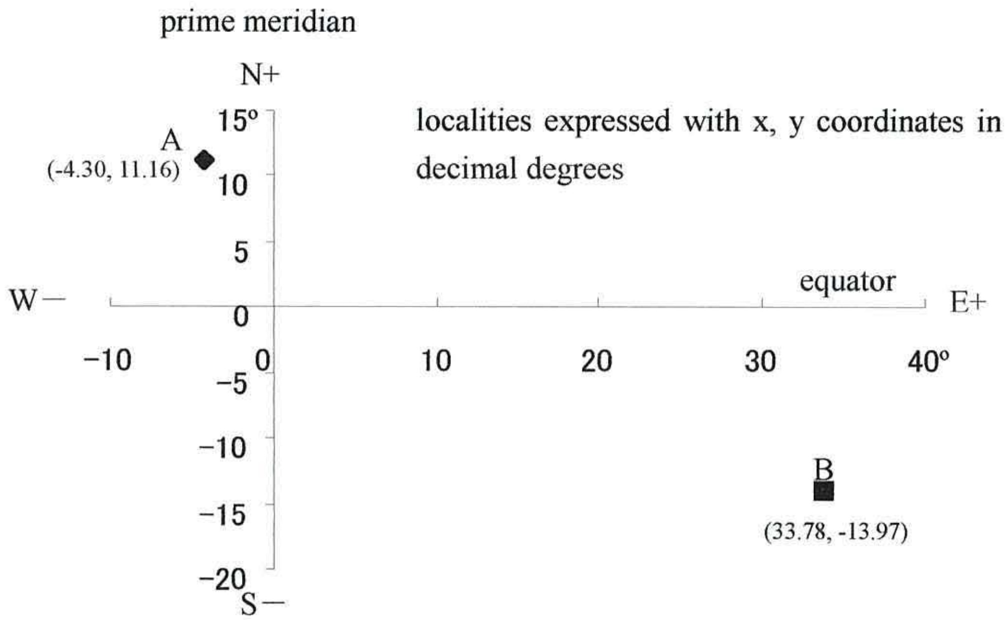
Temperatures at the stations especially in mountainous areas were adjusted for localities of species at ± 0.6℃ per 100 m in altitude, if the elevation difference between the meteorological station and the species location exceeded 200 m.

3.3 Integrating *Oxytenanthera abyssinica* occurrences and environmental data through IDRISI

3.3.1 Continental scale

3.3.1.1 Localities

Localities are expressed as numerically (coordinate)-defined elements in IDRISI vector files (Appendix V). Coordinates of assembled localities were converted to decimal degrees using Excel (Figure 3.1). Northern and eastern coordinates were expressed as positive values while southern and western coordinates were expressed as negative values. Vector files were made as described hereafter:



A = (Bobo-Dioulasso, Burkina Faso, 11°10'N, 4°18'W) = (-4.30, 11.16)

B = (Lilongwe, Malawi, 13°57'S, 33° 47'E) = (33.78, -13.97)

because (Degree + (Min/60) + (Secs/3600)), (Degree + (Min/60) + (Secs/3600)) = (x, y)

where: x = longitude, y = latitude.

Figure 3.1 : Style of localities in IDRISI vector files

To start line with coordinates in an Excel file, two single values (1, 1) are added, to indicate the coordinate with ID (1) and to represent a single point. The Excel sheet is copied and pasted in a text file with RTF format and then saved as MS-DOS text with Layout. The text has a single value in each line.

Using the MS prompt program in Windows and/or the edit module in IDRISI, figures of the file are to be corrected when necessary. Using Explore, the name of this file is converted from text (.text) to vector (.vec) for IDRISI (Figure 3.2).

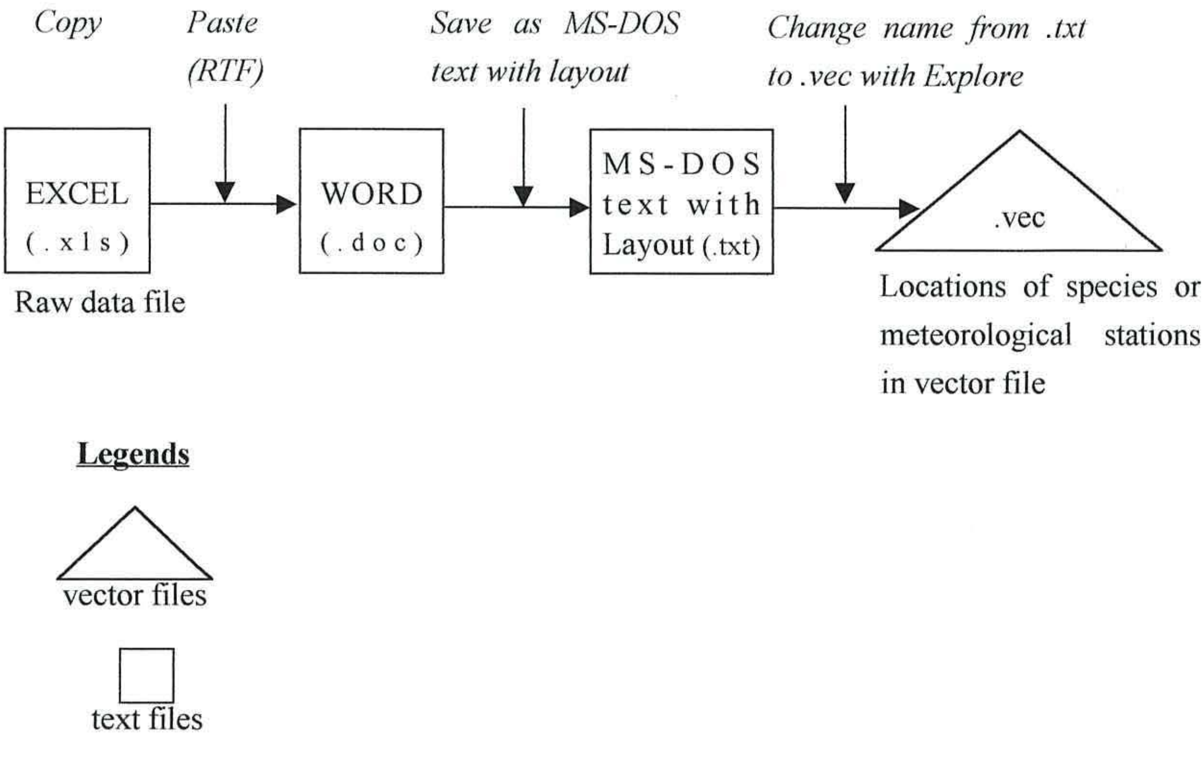


Figure 3.2: Flow diagram to locate species or meteorological stations for IDRISI maps using Word 98 and Excel 97

3.3.1.2 Producing images of environmental conditions

Four factors were explored to cover the localities of *Oxytenanthera abyssinica*, using IDRISI as indicated under the subheadings which follow. For each parameter considered the closest co-incidence of the specified conditions with the swarm of mapped points of occurrence was taken as an approximation to suitable conditions.

Dry months

Monthly rainfall 50 mm was determined as the line of demarcation between wet and dry months since past study suggests this value is reasonable in the lowland tropics and other thresholds show broadly the same patterns (Griffiths, 1969).

There are 12 image files which show amounts of monthly rainfall for Africa respectively. In a dry month, there is less than 50 mm rainfall. Monthly images of rainfall were reclassed with the value of <50 mm = 1 and >50 mm = 0 to make new images of dry months. For instance, rainfall in January (JANPREC) was reclassed and the new file was called JANPRECR. Subsequently, 12 reclassed images were overlaid to make a file of the dry month periods (DRYMOTH <50 mm monthly rainfall), using an additional overlay of the EDIT module. DRYMOTH was reclassed to make a new file (DRYMOT) of suitable periods of dry months for a species. The number of dry months was explored and determined.

The reclassifying and overlaying processes can be carried out with a macro file (Appendix VI).

Annual rainfall, elevation and soils

Files of annual rainfall, elevation and soils for the African continent were already retrievable from IDRISI. Each was reclassed to make suitable background images for the species. Localities were overlaid on each background image.

The range of conditions associated with localities was explored with reclassed visual maps. Reclassed files are called ANNPRECT, DEM2, and SOIL2 respectively (Figure 3.3).

Data tabulation for the number of localities in specified environmental conditions

Visualised image maps of environmental conditions combined with vector files of localities were used to find suitable conditions for a species. Climate conditions mentioned in the literature were always referred.

Also, statistical analysis was carried out with tabulated data:

Process 1

A different ID (identity) was given to each locality in a vector file (e.g. file: oxy2.vec).

Process 2

An existing file which has the same definition of localities in Africa (Land file.img) was initialised to a file with value = 0 using INITIAL (the file becomes: oxy2.img).

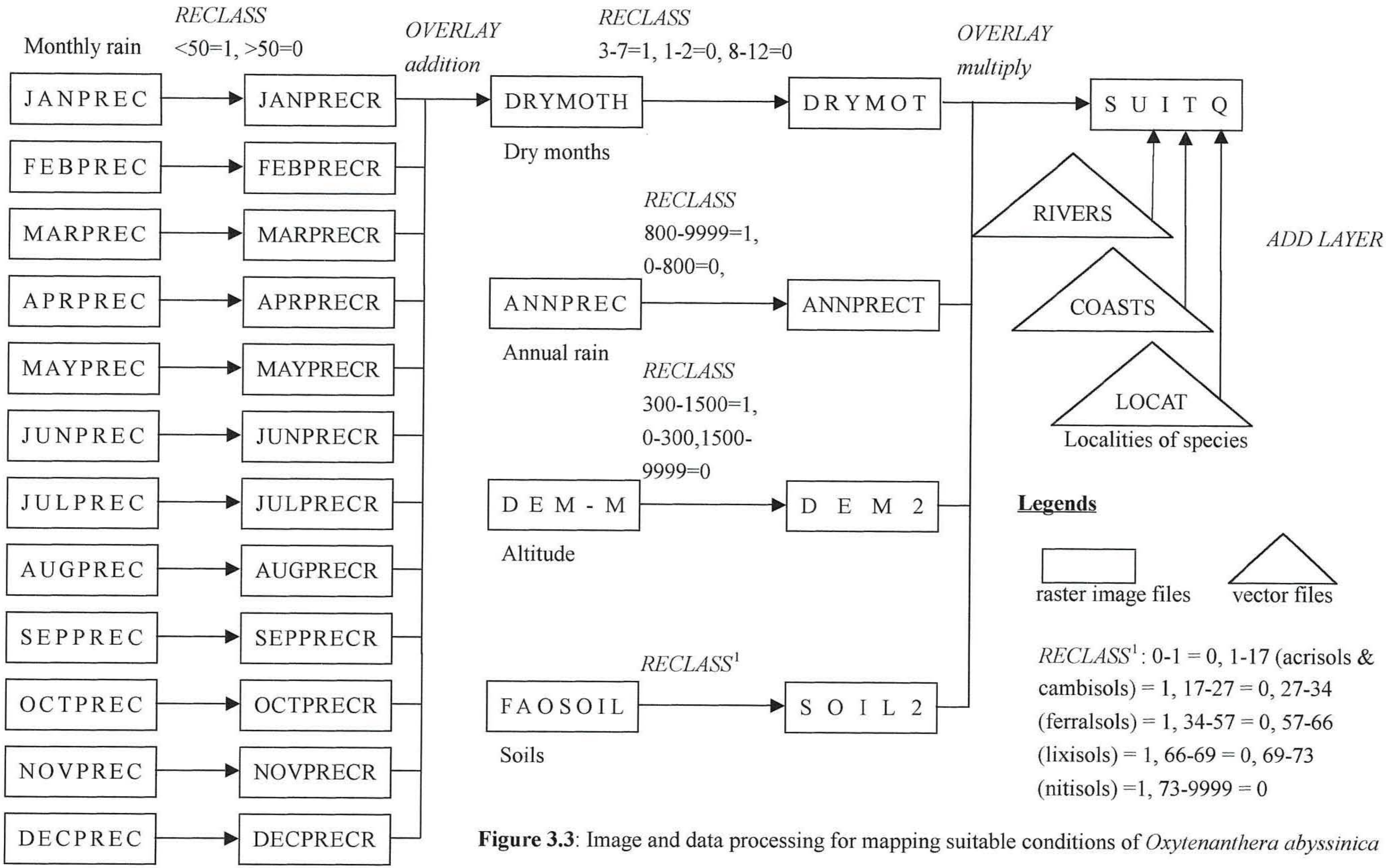


Figure 3.3: Image and data processing for mapping suitable conditions of *Oxytenanthera abyssinica*

Process 3

The vector file made in Process 1 (oxy2.vec) was converted to an image file using the image file made in Process 2 (oxy2.img) with POINTRAS in the Raster/Vector conversion. In this case, the processed image file also becomes oxy2.img.

Process 4

Points of localities were extracted from climate conditions with Tabular in EXTRACT. The climate category for each locality was observed in spreadsheets. Using the majority of climate categories, final image maps were produced with RECLASS (Figure 3.4).

Visual image maps were always examined carefully to confirm the conditions of the localities.

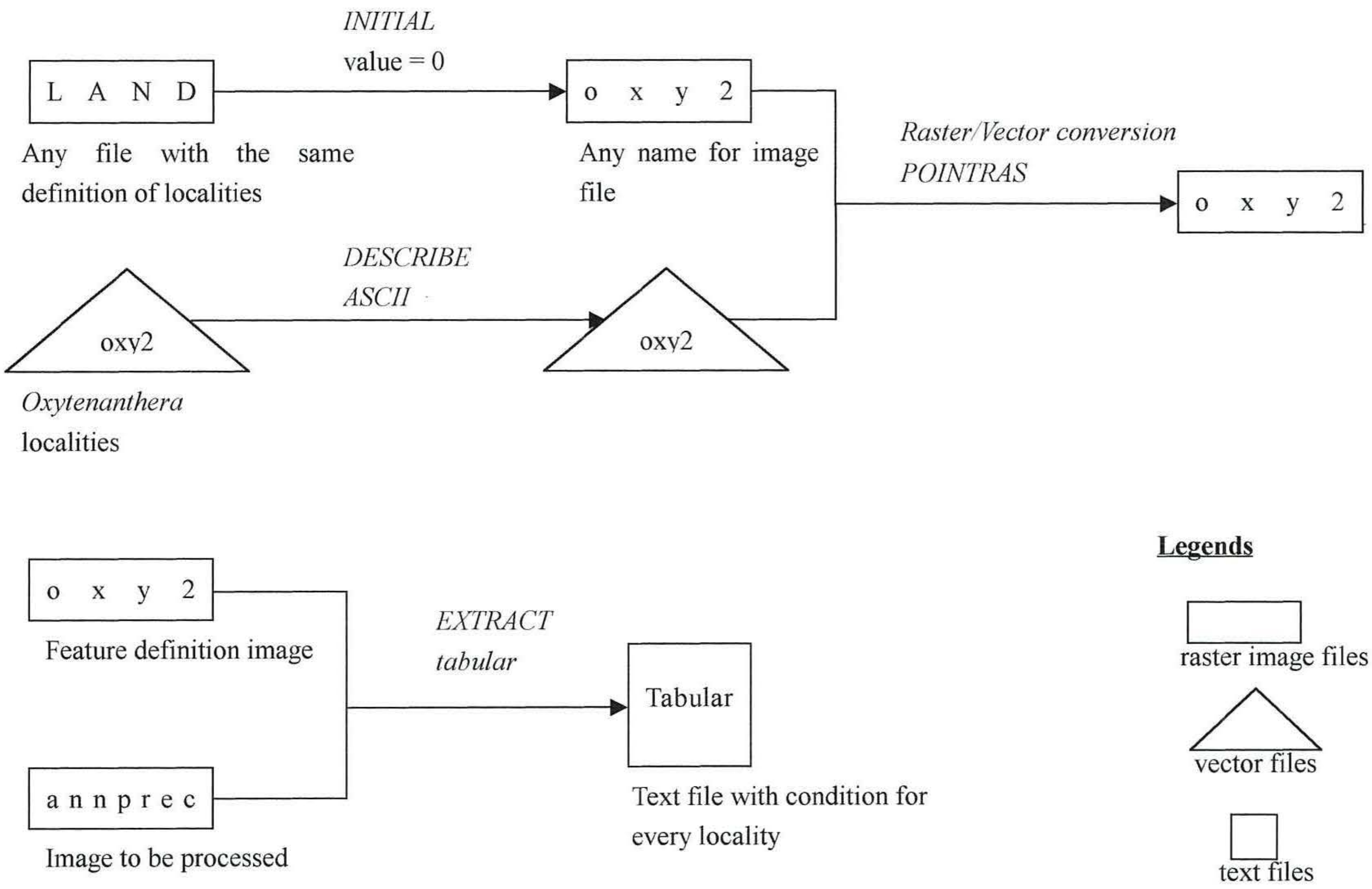


Figure 3.4: Data tabulation analysis for climatic conditions on each locality

Final image

The four factors (DRYMOT, ANNPRECT, DEM2 and SOIL2) were combined as a single overlay, using the multiplication option of the EDIT module. The final image (SUITQ) shows suitable areas (value = 1) and unsuitable areas (value = 0) based on combinations of relevant values of the factors. The process of reclassifying and overlaying can alternatively be carried with macro files (Appendix VI).

Vector files of localities of the species, the African coastline and rivers were overlaid on SUITQ, using the ADD LAYER in COMPOSER (Figure 3.3).

3.3.2 Malawi

There was a relatively large number of *Oxytenanthera abyssinica* localities (>20) specifically for Malawi, accumulated through deskwork and the field surveys. A national scale map was made by matching those localities with environmental data (elevation and rainfall) for Malawi. More detail of environmental conditions appears on this map than on the continental map, because for smaller areas much finer resolution can be obtained.

3.3.2.1 Localities

Records of occurrence of *Oxytenanthera abyssinica* in Malawi were assembled from literature, information with specimens in the Zomba Herbarium and author's direct observation in Malawi from 2001 to 2002. In total, 26 records were assembled and localised. A vector file for these localities was created and called MALOC (see Subsection 3.3.1.1).

3.3.2.2 Producing images of environmental conditions

No data of annual rainfall in Malawi were available in IDRISI format. Records of annual rainfall in over 200 meteorological stations in Malawi were, however, available as spreadsheets from FRIM and they were converted to IDRISI. Firstly, each station was characterised for the amount of annual rainfall. A vector file of these stations was converted to an image file using RASTER VECTOR CONVERSION. A THIESSEN command sectioned Malawi generating a polygon for which the value of the nearest meteorological station was representative and produced an image file (MALADM3) of annual rainfall across the country. This image file was then reclassed with values 1 for suitable (800-9999) and 0 for unsuitable (0-800).

An existing IDRISI image file of elevation in Malawi was reclassed to cover the localities.

A reclassed image file of annual rainfall was overlaid on an elevation file with multiplication option to produce a final image of environmental conditions. The final image (MALAWS) shows suitable areas (value = 1) and unsuitable areas (value = 0). A vector file of the species localities (MALOC) was overlaid on the final image with ADD LAYER in COMPOSER (Figure 3.5).

3.4 Integration with FAO temperature data

Meteorological stations less than 50 km away from localities of a species were considered as representative for the localities. About 50 meteorological stations satisfied this condition for *Oxytenanthera abyssinica* localities across the continent, including Malawi.

The following temperature variables for the meteorological stations of FAO (1984) were considered and suitable ranges for *Oxytenanthera abyssinica* were investigated (Figure 3.6):

Mean annual temperature
Highest monthly mean of the daily maximum temperature
Lowest monthly mean of the daily minimum temperature

Temperatures were adjusted on the basis of at ± 0.6℃ per 100 m in altitude if the elevation difference between the meteorological station and the species location exceeded 200 m.

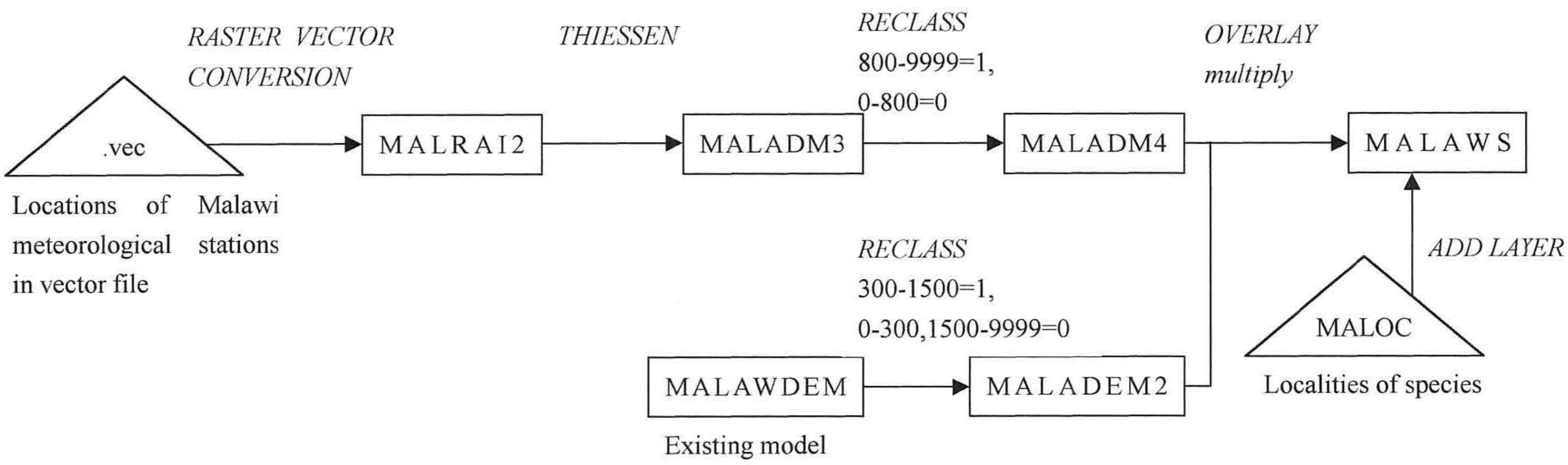


Figure 3.5: Flow diagram of IDRISI to produce climatic visual images from existing numerical information at meteorological stations in Malawi

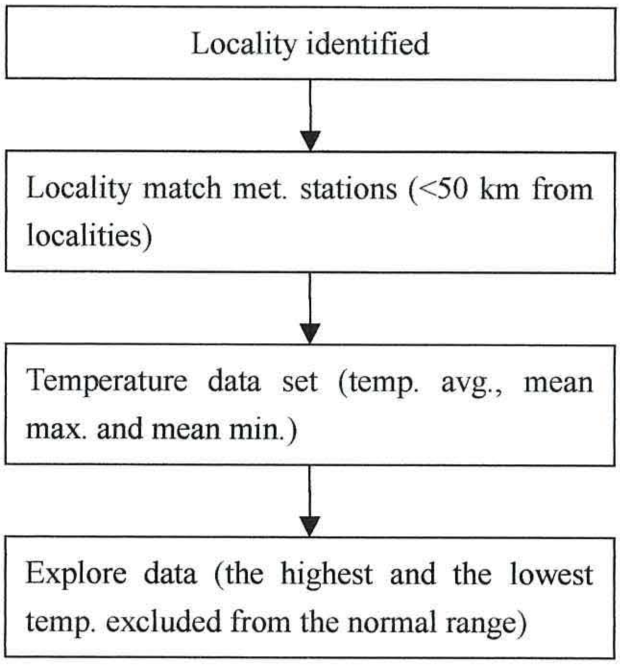


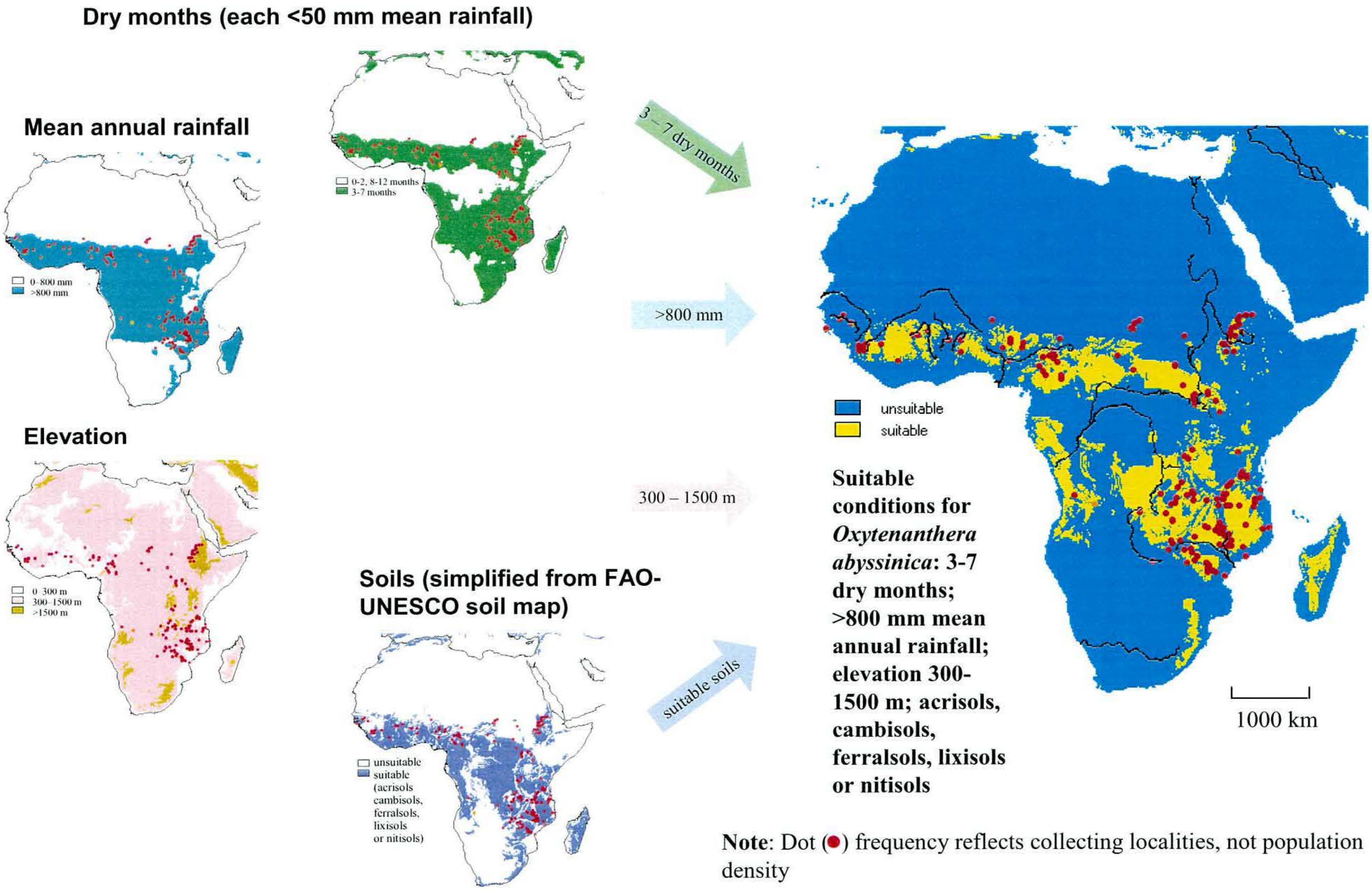
Figure 3.6: Flow diagram for finding associated temperatures

3.5 Results and discussion

Figures 3.7 and 3.8 show suitable ecological areas of *Oxytenanthera abyssinica* in Africa and in Malawi, respectively.

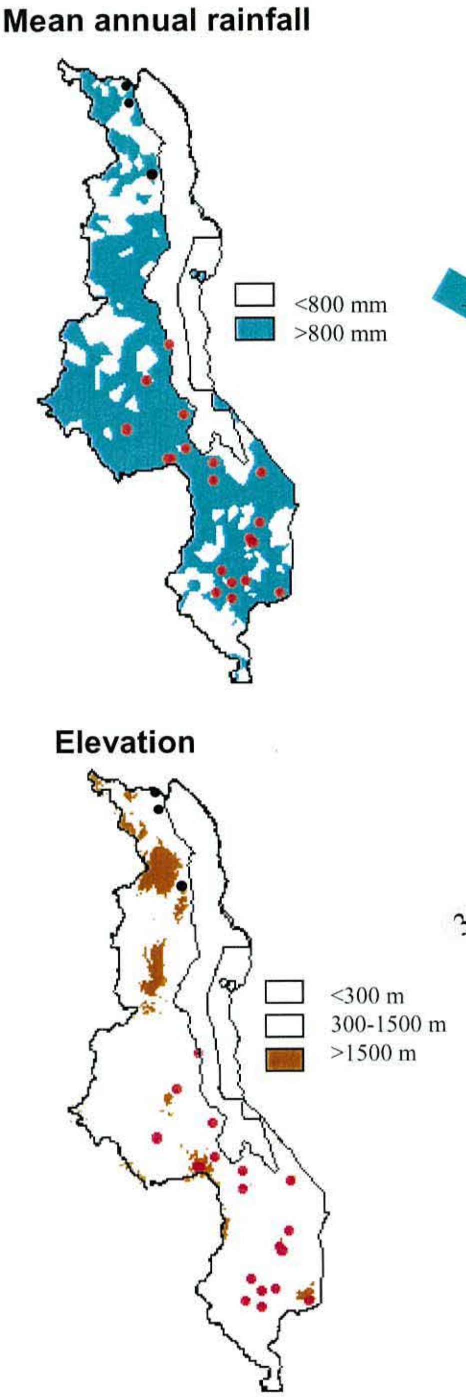
Elevation and temperature regime

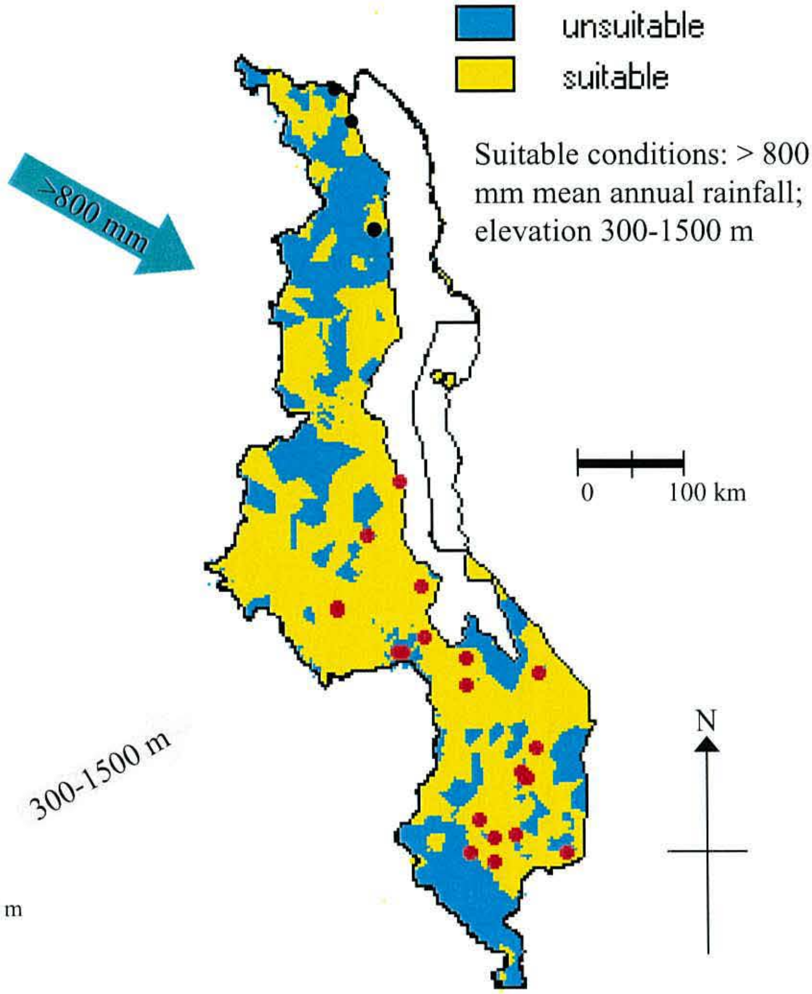
Oxytenanthera abyssinica occurs at a range of altitudes from 300 m to 1500 m on the lower parts of mountainous areas (Table 3.1), but is also present in coastal areas less than 50 m above sea level in Senegal, where the maritime climate may ameliorate what would otherwise be unfavourably high temperatures. In Tanzania and Mozambique, other low elevation occurrences are present in an area where temperatures are approximately 1-5℃ lower than would be expected for the latitude and elevation (Griffiths, 1969). LUSO CONSULT (1997a) mapped potential zones for *Oxytenanthera abyssinica* in Ethiopia, which are situated at 1000-1800 m in altitude. In Malawi, however, *Oxytenanthera abyssinica* is absent from areas above 1500 m (Figure 3.8).



Note: Dot (●) frequency reflects collecting localities, not population density

Figure 3.7: Suitable ecological areas for *Oxytenanthera abyssinica* in Africa





Note: Dot (●) frequency reflects collecting localities, not population density.
(●): writer's (Inada) personal collection.

Locality (N-S)	Rainfall (mm)[1] (772-1908)	Elevation (m)[2] (482-1460)
Karonga	1191	488
Nsawagi[3]	772	990
NkhotaKota	1500	500
Nchisi	1300	1200
Salima	1277	510
Lilongwe	837	1060
Mua	965	719
Dedza[4]	1068	1460
Nankumba	831	520
Mangochi	777	482
Zomba	1205	980
Blantyre	857	1280
Mulanje	1908	995
Chikwawa	823	530

[1]Rainfall data from meteorological stations. [2]Elevation (m) of *Oxytenanthera abyssinica* occurrences. [3]Rainfall data from the nearest meteorological station, Mzokoto. [4]Very small population in Dedza.

Figure 3.8: Suitable ecological areas for *Oxytenanthera abyssinica* in Malawi

Table 3.1: Environment conditions typically associated with *Oxytenanthera abyssinica*

Category	Range
mean annual temperature (℃)	20-27
lowest monthly mean of the daily minimum temperature (℃)	7-17
highest monthly mean of the daily maximum temperature (℃)	30-36
rain: yearly mean for a certain period (mostly 30 years) (mm)	>800
dry months <50 mm	3-7
altitude (m)	300-1500
soil fertility: categories (FAO-UNESCO, 1977, 1988)	
poor	acrisols, ferralsols
intermediate	lixisols
high	cambisols, nitisols

Oxytenanthera abyssinica is associated with a wide range of the mean annual temperature from 20-27℃, and is also associated with a wide range of the lowest monthly mean of the daily minimum temperature (7-17℃). The highest monthly mean of the daily maximum temperature associated with *Oxytenanthera abyssinica* is 30-36℃: values in West Africa (typically 34-36℃) are generally higher than in the Somalia-Masai and Zambezian regions (30-36℃).

Rainfall

Mean annual rainfall associated with *Oxytenanthera abyssinica* is usually more than 800 mm. LUSO CONSULT (1997a) determined mean annual rainfall at more than 700 mm for mapping potential growing areas of *Oxytenanthera abyssinica* in Ethiopia. While the reason for this was not specified, it may have been derived from rainfall records of *Oxytenanthera abyssinica* plantations in Sudan (mean annual rainfall 600 mm). In Asosa, Wellega region, and in central Gojam, where existing natural *Oxytenanthera abyssinica* stands were mapped in the Ethiopian study, mean annual rainfall is 1116 mm (Asosa) and 1909 mm (Chagni) respectively (FAO, 1984). As mapped at continental scale and for Malawi (Figures 3.7 and 3.8), *Oxytenanthera abyssinica* occurrences are in areas which receive mean annual rainfall more than 800 mm. *Oxytenanthera abyssinica* is, however, present in coastal areas with less than 800 mm in Senegal. Here, the humid maritime climate probably compensates for low rainfall.

Oxytenanthera abyssinica is suited to a unimodal rainfall pattern and relatively dry conditions (3-7 dry months, <50 mm). There is an anomalous presence of *Oxytenanthera abyssinica* in the Jebel Marra area in Sudan where the dry period is more than 7 months and mean annual rainfall is less than 800 mm for the indicative meteorological station (Murundo), but high elevation (more than 1000 m) and mountain topography may result in a locally wet microclimate not revealed in the station data.

Soils

Oxytenanthera abyssinica is associated with various types of soils from relatively high fertility (cambisols and nitisols) to intermediate fertility (lixisols) and poor fertility (acrisols and ferralsols) fertility. Ferralsols with poor mineral content are distributed throughout central Africa, and acrisols, generally poor in agricultural terms, occur locally in the Sudano-Zambezian zone (FAO-UNESCO, 1977). Sometimes, *Oxytenanthera abyssinica* occurs even on these poor soils.

Chapter 4

Other African bamboos - current state of knowledge

This chapter describes the phylogeny (4.1), biology (4.2), ecology (4.3), silviculture (4.4) and resource roles (4.5) of five African bamboos mainly using comparative tabular summaries with key points highlighted in supporting text. In the text, sections are subdivided as appropriate.

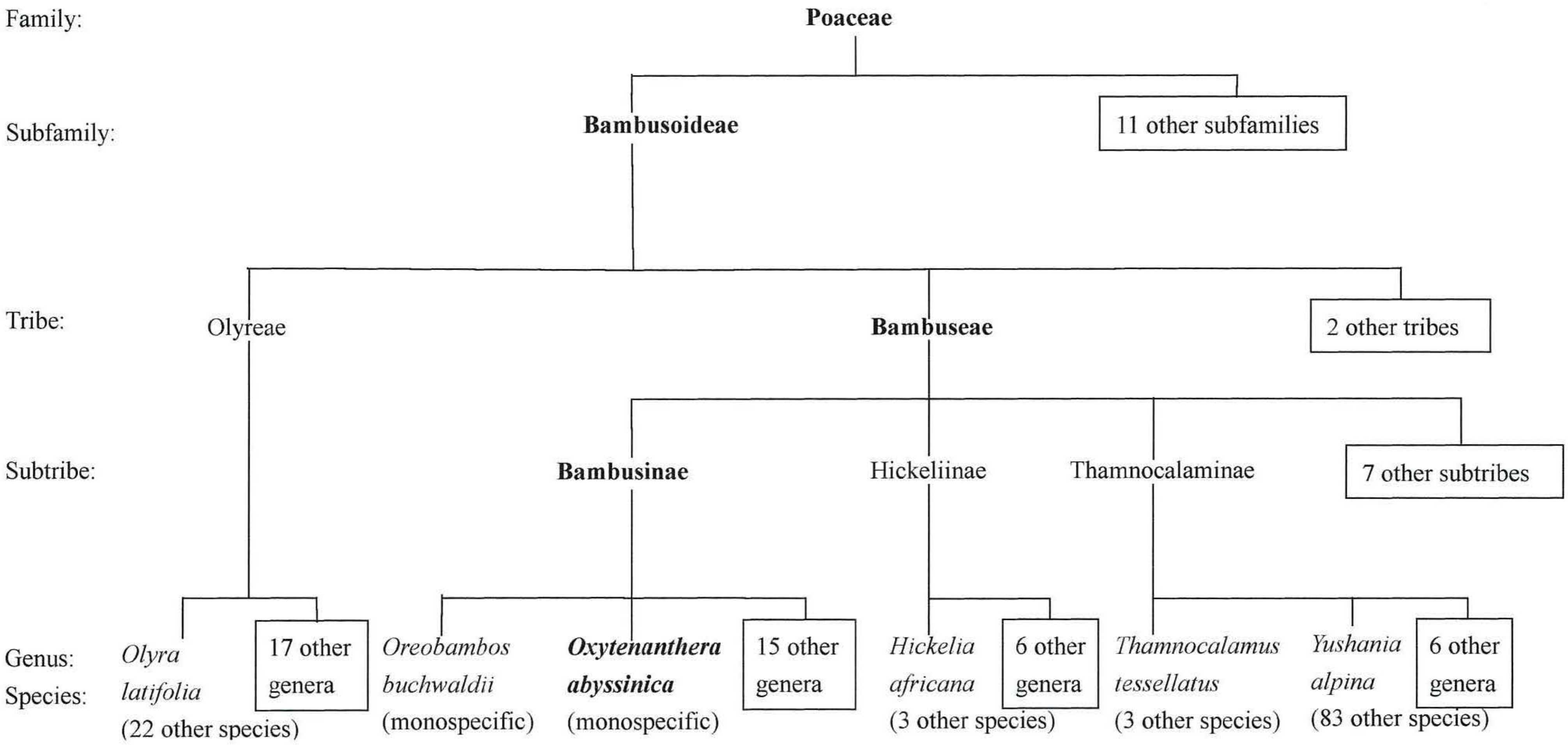
There was an opportunity to gather information on the other bamboo species during the collation of *Oxytenanthera abyssinica* data, using a comprehensive and consistent approach. There has been no previous attempt to draw together African bamboo information except in the taxonomic sense. Providing the review underlines contrasts and similarities of other species with *Oxytenanthera abyssinica* and facilitates comparison of any African bamboo with any other as a possible or actual resource. Hopefully, the review will promote original and more detailed research into the character and silviculture of the other species within a general African bamboo framework. Information is very scattered, and it is therefore useful to bring it together to highlight particular characteristics that relate to particular bamboo species. It would be wrong to assume all the bamboos can be represented by any one species as a model for progress towards domestication or conservation. While they are so distinctive as a group compared with typical dicotyledon trees, they have widely contrasting morphologies and ecologies among themselves. Better awareness could guide propagation and domestication initiatives and perhaps raise interest among molecular taxonomists in including African species in future research on bamboo phylogeny. If they were included, it might help to resolve some of the many questions about the origins and affinities of Africa's bamboos.

4.1 African bamboos in bamboo phylogeny

The bamboos, and the woody bamboos in particular, are notorious as a taxonomically challenging group of plants. Within the group, different people have offered widely diverging views of relations between species, genera and higher taxa. For the purposes of this thesis, Ohrnberger's (1999) circumscription of the bamboos has been adopted, with the modification of excluding from the group the genera *Guaduella* and *Puelia*. Following recent molecular studies (Clark *et al.*, 2000), convincing arguments have been put forward for separating these two genera from the bamboos as a new subfamily of grasses, the Puelioideae. This exclusion reduces the number of true bamboo species indisputably native to continental Africa from 16 to 5. Because of the possibility that the herbaceous bamboo, *Olyra latifolia*, reached Africa by natural dispersal and not as an introduced weed (Lovett, 1994), it is included here as a sixth species, although none of the other 80 or so species of the tribe Olyreae occurs in Africa (Figure 4.1, Table 4.1).

Research so far has excluded all continental African woody bamboos from any molecular studies, so the current views on affinities derive from morphological/anatomical considerations. In the broader sense there is considerable support from recent molecular work (Clark *et al.*, 1995; Kelchner and Clark, 1997; Soreng and Davis, 1998) for separating herbaceous (including Olyreae) and woody tribes as an initial split and general agreement on a monophyletic origin for the woody bamboos. The main differentiations of the woody bamboos are into primarily warm temperate/subtropical and primarily tropical sets, and recognition within the latter of Neotropical and Palaeotropical (in practice, Asian/Pacific) subsets. Ohrnberger's scheme of subtribes within tribe Bambuseae appears reasonably consistent with these major divisions. However, it is unclear where the African woody bamboo species, overall, fit into such a structure.

There are six species considered native to the African continent and 37 species to Madagascar (Ohrnberger, 1999). It can be noted that the three genera associated with warmer environments occur only in the Africa/Madagascar region and that they appear to be fairly well-defined taxonomic entities. The genus *Hickelia*, with four species, is not endemic to continental Africa but, apart from *Hickelia africana*, the species are Madagascar endemics. The remaining members of subtribe Hickeliinae, as circumscribed by Ohrnberger (1999), are all tropical Asian/Pacific taxa. Genus *Oreobambos* has remained monospecific since it was described in 1896, is exclusively continental African, and *Oreobambos buchwaldii* has never been referred to any other genus. Ohrnberger includes *Oreobambos*, with *Oxytenanthera* and 15 tropical Asian genera, in subtribe Bambusinae. Like *Oreobambos*, *Oxytenanthera* is monospecific and exclusively continental African. It has even been suggested by Tzvelev (1989) that *Oxytenanthera* should be assigned to its own monogeneric tribe.



Based on: Grass Phylogeny Working Group (2001) and Ohrnberger (1999)

Figure 4.1 : Taxonomic position of African bamboos in the family Poaceae

Table 4.1: Summary of taxonomical and distributional information relevant to five African bamboos

Current name (Ohrnberger, 1999)	*Hickelia africana* S. Dransf.	*Olyra latifolia* L.	*Oreobambos buchwaldii* K. Schum.	*Thamnocalamus tessellatus* Soderstr. and R. P. Ellis	*Yushania alpina* (K. Schum.) W. C. Lin
Tribe	Bambuseae	Olyreae	Bambuseae	Bambuseae	Bambuseae
Subtribe	Hickeliinae	n.a.	Bambusinae	Thamnocalaminae	Thamnocalaminae
Species in genus	4	23	1	4	84
Distribution of genus	Madagascar, Tanzania	tropical America, Africa	East African highlands	South Africa, Madagascar, Sino-Himalayan	Africa, east and south east Asia, India
Principle synonyms	n.a.	n.a.	n.a.	*Arundinaria tessellata* (Nees) Munro	*Arundinaria alpina* K. Schum. *Sinarundinaria alpina* (K. Schum.) C. S. Chao & Renvoize
Other synonyms	n.a.	see below[1]	n.a.	*Nastus tessellatus* Nees	*Arundinaria fischeri* K. Schum. *Oxytenanthera ruwensorensis* Chiov. *Arundinaria tolange* K. Schum.
Sources	Dransfield, 1994; Ohrnberger, 1999	Ohrnberger, 1999; Soderstrom and Zuloaga, 1989	Clayton, 1970; Launert, 1971; Ohrnberger, 1999	Ohrnberger, 1999; Soderstrom and Ellis, 1982	Launert, 1971; Ohrnberger, 1999

[1] *Olyra arundinacea* Kunth, *Olyra latifolia* var. *arundinacea* (Kunth) Griseba., *Olyra brasiliensis* Desv., *Olyra brevifolia* Schumach., *Olyra cordifolia* Kunth, *Olyra pubescens* var. *glabra* Nees., *Olyra latifolia* var. *glabriuscula* Doell., *Olyra media* Desv., *Olyra paniculata* Sw., *Olyra pubescens* Raddi, *Olyra latifolia* var. *pubescens* (Raddi) Doell., *Olyra scabra* Nees., *Olyra cordifolia* var. *scabriuscula* Doell., *Olyra latifolia* var. *vestita* Henrard

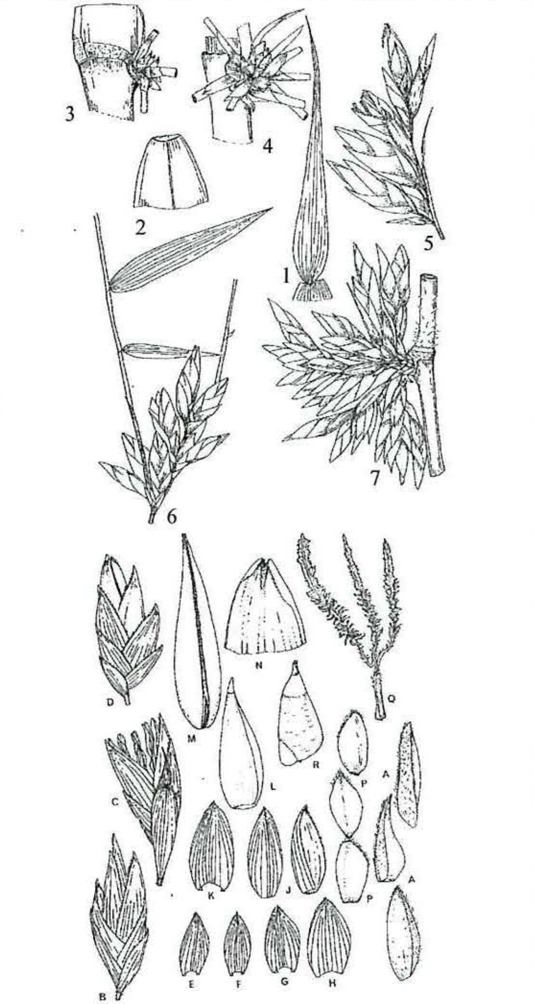
Placement relative to the wider picture is more controversial where *Thamnocalamus* and *Yushania* are concerned. As a species, *Thamnocalamus tessellatus* is restricted to the Africa/Madagascar region and *Yushania alpina* is endemic to continental Africa. Ohrnberger (1999) includes *Thamnocalamus* and *Yushania* among the eight genera he assigns to subtribe Thamnocalaminae. All eight genera are Asian (six exclusively so), and two Asian species are referred to *Thamnocalamus* and in excess of 50 to *Yushania*. Of these, two (Chao and Renvoize, 1989 – as *Sinarundinaria* spp.) or four (Ohrnberger, 1999) are endemic to Madagascar. Doubts have been expressed explicitly about *Yushania alpina* being correctly referred to *Yushania* (Phillips, 1995, 1999). Similar uncertainties are implicitly expressed about *Thamnocalamus tessellatus* (Soderstrom and Ellis, 1982).

It remains unclear if (taking names in current use) *Thamnocalamus tessellatus* and *Yushania alpina* have arisen within Africa from tropical ancestors. Equally unclear is the possibility of their differentiation from more temperate taxa in the process of reaching and becoming established in montane African environments. Currently, it is premature to relate these two species to the temperate *vs* tropical phylogenetic framework of the woody bamboos.

4.2 Biology

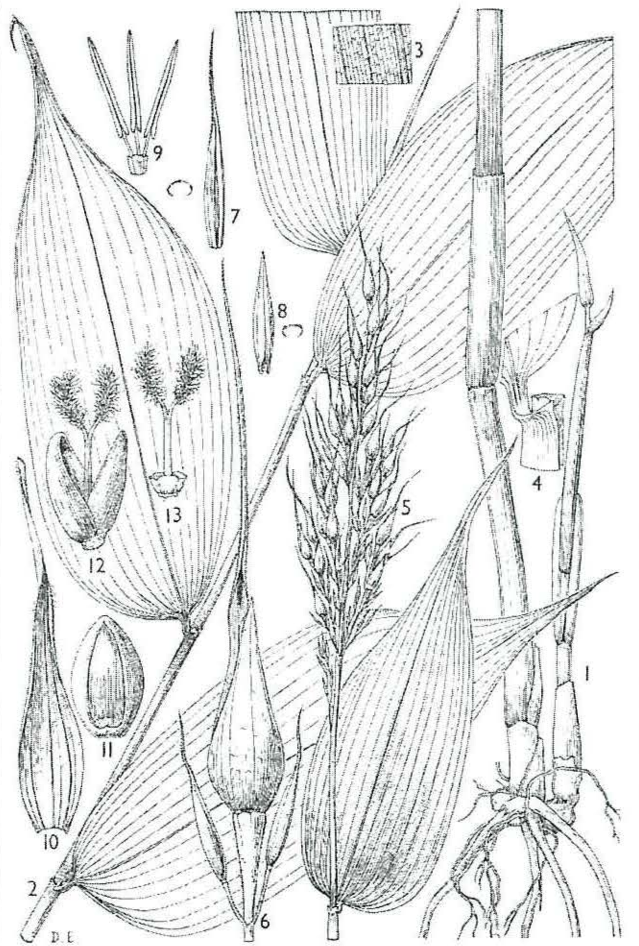
4.2.1 Morphology

There are wide variations among African bamboo species in terms of their habit. *Olyra latifolia* culms are short-lived, tufted and erect (Soderstrom and Zuloaga, 1989), *Hickelia africana* is scrambling (Dransfield, 1994) and *Oreobambos buchwaldii*, *Thamnocalamus tessellatus* and *Yushania alpina* are larger or much larger perennials (Clayton, 1970; Launert, 1971; Soderstrom and Ellis, 1982). *Oreobambos buchwaldii* and *Yushania alpina* are the larger species that are exploited as typical bamboo resources for construction and making woven containers (Figures 4.2-4.6, Table 4.2).



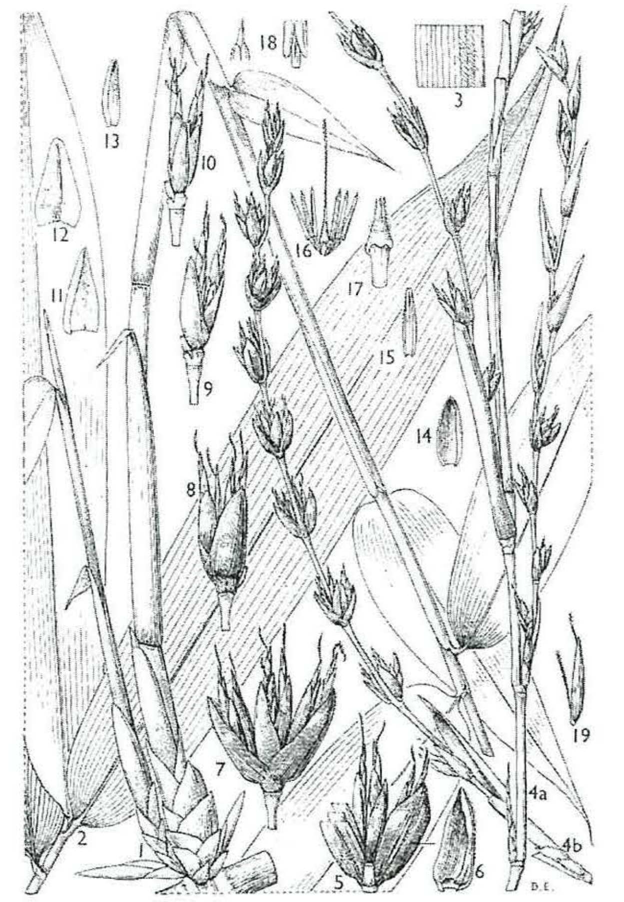
1.culm sheath; 2. top of culm sheath; 3.4. branches; 5. inflorescence terminating leafy branch; 6. inflorescence with leafy branch; 7. group of inflorescences; 1-4 from Congdon 221, 5-7 from Bidgood *et al.* 873. A. prophylls; B. spikelet before anthesis; C. during anthesis; D. after anthesis; E-K. transitional glumes; L. lemma; M. palea; N. apex of palea (viewed from inside); P. lodicules; Q. ovary; R. caryopsis; A-Q from *Bidgood et al.* 873, R from *Congdon* 221. Reproduced from Dransfield (1994)

Figure 4.2: Illustration of *Hickelia africana*



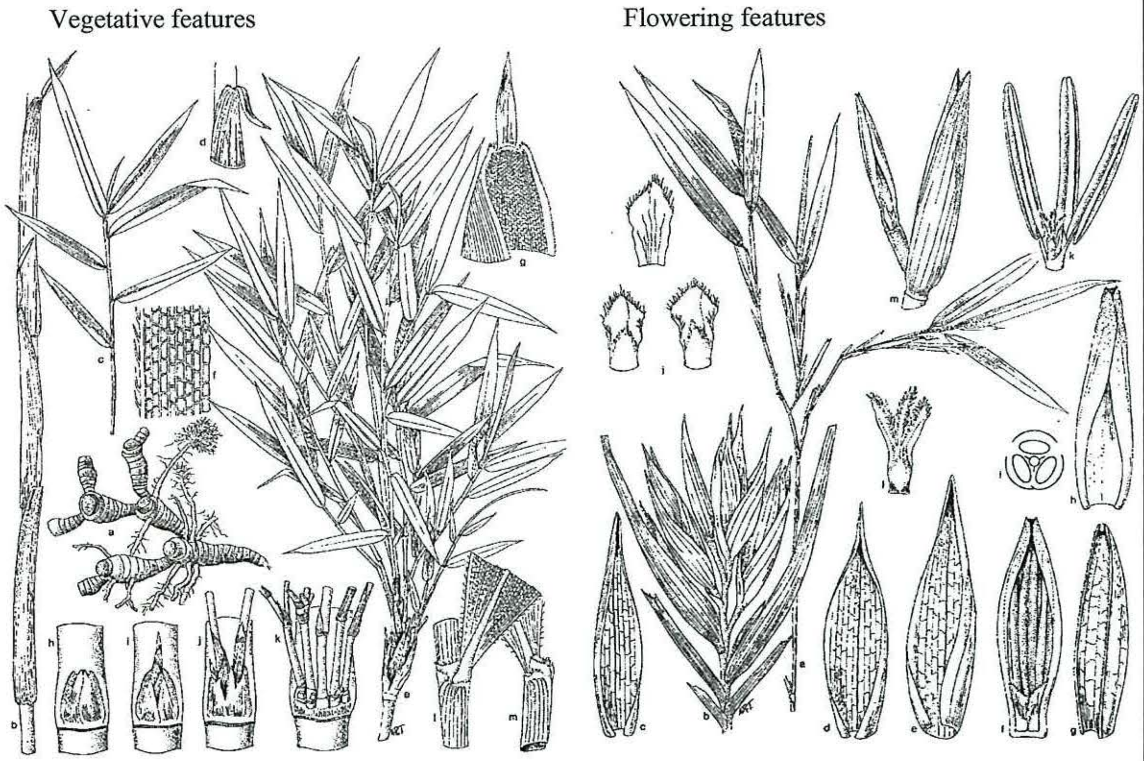
1. base of plant; 2. leafy shoot; 3. part of underside of leaf-blade showing tessellate venation; 4. detail of false petiole and ligule; 5. inflorescence; 6. cluster of one female and two male spikelets; 7. lemma of male spikelet; 8. palea of same; 9. male flower; 10. lower glume of female spikelet; 11. female floret; 12. female floret, opened; 13. female flower; 1 from *Gomes e Sousa* 4375; 2-4 from *Schweinfurth* 7579; 5. from *Grosweiler* 625; 6-13 from *Torre & Paiva* 10460. Reproduced from Clayton (1970)

Figure 4.3: Illustration of *Olyra latifolia*



1. leafy branchlet; 2. leaves; 3. part of dorsal surface of leaf-blade showing tessellate venation; 4a, 4b. flowering branchlets showing spikelet-clusters; 5. spikelet-cluster, ventral view; 6. bract removed from same; 7. spikelet-cluster, dorsal view; 8. spikelet-cluster, lateral view; 9. spikelet cluster partly dissected; 10. two spikelets after removal of bracts; 11. 12. bracts; 13. upper glume; 14. lemma terminal floret showing rhachilla-extension. 1 from *Hoyle* 1359; 2.3. from *Burtt Davy* 1192; 4a from *Greenway* 3705; 4b-19 from *Greenway* 2795. Reproduced from Clayton (1970)

Figure 4.4: Illustration of *Oreobambos buchwaldii*

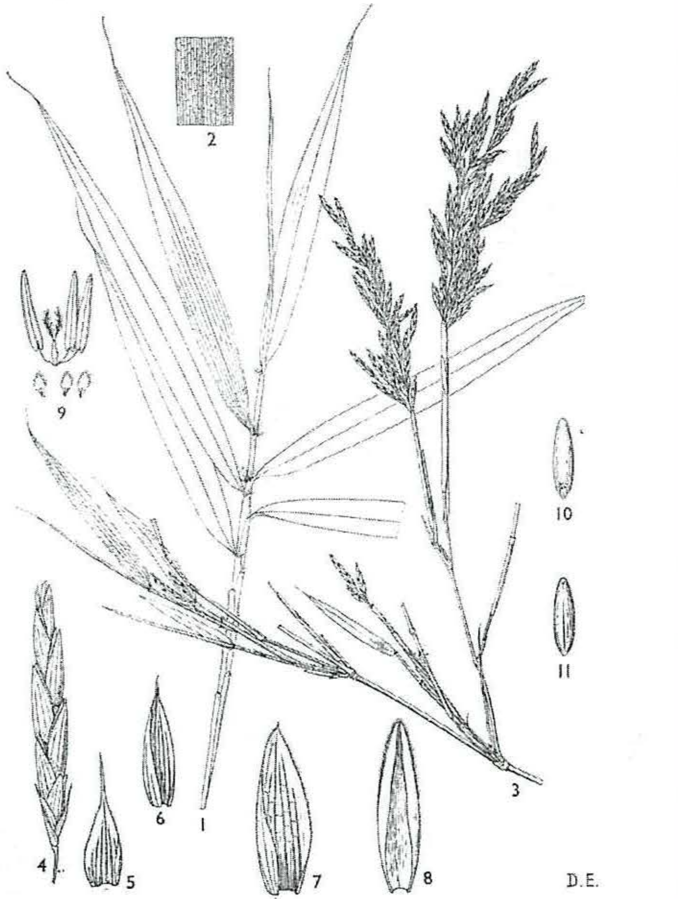


Vegetative features. a. rhizomes, somewhat diagrammatic; b. new culm showing erect blades; c. leaf complement; d. summit of culm leaf showing reflexed blade; e. branches with foliage; f. section of leaf blade showing cartilaginous margin and tessellate venation; g. new culm leaf inside view; h. branch bud covered by prophyllum; i. bud emerging through prophyllum as primary branching; j. young primary and secondary branches; k. branch complement; l. under part of foliage leaf showing outer and inner ligules; m. upper part of foliage leaf showing outer and inner ligules. (all figures from *Soderstrom & Du Toit* 2610 except c from *Van Zinderen Bakker* 13 and e, f, l and m from *Codd & Dyer* 2778).

Flowering features. a. branch at commencement of flowering with small leaf blades that precede spikelet formation; b. spikelet; c. glume; d. glume; e. lemma; f. palea, front view, showing the anterior pair of lodicules with overlapping margins and enclosed anthers; g. palea, back view, showing the two strong keels; h. palea, front view; i. schematic of flower in cross section showing 3 lodicules, 3 stamens and ovary with 3 stigmas; j. lodicules; k. stamens and pistil; l. gynoecium, showing the 3 stigmas; m. upper part of spikelet with 2nd, 3rd and 4th florets, the 4th a rudimentary flap of tissue enclosed within the small lemma of the 3rd floret. (a based on *Killick* 1863, b-m on Medley Wood 11336 (= *Galpin* 8576).

Illustration by Alice R. Tangerini Reproduced from Soderstrom and Ellis (1982)

Figure 4.5: Illustration of *Thamnocalamus tessellatus*



1. leafy shoot; 2. part of underside of leaf blade showing tessellate venation; 3. flowering shoot; 4. spikelet; 5. lower glume; 6. upper glume; 7. lemma; 8. palea; 9. flower with lodicules dissected free; 10. caryopsis; dosal view; 11, same, ventral view. 1-9 from *Glover, Gwynne & Samuel* 1187; 10, 11, from *Herklots*. Reproduced from Clayton (1970)

Figure 4.6: Illustration of *Yushania alpina*

Table 4.2: Gross morphology of five African bamboos

Current name	*Hickelia africana*	*Olyra latifolia*	*Oreobambos buchwaldii*	*Thamnocalamus tessellatus*	*Yushania alpina*
Habit	culms erect at the lower part, culms at the upper part and branches scrambling or entangled in vegetation nearby	caespitose perennials, forming clumps of to 20 culms. Culms erect, climbing and leaning on shrubs or decumbent	in small dense patches or solitary clumps. Culms arching or spreading	in loose clumps, with culms separated by the short necks of rhizomes. Culms erect or slightly arching	in dense thicket, culms arising singly from rhizomes
Rhizomes and roots	pachymorph	pachymorph	pachymorph	pachymorph, thick roots	pachymorph
Culm height (m)	3	1 - 6	5 - 20	1 - 5	5 - 20
Culm diameter (cm)	0.8	1	5 - 10	0.5 - 2.0	5 - 12.5
Internode length (cm)	40	10	50	12	50
Culms	thick-walled	hollow	0.8 cm (hollow)	hollow	hollow, thin-walled
Culm Sheath (cm)	13-22 × 2.5-3.5	short bladeless sheath	covered with appressed hairs when young, fimbriate at the mouth, with a short subulate lamina	sheath pale maroon with fine pencil-thin stripes when young, blade persistent, at first ascending, becoming horizontal-concave	ovate, oblong or oblong lanceolate, covered with reddish or reddish brown stiff hairs, tipped with a linear acute lamina and fimbriate lateral auricles
Leaf (cm)	5-12 × 0.7-1.1	7-20 × 2.5-7	blades indistinctly cross-veined, 10-35 × 2.5-6	15 × 1-1.5	blades strongly cross-veined, 5-20 × 0.6-1.5
Leaf sheath	glabrous, no auricles	glabrous or scattered pilose, the lower ones deciduous, the upper ones persistent, auricles present	no auricles	strongly ribbed, glabrous on the back, no auricles	small deciduous auricles with smooth setae
Branch organisation	many branches at each node with primary branch dominant and elongating	unbranched at the lower part, orthotropic branching at the upper nodes to produce many leaves and inflorescences	branching at each node, primary branch dominant	subequal branching at the upper node of the culm, intravaginal	branching at each node, primary branch dominant
Sources	Dransfield, 1994	Clayton, 1970; Gibbs Russell, *et al.*, 1990; Hutchinson and Dalziel, 1972; Launert, 1971; Phillips, 1995; Soderstrom and Zuloaga, 1989	Clayton, 1970; Inada *et al.*, 2003; Launert, 1971; Lemmens, 2002; Watson and Dallwitz, 1992 onwards	Gibbs Russell *et al.*, 1990; Ohrnberger, 1999; Soderstrom and Ellis, 1982	Clayton, 1970; Friis, 1992; Launert, 1971; LUSO CONSULT, 1997b; Phillips, 1995; Wimbush, 1945, 1947

The inflorescence structure of *Oreobambos buchwaldii* (axillary racemes) is distinct from that of the others (terminal panicles). There are also differences in style and stamen numbers and, in whether fertile spikelets are unisexual in monoecious inflorescences (*Olyra latifolia*) or hermaphrodite (others), underlining the lack of close taxonomic relationships (Clayton, 1970; Dransfield, 1994; Launert, 1971; Soderstrom and Ellis, 1982; Soderstrom and Zuloaga, 1989) (Table 4.3).

Culms of *Oreobambos buchwaldii* and *Yushania alpina* grow much taller than *Hickelia africana*, *Olyra latifolia* and *Thamnocalamus tessellatus* (Dransfield, 1994; Soderstrom and Ellis, 1982; Soderstrom and Zuloaga, 1989). There are clear differences among the species in the sizes and shapes of leaves. Leaves of *Hickelia africana* are acuminate and glabrous or minutely pubescent (Dransfield, 1994). Leaves of *Yushania alpina* are generally slender, while those of *Oreobambos buchwaldii* are wider and larger (Clayton, 1970; Launert, 1971). Leaves of *Olyra latifolia* are relatively large for its small culms, and larger than those of *Yushania alpina* (Clayton, 1970). *Thamnocalamus tessellatus* leaves are stiff and closely overlapping (Soderstrom and Ellis, 1982). Auricles are present on the leaves of *Olyra latifolia* (Soderstrom and Zuloaga, 1989) and *Yushania alpina* (Clayton, 1970) but not on the leaves of the others (Dransfield, 1994; Soderstrom and Ellis, 1982; Watson and Dallwitz, 1992 onwards).

4.2.2 Life cycle and phenology

Flowering of *Olyra latifolia* (Gibbs Russell *et al.*, 1990) and *Oreobambos buchwaldii* (Clayton, 1970) occurs every year. There is synchronised flowering at much longer intervals (Table 4.4) in *Hickelia africana* (Dransfield, 1994), *Thamnocalamus tessellatus* (Gibbs Russell *et al.*, 1990) and *Yushania alpina* (Langdale-Brown *et al.*, 1964; Were, 1990; Wimbush, 1945).

Table 4.3: Reproductive morphology of five African bamboos

Current name	*Hickelia africana*	*Olyra latifolia*	*Oreobambos buchwaldii*	*Thamnocalamus tessellatus*	*Yushania alpina*
Inflorescence	terminal on leafy or leafless branches, one or several spikelets	a monoecious terminal panicle	axially racemes	a terminal panicle	a terminal panicle
	inflorescence branches are solitary, each is subtended by a bract or a sheath and bears an asymmetrical 2-keeled prophyll, 4-5 cm	lax and diffuse, pyramidal, 12.5-21 cm × 4-14 cm	very large, loose, clusters of spikelets 1.5-2 cm × 0.8-2.25 cm	consists 3-5 spikelets	many spikelets, 5-15 cm long
Spikelets (cm)	comprise 5 transitional glumes, hermaphrodite, 1 floret, 1.5	monoecious, 1 floret, 0.7-1.0	hermaphrodite sessile, 1.2-1.5	hermaphrodite, 4 florets, 1.6-1.8	hermaphrodite pedicellate, 1.5-4 × 0.3-0.4
Bracts and glumes (mm)	bract resemble lower glume; 4 lower glumes 11-12	lower glume, long aristate; upper glume 9.4-12	bracts 8-14; lower glume absent, upper glume rounded on the back 9-11	2 glumes (9.9-11.5, 14-15)	glumes 4-8
Florets (mm)	lemma, 14; palea, 13	lemma, aristate 5-6; palea, 4.4-6.4	lemma, ovate to ellipitic ovate 10-13.5; palea 8-12	lemma, oblong-lanceolate 11.1-15; palea, broadly lanceolate 10-12.5	lemma, ovate 7-10; palea, linear oblong
Stamens	6	3	6	3	3
Ovary and styles	ovary slender; stigmas 3, jointed at the top of ovary	ovary glabrous, stigma 2	ovary hairy at the tip, stigma 1	ovary glabrous, 3 short stigmas	ovary subglobular, 2-3 stigmas
Sources	Dransfield, 1994	Clayton, 1970; Launert, 1971; Soderstrom and Zuloaga, 1989	Clayton, 1970; Launert, 1971	Soderstrom and Ellis, 1982	Clayton, 1970; Launert, 1971; Langdale-Brown *et al.*, 1964; Wimbush, 1945

Table 4.4: Phenology of five African bamboos

	Hickelia	*Olyra*	*Oreobambos*	*Thamnocalamus*	*Yushania*
Synchronous flowering	yes	n.a.	yes	yes	yes
Monocarpy	uncertain	no	yes	yes	yes
Flowering interval (years)	over 35	every year	every year	many years	15-40
Flowering season	late dry season	most of year; hot wet at southern limit	dry	hot wet (Dec-May)	dry and early rainy
Deciduous	uncertain	uncertain	yes	uncertain	evergreen

n.a., not applicable

Sources: Clayton (1970), Dransfield (1994), Friis (1992), Gibbs Russell *et al.* (1990), Launert (1971), Wimbush (1945)

Hickelia africana flowered in October (late dry season) in Mufindi, Tanzania (Dransfield, 1994). *Olyra latifolia* flowers from December to May, the hot wet season, every year in South Africa (Gibbs Russell *et al.*, 1990), but in most months at lower latitudes because seasonality is less pronounced in the tropical moist forest habitat. *Oreobambos buchwaldii* flowers in the January - February period (driest time of year) in the East Usambara mountains of Tanzania (Clayton, 1970). *Thamnocalamus tessellatus* flowered in the hot season after many years in South Africa (Gibbs Russell *et al.*, 1990). *Yushania alpina* flowered extensively in January (dry season), 1918 and 1936 on Mt. Elgon, Uganda and in March (early rainy season), 1922, on the Aberdare Range, Kenya (Clayton, 1970; Wimbush, 1945). In 1937, flowering started in December (the start of the dry season) in Ethiopia (Alvino, 1949).

According to a note by Peter Greenway, in Tanzania, clumps of *Oreobambos buchwaldii* died within six to twelve months after flowering (Clayton, 1970). Culms of *Oreobambos buchwaldii* were flowering in the Lilongwe Nature Sanctuary, Malawi, in November, 2001, the beginning of the rainy season, and flowers persisted for more than six months (personal observation). Culms which flowered were dying at the same time. Williamson (1975), however, reports *Oreobambos buchwaldii* culms persisted after flowering. Culms of *Thamnocalamus tessellatus* and *Yushania alpina* die after flowering and fruiting (Beentje, 1994; Gibbs Russell *et al.*, 1990).

During the flowering event witnessed in November 2001 in Malawi, no caryopses could be found in the flowers of *Oreobambos buchwaldii* (Inada, 2003). It is said that flowers of *Yushania alpina* usually produce infertile seeds but fertile seeds can be developed if there is an unusually long period after the long rains and just before the short rains (Were, 1990).

Almost all leaves of *Oreobambos buchwaldii* fall in the late dry season, from September to October in Lilongwe, Malawi (personal observation). *Yushania alpina* is evergreen and constantly sheds older leaves in Gecha - Masha, Ethiopia (LUSO CONSULT, 1997b).

Pests and diseases

Old culms are vulnerable to borers (Wimbush, 1945). *Yushania alpina* hosted epiphytic rhizomorphs of *Armillaria mellea* which caused root disease in pine plantations in Kenya (Gibson, 1960).

4.3 Ecology and distribution

Information about geographical distribution, elevation, rainfall, temperature and soils associated with African bamboos was assembled from past studies. Gross ecological relationships were established in this study, using GIS. In the following text, it is the findings from the GIS study and from integration with FAO temperature data that are mainly discussed, except where specific references have been made to earlier work. The GIS method followed the process used for *Oxytenanthera abyssinica* (Chapter 3). Collection localities were traced in floras, ecological literature and in the web site of Missouri Botanical Garden (2003). Four records were gathered for *Hickelia africana*, 210 for *Olyra latifolia*, 20 for *Oreobambos buchwaldii*, 48 for *Thamnocalamus tessellatus*, and 96 for *Yushania alpina*.

4.3.1 Geographical distribution

The African continent, including Madagascar, is divided into 20 main floristic vegetation types by White (1983). Subdivisions are based on vegetation structure and predominant taxa. *Hickelia africana, Thamnocalamus tessellatus* and *Yushania alpina* mostly occur in the Afromontane archipelago. *Olyra latifolia* is pluriregional and represented in six phytochoria - the Guineo-Congolian, Somalia-Masai and Zambezian regional centres of endemism, the Guinea-Congolia/Sudania regional transition zone, and the Lake Victoria and the Zanzibar-Inhambane regional mosaics. *Oreobambos buchwaldii* occurs in the Zambezian region and in the Lake Victoria regional mosaic. All these five African bamboos grow at forest margins and in open places within forest. All enjoy wet conditions along rivers and bordering swamps (Table 4.5).

The five species of interest here rarely occur coincidentally. They occur in relatively distinct regions, habitats and elevations. Of the five, *Olyra latifolia* is the most widespread, occurring in forest ecosystems at low (or less commonly medium) altitude across the continent and is also present in Madagascar. It is the only one of the five species reported to occur in localities where *Oxytenanthera abyssinica* occurs (Acholi, Uganda) but this is unusual and reflects mosaic vegetation. *Yushania alpina* occurs in the mountain terrain of eastern Africa and in a disjunct population in the mountains of Cameroon. This species extends to much higher elevations than the others and apparently grows under conditions of distinctly lower temperature than *Hickelia*, *Olyra* or *Oreobambos*. *Oreobambos buchwaldii* occurs as apparently discrete populations in a few east African mountain areas in fairly humid climates in mountain foothills and warmer sites at moderate elevation. *Oreobambos* is, like *Oxytenanthera*, a genus endemic to continental Africa. *Hickelia africana* and *Thamnocalamus tessellatus* are more restricted than *Oreobambos buchwaldii*: *Hickelia africana* - apparently endemic to southern Tanzania; *Thamnocalamus tessellatus* - Lesotho, South Africa and, subject to confirmation, Madagascar and Mauritius. *Thamnocalamus tessellatus*, in the mountains of South Africa, grows under temperature regimes more similar to those where *Yushania alpina* grows but there is a clear latitudinal interval between the natural ranges of the two species. There are four species recognised in *Hickelia*, of which *Hickelia africana* has been recorded only from Tanzania. The other three species occur in Madagascar (Dransfield, 1994).

Table 4.5: Distribution and habitat information recorded for five African bamboos

Current name	*Hickelia africana*	*Olyra latifolia*	*Oreobambos buchwaldii*	*Thamnocalamus tessellatus*	*Yushania alpina*
Distribution	Tanzania endemic	possibly introduced from America. African lowlands	eastern African	South Africa (possibly in Madagascar and in Mauritius)	Ethiopian and eastern African highlands; Cameroon
Range limit	8°35'-9°35'N; 34°35'-35°18'E	13°45'N-31°20'S; 16°45'W-49°47'E	1°47'N-21°00'S; 31°30'-38°53'E	28°13'-33°49'S; 26°5'-29°30'E	11°00'N-15°58'S; 10°27'-39°48'E
Environment: Typical elevation (m)	around 1800	<1000 (300-1300)	600-1400	1500 (1200)-2500 (2700)	2000 (1500) - 3000
Mean annual rainfall (mm)	900-1500	>1000	>750	600-730	1500 (875) - 2500
Vegetation types	wet montane forest,	margins of rain forest, gallery and secondary forest	open places in forest, often beside rivers, swamp forest	margins of high altitude forest, along stream banks and sheltered ravines	mountain slopes, ravines, along streams
Climate type	seasonally dry subtropics and tropics	humid tropical	seasonally dry subtropics and tropics	temperate	seasonally dry tropics in mountainous regions
Sources	Dransfield, 1994; Ohrnberger, 1999	Clayton, 1970; Langdale-Brown *et al*., 1964; Lovett and Wasser, 1993; Ohrnberger, 1999; Phillips, 1995; Schnell, 1952b; Synnott, 1985	Clayton, 1970; Launert, 1971; Ohrnberger, 1999; Palgrave *et al*., 1993; White, 2001; Williamson, 1975	Gibbs Russell *et al*., 1990; Ohrnberger, 1999; Palgrave *et al*., 1993	Beentje, 1994; Chaffey, 1979; Cheek *et al*., 2000; Edwards, 1940; Friis, 1992; Keay, 1955; Langdale-Brown *et al*., 1964; Launert, 1971; Letouzey, 1968; Phillips, 1995; Snowden, 1933, 1953; Were, 1990; Wimbush, 1945; WWF *et al*., 2003

For mapping climatic zones, FAO (1978) takes into account temperature, rainfall, evapotranspiration and soil moisture content (100 mm). Tropical regions have monthly mean temperatures, corrected to sea level, of >18℃ for all months. Subtropical regions are with monthly mean temperatures, corrected to sea level, of <18℃ for one or more months. Temperate regions are with monthly mean temperatures, corrected to sea level, of <5℃ for one or more months. Growing periods are defined as continuous periods when rainfall exceeds half of the potential evapotranspiration plus the days to evaporate 100 mm of stored soil moisture. Subhumid zones are associated with a growing period of 180-270 days, and humid zone with one >270 days. Climatic types with which each species is associated are tabulated (Table 4.5).

4.3.2 Environmental factors

Habitat information recorded for five African bamboos (Table 4.5) and ecological conditions associated with African bamboos inferred from GIS study and from integration with elevation adjusted FAO station temperature data (Table 4.6) is discussed below. Figures 4.7-4.11 show distribution of African bamboos in relation to what have been concluded to be suitable growing conditions.

4.3.2.1 Elevation

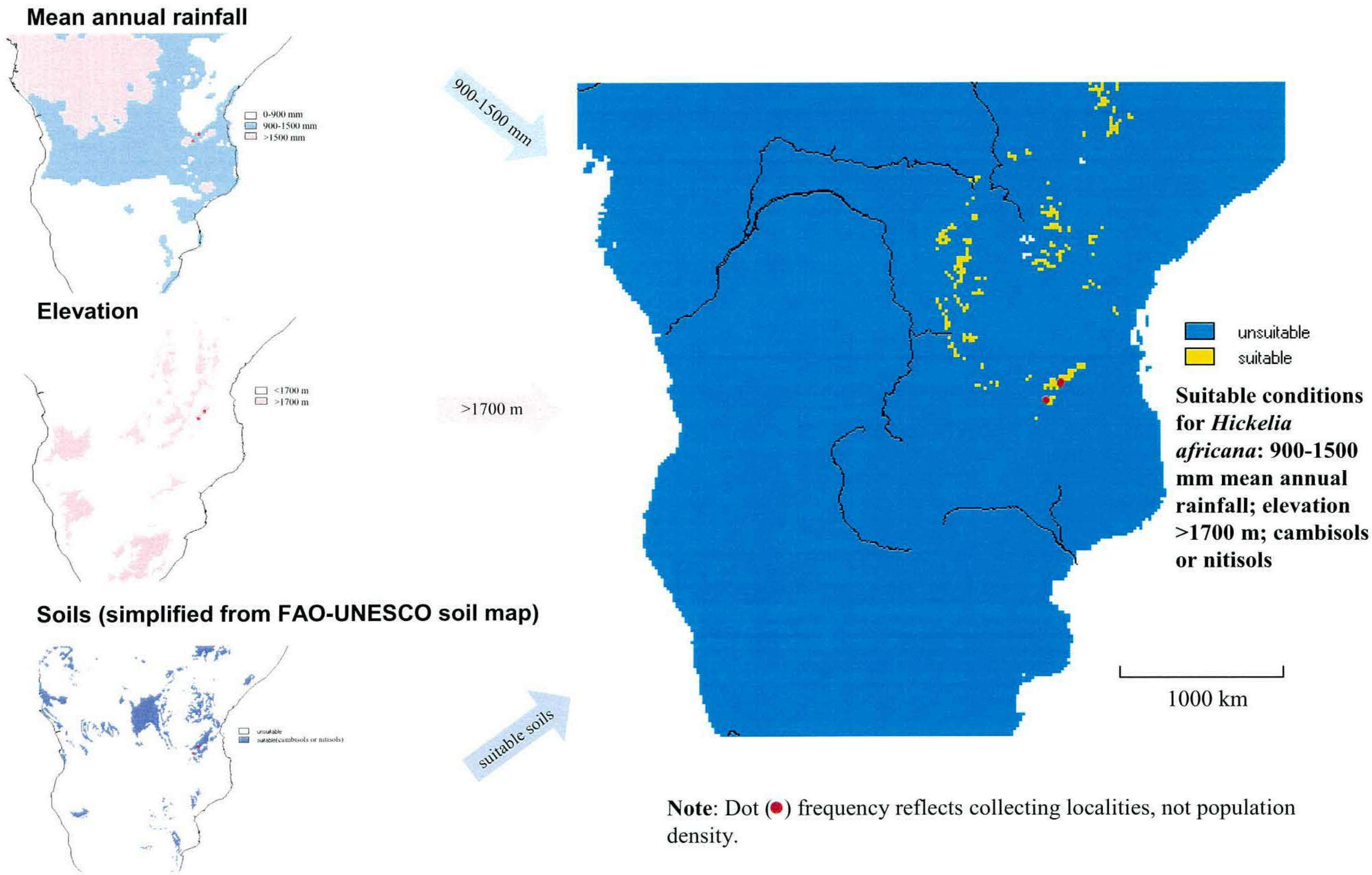
African bamboos are associated with both drier and moister phytochoria but mainly associated with montane areas: the Afromontane region (*Thamnocalamus tessellatus*, *Yushania alpina*) and the rugged terrain of lower mountains and the lower slopes of the higher mountains (*Hickelia africana*, *Oreobambos buchwaldii*).

Hickelia africana is recorded only in southern Tanzania, between 1700 m and 1800 m (Dransfield, 1994). *Olyra latifolia* is unquestionably primarily a lowland species, occurring at elevations from sea level to 1000 m, although there are anomalous occurrences of *Olyra latifolia* at more than 1000 m in the East African highlands. *Oreobambos buchwaldii* occurs only below 2000 m and mostly, from the few available reports, below 1500 m. The higher regions of the altitudinal range of *Olyra latifolia* overlap with the lower regions of the ranges of *Oreobambos buchwaldii* and both species are present at Amani, Tanzania, and in the Budongo Forest, Uganda.

Table 4.6: Ecological conditions typically associated with five African bamboos inferred from GIS study and from integration with FAO temperature data

Current name	*Hickelia africana*	*Olyra latifolia*	*Oreobambos buchwaldii*	*Thamnocalamus tessellatus*	*Yushania alpina*
Mean annual daily temperature (°C)	17.5	>20	19-23	14-16	14-17
Lowest monthly mean of daily minimum temperature	7-9	13-20	10-16	-5-0.3	-4-11
Highest monthly mean of daily minimum temperature	25-26	30-34	27-30	24-28	13-32
Dry months (<50 mm)	6	0-2 (Guineo-Congolian) 3-7 (Somalia-Masai, Zambezian)	0-2 (Tanzania) 4-6 (Malawi, Zambia)	5-7	3-6
Mean annual rainfall	900-1500	>1000	>750	600-800	>900
Altitude (m)	>1700	<1000	600-1400	1500-2500	>2000
Soil fertility	n.a.				
poor		ferralsols	ferralsols	n.a.	ferralsols
intermediate	n.a.	lithic leptosols, lixisols	lithic leptosols, lixisols	lithic leptosols, lixisols	n.a.
high	cambisols, nitisols	nitisols	nitisols	n.a.	cambisols, nitisols, andosols

n.a., not applicable; temperatures based on data in FAO (1984); Soil categories from FAO-UNESCO (1977), (1988).



Note: Dot (●) frequency reflects collecting localities, not population density.

Figure 4.7: Suitable ecological areas for *Hickelia africana* in Africa (8°N-27°S)

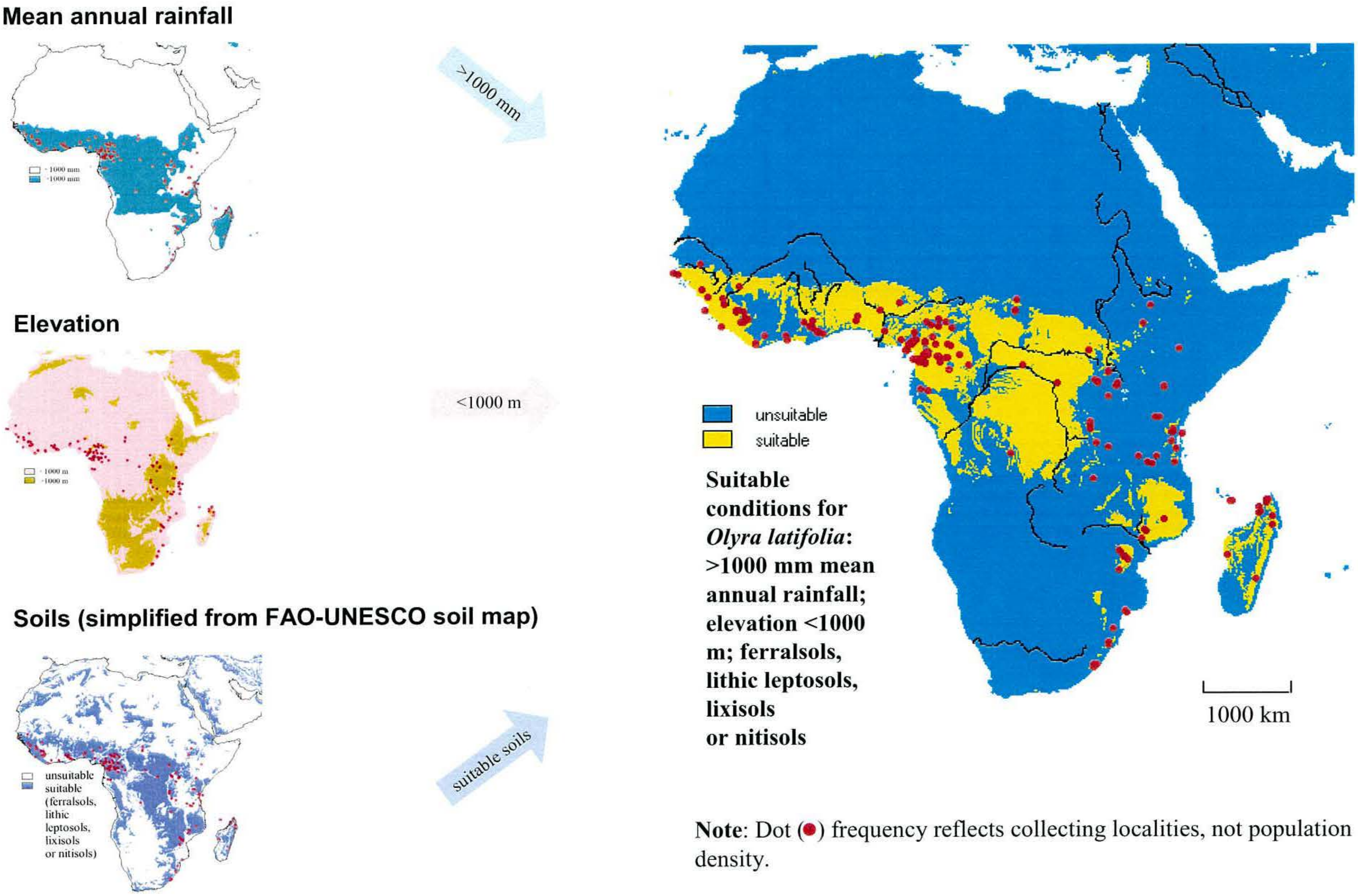
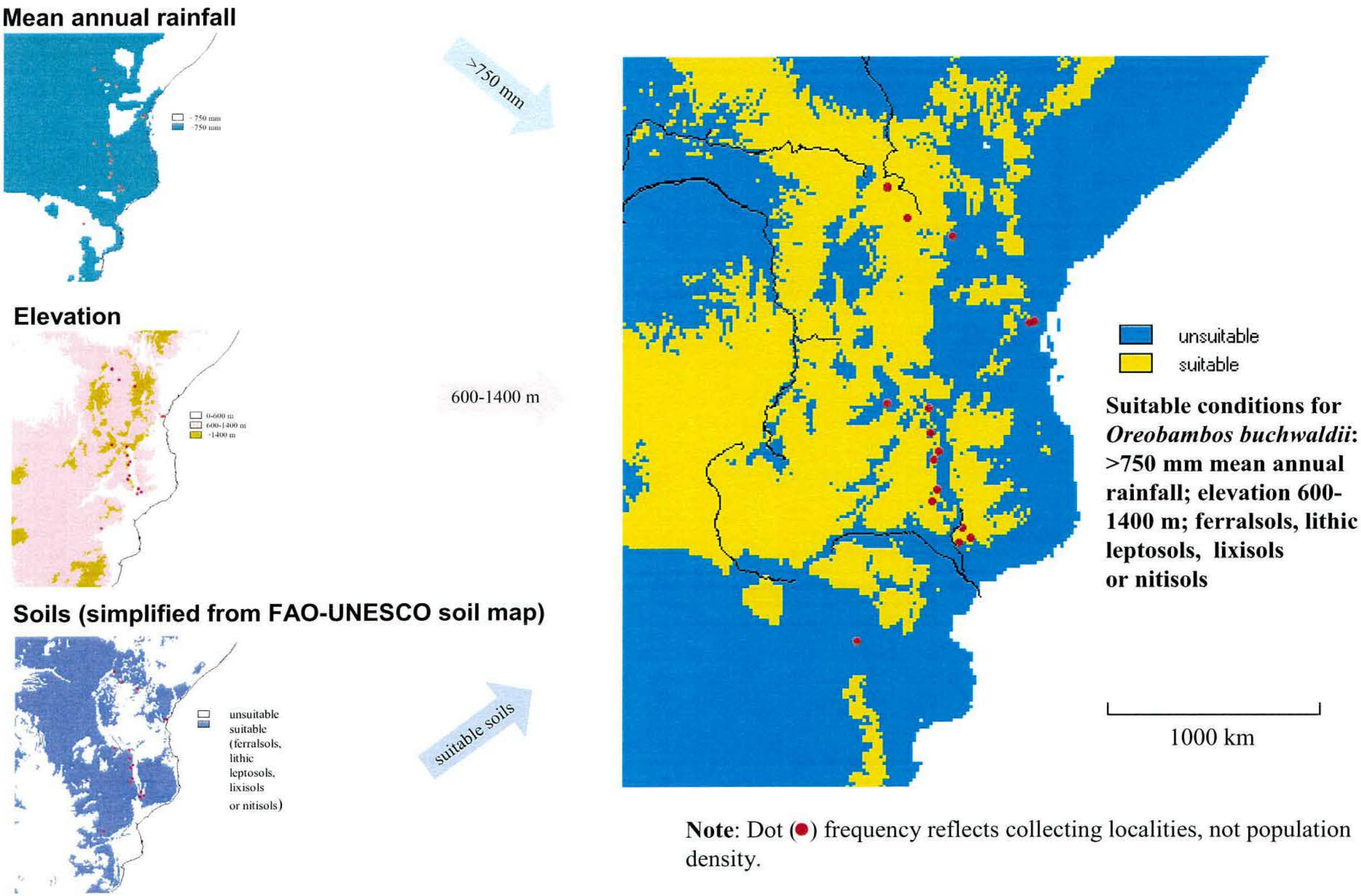


Figure 4.8: Suitable ecological areas for *Olyra latifolia* in Africa



Note: Dot (●) frequency reflects collecting localities, not population density.

Figure 4.9: Suitable ecological areas for *Oreobambos buchwaldii* in Africa (8°N-27°S; 19°E-50°E)

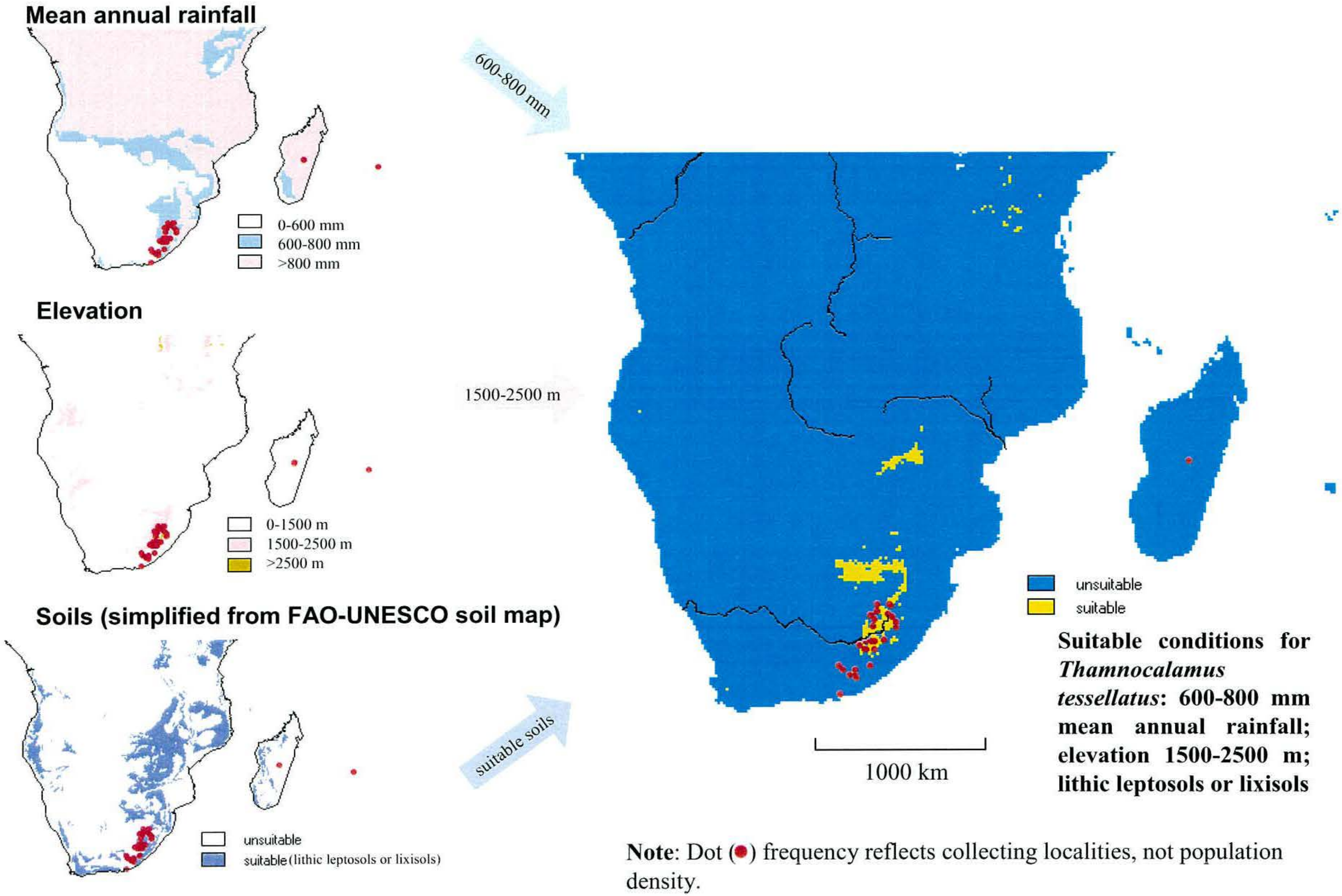
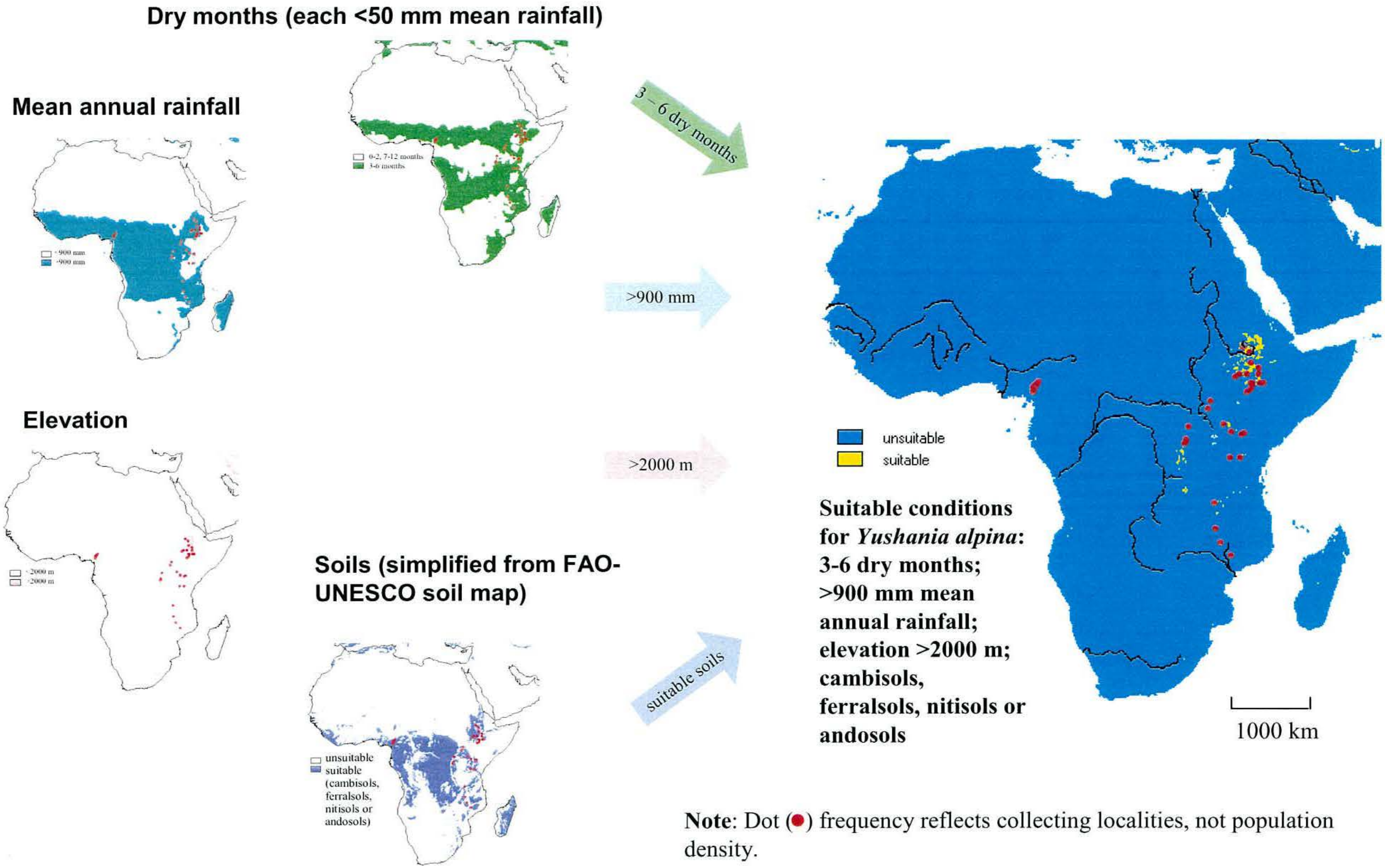


Figure 4.10: Suitable ecological areas for *Thamnocalamus tessellatus* in Africa (south of latitude 1°S)



Note: Dot (●) frequency reflects collecting localities, not population density.

Figure 4.11: Suitable ecological areas for *Yushania alpina* in Africa

Most occurrences of *Thamnocalamus tessellatus* are between 1500 m and 2500 m in the Natal Drakensberg, Lesotho and the Stormberg Series, South Africa. *Yushania alpina* occurs mostly between 2380 m and 3000 m (White, 1983). In Ethiopia, however, occurrence up to 3500 m is reported for *Yushania alpina* by LUSO CONSULT (1997a), and to 4000 m by Friis (1992) at the other extreme. Logan (1946) reports it to be present from 1500-2500 m in the Iechi Forest. In Cameroon, *Yushania alpina* occurs between 2000-3000 m (Cheek *et al.*, 2000) but it is absent from Mount Cameroon, the only place in the country where elevation exceeds 3000 m.

4.3.2.2 Mean annual rainfall

Hickelia africana occurs in wet mountain forest (Dransfield, 1994) receiving between 900 mm and 1500 mm mean annual rainfall. Most localities of *Olyra latifolia* are associated with quite wet climates with the local meteorological stations recording more than 1000 mm mean annual rainfall. This species also occurs in some areas near Mombo, Tanzania (4°54'S, 38°43'E), and Isiolo, Kenya (0°04'S, 37°45'E) which receive only 600 mm rainfall per annum. However, in both these areas there are gradients of considerable mean annual rainfall change over short distances and it is unlikely that *Olyra latifolia* is growing where mean annual rainfall is only 600 mm. Further, *Olyra latifolia* is associated with various severities of dry season - from 0-2 months <50 mm mean rainfall areas in the Guineo-Congolian region to 3-7 months <50 mm mean rainfall in forest outliers in the Somalia-Masai and Zambezian regions. The localities of *Oreobambos buchwaldii* in Malawi and in Zambia enjoy relatively dry conditions (4-6 months <50 mm; mean annual totals 800-1300 mm). *Oreobambos buchwaldii* in Kampala, Uganda and in the Usambara mountains of Tanzania, however, occurs in more humid conditions (>10 wet months ≥50 mm; mean annual totals 1200-1900 mm). *Thamnocalamus tessellatus* occurs near meteorological stations where mean annual rainfall 600-800 mm has been recorded. Mean annual rainfall may, however, be higher in the vicinity of these locations because of climatic patterns imposed by mountain terrain, with significant changes over short distances. Locally wetter conditions may also be associated with the water courses along which the species occurs. *Yushania alpina* is present in conditions of rather lower mean annual rainfall conditions in Tanzania (800-900 mm) than in the other countries of the range (mean annual rainfall; >1000 mm). In Ethiopia *Yushania alpina* occurs under mean annual rainfall 1500-2000 mm (Friis, 1992; LUSO CONSULT, 1997a). In most localities of *Yushania alpina* there are 3-6 months <50 mm mean rainfall.

4.3.2.3 Temperature

In its typical high mountain habitat, *Yushania alpina* (mean annual temperatures usually 14-17℃) and *Thamnocalamus tessellatus* (14-16℃) are associated with lower temperatures than is *Oreobambos buchwaldii* (19-23℃). *Hickelia africana* (17.5℃) occurs in areas where mean annual temperature is intermediate. *Olyra latifolia* is associated with the warmest conditions, at mean annual temperatures of more than 20℃.

The lowest monthly mean of the daily minimum temperature varies widely among the five species. Values associated with *Hickelia africana* and *Thamnocalamus tessellatus* are 7-9℃ and -5-0.3℃ respectively. Values are much higher for *Oreobambos buchwaldii* (10-16℃) except at Lilongwe where the value is 6℃. *Yushania alpina* is associated with lowest values of monthly mean of the daily minimum temperature from -4℃ to 11℃. The value for *Yushania alpina* in Cameroon (9℃) is within the range of the Somalia-Masai and in Zambezian regions (6-16℃). Typical values for *Olyra latifolia* are from 13-20℃ but it is also present where a value of 6℃ applies in Inyanga area, Zimbabwe.

The highest values of monthly mean of the daily maximum temperature also vary with species. A value for *Olyra latifolia* is high at 30-34℃. Within *Yushania alpina* localities the values considerably differ from 13℃ (high altitude, Ethiopia) to 32℃ (Mt Elgon, Uganda).

4.3.2.4 Soils

Approximate relationships with the soil categories of FAO-UNESCO (1977) emerge from the GIS exercise but should be interpreted cautiously, given the complex soil variation at scales not reflected in the resolution of the maps. There are possibly some differences for African bamboos in ability to cope with infertile soils. *Hickelia africana* and *Thamnocalamus tessellatus* appear associated with soils of high or intermediate fertility, while *Olyra latifolia, Oreobambos buchwaldii* and *Yushania alpina* are associated with more diverse conditions, varying from low to high fertility.

Hickelia africana, Olyra latifolia, Oreobambos buchwaldii and *Yushania alpina* are all associated with fertile nitisols. *Olyra latifolia, Oreobambos buchwaldii* and *Yushania alpina* are also present on ferralsols which are poor in mineral reserves. *Thamnocalamus tessellatus* is present on soils, lithic leptosols and lixisols, of intermediate fertility. Lithic leptosols occur, however, on steep rocky slopes and are usually not suitable for agriculture (FAO-UNESCO, 1988).

More information is available for *Yushania alpina*. This species flourishes on deep volcanic humus soil (Launert, 1971; Phillips, 1995; Were, 1990). Deep humid soils are favoured because in these the thick rhizomes can extend freely. *Yushania alpina* is also present on yellow or brown loams and clays (Langdale-Brown *et al.*, 1964). FAO (1965a) described the soils under communities of *Yushania alpina* as having developed deep organic top layers, due to the heavy leaf fall. However, soil where *Yushania alpina* grew was extremely deficient in P and poor in K in Ethiopia (Embaye, 2003).

4.3.3 Plant communities

Hickelia africana and *Thamnocalamus tessellatus* are species of Afromontane forest in eastern Africa.

Olyra latifolia occurs mainly in lowland rain forest where mean annual rainfall exceeds 1200 mm but in Malawi and Zimbabwe, it extends to miombo communities in lower mountain regions, occurring with species of *Brachystegia*, alone or with *Julbernardia* or *Isoberlinia* (Werger and Coetzee, 1978). Langdale-Brown *et al.* (1964) found *Olyra latifolia* growing under *Oxytenanthera abyssinica* in lowland bamboo thicket at 1200 m in Acholi, Uganda.

In the Zambezian regional centre of endemism, *Oreobambos buchwaldii* occurs in both wetter (mean annual rainfall >1000 mm) and drier (mean annual rainfall < 1000 mm) Zambezian miombo woodland. It also occurs in mixed forests which include *Oxytenanthera abyssinica* in Lilongwe and Zomba, Malawi (personal observation).

Yushania alpina generally occurs between 2300 m and 3000 m in the Afromontane archipelago (White, 1983). *Yushania alpina* appears as extensive pure stands in the eastern African mountains at elevations above 2300 m (Langdale-Brown *et al.*, 1964; LUSO CONSULT, 1997a; Wimbush, 1945), and as pure stands or scattered between 2100 m and 2400 m in Cameroon (Lightbody, 1952). Below 2300 m, *Yushania alpina* clumps tend to be scattered among other Afromontane trees (Friis, 1992; Phillips, 1995 - Ethiopia; Kerfoot, 1964 - Kenya; Langdale-Brown *et al.*, 1964 - Uganda).

4.3.4 Ecosystem interactions

Leaves and dense litter of *Yushania alpina* (Langdale-Brown *et al.*, 1964; Wimbush, 1945) cover and protect the soil from drying up and from massive rain.

Elephants, buffalo, bushbuck and Syke's monkeys eat *Yushania alpina* in Kenya (Snowden, 1953; Were, 1990). Elephants and buffaloes eat young shoots and leaves in Uganda (Snowden, 1953). Young shoots are eaten especially by primates in Bwindi national park in Uganda (WWF *et al.*, 2003). Gorillas eat young shoots on the Mufumbiro mountains, Uganda (Snowden, 1953). A seed eating bird, *Lonchura fringilloides* (Lafresnaye), has been described as a specialised consumer of *Oreobambos buchwaldii* seeds in Malawi (White *et al.*, 2001).

4.4 Silviculture

A silvicultural aspect (propagation, management and conservation) has been reported only for *Yushania alpina*.

4.4.1 Silviculture and management

4.4.1.1 Nursery and plantation initiatives

Planting of *Yushania alpina* in farmlands has been reported from Ethiopia. It has been recently increased, because there is higher demand of bamboos as construction and furniture material. Planting technique is, however, poor and the survival rate of planted culms was less than 50% (LUSO CONSULT, 1997a). It is not clear what propagation techniques are used for these *Yushania alpina* culms. Rhizome and seed plantings would be possible options as recorded by Wimbush (1945). Planting by farmers lowers the range of the distribution from >2200 m (natural stands) to 1800 m (LUSO CONSULT, 1997a).

Culm cuttings

Culm cuttings, the lower parts being dipped in rooting powder, were unsuccessful for *Yushania alpina* in an experiment of Moi University, Kenya (Kamondo and Haq, 1990). Only five out of 40 (13%) culm cuttings dipped in rooting hormone had shoots while three out of 20 (15%) control cuttings had shoots four months after planting.

Rhizome propagation

Rhizomes of *Yushania alpina* with 60 cm of culms are possible units for propagation. Culms should be one year old. The season just before new culms grow is recommended for planting (Wimbush, 1945). A single culm, or several culms attached to rhizomes were separated from clumps and planted as a single propagation unit at Moi University, Kenya. Four months later, 100% of the planted units sprouted 2-4 new shoots (Kamondo and Haq, 1990).

Seed propagation

Seedlings of *Yushania alpina* can be transplanted into soil boxes when they reach 2.54 cm in height and after 8-12 months from the date of sowing the seeds they can be transplanted to field sites. It takes 5-6 years to produce full size (5-20 m) culms (Wimbush, 1945). However, no seed germinated in the experiment at Moi University, Kenya (Kamondo and Haq, 1990).

4.4.1.2 Natural stands, yield and production

It is estimated that *Yushania alpina* covers 50 000 ha in Uganda (Persson, 1975) and

130 000 ha in Ethiopia (LUSO CONSULT, 1997a). LUSO CONSULT (1997a) estimates biomass of *Yushania alpina* in the Ethiopian highlands: 5869 culms/ha and 51.3 t/ha, of which 4893 culms (83%) are >1 year and 976 culms (17%) are <1 year (new shoots produced within a year). The biomass <1 year old converts to a mean annual increment of oven dry culms of 8.6 t/ha (LUSO CONSULT, 1997a, 1996b). *Yushania alpina* culms were produced prolifically (>3000 culms/ha) one year and sparsely (<200 culms/ha) in another year on the Aberdare Range, Kenya (Wimbush 1945). This large difference in the new shoot production may have been caused by rainfall patterns (LUSO CONSULT, 1997b; Were, 1990). In nutrient accretion terms annual shoot production of 8 t/ha equates to 44 kg/ha of N, 6 kg/ha of P, 122 kg/ha of K and 2 kg/ha of Ca (Embaye *et al.*, 2003).

With regard to a biomass component, Embaye *et al.* (2003) report that oven dried culms of *Yushania alpina* contribute 82%, branch 13% and leaf 5% to the 110 t/ha total aboveground biomass. LUSO CONSULT (1997a, 1997b) reports similar proportions. The mean fresh weight of a culm (mean length 16.9 m and diameter at the middle of the second internode 8 cm) was 29.6 kg, of which 24.9 kg (84%) was from the main axis and 4.7 kg (16%) from branches and leaves. The oven dry density of solid culms adjusted for lumen is 477 kg/m^3 (LUSO CONSULT, 1997a, 1996b). For comparisons, a single culm of *Oreobambos buchwaldii*, which had been air dried for two weeks, was partitioned as culm 1.8 kg (61%), branches 0.78 kg (26%) and leaves 0.37 kg (13%) (Inada *et al.*, 2003).

4.4.1.3 Harvesting systems

Wimbush (1945) reports that if 10% of old culms of *Yushania alpina* are left evenly distributed through the clump, a cutting cycle cutting only culms more than one year old, will be 12-19 years, two years shorter than that of clear cutting. Higher felling intensity (25-50% of *Yushania alpina* culms older than 3 years every year) is recommended by Embaye *et al.* (2003). Cutting is not recommended during the growing season (Wimbush, 1945) and therefore can be carried out early in the dry season (Embaye *et al.*, 2003). Over-mature culms more than three years old should be felled for sustainable management of clumps (Embaye *et al.*, 2003).

4.4.2 Conservation

In the recent regional guide to threatened species in southern Africa (Golding, 2002), *Oreobambos buchwaldii* in Zambia is recorded as critically endangered because it appears to be extinct at most of the known localities. *Oreobambos buchwaldii* is also endangered in Zimbabwe, because significant numbers of plants have been destroyed in mining operations. *Thamnocalamus tessellatus* in Lesotho is listed as a vulnerable species because the number of mature individuals is less than 1000. IUCN - The World Conservation Union - highlights taxa which are in danger of extinction and promotes actions to conserve plant biodiversity (Walter and Gillett, 1998). *Thamnocalamus tessellatus* is accorded the status R: a vulnerable species (rare 21-100 occurrences or 3000-10000 individuals). With reference to *Yushania alpina*, Snowden (1953) reports damage to stands near centres of population, implying excessive harvesting for house-building poles is responsible. He notes, however, that Government regulation of *Yushania alpina* harvesting had been instituted to address the problem of overexploitation. In Ethiopia, access to natural bamboo forests of *Yushania alpina* for household consumption is free, although licences are sold for commercial users (LUSO CONSULT, 1997a, 1997b). No management guideline for natural bamboo stands in Ethiopia has yet been established by the government (Boa, 1997b). Bamboos are absent from lists of FAO-Panel of Experts on Forest Gene Resources (2001) - this is not because there is no threat or because African bamboos are not important resources, but because the Panel has taken its remit to be gymnosperms, dicotyledonous trees and palms, but not woody grasses. Absence of names does not mean absence of conservation needs or absence of potential conservation problems. FAO-REFORGEN (2004) includes *Yushania alpina* in the list of native plants of Kenya but does not express it is threatened.

4.5 Resource roles

Properties

From livestock point of view, Ayre-Smith (1963) investigated the chemical composition of leaves and twigs of *Yushania alpina* (Table 4.7) and concluded they are unlikely to be harmful to browsing cattle.

Table 4.7: Chemical composition of *Yushania alpina* leaves and twigs in % of dry matter

	Leaves	Twigs
Crude protein	18.5	8.1
Ether extract	2.6	1.1
Crude fibre	26.6	40.2
Nitrogen free extract	37.0	40.7
Ash	15.3	10.9

Source: Ayre-Smith (1963)

Preservative treatment

Yushania alpina culms are susceptible to borers and termite attack. It should be effective to immunise 2.5% of Wolman salts for 24 hours or 4% of borax for 24 hours as preservative treatments. The butt ends of standing bamboos with all leaves off are left in this solution for 24 hours (Wimbush, 1945).

Uses

Culms of *Oreobambos buchwaldii* and *Yushania alpina* are mainly used for fencing and temporary construction (granaries). Culms of *Yushania alpina* in Kenya are largely used for fencing by the horticulture industry (Ongugo, *et al.*, 2000). They are also used as material for weaving baskets (Boa, 1997a; FAO, 1965; Logan, 1946; Oryem-Origa *et al.*, 1995; Were, 1990; White, 2001; Williamson, 1975; Wimbush, 1945; WWF *et al.* 2003). *Yushania alpina* has been used for water pipes in Tanzania (Mgeni and Swai, 1982).

Yushania alpina has potential for agroforestry, because the vegetation provides soil protection and sustains water supplies to lower lying areas (Langdale-Brown *et al.*, 1964). *Yushania alpina* has been used for firewood and charcoal in the absence of alternative materials (Boa, 1997a; Lightbody, 1952). Young shoots of *Yushania alpina* are eaten by animals and people (Langdale-Brown *et al.*, 1964; Snowden, 1953).

Yushania alpina is a possible source of pulp, since the average cellulose content of air dry bamboo is high at 47.5% of dry matter (Wimbush, 1945), although it is lower than for *Oxytenanthera abyssinica* (60%) (Khristova *et al.*, 1982). *Yushania alpina* from

Ethiopia is a suitable pulp raw material, because it is bleachable and has satisfactory strength characteristics (Cunningham *et al.*, 1970).

Table 4.8: Documented major usage of four African bamboos

Current name	*Hickelia*	*Oreobambos*	*Thamnocalamus*	*Yushania*
Direct use of culms		livestock fences		baskets, fences, furniture, granaries, houses, water pipes
Crafted use of culms		grain bins, baskets	Framework of shields for festivals, arrow shafts, spear handles	
Other reported uses	straws to drink beer			charcoal, entertainment, firewood, famine food
Local names		Mwanzi (Swahili)	South African mountain bamboo (English), Bergbamboes (Afrikaans), Südafrikanischer Bergbambus (German)	Kenya: Mwanzi (Swahili), Murangi (Kikuyu), Ol-diani (Maasai), Tegaat, Terga (Kipsigis, Lumbwa, Marakwet), Tegat (Nandi, Ndorobo), Tegundet (Sebei), Mrangi (Taita); Ethiopia: Karkaha, Lemen (Shoa, Arussi and Sidamo)
Sources	Lovett, 1994	White *et al.*, 2001; Williamson, 1975	Ohrnberger, 1999; Soderstrom and Ellis, 1982	FAO, 1965; Langdale-Brown *et al.*, 1964; Lightbody, 1952; Logan, 1946; LUSO CONSULT, 1997a; Mgeni and Swai, 1982; Oryem-Origa *et al.*, 1995; Snowden, 1953; Tweedie, 1977; Were, 1990; Wimbush, 1945; WWF *et al.* 2003

<u>**Note**</u>: No information is available for usage of *Olyra latifolia*.

Chapter 5

Malawi sites of field work and environmental conditions

There were four study sites in Malawi. Their location (5.1), topography, geology and soils (5.2), climate (5.3), biotic factors (5.4), fauna (5.5) and land ownership (5.6) are described in this chapter. Tables 5.2 and 5.3 shows environmental factors of four survey areas and Figure 5.1 shows climatic diagrams of these areas.

This thesis involved two field activities, (a) monitoring and (b) propagation:

(a) Monitoring activities was carried out to link knowledge of clump structure and patterns of culm development to the broader picture (global) of bamboo management, and harvesting strategies, based on clump characteristics that has previously been developed for other economically important species (e.g. Azmy, 1996; Dransfield and Widjaja, 1995; Manthauda, 1960).

(b) Various propagation methods were attempted referring to past reports of successes - specifically with *Oxytenanthera abyssinica* (Abeels, 1961; Khan, 1966), but also with other commercially valuable species (Liese, 1985; Shibata, 2000).

The three monitoring areas represented the north (Nsawagi), the central (Lilongwe) and the southern (Zomba) regions. Clump monitoring was carried out at three locations, and also at an additional site (Mua), propagation studies were conducted (Table 5.1). Three sites were chosen across the country to quantify the relations between clump size, the number of culms per clump, and new culm production at a population level for *Oxytenanthera abyssinica* under following criteria:

- accessibility (close to Tarmac roads)
- abundant population
- free from disturbance

Table 5.1: Four study sites in Malawi

Activity	Nsawagi	Lilongwe	Mua	Zomba
Clump monitoring	+	+		+
Propagation		+	+	

5.1 Locations

Lilongwe Nature Sanctuary and Zomba National Botanic Garden are essentially protected from disturbance. The area of the river Lukulu at Nsawagi is traditionally managed by local villagers. At Nsawagi, there was an abundant population of *Oxytenanthera abyssinica* which showed few marks of disturbance and had not been used frequently, perhaps because there was relatively few farmers nearby being far from large cities. There were a large number of unharvested clumps. There was no other population of *Oxytenanthera abyssinica* known to the author in the northern region. Consequently, three areas were thought to be the best sites nationally for monitoring activities.

Lilongwe Nature Sanctuary was selected for the collection of cuttings for propagation and for monitoring the growth of new shoots, because, in addition to above environmental conditions, Ministry of Tourism, Parks and Wildlife, the owner, approved this study and permitted harvesting culms for experiments and accessing the Sanctuary for monitoring throughout the year. There was no other option which satisfied these conditions in the country.

Mua was selected for the collection of cuttings for propagation studies in Lilongwe. The Department of Forestry reported to the author that Tuma and Mua-Livulezi Forest Reserves have *Oxytenanthera abyssinica* clumps. They are closest locations to Lilongwe in forest reserves but it was considered that their physical environmental factors were distinct to Lilongwe where other culms for cutting propagation were harvested. The in-forest roads in Tuma Forest Reserve were significantly damaged by the rain in January 2003 but those of Mua-Livulezi were not. Mua-Livulezi Forest Reserve was therefore selected to collect culms of *Oxytenanthera abyssinica*.

The Lilongwe study area was Lilongwe Nature Sanctuary (13°57'S, 33°47'E; 1060 m). At Nsawagi in the northern region (10°49'S, 34°06'E; 990 m), the study area is on the east bank of the South Lukulu river. Zomba (the old capital) represented the southern region - the study area was in the Zomba National Botanic Garden (15°22'S, 35°20'E; 980 m). Mua-Livulezi Forest Reserve (14°36'S, 34°51'E; 719 m) is located in the Central Region. Cuttings were collected near the Mua Mission, on the slope of the reserve near Lake Malawi.

5.2 Topography, geology and soils

The Lilongwe Nature Sanctuary is at level (less than 8%) to hilly (8-30%) ground along the Lingazi river, at 1060 m. The soils of the area are mapped as ferric lixisols associated with chromic lixisols and lithic leptosols (FAO-UNESCO, 1977), which are slightly acid (pH 5.4-6.1, four random samples). Geologically this is an area of early Precambrian to early Palaeozoic formations (Table 5.2).

The research area in Nsawagi lies on a slope (gradient more than 30%) along the Lukulu river. The soils are lithic leptosols associated with chromic cambisols (FAO-UNESCO, 1977). The underlying geology are tertiary and recent (National Atlas of Malawi, 1983).

Zomba National Botanic Garden has a gradient of 30% along the Mulunguzi river at the foot of Zomba Mountain. The soils are lithic leptosols associated with chromic cambisols (FAO-UNESCO, 1977). Geological age is from upper Jurassic to late Cretaceous (National Atlas of Malawi, 1983).

The research area in Mua has a gradient of more than 30%. The soils are lithic leptosols associated with chromic cambisols (FAO-UNESCO, 1977). The underlying geology is early Precambrian to early Palaezoic (National Atlas of Malawi, 1983).

5.3 Climate

Throughout Malawi, there are two distinct climatic seasons: rainy and dry. The rainy season starts in December and ends in March. Climate conditions are similar across the four field sites. All sites have six dry months <50 mm a year, which is generally harsh condition for plant growth. There are higher temperatures at Mua than in the other sites (Table 5.3).

According to the Thornthwaite scheme (index value = -18, based on the soil storage capacity of 100 mm available moisture; Pratt and Gwynne, 1977), Lilongwe's climate is sub-humid to semiarid. Climate is moderately hot with six months (May-October) having less than 10 mm monthly rainfall. Mean annual rainfall is 837 mm, of which 734 mm (88%) falls from December and March. The mean annual temperature is 20°C.

Table 5.2: Terrain and landuse information for four Malawi field sites

	Nsawagi (10°49'S, 34°06'E; 990 m)	Lilongwe (13°57'S, 33°47'E; 1060 m)	Mua (14°36'S, 34°51'E; 719 m)	Zomba (15°22'S, 35°20'E; 980 m)
Geology [(2)]	Alluval, colluvial and residual deposits: tertiary to recent	Biotite and hornblende rich gneisses: early Precambrian to early Palaezoic	Charnockitic suite: early Precambrian to early Palaezoic	Syenite (Chilwa Alkaline province): upper Jurassic to late Cretaceous
Silvicultural zones [(2)]	Moderately hot: harsh-24 weeks, 1000-1200 m	Moderately hot: harsh-24 weeks, 1000-1200 m	Hot: annual drought severe 31 weeks, 500-1000 m	Moderately hot: moderate 19 weeks, 900-1500 m
Soils [(1)]	Lithic leptosols associated with chromic cambisols	Ferric lixisols associated with chromic lixisols and lithic leptosols	Lithic leptosols associated with chromic cambisols	Lithic leptosols associated with chromic cambisols
Land use [(2)]	Natural forest	Intensive mixed farming	Natural forest	Intensive mixed farming
Vegetation types [(3)]	Drier Zambezian miombo woodland	North Zambezian undifferentiated woodland	Drier Zambezian miombo woodland	Wetter Zambezian miombo woodland
Species [(3)]	*Brachystegia spiciformis, B. boehmii, Julbernardia globiflora*	*Afzelia quanzensis, Burkea africana, Dombeya rotundifolia, Pericopsis angolensis, Pseudolachnostylis maprouneifolia, Pterocarpus angolensis, Terminalia sericea*	*Brachystegia spiciformis, B. boehmii, Julbernardia globiflora*	*Brachystegia floribunda, B. glaberrima, B. taxifolia, B. wangermeenana, Marquesia macroura*

Sources: [(1)] FAO-UNESCO (1977), (1988); [(2)] National Atlas of Malawi (1983); [(3)] White (1983)

Table 5.3: Climatic conditions for four Malawi field sites

	Nsawagi 10°49'S, 34°06'E; 990 m	Lilongwe 13°57'S, 33°47'E; 1060 m	Mua 14°36'S, 34°51'E; 719 m	Zomba 15°22'S, 35°20'E; 980 m
Mean annual rain (mm)	772 [1]	837	965	1205
Dry month <20 mm	6 (May-Oct) [1]	6 (May-Oct)	6 (May-Oct)	6 (May-Oct)
Wet month >100 mm	4 (Dec-Mar) [1]	4 (Dec-Mar)	4 (Dec-Mar)	4 (Dec-Mar)
Mean temperature, °C	21.5 [2]	20	24.3 [3]	21.2
Monthly max. (l - h), °C	n.a.	22.9 (Jul)-29.9 (Nov)	26.1 (Jul)-32.9 (Nov) [3]	22.3 (Jul)-29.9 (Oct)
Monthly min. (l - h), °C	n.a.	9.4 (Jul)-18.2 (Dec)	15.6 (Jul)-22.4 (Nov) [3]	12.3 (Jul)-19 (Nov)

[1] at Mzokoto (10°55'E, 34°01'S; 1035 m); [2] at Borelo (11°01'E, 33°47'S; 1050 m); [3] at Salima (13°45'E, 34°35'S; 510 m).

monthly max: monthly means of the daily maximum temperature (lowest - highest).

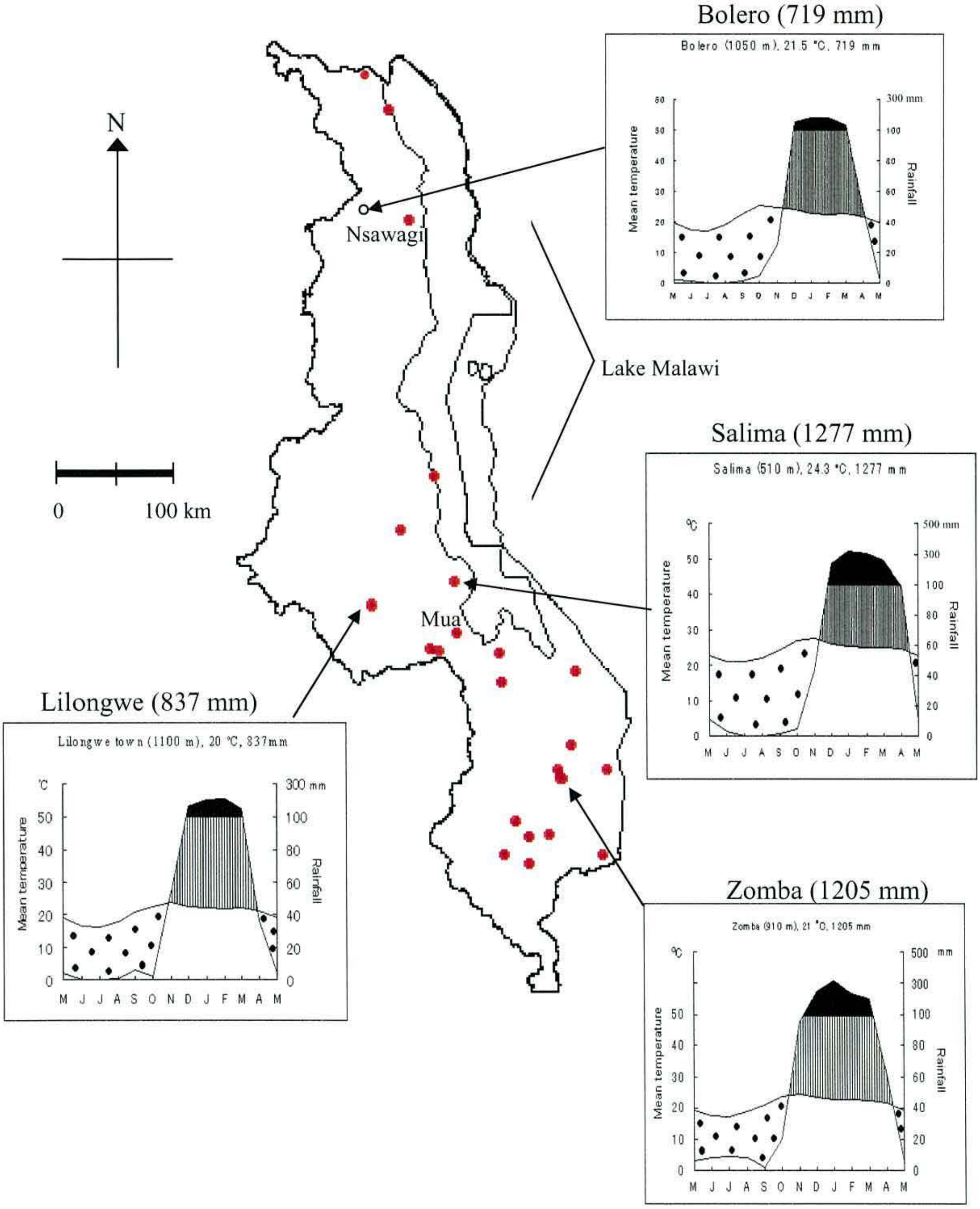
monthly min: monthly means of the daily minimum temperature (lowest - highest).

At Mzokoto, nearest weather station to Nsawagi, mean annual rainfall is 772 mm, of which about 81%, 623 mm, falls from December to March. Mean monthly rainfall from December to March ranges from 138 mm (December) to 169 mm (March). Mean monthly rainfall from May to October is consistently less than 20 mm. At the Borelo weather station near to Nsawagi from where temperature records are available, mean annual temperature is 21.5°C.

At Zomba town, the nearest weather station to Zomba National Botanic Garden, mean annual rainfall is 1205 mm, of which about 83%, 995 mm, falls from December to March. Mean monthly rainfall from December to March exceeds 200 mm. Mean monthly rainfall from May to October is less than 20 mm. Mean annual temperature is 21°C.

In Mua, mean annual rainfall is 965 mm, of which 860 mm falls from December to March. Salima is the nearest weather station to Mua which maintain temperature records. The mean annual temperature at Salima (510 m) is 24.3°C, so at Mua, because of the difference in altitude (Mua is 200 m higher), the mean annual temperature will be 23°C. In Figure 5.1, a climate diagram for Salima represents this site.

Thornthwaite index value was not calculated for Mzokoto, Zomba and Salima due to lack of data of evapotranspiration.



Legend

●: occurrences of *Oxytenanthera abyssinica*

Figure 5.1: Locations of *Oxytenanthera abyssinica* with climate diagrams for four study sites in Malawi

5.4 Biotic factors

A large region of Malawi is covered by large-leaved rain green dry forest (miombo) which is dominated by *Brachystegia*, either alone or with *Julbernardia* or *Isoberlinia* (FAO-UNESCO, 1977). Most *Brachystegia* species are semi-deciduous or briefly deciduous. The old leaves are shed as the new leaves unfold some weeks or even months before the end of the dry season. Most species in miombo are fire resistant to some extent. There are few other canopy species. In wetter miombo where rainfall is more than 1000 mm per year, there are all the miombo dominants: *Brachystegia floribunda* Benth., *B. glaberrima* R. E. Fries, *B. taxifolia* Harms, *B. wangermeenana* De Wild. and *Marquesia macroura* Gilg. In drier miombo where rainfall is less than 1000 mm per year, *Brachystegia floribunda* Benth. is absent. *Brachystegia spiciformis* Benth., *B. boehmii* Taubert and *Julbernardia globiflora* (Benth.) Troupin are often dominant (White, 1983).

The Lilongwe Nature Sanctuary is covered by the *Acacia/Piliostigma/Combretum* woodland. This has an open canopy and occurs on fertile soils. Many other trees also grow in this vegetation although *Acacia*, *Piliostigma* and *Combretum* species are very common (Wildlife Society of Malawi, 1989). White (1983) defined Lilongwe and surrounding areas as north Zambezian undifferentiated woodland in the continental scale, where dominants of miombo species are normally absent (Table 5.2).

The research areas in Nsawagi and in Mua are where the natural vegetation is woodland on stony soils which is dominated by *Brachystegia boehmii* Taubert and *Uapaca kirkiana* Müll. Arg. (Wildlife Society of Malawi, 1989). They are defined as drier Zambezian miombo woodland where rainfall is less than 1000 mm and canopy height is usually less than 15 m (White, 1983).

The natural vegetation cover of the research area in Zomba is woodland in which the branches and leaves of *Brachystegia* trees do not touch each other and sufficient light penetrates to the ground for a short grass to develop. The associated soils are sandy or stony, and infertile (Wildlife Society of Malawi, 1989). They are wetter Zambezian miombo woodland where rainfall is usually more than 1000 mm and canopy height is often more than 15 m (White, 1983).

5.5 Fauna

In the Lilongwe Nature Sanctuary, bushpigs eat new shoots of *Oxytenanthera abyssinica* at the beginning of the rainy season when shoots are soft, and vervet monkeys eat leaves and seeds of *Oxytenanthera abyssinica*. It was noted (the direct observations of the author) that birds, the white-flanked batis - *Batis molitor* also eat the seeds.

At the other sites, it is not clear how much *Oxytenanthera abyssinica* is affected by browsing or seed-eating animals. However, in Nsawagi and in Zomba vervet monkeys and baboons are active. Wildboars and bushpigs are few in Nsawagi and Zomba because here, in contrast with Lilongwe Nature Sanctuary, they are not protected from poachers.

Vervet monkeys and baboons are also active in Mua-Livulezi Forest Reserve.

5.6 Land ownership

Lilongwe Nature Sanctuary belongs to Ministry of Tourism, Parks and Wildlife. The area of the River Lukulu at Nsawagi is traditionally managed by local villagers. Zomba National Botanic Garden is owned by the National Herbarium and Botanic Gardens. The Mua-Livulezi Forest Reserve is owned and managed by the Department of Forestry.

Chapter 6

Clump and culm characterisation and monitoring

This chapter is in three main parts. The first part reports clump description and general background information for field surveys (6.1). The second part reports baseline clump monitoring undertaken in north, central and south Malawi (6.2). The third part describes the monitoring of harvest intensity impact (6.3). Subsections are devoted to protocols for the work carried out and to the findings.

6.1 Background

6.1.1 The concept of bamboo clumps for management and silviculture

A clump is assumed to represent roughly the set of shoots resulting from the germination of a single seed, and arising from a connected rhizome system (McClure, 1966). If groups of shoots interconnected by rhizomes but isolated from other groups that were connected in the past are present, for convenience, each group is considered a clump from the management perspective. This possibility is more likely in species which in normal growth (unlike *Oxytenanthera abyssinica*) have leptomorphic rhizome systems and widely separated culms (Ueda, 1960).

There is considerable variation in how discrete individual clumps are, depending on whether there are bamboos brakes or the clumps are dispersed among other (non-bamboo) vegetation. Bamboo culms are produced from rhizomes as lateral branches or apical projection of rhizomes (McClure, 1966). Therefore, the clarity of individual clumps in bamboo brakes depends on whether the rhizomes extend widely (leptomorphic systems) or form a compact, connected mass (pachymorphic systems) giving rise to dense contiguous clusters of culms (McClure, 1966). Bamboo stands of pachymorphic systems are managed at each small clump level (Deogun, 1937; Dransfield and Widjaja, 1995; Fanshawe, 1972; Liese, 1985; Parkash, 1991; Troup, 1921; Varalakshimi, 1992), but the stands of leptomorphic systems are generally managed on the basis of unit areas which may contain one or more clumps (Quantai, 1980; Ueda, 1960; Xinglin *et al.*, 1995), due to the unclear distinction between clumps.

Soil working and fertiliser applications are applied at clump level rather than at stand or culm level for pachymorph bamboos (Azmy, 1996). Harvesting schedules for pachymorph bamboos are based on the balance of culms of different ages within clumps and prescriptions for culm harvesting are per clump (Deogun, 1937; Dransfield and Widjaja, 1995; Fanshawe, 1972; Liese, 1985; Parkash, 1991; Varalakshimi, 1992). Variation in clump character from one bamboo species to another makes it important to have a clear understanding of the typical clump structure of any species of interest (McClure, 1966). An uneven age partitioning of culms within clumps is normal.

At different ages, culms have different use potential (Inada, 2000; Troup, 1921), so the management aim is to optimise clump composition to combine taking maximal advantage of shoot production potential and achieve a spatial distribution of culms which favours their rapid growth (Deogun, 1937; Huberman, 1959; Parkash, 1991; Ueda and Numata, 1961) whilst not impairing the sustained production of shoots by the clump (and is a spatial arrangement also convenient for harvesting). Experimental initiatives are needed to establish what management should recognise as this optimal balance and this optimal spatial arrangement of age classes.

6.1.2 Intention of this study

This aspect of the present study was composed of two field activities. Objectives were:

- to determine whether there were the differences in growth, culm maturation, reproduction and morphology of *Oxytenanthera abyssinica* between populations/regions of Malawi
- to examine the impact of different levels of harvesting on new shoot production, in Malawian *Oxytenanthera abyssinica* populations.

Two null hypotheses were to be tested:

- there are no differences in clump characteristics between populations of *Oxytenanthera abyssinica* in different regions of Malawi
- harvesting culms does not reduce or increase new shoot production in clumps of *Oxytenanthera abyssinica* in Malawi.

6.1.3 General framework for clump observations

6.1.3.1 Identification of research clumps and definitions for culm characteristics

Clump structure and site

A clump is composed of one or more culms and/or shoots (culms <1 year) originating from the same rhizome system. A clump extension is made with further development of the rhizome system and the emergence from the ground of new shoots at and beyond the previous year's edge of the clump. In practice, however, the boundaries of clumps may be unclear. As a preliminary to the field research, the soil around a clump of *Oxytenanthera abyssinica* in the Zomba Botanic Garden in southern region and another clump in Lilongwe Nature Sanctuary was excavated to expose the rhizome system and the nature of the clump boundary (Plate 1: p.138). Some culms away from a clump were found to be connected to it by the rhizome system. Culms bend usually towards the periphery of the clump to which they belong and culms which bent outward from the centre of a clump were considered part of it. Clumps where there was any ambiguity about where the periphery was located were not included in research activity.

To reduce uncontrolled variation between experimental clumps, the clump environment was standardised in terms of exposure (mid slope sampling only), gradient (10-30% gradient only), soil depth (not less than 50 cm) and topographic position (within 30 m of watercourse). Only clumps of 20-50 culms and shoots (combined) were considered. Clumps which had been exploited were not sampled.

Culm age

Monitoring activities involved shoots, culms and clumps. Shoots arise from rhizome apices. In this thesis, the term 'shoot' is used for shoots which started sprouting above the soil surface in the rainy season just before monitoring (Plate 2). Mortality of bamboo shoots is high. About 80% of new shoots of *Phyllostachys edulis* died before they became culms according to Ueda (1983). It was also observed for *Oxytenanthera abyssinica* at the beginning of the monitoring that the mortality rate of new shoots was high until they exceeded 30 cm above the ground. It was roughly estimated about 10% of new shoots of the total new shoots sprouted died from insect attack and due to disturbance of mammals before reaching 30 cm above the ground in 2002. New shoots (shorter than about 30 cm) which appeared at the beginning of the rainy season were likely to be eaten by mammals (monkeys and bushpigs), probably because they were soft. Therefore, culms with apices less than 30 cm above ground level were not counted for experimental purposes.

Young culms were culms 12-16 months (two seasons) old in March-April 2002, and could be assumed to have sprouted in the previous rainy season, December 2000 to March 2001. Such young culms are covered with appressed white hairs and the culm colour is green. There are white rings around nodes and few branches and leaves on culms. Mature culms were culms more than 16 months (>2 seasons) old in March-April 2002, which could be assumed to have sprouted in the rainy seasons before March 2000. Mature culms have few hairs and the colour is brownish green. There are more branches and leaves on mature culms than on young culms.

6.1.3.2 Timing of research activity

Azmy (1996) and Kleinhenz and Midmore (2001) reported that where two distinct seasons exist (rainy and dry seasons) recruitment of shoots occurred only in the rainy season. New shoots of *Oxytenanthera abyssinica* are also produced in the rainy season according to the past studies (Anon., 1944; Fanshawe, 1972; Kigomo and Kamiri, 1985; Pardy, 1954). It was known (personal observation, 2000) that the production of new shoots in *Oxytenanthera abyssinica* usually ends at the end of the rainy season (March, in Malawi). For this study, recording of new shoots was therefore carried out in March and April, 2002.

6.2 Clump characterisation

6.2.1 Protocol

Assessment activities were carried out in Lilongwe, Nsawagi and Zomba when the initial growth of new shoots had stopped and when the rains had also stopped (March-April). Information was collected from eight clumps at each location to compare the number and the diameter of new shoots sprouted in 2002 with those of culms present which were more than one year old. Monitoring involved counting young and mature culms and shoot numbers and measuring the diameter of each culm and shoot at breast height. Length was measured for representative mature culms (one per clump).

Investigation period

Clumps to be sampled for recording purposes were identified on 14 April 2002 in Lilongwe, 1 April 2002 in Nsawagi and 8 March 2002 in Zomba. Recording was carried out on 15 April 2002 in Lilongwe, 2 April 2002 in Nsawagi and 9 March 2002 in Zomba. Identifying the sample clumps and actual recording each took a single day at each site.

Basic parameters recorded

Culms over 2 cm in diameter at 120 cm above ground were counted, separating them into shoots less than 12 months old (sprouted in the current rainy season), young 12-16 months old (two seasons) or mature more than 16 months old (>2 seasons) and the diameter at 120 cm above ground was measured with callipers. Where there was a node at 120 cm above ground, diameter was measured just below the node. Culms extending less than 30 cm length above ground were not counted. Diameter at the middle point was measured for culms and shoots over 30 cm long but less than 120 cm above the ground. If the middle point diameter was over 2 cm, these culms were also counted and their diameter was recorded. Counting was carried out using temporary grids of nylon strings and bamboo and wooden sticks to ensure no culms or shoots were missed or recorded in error. Grid units were 1 m × 1 m.

After eliminating clumps/culms which did not meet the specifications set (more than 16 culms of dbh >2 cm), representative clumps/culms from the remainder were used as the sample. Selected culms existed on the periphery so that the measurements of the length with scales and clinometers could appropriately be done.

Derived parameters

New culm production relative to the numbers of existing culms varies with bamboo species (Kleinhenz and Midmore, 2001; Manthauda, 1960; Tomar, 1963; Ueda, 1960). The average number of culms produced annually by clumps of *Oxytenanthera abyssinica* was 17-20% of >1 year old culms in Zimbabwe (Henkel, 1927) and 50% in Ethiopia (LUSO CONSULT, 1997a). The ratio, new shoots/culms surviving from previous years' recruitment, was, therefore, determined. The cross sectional area and length of culms are correlated for *Oxytenanthera abyssinica* (Inada *et al.*, 2003). Therefore, the volume of culms including lumina can be estimated with the cross sectional area. In this study, the cross sectional area was recorded and included for analysis to examine the relation of new shoots and culms surviving from previous years' recruitment more precisely rather than solely analysing with the numbers. Ratios were also determined for:

- ratios of number of culms <1 year (recorded after one growing season) old /number of culms ≥1 year (>1 season) old
- ratios of number of culms 12-16 months (recorded after two growing seasons) old/number of culms >16 months (>2 seasons) old
- ratios of cross sectional area of culms <1 year (recorded after one growing season) old/ cross sectional area of culms ≥1 year (>1 season) old
- ratios of cross sectional area of culms 12-16 months (recorded after two growing seasons) old/cross sectional area of culms >16 months (>2 seasons) old.

6.2.2 Data processing

Clump composition in terms of numbers of culms and diameter for the three age categories was summarised in tables by site as observed numbers and the percentage combination of each age of culms to the total. Culm categories were: less than one year (new culms), 12-16 months - two seasons (young culms) and more than 12 months - >2 seasons (mature culms). Mean diameters at breast height (cm) with ±95% confidence limits were tabulated by site. Frequency histograms of each age category in each site were made.

Mean numbers of new shoots and culms per clump for each site were expressed with ±

95% confidence limits. One way analysis of variance (ANOVA) was carried out to compare the mean numbers of new shoots and culms within sites, and also to compare the mean numbers of new shoots and culms, and mean culm diameter and length per clump among sites. F ratios for one way ANOVA were calculated:

F ratio = SS between-group/SS within-group

where:

SS = sum of squares of deviations from the mean = $\sum x^2 - \frac{(\sum x)^2}{n}$

where:

x is parameter value and n is number of observation made.

The Minitab, computer package was used to calculate F ratios. For each site, actual values of the numbers of new shoots less than 12 months old and culms 12-16 months and more than 16 months old were separately entered via Minitab worksheets. Mean culm diameter and culm length per clump were also entered on worksheets.

Means of derived parameters for (new <12 months old) : (young 12-16 months old + mature >16 months old) and (young) : (mature) of culm numbers and of cross sectional areas at each locality were also tabulated. Relationship between these parameters were examined by Spearman rank correlation. Culm numbers and cross sectional areas of new shoots, young and mature culms were re-coded as their rank order at each locality, assigning 1 to the smallest value and 8 to the largest. Correlation between the ranks were examined by calculating r_s :

$$r_s = 1 - \left[\frac{6\sum d^2}{(n^3 - n)} \right]$$

where:

n is the number of units in a sample and d is the difference between ranks.

r_s was compared with critical value for two-tailed test with the appropriate observation number. In this case, the observation number was eight and the critical value was 0.881 at 1% level and 0.738 at 5% level.

Also, one way ANOVA tested whether mean ratios of derived parameters for (new) : (young + mature) and (young) : (mature) of culm numbers and of cross sectional areas differed among sites and among seasons at each locality. (young) : (mature culms) was the ratio for the previous season (2001) and (new shoots) : (young + mature culms) for this season (2002). New (<12 months) young (12-16 months) and mature (>16 months) were the ages when they were observed in March-April 2002. Data were expressed as proportions of the total and arcsine transformation applied to values before analysis. ANOVAs were carried out on the transformed data. Minitab was used to calculate F ratios.

6.2.3 Results

Culm number

The eight *Oxytenanthera abyssinica* clumps sampled at each location are characterised in Table 6.1. Within clumps in Nsawagi, 13-75% of culms were <12 months old and there were significantly more new shoots (<12 months old) present in each clump in Nsawagi than in Lilongwe and in Zomba (Tables 6.1-6.4).

One way analysis of variance (ANOVA) test shows that the (young) : (young + mature) and (new) : (new + young + mature) ratios differ significantly with location, in terms of both culm number and accumulated culm cross sectional area. (Table 6.5). The (young): (mature culms) ratio in 2001 when the clumps were assessed may have reflected the ratio of new shoots produced in the previous season to pre-existing culms. On this basis, there was significant variation of new shoot production against existing culms in different years, because there were significantly different means in (young) : (mature) and (new) : (young + mature) ratios in each site (Tables 6.5-6.6, Figure 6.1).

Only in Nsawagi (Table 6.7) was there a statistically positive significant correlation between the cross sectional areas of young culms and the cross sectional areas of mature culms. It would be difficult to suggest a certain proportion of new shoot production against existing culms for *Oxytenanthera abyssinica*. Recruited new shoots can be 20-28% of the number of existing culms and 27-31% to the clump's accumulated cross sectional area (Table 6.8).

Table 6.1: Characterisation of *Oxytenanthera abyssinica* clumps sampled in Lilongwe, Nsawagi and Zomba, Malawi (eight clumps per site)

Lilongwe (age by month)								Nsawagi (age by month)								Zomba (age by month)							
Clump	All ages	<12		12-16		>16		Clump	All ages	<12		12-16		>16		Clump	All ages	<12		12-16		>16	
1	29	4	(14)	7	(24)	18	(62)	1	46	15	(33)	8	(17)	23	(50)	1	18	3	(17)	5	(28)	10	(55)
2	30	3	(19)	7	(23)	20	(67)	2	28	8	(28)	3	(11)	17	(61)	2	25	6	(24)	8	(32)	11	(44)
3	37	3	(8)	17	(46)	17	(46)	3	27	7	(26)	3	(11)	17	(63)	3	26	6	(23)	5	(19)	15	(58)
4	48	9	(19)	16	(33)	23	(48)	4	29	7	(24)	1	(4)	21	(72)	4	35	3	(8)	10	(29)	22	(63)
5	18	4	(22)	6	(33)	8	(45)	5	45	6	(13)	6	(13)	33	(73)	5	25	3	(12)	3	(12)	19	(76)
6	26	9	(34)	2	(8)	15	(58)	6	34	16	(47)	4	(12)	14	(41)	6	29	1	(4)	5	(17)	23	(79)
7	33	10	(30)	10	(30)	13	(40)	7	37	20	(54)	6	(16)	11	(30)	7	18	2	(11)	6	(33)	10	(56)
8	22	6	(27)	5	(23)	11	(50)	8	16	12	(75)	0	(0)	4	(25)	8	52	14	(27)	10	(19)	28	(54)

Notes: Numbers in brackets indicate % of all ages. Recorded in March-April, 2002.

Table 6.2: Percentages of the number and cross sectional areas of young culms against mature, and new shoots against young plus mature culms of *Oxytenanthera abyssinica* (eight clumps) in Lilongwe, Nsawagi and Zomba, Malawi

		Lilongwe		Nsawagi		Zomba	
	Clump	y/m	n/(y+m)	y/m	n/(y+m)	y/m	n/(y+m)
Number	1	39	16	35	48	50	20
	2	35	11	18	40	73	32
	3	100	9	18	35	33	30
	4	70	23	5	32	45	9
	5	75	29	18	15	16	14
	6	13	53	29	89	22	4
	7	77	43	55	118	60	13
	8	45	38	0	300	36	37
Cross section (cm^2)	1	68	29	43	75	53	21
	2	20	61	21	42	98	46
	3	87	42	27	60	32	40
	4	86	40	5	42	54	10
	5	53	19	25	20	16	26
	6	57	8	28	125	26	4
	7	185	16	77	152	79	22
	8	118	35	0	428	33	46

Note: n: new (<12 months); y: young (12-16 months); m: mature (>16 months) are the ages when they were observed in March-April 2002.

Table 6.3: Mean number of new shoots and culms per clump (8 clumps observation for each location) with 95% confidence limits (March-April, 2002)

	Lilongwe	Nsawagi	Zomba
new shoots <12 months	6.00 ± 2.46	11.25 ± 4.14	4.75 ± 3.45
young culms 12-16 months	8.75 ± 4.42	3.86 ± 2.25	6.50 ± 2.14
mature culms >16 months	15.30 ± 4.09	17.50 ± 7.21	17.25 ± 5.68

Table 6.4: One way analysis of variance (ANOVA) for the mean number of culms per clump, by category at Lilongwe, Nsawagi and Zomba, Malawi

Culm category		Degree of freedom	Sum of squares	Mean squares	F ratio	Significance
<12 months (new)	between sites	2	190.3	95.2	5.69	*
	within sites	21	351.0	16.7		
	total	23	541.3			
12-16 months (young)	between sites	2	95.2	47.6	3.42	n.s.
	within sites	21	292.4	13.9		
	total	23	387.6			
>16 months (mature)	between sites	2	16.6	8.3	0.17	n.s.
	within sites	21	1011.4	48.2		
	total	23	1028.0			

* = significant at 5% level (significance probability) ; n.s. = not significant

8 clumps observed for each location

Table 6.5: One way ANOVA for (young) : (young + mature) and (new) : (new + young + mature) ratios of *Oxytenanthera abyssinica* clumps at Lilongwe, Nsawagi and Zomba, Malawi

number		Degree of freedom	Sum of squares	Mean squares	F ratio	Indication
y/(y + m) [a]	between sites	2	775.1	387.5	5.00	*
	within sites	21	1628.0	77.5		
	total	23	2403.0			
n/(n + m+ y) [b]	between sites	2	931.1	465.5	5.66	*
	within sites	21	1728.6	82.3		
	total	23	2659.7			
Cross section areas						
y/(y + m) [a]	between sites	2	1053.6	526.8	5.33	*
	within sites	21	2076.3	98.9		
	total	23	3129.9			
n/(n + m+ y) [b]	between sites	2	1156.4	578.2	6.26	**
	within sites	21	1939.9	92.4		
	total	23	3096.3			
Number						
Lilongwe (a: b)	between	1	324.8	324.8	5.67	*
	within	14	801.4	57.2		
	total	15	1126.2			
Nsawagi (a: b)	between	1	937.0	937.0	6.80	*
	within	14	1927.0	138.0		
	total	15	2864.0			
Zomba (a: b)	between	1	343.6	343.6	7.66	*
	within	14	628.0	44.9		
	total	15	971.5			
Cross section areas						
Lilongwe (a: b)	between	1	626.9	626.9	9.76	**
	within	14	899.5	64.2		
	total	15	1526.3			
Nsawagi (a: b)	between	1	1190.0	1190.0	7.46	*
	within	14	2234.0	160.0		
	total	15	3424.0			
Zomba (a: b)	between	1	228.0	228.0	3.61	n.s.
	within	14	882.9	63.1		
	total	15	1110.9			

__Keys__: Cross sectional areas (cm^2). Data first converted to the proportion of the total. ANOVA applied to the arcsine transformed data. n = new shoots <12 months; y = young culms 12-16 months; m = mature culms >16 months in March-April 2002. * = significant at 5%, ** = significant at 1% level; n.s. = not significant (significance probability)

Table 6.6: One way analysis of variance (ANOVA) for the mean number of new shoots and culms per clump at Lilongwe, Nsawagi and Zomba, Malawi

		Degree of freedom	Sum of squares	Mean squares	F ratio	Significance
Lilongwe	between ages	2	393.2	196.6	9.75	**
	within ages	21	423.4	20.2		
	total	23	816.6			
Nsawagi	between ages	2	744.2	372.1	10.53	**
	within ages	21	742.4	35.4		
	total	23	1486.6			
Zomba	between ages	2	733.0	366.5	15.74	**
	within ages	21	489.0	23.3		
	total	23	1222.0			

** = significant at 1%, *** = significant at 0.1% level (significance probability); 8 clumps observation for each location

Table 6.7: Spearman rank correlations between culm categories

	young and mature culms		new and older culms	
	Numbers	Cross section areas	Numbers	Cross section areas
Lilongwe	n.s.	n.s.	n.s.	n.s.
Nsawagi	n.s.	*	n.s.	n.s.
Zomba	n.s.	n.s.	n.s.	n.s.

*= significant at 5% level, (Spearman rank correlation); n.s. = not significant

Table 6.8: Number and cross sectional area ratios expressed as percentage for young culms/mature culms, and new shoots/young plus mature culms of *Oxytenanthera abyssinica* in Lilongwe, Nsawagi and Zomba, Malawi

		Average of eight clumps in each location	
		young as % of mature	new as % of (mature + young)
Number	Lilongwe	57	28
	Nsawagi	22	85
	Zomba	42	20
Cross sectional areas	Lilongwe	84	31
	Nsawagi	28	118
	Zomba	49	27

New, <12 months; young, 12-16 months; mature, >16 months; ages as in March-April 2002.

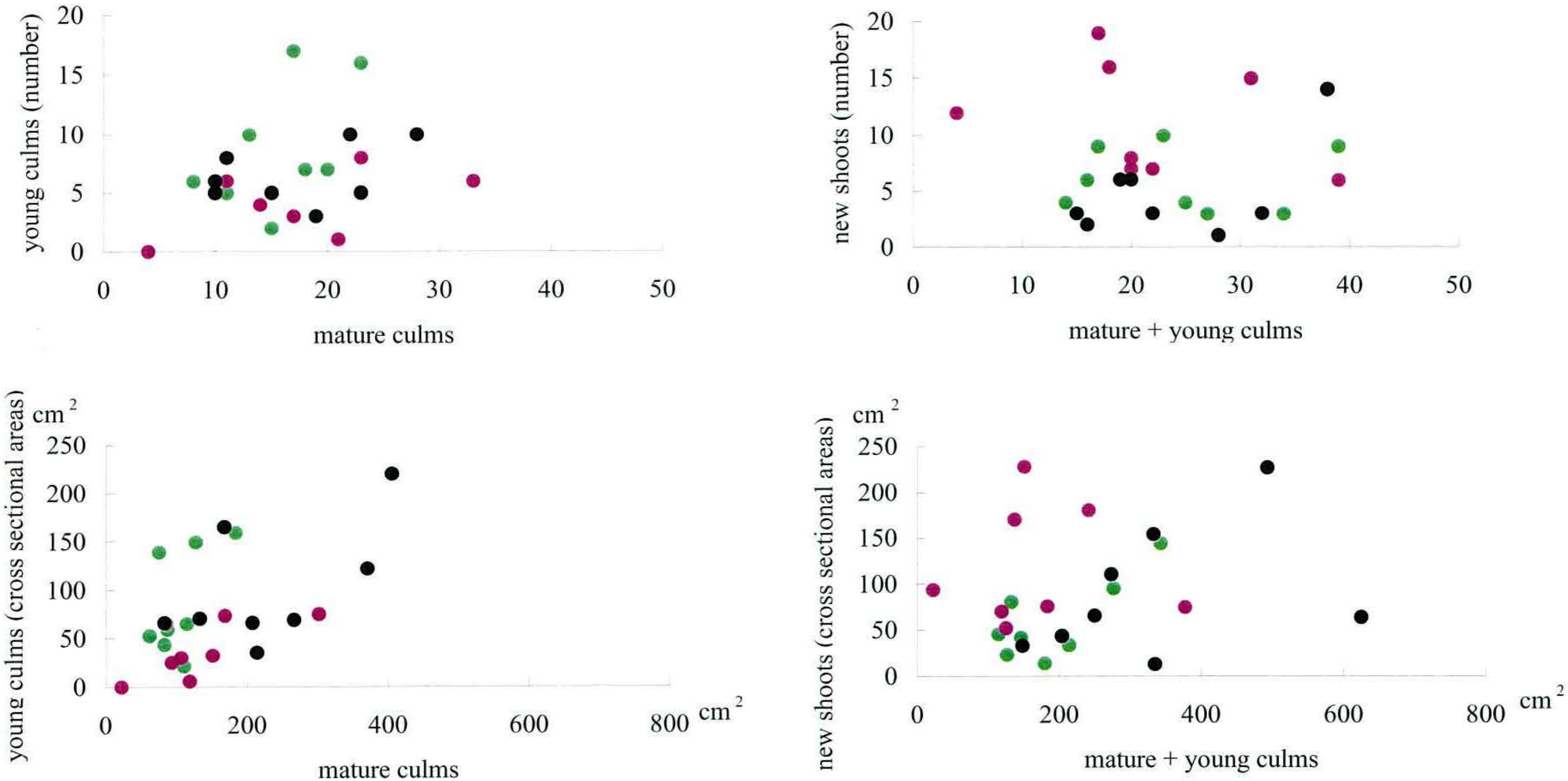


Figure 6.1: The relations between (young 12-16 months) : (mature >16 months) and (new <12 months) : (young + mature) culms of *Oxytenanthera abyssinica* in terms of their number (upper) and cross sectional areas (below) for Lilongwe (●), Nsawagi (●) and Zomba (●), Malawi (March-April 2002)

Culm diameter and length

Culms in Zomba had larger diameters at breast height (mean 4.2 cm) than did those in Lilongwe (mean 3.2 cm) and Nsawagi (mean 3.3 cm) (Tables 6.9-6.10, Figure 6.2). There are relatively more culms >16 month old (mature) in the 2-3 cm diameter class than other classes in Lilongwe. The mean length of representative culms at least 12 months old in Zomba (14.6 m) was significantly greater than the corresponding values for Lilongwe (8.3 m) and Nsawagi (6.7 m) (Table 6.11).

Table 6.9: One way analysis of variance (ANOVA) for the mean of culm diameter at breast height (dbh) and for the mean length among sites

		Degree of freedom	Sum of squares	Mean squares	F ratio	Significance
mean culm dbh (cm)	between sites	2	151.3	75.6	120.31	***
	within sites	718	451.3	0.6		
	total	720	602.6			
mean culm length (m)	between sites	2	182.1	91.0	8.87	**
	within sites	15	154.0	10.3		
	total	17	336.1			

** = significant at 1%, *** = significant at 0.1% level (significance probability)

6.2.4 Conclusions

Clump compositions of age classes varies with site. Mean culm diameter at breast height and mean culm length were significantly different among sites. There was also significant variation of new shoot production against existing culms in different years within the sites. Recruited new shoots can be 20-28% of the number of existing culms and add 27-31% to the clump's accumulated cross sectional area. Possibly mortality of shoots in 2002 was high in Lilongwe and in Zomba, but low in Nsawagi or there is significant yearly variation in new shoot production.

Table 6.10: Culm diameter characterisation (mean ± 95% confidence limit) of *Oxytenanthera abyssinica* clumps sampled in Lilongwe, Nsawagi and Zomba, Malawi (eight clumps per site) unit: cm

clump	Lilongwe (age by month)			Nsawagi (age by month)			Zomba (age by month)		
	<12	12-16	>16	<12	12-16	>16	<12	12-16	>16
1	2.7 ± 0.61	2.8 ± 0.58	2.3 ± 0.32	3.9 ± 0.41	3.4 ± 0.31	3.0 ± 0.32	4.3 ± 0.93	4.2 ± 1.05	4.0 ± 0.80
2	2.5 ± 0.50	3.3 ± 0.83	2.7 ± 0.21	3.5 ± 0.30	3.6 ± 2.27	3.3 ± 0.32	5.7 ± 0.58	5.1 ± 0.61	4.3 ± 0.62
3	3.7 ± 2.70	3.2 ± 0.28	2.3 ± 0.25	3.6 ± 0.48	3.3 ± 0.76	2.6 ± 0.25	4.7 ± 1.26	4.0 ± 1.04	4.1 ± 0.48
4	3.6 ± 0.46	3.4 ± 0.25	2.5 ± 0.31	3.0 ± 0.59	2.8 ± 0	2.7 ± 0.20	5.1 ± 2.86	5.3 ± 0.40	4.8 ± 0.34
5	3.7 ± 0.26	3.5 ± 0.49	3.7 ± 0.23	4.0 ± 0.52	4.0 ± 0.29	3.4 ± 0.13	5.3 ± 0.87	3.8 ± 2.28	3.7 ± 0.32
6	3.4 ± 0.37	3.7 ± 9.02	3.0 ± 0.30	3.6 ± 0.39	3.1 ± 0.69	3.0 ± 0.43	4.0 ± 0	4.1 ± 0.88	3.8 ± 0.19
7	4.3 ± 0.39	4.5 ± 0.52	4.2 ± 0.36	3.9 ± 0.28	3.7 ± 0.76	3.1 ± 0.35	4.6 ± 2.15	3.7 ± 0.43	3.2 ± 0.47
8	3.1 ± 0.53	3.6 ± 0.98	2.6 ± 0.36	3.1 ± 0.27	n.a.	2.6 ± 1.28	4.5 ± 0.51	3.9 ± 0.56	4.0 ± 0.29

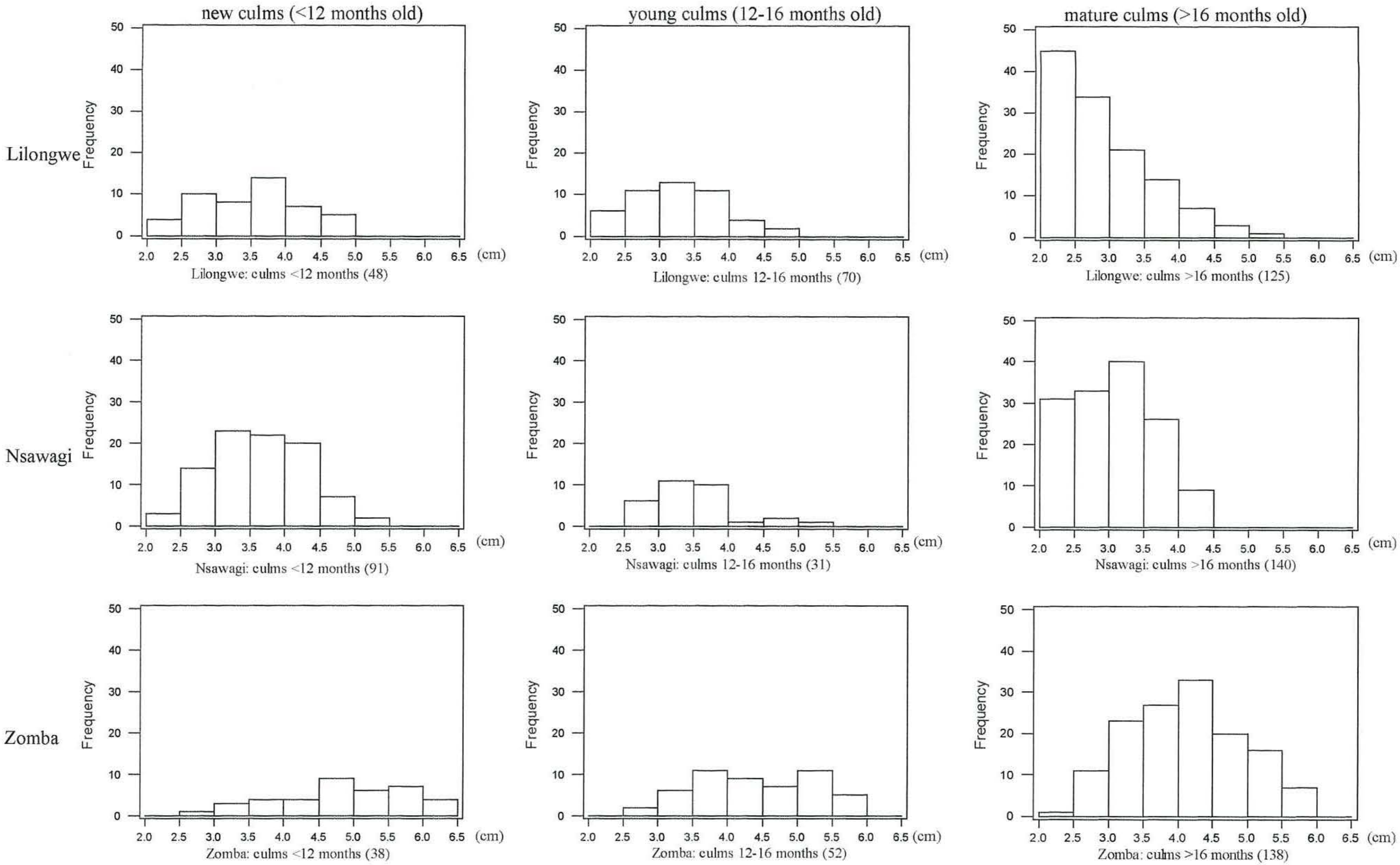


Figure 6.2 : Frequency of culm diameters (dbh in cm) in each site and age categories

Table 6.11: Length of representative culms and their diameter at breast height in Lilongwe, Nsawagi and Zomba (1 culm per clump)

Clump	Lilongwe		Nsawagi		Zomba	
	length (m)	dbh (cm)	length (m)	dbh (cm)	length (m)	dbh (cm)
1	8.8	3.2	7.0	3.9	10.8	5.2
2	8.5	2.5	6.3	2.9	16.9	2.7
3	10.5	2.9	6.8	3.8	19.3	5.5
4	17.0	3.4	6.6	3.6	12.3	4.8
5	6.9	3.0	n.a.	n.a.	16.2	5.6
6	6.9	3.1	n.a.	n.a.	12.0	3.0
7	5.5	2.6	n.a.	n.a.	n.a.	n.a.
8	5.8	2.0	n.a.	n.a.	n.a.	n.a.
mean (n)	8.7 (8)	2.8 (8)	6.7 (4)	3.6 (4)	14.6 (6)	4.5 (6)

6.3 New culm production under different felling intensities

In general management of pachymorph bamboos, the cutting cycle and culm felling intensity are optimised for each species on a clump basis with some mature culms being retained to support new shoot production and maintain a vigorous rhizome system (Huberman, 1959; Liese, 1985). A three to four years cutting cycle is usually recommended (Ahmad and Haron, 1994; Wong, 1995a - Malaysia, *Bambusa, Dendrocalamus, Gigantochloa* and *Schizostachyum* spp.; Varmah and Bahadur, 1980 - India, *Dendrocalamus strictus* (Roxb.) Nees; Vivekanandan, 1980 - Sri Lanka, *Bambusa blumeana* Schult. f.). Troup (1921) recommended cutting 50% of mature culms more than one year old every 1-3 years for the management of *Dendrocalamus strictus* clumps in India. Azmy (1996) recommends a lower harvesting intensity but was more strict the culm age for *Gigantochloa scortechinii* Gamble in Malaysia: 40% cutting of mature culms more than three years old. With clear cutting, a clump would produce small culms in the following year (Varmah and Bahadur, 1980 - India, *Dendrocalamus strictus*) or die (Chinte, 1965; Virtucio, 1976 - Philippines, *Bambusa blumeana, Bambusa vulgaris* J. C. Wendl. and *Dendrocalamus asper* (Schult. f.) K. Heyne). Further, clear cuttings should be avoided, as it would take more time for clumps to produce full sized culms (Liese, 1985).

It is common practice when harvesting *Oxytenanthera abyssinica* in Malawi to clear clumps but this tends to bring about their death. Also, cutting out all soft culms of less than one year old for baskets leads to the death of clumps. Further, exposure to fire after harvesting exacerbates the adverse impact and promotes clump mortality (Anon., 1954a; Inada, 2000). Unsuitable harvesting, as widely applied in Malawi, leads to low clump productivity (Inada, 2000). New shoots are produced at the perimeter of the clump (Fanshawe, 1972). In southern Malawi, culms are harvested from the perimeter because those at the centre of clumps are laborious to harvest, and are often dead.

One recommendation to improve clump condition of *Oxytenanthera abyssinica* is to cut only mature culms and leave young ones for future harvesting (Anon., 1957). Indeed, no past reports seem to recommend harvesting any young culms for *Oxytenanthera abyssinica* and for bamboos in general. Anon. (1962a), Fanshawe (1972) and Mooney (1959) recommend harvesting 25-50% of "old" culms in each clump of *Oxytenanthera abyssinica* every year. Anon. (1954) recommends leaving a sufficient number of more than one year old culms for the growth of the new *Oxytenanthera abyssinica* culms but no specific number or proportion has been recommended. Farmers, however, use young culms less than one year old of *Oxytenanthera abyssinica* for basket making in Malawi, and basket making provides higher income than other alternatives in the rural areas (Inada, 2000; Inada, 2001a). In India, young culms less than one year old of *Dendrocalamus strictus* were allowed to harvest only for basket making under supervision according to Troup (1921), but felling intensity and cycle on this harvest were not reported. Harvesting intensities for young and mature culms of *Oxytenanthera abyssinica* therefore merit investigation with a view to specifying appropriate schedules for sustained culm production.

Monitoring of harvest intensity impact on *Oxytenanthera abyssinica* was carried out in Lilongwe, Malawi, to observe the production of new shoots under various felling intensities of young culms 7-12 months old culms and more than 12 months old culms to determine an optimal number of culms to be retained. Culms were referred to age categories before additional new shoots appeared, so that ageing the culms preserved was simpler.

6.3.1 Choice of location and identification of experiment clumps

Lilongwe Nature Sanctuary was selected for the clump monitoring experiment because it was well protected by forest guards from poachers and illegal exploitation of trees and bamboos. Also, visitors passing across the sanctuary reinforced guarding. It has consequently had a core of relatively undisturbed vegetation for 30 years, since establishment in 1972.

The sanctuary is 166 ha in extent and covered by *Acacia/Piliostigma/Combretum* woodland. The woodland is divided into three zones from A to C (Map 6.1). The east bank of the Lingazi river in Zone A was selected as the research area for this study and in Zone A *Oxytenanthera abyssinica* grew naturally. Zone B (near the boundary of the sanctuary) was not selected because there was high exploitation of *Oxytenanthera abyssinica*. There were no clumps of *Oxytenanthera abyssinica* in Zone C. The experimental site in Zone A extends about 1 km from south to north and 600 m from east to west.

Clump environment was standardised in terms of exposure (mid slope sampling only), gradient (10-30% gradient only), soil depth (not less than 50 cm) and topographic position (within 30 m of watercourse). There were about 200 clumps of *Oxytenanthera abyssinica* in such conditions in Zone A of the site. Some were composed of only a few culms and some were composed of more than a hundred culms. Of the 200 clumps, the most commonly occurring size of clump (containing 20-80 culms) was considered experimentally suitable as representing the typical clump size of the species. However, clumps which had been exploited were not sampled and nor were clumps which had ambiguous boundaries with other clumps. A point was located every 20 m along a south-north line through Zone A and the nearest acceptable clump with ca 20-80 culms to each point was taken as an experimental clump.

6.3.2 Protocol

Thirty six clumps were sampled for this experiment. There were four replications for each of nine treatments. The minimum distance between neighbouring experimental clumps was 5.7 m and the maximum was more than 30 m.

Investigation period

Field study in the Lilongwe Nature Sanctuary started on 30 October 2001 (end of dry season), and ended on 4 June 2003 (end of main rainy season). Basic parameters for the experiment were recorded for 19 months in total. Clumps and culms were marked from 30 October to 4 November 2001. Culms were felled on 6 and 7 November 2001 before new shoots appeared. New shoots of *Oxytenanthera abyssinica* are produced only in the rainy season according to past studies (Anon., 1944; Fanshawe, 1972; Kigomo and Kamiri, 1985; Pardy, 1954) and personal observations. Recording of new shoots was carried out in the dry season in April 2002 and in June 2003. Assessment dates are tabulated in Table 6.12. The length of the first shoot sprouted for each clump since the experiment started was recorded weekly during the first six months until growth in length stopped. If the shoot died, the weekly increment of the length of a shoot secondly sprouted in each clump was recorded.

Table 6.12: Dates of assessment activities of culm production

	2001	2002	2003
	30 Oct. - 4 Nov.	15-16 April	2 - 4 June
Number of shoots	+	+	+
Number of culms	+	+	+
Diameter at breast height	+	+	+
Culm growth	Weekly*	n.a.	n.a.

* weekly from November 2001 to April 2002 - representative culms (1 per treatment)

Mapping procedure

The positions of culms (where each culm emerged from the soil surface and survived) were mapped in each clump with reference to a 1 m × 1 m grid (Figure 6.3). The grids were made with nylon strings and wooden sticks. Grids were positioned 120 cm above the ground to raise them above the congested lower parts of the clumps. They were left in place throughout the experimental observation period.

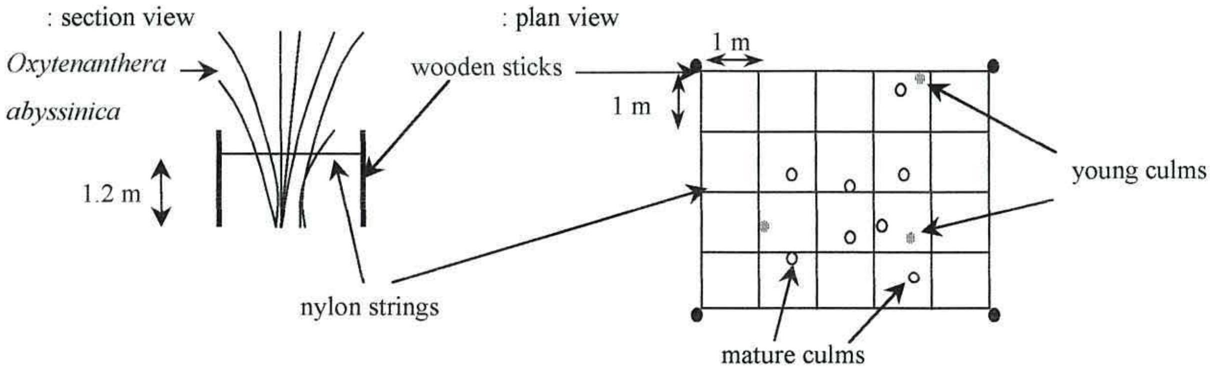
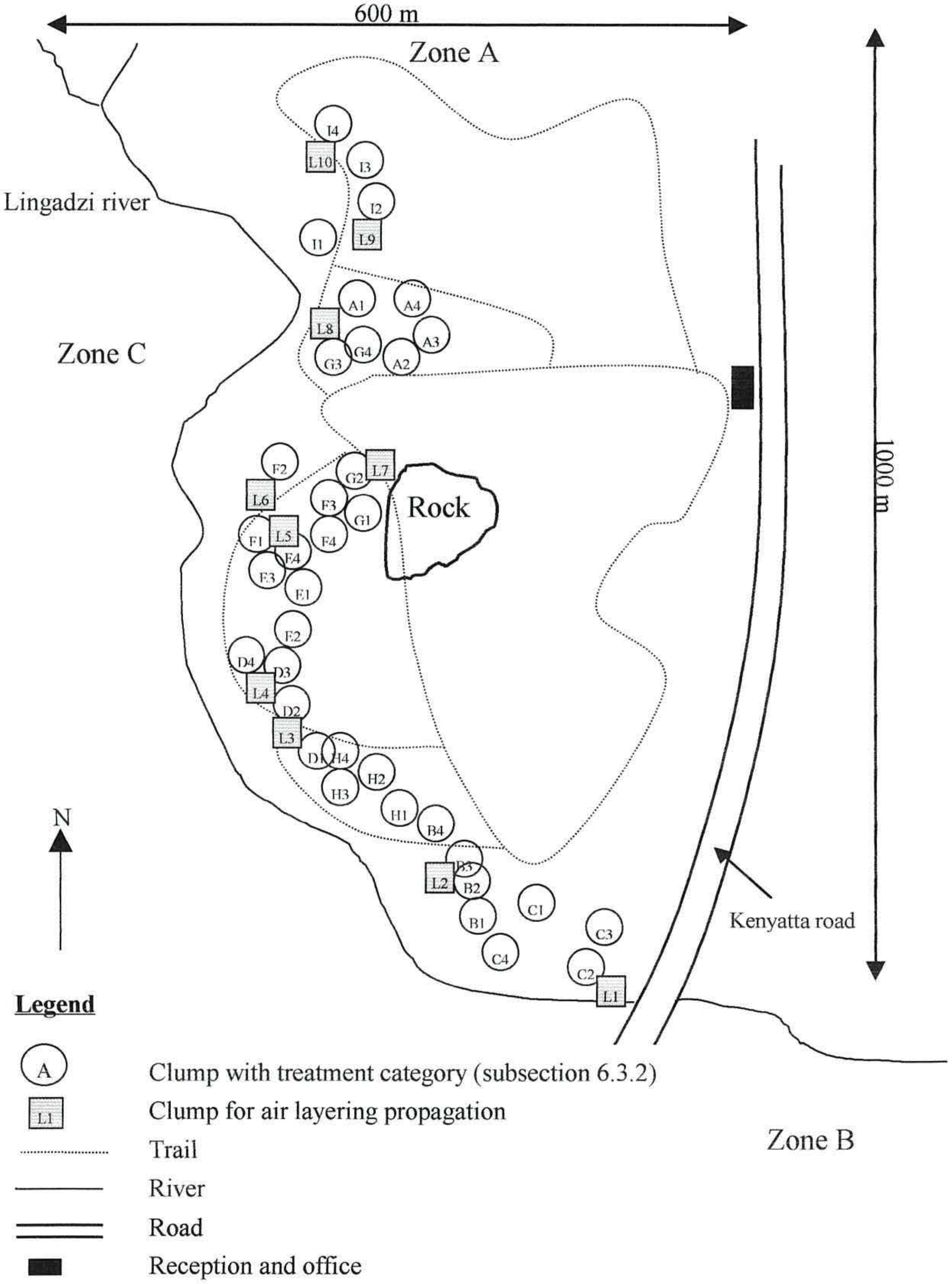


Figure 6.3: Grid positioning for assessing the research clumps



Map 6.1: Location of research clumps of *Oxytenanthera abyssinica* in Lilongwe Nature Sanctuary, Malawi

Treatments and implementation of treatments

Nine treatments were applied:

- **A**, 0% felling of young culms; 0% felling of mature culms
- **B**, 0% felling of young culms; 40% felling of mature culms
- **C**, 0% felling of young culms; 80% felling of mature culms
- **D**, 40% felling of young culms; 0% felling of mature culms
- **E**, 40% felling of young culms; 40% felling of mature culms
- **F**, 40% felling of young culms; 80% felling of mature culms
- **G**, 80% felling of young culms; 0% felling of mature culms
- **H**, 80% felling of young culms; 40% felling of mature culms
- **I**, 80% felling of young culms; 80% felling of mature culms

Culms 7-12 months old in November 2001 were 'young' culms, while culms >12 months old in November 2001 were 'mature' culms. Before new shoots appeared for the 2002 growing season, treatments were applied to clumps. Four replicate spatially adjacent clumps were put together in the same group to avoid confusion during harvesting and assessment activities. After the numbers of young 7-12 months old and mature >12 months old culms were counted, those identified for harvesting were cut <30 cm off the ground at the assigned felling intensity. Saws were used to minimise the risk of damage to other culms in the felling process (Plate 3). After treatment (felling), retained culms 7-12 months old in November 2001 were marked with white nylon string to ensure they would remain distinct from any new shoots. Harvested culms and associated debris were removed from the clumps.

Basic parameters recorded

The term 'young culms' was used for culms 7-12 months (two seasons) old and the term 'mature culms' for culms more than 12 months (>2 seasons) old in November 2001. 'Shoots in 2002' refers to shoots appearing from November 2001 to April 2002 and 'shoots in 2003' for shoots appearing from May 2002 to June 2003.

Culms over 2 cm in diameter at 120 cm above the ground were counted, before harvesting at time 0 (November 2001), at 5 months (after harvesting in April 2002) and at 19 months (June 2003). The numbers of new shoots and any mortality in each clump were recorded weekly. Where there was a node at 120 cm above the ground, the diameter was measured just below the node. Culms extending less than 30 cm length above the ground were not counted. Diameter at the middle point was measured for culms and shoots over 30 cm long but less than 120 cm above the ground. If the middle point diameter was over 2 cm, these culms were also counted. Mortality was recorded only after being recorded for shoots at least at 30 cm tall. Counting was carried out using temporary grids of nylon strings and bamboo and wooden sticks to ensure no culms or shoots were missed or recorded in error. Grid units were 1 m × 1 m.

Culm diameter was measured in each experimental clump, 120 cm above the ground before harvesting at time 0 (November 2001), at 5 months (after harvesting in April 2002) and at 19 months (June 2003). Callipers were used for the measurements. Where there was a node at 120 cm off the ground, diameter was measured just below the node. Only culms over 2 cm in diameter at 120 cm above the ground were recorded, and these were assigned to the categories of young (7-12 months old) and mature (>12 months old) culms. Mid-length diameter was measured for culms less than 120 cm (distal end of axes) but over 30 cm above the ground. Shoots less than 30 cm long (distal end of axes) were not measured.

Initial lengths of culms (distal end of axes) were measured. The first shoot sprouting in each clump during the experimental period was monitored, its weekly increment in length being recorded until extension growth ceased. When a monitoring shoot died or disturbed by mammals, a shoot subsequently appearing above the ground (<30 cm) at that time was monitored.

Harvested culms were air-dried on the ground for two weeks. A single mature culm and a young culm were selected in each clump and were weighed with a spring balance. Because treatments varied and no young or mature culms, or none were harvested in 20 clumps out of the 36 clumps investigated, 24 culms in each age category were in total sampled. Descriptive statistics of culm diameters, initial length and dry weight of the 24 culms were tabulated.

Derived parameters

Two aspects of clump dynamics in the context of a harvesting regime are of particular interest: post-harvesting restoration of the resource and the risk of culm congestion. Clump production can be considered to be sustained if, over time, the original number and cross sectional area of culms are restored or exceeded. In this study, restored ratio in April 2002 and in June 2003 were calculated by the following formula:

$$\text{Restored ratio (numbers)} = \frac{\text{no. of recruited shoots + no. of retained culms in November 2001}}{\text{no. of original culms in November 2001}}$$

$$\text{Restored ratio (cross sectional areas)} = \frac{\text{sectional area of recruited shoots + sectional area of retained culms in November 2001}}{\text{seciotnal area of original culms in November 2001}}$$

where:

- original culms = those existing before harvest in November 2001.
- retained culms = those retained in November 2001
- recruited shoots 2002 = those produced between November 2001 and April 2002 for the ratio in April 2002
- recruited shoots 2003 = those produced between November 2001 and June 2003 for the ratio in June 2003

Means of restored ratios for each clump category were tabulated.

With regard to culm congestion, if clumps are congested with culms, only culms near the periphery are harvested by farmers. This practice brings about the death of culms in the clump interior without their use. Dead culms present within clumps interfere with the vertical growth of other culms, causing them to bend and eventually to die (Chaturvedi, 1988 - general bamboos in India; Deogun, 1937 - *Dendrocalamus strictus* in India; Inada, 2000 - *Oxytenanthera abyssinica* in Malawi). Therefore, clump congestion should be avoided by maintaining an appropriate number of culms appropriately distributed through the clump. Overall culm density was calculated in each clump based on the number and cross sectional areas (cm^2) of culms per clump area (m^2) and expressed by:

$$\text{Culm density} = \frac{\text{number of all existing culms and shoots}}{\text{clump area (m}^2\text{)}}$$

$$\text{Culm basal area} = \frac{\text{the aggregate cross sectional area (cm}^2\text{) of all existing culms and shoots}}{\text{clump area (m}^2\text{)}}$$

The clump area was estimated by multiplying the clump length by the width. The maximum distance between any two culms was recorded as clump length. The summed perpendicular distances from the line joining the two most widely separated culms (clump length line) to the most distant culm on each side was taken as clump width. Clump areas calculated from clump length and width changed from 2001-2003. Culm densities in November 2001 (pre-harvest) were compared with the densities in April 2002 and in June 2003 at each treatment category (A-I, see above). The 1 m × 1 m units were subdivided into 25 cm × 25 cm to improve the indications of whether parts of clumps were congested.

6.3.3 Data processing

Clump structure

Composition data were summarised by clump and culm age category, as numbers of culms present when observations started (Table 6.14). The percentage of each clump's culms in each age category was also indicated. Descriptive statistics (means, standard deviation, range of values) were based on the percentages of culms in different age categories in each clump. These data were arcsine transformed.

The spatial organisation within clumps was summarised as a map of each one showing the positions of culms and their age category. The maps indicated variations in culm numbers in different parts of the clumps and the distance from any culm to any other culm within the same clump. Clump dimensions were recorded and tabulated.

To summarise changes in clumps through time diagrams were devised to show culm numbers by age category in 2001 (November - before harvesting), 2002 (April) and 2003 (June) for each of the 36 clumps. The diagrams also indicated the number of the culms of each category harvested under the relevant experiment treatment. Spatial change in clump structure was incorporated in the clump maps (Map 6.2; Appendix V). Culms and shoots of different ages, and the positions of culms harvested when treatments were applied were distinguished, as were the 2002 and 2003 cohorts of new shoots.

The data of the harvesting intensity experiment were examined through a scatter plot approach and Spearman rank correlation (r_s). There were 36 points plotted in each scatter with y axis of the number of new shoots and x axis of the number of initial culms (young, mature and both ages). The scatters used the same data but displayed in a form facilitating detection of trends and groupings corresponding to harvesting intensities. Broad levels of harvesting intensity were distinguished as follows:

- High intensity
  80% mature 80% young; 80% mature 40% young; 40% mature 80% young

- Moderate intensity
  80% mature 0% young; 40% mature 40% young; 0% mature 80% young

- Low intensity
  40% mature 0% young; 0% mature 40% young; 0% mature 0% young

Interpretation of the scatters involved inspection of the scatters for indications of effects on the recruitment of new shoots in 2002 and 2003. Point configurations within scatters could indicate:

- absence of any effect - no concentration of related treatments within the scatter; no trend to the scatter
- an effect of clump size only - no groupings of related treatments but indications of a direct or inverse relationship between new shoot production level and clump size
- an enhancing effect of harvesting culms from the two age categories with scatter points grouped according to harvesting intensity and directly or inversely related to clump size
- dominance of the effect of cutting mature culms with scatter points grouped according to mature culm harvesting intensity, possibly interacting with clump size
- dominance of the effect of cutting young culms with scatter points grouped

according to young culm harvesting intensity, possibly interacting with clump size.

Values were taken on a per clump basis, so that r_s calculation entailed ranking 36 values. To overcome the problem of departure from normality the non-parametric r_s was considered appropriate. The Spearman rank correlations were used to determine if the number of new shoots showed any dependence on the original or post harvest clump size, expressed in terms of initial or retained culms (in total or as separate young and mature categories).

Spearman rank correlation coefficients were determined for the 2002 season new shoot production and the 2003 season new shoot production (separately and both years combined) against six clump size categories:

- initial young culms in November 2001 (pre-harvest)
- initial mature culms in November 2001 (pre-harvest)
- initial total culms (both categories) in November 2001 (pre-harvest)
- retained young culms in November 2001 (post-harvest)
- retained mature culms in November 2001 (post-harvest)
- retained total culms (both categories) in November 2001 (post-harvest)

Therefore, in all, 18 Spearman rank correlation coefficients involving clump size were calculated, each one based on values for 36 clumps.

A two way ANOVA determined whether harvesting intensity of young and mature culms affected the new shoot production. The number of new shoots was standardised to a value per initial culm (young, mature and both). The following standardised values were determined for each of the 36 clumps for both the 2002 season new shoot production and the 2003 season new shoot production:

- new shoots per young culms in November 2001 (pre-harvest)
- new shoots per mature culms in November 2001 (pre-harvest)
- new shoots per culm (both categories) in November 2001 (pre-harvest)

Therefore, six two way ANOVA tests were carried out in total. Data were expressed as proportions of the total and arcsine transformation applied to values before analysis. ANOVAs were carried out on the transformed data.

Culm diameters, lengths and dry weight

Culm diameters were diagrammatically summarised as frequency values for each age category, aggregated across all 36 clumps. Descriptive statistics (means, standard deviations, range of values) were determined for representative culms included in the initial harvesting. Because treatments varied in which culms were harvested, descriptive statistics were based on a sample replication of the 24 culms, one young culm from every clump where young culms were harvested, and one mature culm from every clump where mature culms were harvested. Descriptive statistics for culm diameter, culm length and culm dry weight were tabulated.

A two-way ANOVA investigated whether harvesting intensity affected the diameter of new shoots, with the Minitab package. Input variables were diameters of new shoots in relation to harvesting intensities of young culms (0%, 40%, 80%) and mature culms (0%, 40%, 80%). The term 'young culms' was used for culms 7-12 months (two seasons) old and 'mature culms' for culms more than 12 months (>2 seasons) old in November 2001. 'Shoots in 2002' was used for shoots produced from November 2001 to April 2002 and 'shoots in 2003' for shoots produced in May 2002 and June 2003.

Monitored culm growth

The cumulative growth of the developing shoots monitored was summarised graphically with grouping according to the harvesting intensity that had been applied to mature culms >12 months (two seasons) old in the clump in November 2001.

Restoration and clump density

Clump restoration was determined for each clump as the extent to which recruited shoots in 2002 and in 2003 numerically replaced culms harvested at the end of November 2001. The ratio ((new shoots in 2002 and in 2003) + (retained culms in November 2002)) : (original culms before November 2001) was used as an expression of restoration of total culms existing before harvest in November 2001. Clumps restore their original size (restored ratio = 100%), when (new shoots + retained culms) are equal to original culms. The restored ratio is <100% when (new shoots + retained culms) are less than (original culms) and it is >100% when (new shoots + retained culms) are more than (original culms). Restored ratios were described for each clump category in terms of numbers and total cross sectional areas.

Culm density/clump was derived from the numbers and cross sectional areas (cm^2) of culms per clump area (m^2) and tabulated for each clump. Culm densities (no./m^2) and basal areas (cm^2/m^2) in November 2001 (pre-harvest) were compared with the corresponding values in April 2002 and in June 2003 for each treatment category (A-I, see above) by two-way ANOVA tests using the Minitab package.

6.3.4 Results

Clump structure

Clump length was mostly slightly greater than width and the shape of clumps was near circular to broadly elliptic (Table 6.13). The lengths were less than 4 m (Figure 6.4). Young culms (7-12 months old) were present not only at peripheries of clumps but also in the clump interior (Map 6.2, Appendix VII). Culm densities in clumps varied from scattered (C4 and I2 clumps) to congested (4-6 culms/25 cm × 25 cm grid unit A2, H3 and D2 clumps). Clumps were composed of approximately one-third young culms 7-12 months old and two-thirds mature culms more than 12 months old (Tables 6.14-6.15).

The rainy season started in November 2001 after harvesting was carried out, and shoots started appearing above the ground in the late December 2001. Most of the 2001-2002 season's new shoots were produced in January 2002 (Figure 6.5). Most (29 out of 36) clumps produced more new shoots in 2003 than in 2002 (Appendix VIII). The number of new shoots sprouted from November 2001 to April 2002 per clump ranged from zero to 17. The number of new shoots sprouted from April 2002 to June 2003 ranged from zero to 29 per clump. More intense harvesting of culms 7-12 months old in November 2001 appeared to have a positive effect on new shoot production in 2002. Any harvesting in November 2001 had some positive impact on the number of new shoots in 2003 (Figures 6.6-6.8).

Within clumps, new shoots occurred in any space at the clump periphery and in the clump interior in 2002 and 2003 (Map. 6.2, Appendix VII).

Table 6.13: Clump dimensions and area for *Oxytenanthera abyssinica* at Lilongwe, Malawi

	Nov. 2001(pre-harvest)			April 2002			June 2003		
	length (m)	width (m)	area (m^2)	length (m)	width (m)	area (m^2)	length (m)	width (m)	area (m^2)
A1	1.7	1.4	2.4	1.8	1.4	2.5	1.8	1.4	2.5
A2	1.5	1.1	1.7	1.6	1.0	1.6	1.8	2.8	**5.0**
A3	2.4	1.5	3.6	2.5	1.5	3.8	2.7	2.0	**5.4**
A4	2.1	1.6	3.4	2.2	1.6	3.4	2.2	1.6	3.5
B1	3.1	1.6	5.0	2.2	2.3	5.1	2.2	2.6	5.7
B2	1.9	1.7	3.2	1.8	1.5	2.7	2.1	1.5	3.2
B3	1.8	1.1	2.0	1.8	1.4	2.4	2.5	1.6	**4.0**
B4	1.9	0.8	1.5	1.9	0.8	1.5	2.0	0.6	1.2
C1	2.8	1.7	4.8	2.8	1.9	5.3	3.1	1.9	5.9
C2	2.9	1.9	5.5	2.8	1.9	5.3	2.8	2.0	5.6
C3	1.9	1.1	2.1	1.6	1.0	1.6	1.9	1.0	1.9
C4	2.8	2.1	5.9	2.8	2.1	5.9	2.9	2.3	6.7
D1	2.2	1.7	3.7	2.1	1.8	3.8	2.1	2.3	4.8
D2	2.6	2.0	5.2	2.4	2.0	4.8	3.0	2.5	**7.4**
D3	2.3	1.9	4.4	2.3	1.9	4.4	2.7	1.9	5.1
D4	1.7	1.7	2.9	1.8	1.3	2.3	2.2	2.0	**4.4**
E1	1.7	1.2	2.0	1.9	1.3	2.4	1.9	1.8	**3.3**
E2	1.5	1.3	1.9	1.5	1.0	1.5	1.7	1.6	**2.7**
E3	1.3	1.1	1.4	1.3	1.1	1.4	1.3	1.1	1.4
E4	3.0	1.5	4.5	2.6	1.8	4.7	2.6	2.2	5.7
F1	2.9	2.2	6.4	2.9	2.5	7.3	3.4	2.5	8.5
F2	2.9	2.1	6.1	3.1	2.0	6.2	3.2	2.1	6.7
F3	3.1	2.2	6.8	3.0	2.0	6.0	3.0	2.0	6.0
F4	2.4	1.8	4.3	2.3	1.7	3.9	2.3	1.7	3.9
G1	3.0	2.2	6.6	3.4	2.5	8.5	3.7	2.3	8.5
G2	3.6	2.0	7.2	3.7	2.2	8.1	3.7	2.4	8.9
G3	2.2	1.6	3.5	2.3	1.8	4.1	2.6	1.9	**4.9**
G4	1.9	1.6	3.0	1.9	1.5	2.9	1.9	1.6	3.0
H1	2.5	1.5	3.8	2.2	1.4	3.1	2.7	1.6	4.3
H2	2.9	2.5	7.3	2.6	2.1	5.5	3.0	2.7	8.1
H3	1.9	1.3	2.5	2.1	0.9	1.9	2.3	1.2	2.8
H4	2.3	1.9	4.4	2.3	2.0	4.6	2.3	2.0	4.6
I1	2.7	1.8	4.9	2.5	1.5	3.8	2.5	1.5	3.8
I2	1.6	1.8	2.9	1.7	1.2	2.0	1.7	1.2	2.0
I3	2.2	1.5	3.3	2.5	1.7	4.3	2.7	1.8	**4.9**
I4	3.3	2.4	7.9	3.1	2.0	6.2	3.1	2.1	6.5

Clumps increasing in area by >40% between November 2001 and June 2003 are indicated in bold (9).

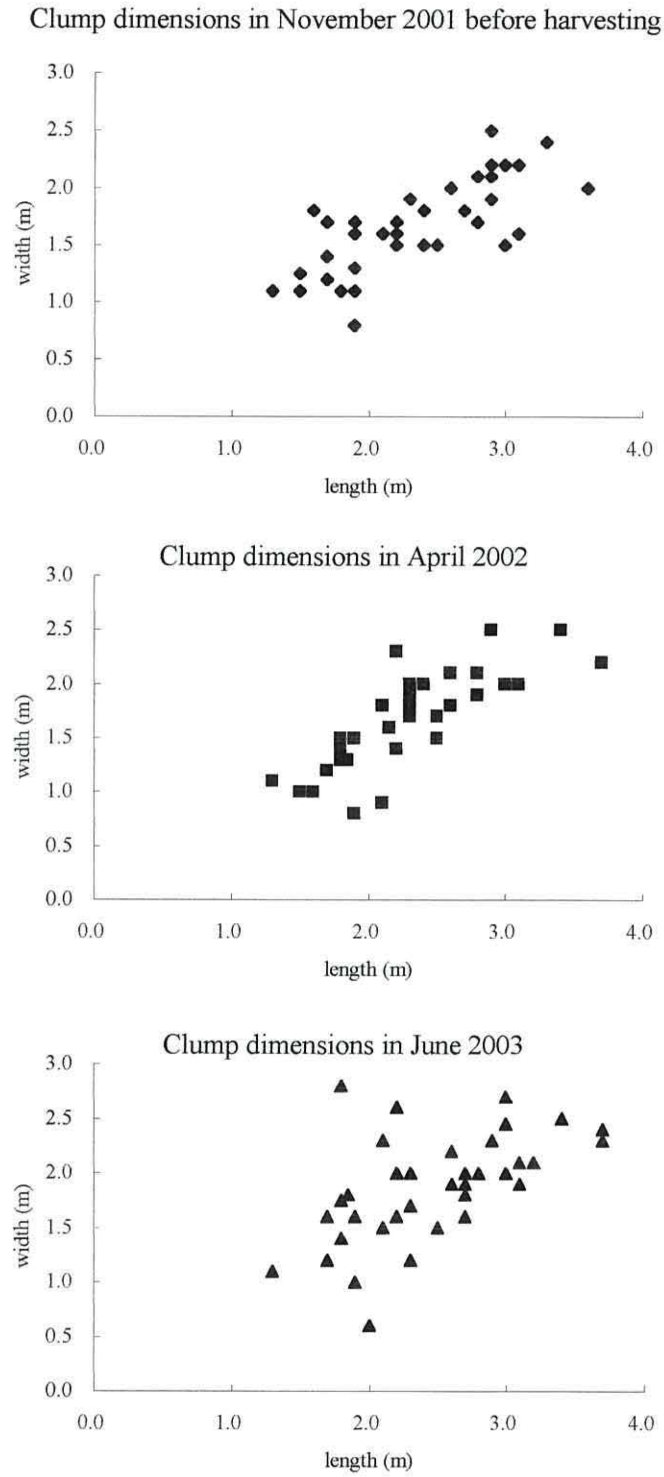
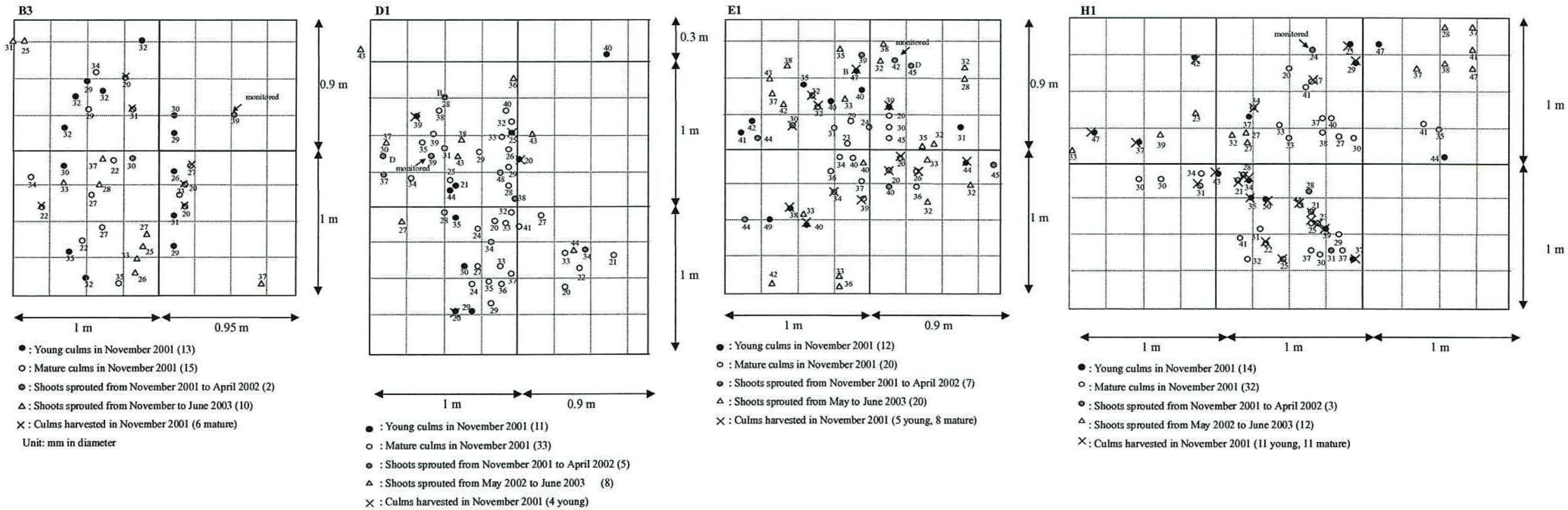


Figure 6.4: Length × width relationship of 36 *Oxytenanthera abyssinica* clumps at Lilongwe, Malawi, in November 2001 (pre-harvest), in April 2002 and in June 2003



Map 6.2: Location of culms within clumps, B3 (0/40), D1 (40/0), E1 (40/40) and H1 (80/40) at Lilongwe, Malawi. (harvesting intensity young 7-12 months old /mature culms >12 months old in %)

Table 6.14: *Oxytenanthera abyssinica* clump composition in Lilongwe, Malawi, before harvesting in November 2001

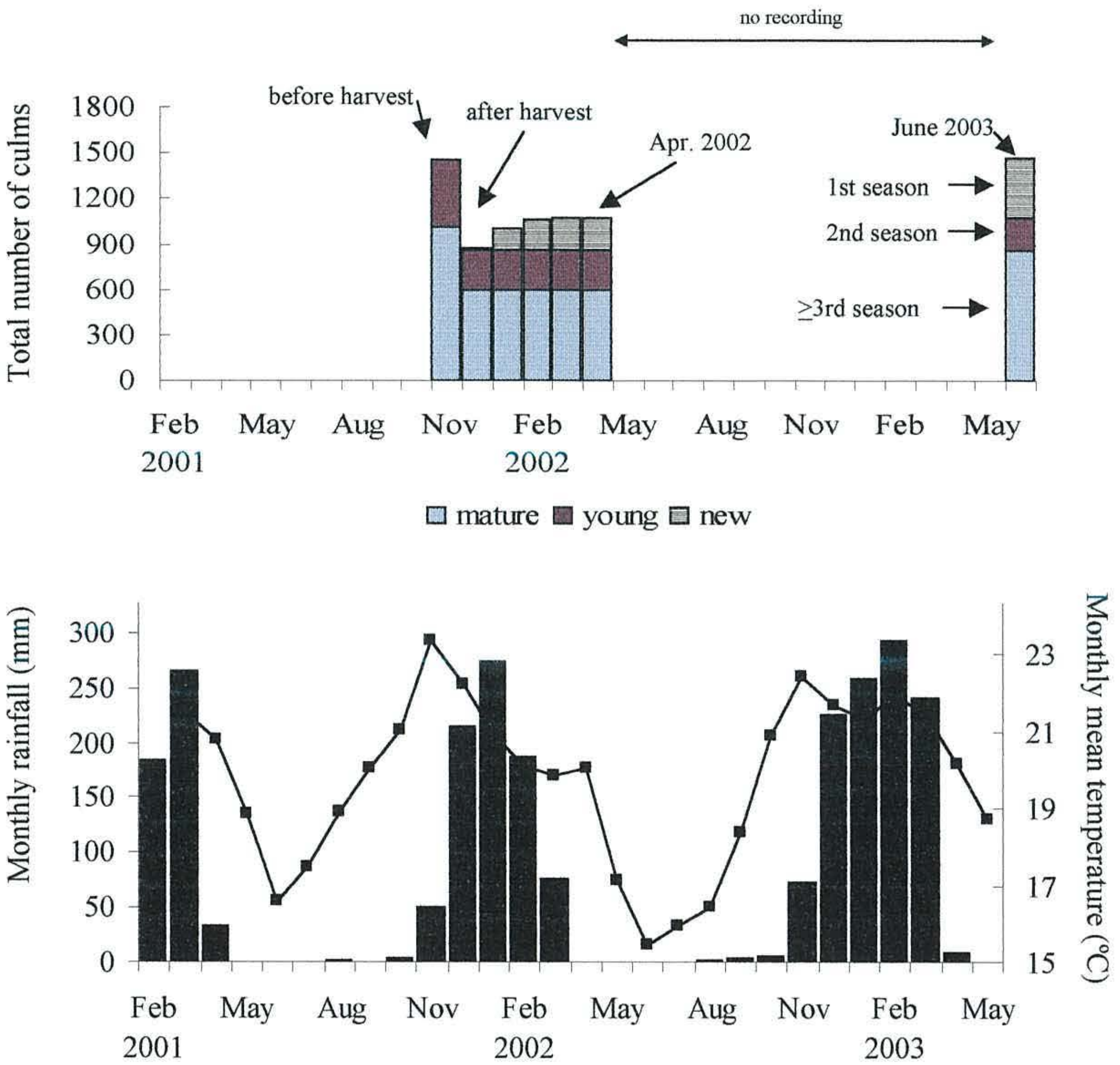
Clump no.	All culms	Culms 7-12 months old (% of total)	Culms >12 months old (% of total)
A1	22	7 (32)	15(68)
A2	27	7 (26)	20(74)
A3	33	17 (52)	16(48)
A4	34	15 (44)	19(56)
B1	45	11 (24)	34(76)
B2	31	9 (29)	22(71)
B3	28	13 (46)	15(54)
B4	17	6 (35)	11(65)
C1	37	12 (32)	25(68)
C2	30	5 (17)	25(83)
C3	29	8 (28)	21(72)
C4	36	19 (53)	17(47)
D1	44	11 (25)	33(75)
D2	80	31 (39)	49(61)
D3	43	13 (30)	30(70)
D4	29	11 (38)	18(62)
E1	32	12 (38)	20(63)
E2	21	10 (48)	11(52)
E3	23	7 (30)	16(70)
E4	56	15 (27)	41(73)
F1	46	10 (22)	36(78)
F2	38	7 (18)	31(82)
F3	79	22 (28)	57(72)
F4	42	6 (14)	36(86)
G1	48	15 (31)	33(69)
G2	52	17 (33)	35(67)
G3	48	15 (31)	33(69)
G4	35	8 (23)	27(77)
H1	46	14 (30)	32(70)
H2	50	22 (44)	28(56)
H3	46	15 (33)	31(67)
H4	66	11 (17)	55(83)
I1	40	8 (20)	32(80)
I2	16	6 (38)	10(63)
I3	32	8 (25)	24(75)
I4	73	13 (18)	60(82)

A-I = treatments (Subsection 6.3.2)

Table 6.15: Mean, standard deviation and ranges of values based on percentage contribution of young or mature culms to total culms in 36 clumps for *Oxytenanthera abyssinica* in November 2001 (pre-harvest) in Lilongwe, Malawi

	Mini. (%)	Max. (%)	Arithmetic mean ± standard deviation	Arcsine transformed mean ± standard deviation	Back transformed (%)
Young culms	14	53	0.31± 0.10	33.61 ± 6.24	31
Mature culms	47	86	0.69± 0.10	56.43 ± 6.22	69

Note: Young culms were 7-12 months (two seasons) old and mature culms more than 12 months (> two seasons) old in November 2001.



Keys

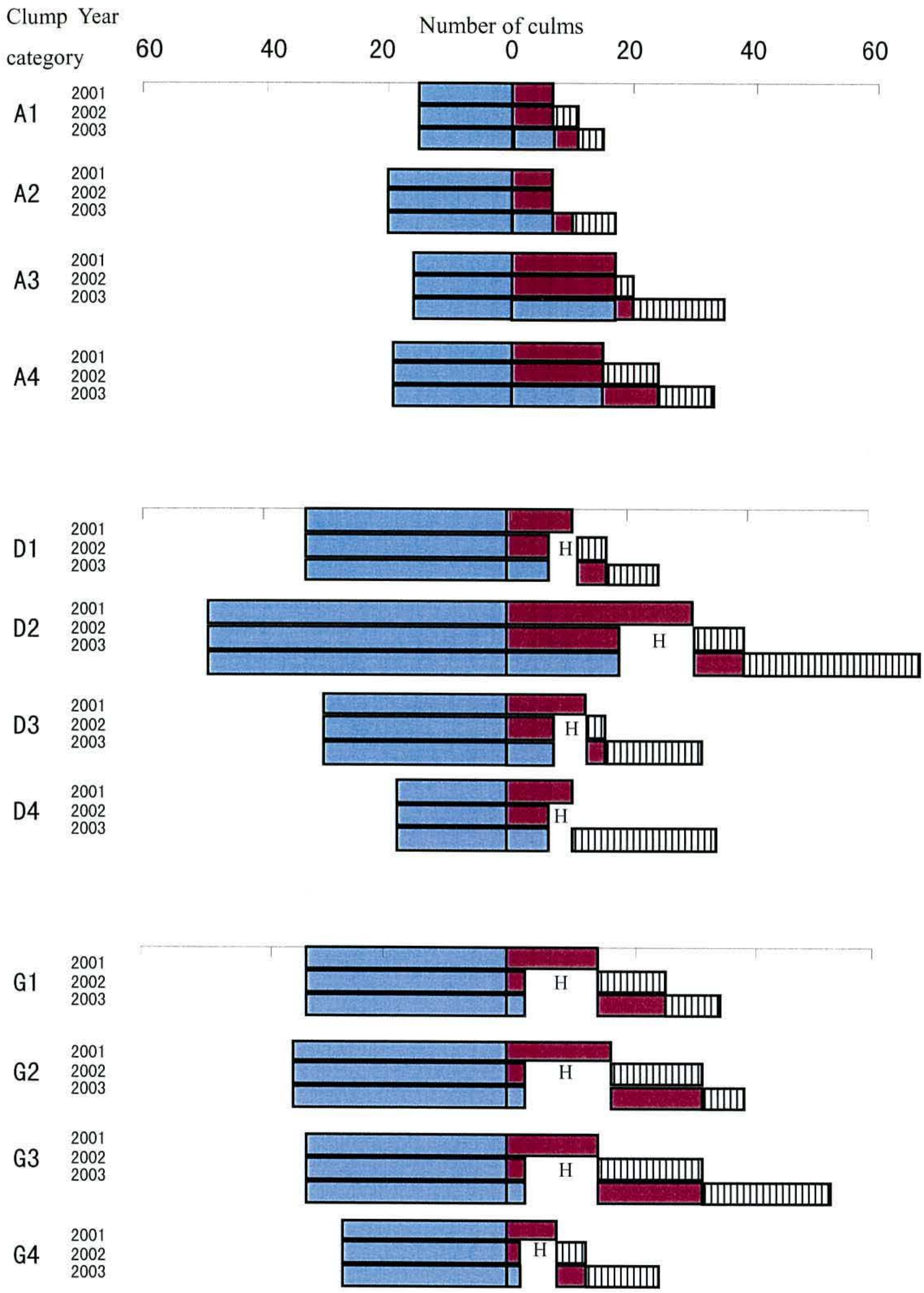
Mature culms: culms >12 months old.

Young culms: culms 7-12 months old.

New shoots: shoots sprouted from November 2001 to June 2003.

Monthly mean temperature: mean of maximum and minimum daily temperatures.

Figure 6.5: Recruitment (36 clumps in aggregate) of *Oxytenanthera abyssinica* shoots at Lilongwe Nature Sanctuary (14°00'S, 33°46'E; 1043 m). The climatic data are from the Bunda College (14°11'S, 33°46'E; 1118 m), 20 km to the south.

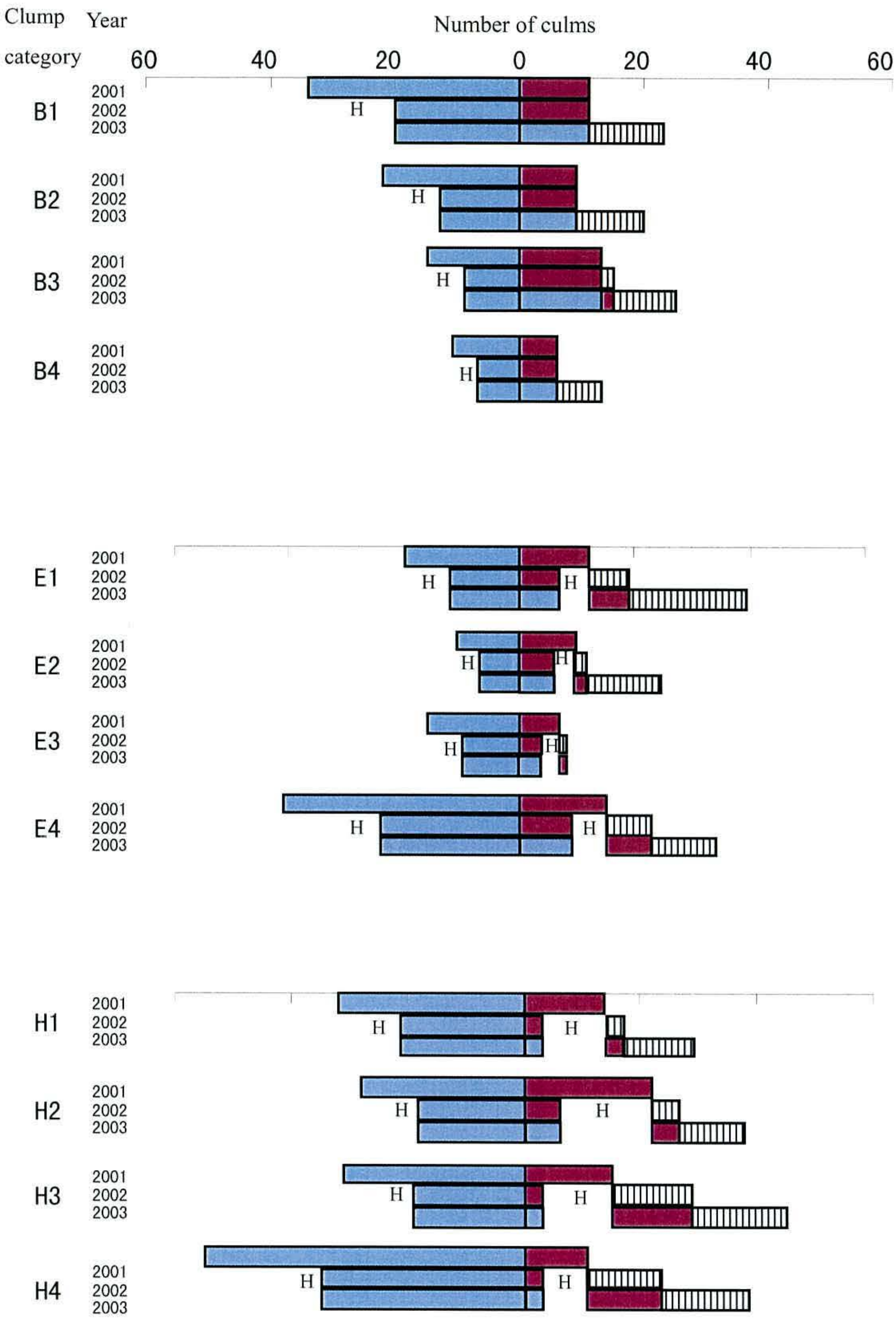


Culm age: >12 months, 7-12 months, <7 months, H = gaps indicating culms harvested.

Observation in November 2001, April 2002 and June 2003 at Lilongwe Nature Sanctuary.

Treatment: harvesting % of (young 7-12 months)/(mature >12 months old) culms, A 0/0%, D 40/0% and G 80/0%.

Figure 6.6: Bar summary of clump character of *Oxytenanthera abyssinica* (A, D, G)

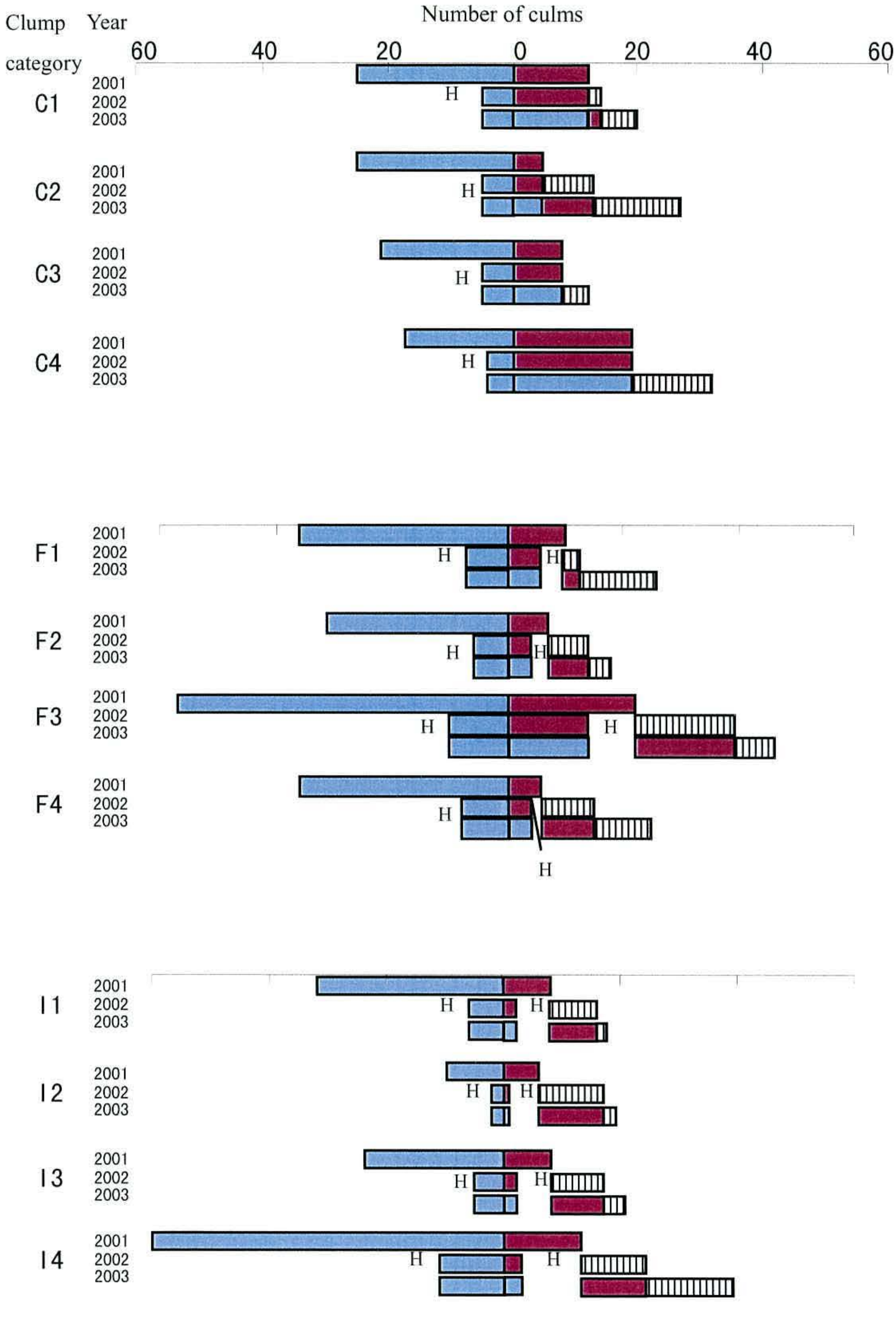


Culm age: >12 months, 7-12 months, <7 months, H = gaps indicating culms harvested.

Observation in November 2001, April 2002 and June 2003 at Lilongwe Nature Sanctuary.

Treatment: harvesting % of (young 7-12 months)/(mature >12 months old) culms, B 0/40%, E 40/40% and H 80/40%.

Figure 6.7: Bar summary of clump character of *Oxytenanthera abyssinica* (B, E, H)



Culm age: >12 months, 7-12 months, <7 months, H = gaps indicating culms harvested.

Observation in November 2001, April 2002 and June 2003 at Lilongwe Nature Sanctuary.

Treatment: harvesting % of (young 7-12 months)/(mature >12 months old) culms, C 0/80%, F 40/80% and I 80/80%.

Figure 6.8: Bar summary of clump character of *Oxytenanthera abyssinica* (C, F, I)

Harvesting impact

Harvesting young culms had a significant positive effect on the production of new shoots in 2002 expressed as new shoots per initial culm (young, mature and both culms) in November 2001 (Table 6.16, Figure 6.9) but not on those in 2003 (Table 6.17). New shoots in 2002 were significantly correlated with the initial mature culms (pre-harvest) and the retained young culms (post-harvest). New shoots in 2003 were significantly correlated with the initial young culms and the retained mature culms (Table 6.18).

Table 6.16: Two-way ANOVA tests for shoots in 2002 per initial culm (arcsine transformed values)

shoots/	Factors	Sum of Squares	df	Mean Square	F ratios	Value	Indication
total	Young	1097.81	2	548.91	9.75	0.001	***
	Mature	248.24	2	124.12	2.21	0.130	n.s.
	Young × Mature	666.94	4	166.73	2.96	0.038	*
	Error	1519.61	27	56.28			
	Total	3532.60	35				
young	Young	3094.32	2	1547.16	10.55	0.000	***
	Mature	945.26	2	472.63	3.22	0.056	n.s.
	Young × Mature	1615.88	4	403.97	2.76	0.048	*
	Error	3958.92	27	146.63			
	Total	9614.38	35				
mature	Young	1323.60	2	661.80	8.47	0.001	***
	Mature	274.14	2	137.07	1.75	0.192	n.s.
	Young × Mature	1009.44	4	252.36	3.23	0.027	*
	Error	2110.88	27	78.18			
	Total	4718.06	35				

Shoots in 2002 per initial young, mature or both categories of culm in November 2001 (pre-harvest). Factors are - harvesting intensity of young (0%, 40% 80%) and mature (0%, 40% 80%) culms in November 2001. Data first converted to the proportion of the total. ANOVA applied to the arcsine transformed data. Indication: * = 5%, ** = 1% , ***= 0.1%, n.s. = not significant

Table 6.17: Two-way ANOVA tests for shoots in 2003 per initial culm (arcsine transformed values)

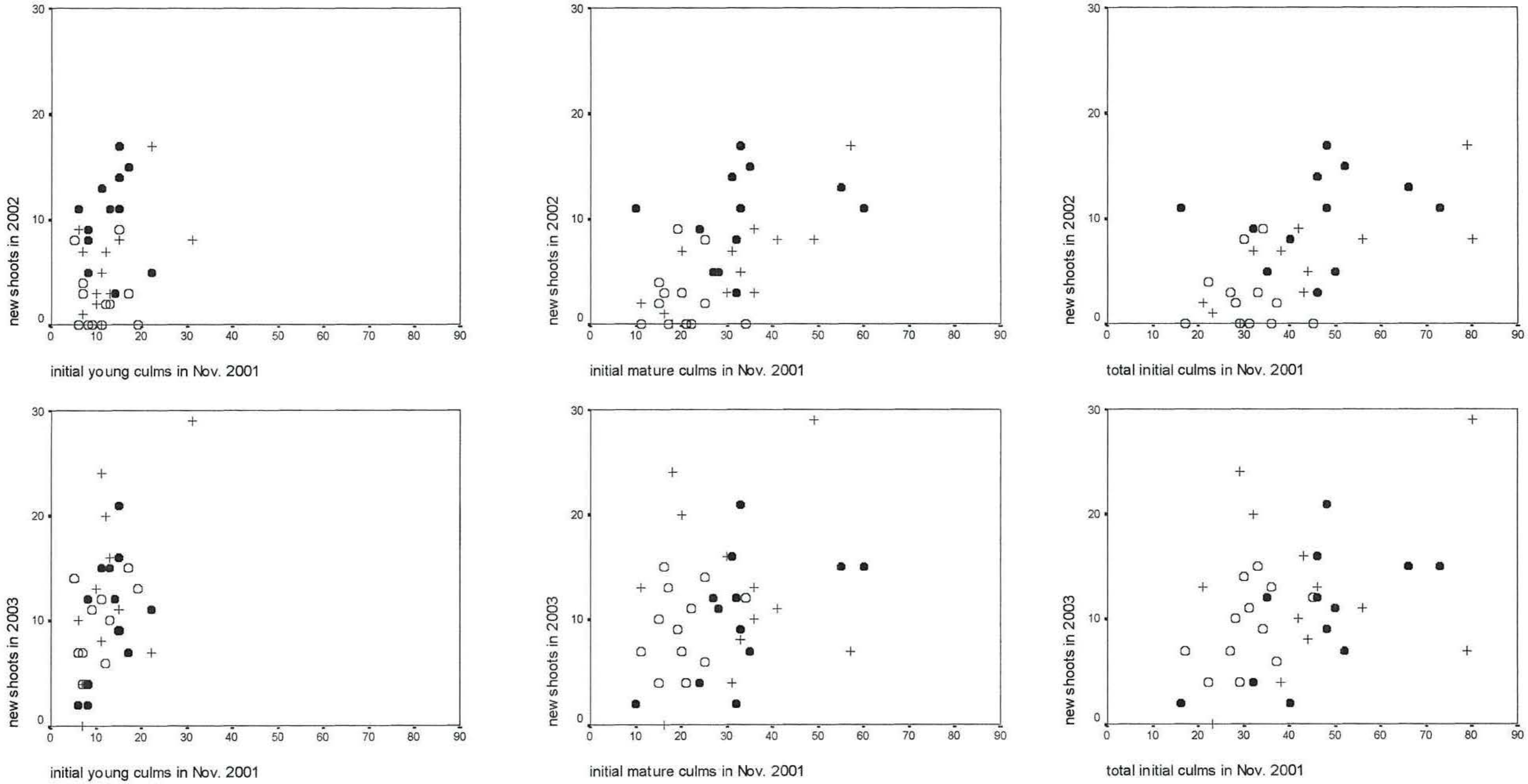
shoots/	Factors	Sum of Squares	df	Mean Square	F ratios	Value	Indication
total	Young	100.30	2	50.15	0.81	0.457	n.s.
	Mature	254.83	2	127.41	2.05	0.149	n.s.
	Young × Mature	143.61	4	35.90	0.58	0.682	n.s.
	Error	1679.57	27	62.21			
	Total	2178.31	35				
young	Young	41.74	2	20.87	0.17	0.842	n.s.
	Mature	91.41	2	45.70	0.38	0.688	n.s.
	Young × Mature	419.21	4	104.80	0.87	0.496	n.s.
	Error	3259.50	27	120.72			
	Total	3811.86	35				
mature	Young	208.06	2	104.03	1.14	0.335	n.s.
	Mature	440.81	2	220.41	2.42	0.108	n.s.
	Young × Mature	169.20	4	42.30	0.46	0.762	n.s.
	Error	2462.56	27	91.21			
	Total	3280.63	35				

Shoots in 2003 per initial young, mature or both categories of culm in November 2001 (pre-harvest). Factors are - harvesting intensity of young (0%, 40% 80%) and mature (0%, 40% 80%) culms in November 2001. Data first converted to the proportion of the total. ANOVA applied to the arcsine transformed data. Indication: * = 5%, ** = 1% , ***= 0.1%, n.s. = not significant

Table 6.18: Spearman rank correlation between the number of new shoots in 2002 or 2003, and initial or retained number of culms in November 2001

new shoots in:	initial no. of culms:	No.	rank	rank value	indication
2002 & 2003	total	36	0.619	0.000	**
	young	36	0.535	0.001	**
	mature	36	0.529	0.001	**
2002	total	36	0.551	0.000	**
	young	36	0.248	0.145	n.s.
	mature	36	0.539	0.001	**
2003	total	36	0.358	0.032	*
	young	36	0.451	0.006	**
	mature	36	0.248	0.145	n.s.
new shoots in:	**retained no. of culms:**	**No.**	**rank**	**rank value**	**indication**
2002 & 2003	total	36	0.443	0.007	**
	young	36	-0.103	0.548	n.s.
	mature	36	0.504	0.002	**
2002	total	36	0.142	0.408	n.s.
	young	36	-0.469	0.004	**
	mature	36	0.287	0.090	n.s.
2003	total	36	0.430	0.009	**
	young	36	0.184	0.283	n.s.
	mature	36	0.424	0.010	**

significance: ** = 1%, *=5% level.



Legends

harvesting intensity young/mature culms in November 2001. ○: 0/0%, 0/40%, 0/80%; +: 40/0%, 40/40%, 40/80%; ●: 80/0%, 80/40%, 80/80%

Figure 6.9: Correlation between the number of new shoots in 2002 and 2003 and initial number of culms in November 2001 (pre-harvest)

Culm character

Most culms and shoots were less than 5 cm in diameter at breast height and less than 10 m in length, although, there was one exceptionally tall culm (in clump D3) more than 16.8 m in length and 4.1 cm in diameter at breast height (Table 6.19, Figure 6.10).

Table 6.19: Culm diameters, length and air dry weight of representative *Oxytenanthera abyssinica* culms in Lilongwe, Malawi

Clump no.	Randomly sampled culms: 7-12 months			>12 months		
	Length (m)	Dry weight (kg)	Dbh (cm)	Length (m)	Dry weight (kg)	Dbh (cm)
A1	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
A2	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
A3	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
A4	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
B1	n.a.	n.a.	n.a.	10.0	9.1	4.5
B2	n.a.	n.a.	n.a.	6.8	2.4	2.4
B3	n.a.	n.a.	n.a.	6.1	3.1	2.9
B4	n.a.	n.a.	n.a.	7.3	3.6	3.0
C1	n.a.	n.a.	n.a.	8.8	4.2	3.4
C2	n.a.	n.a.	n.a.	5.8	1.1	2.0
C3	n.a.	n.a.	n.a.	8.4	4.7	3.4
C4	n.a.	n.a.	n.a.	5.9	1.2	2.9
D1	7.4	3.0	3.9	n.a.	n.a.	n.a.
D2	12.2	4.9	3.5	n.a.	n.a.	n.a.
D3	16.8	7.4	4.1	n.a.	n.a.	n.a.
D4	13.7	9.3	4.3	n.a.	n.a.	n.a.
E1	12.3	5.0	3.9	7.9	4.5	3.5
E2	10.6	4.1	3.0	7.9	3.4	3.1
E3	9.7	5.0	4.1	8.8	4.5	3.8
E4	11.1	5.3	3.2	12.5	7.5	3.6
F1	13.1	11.0	5.3	10.4	6.5	3.6
F2	9.4	12.5	6.2	9.4	4.4	3.5
F3	9.1	2.6	2.8	8.7	3.1	2.8
F4	6.2	2.8	2.9	8.4	5.0	3.4
G1	11.0	7.1	3.9	n.a.	n.a.	n.a.
G2	10.0	4.0	3.1	n.a.	n.a.	n.a.
G3	10.0	6.0	3.9	n.a.	n.a.	n.a.
G4	11.2	4.5	3.1	n.a.	n.a.	n.a.
H1	10.6	5.4	3.4	7.9	4.0	3.3
H2	10.5	7.6	4.5	8.9	4.0	3.1
H3	10.3	4.5	3.0	7.0	1.1	2.0
H4	8.1	3.6	3.1	6.9	3.6	3.1
I1	9.8	7.0	3.5	6.4	1.9	3.1
I2	8.5	4.2	3.1	7.3	2.0	2.2
I3	10.0	6.4	4.0	5.7	1.9	2.6
I4	6.6	3.1	2.8	7.8	2.5	3.4

Culm weight was measured after air drying for two weeks.

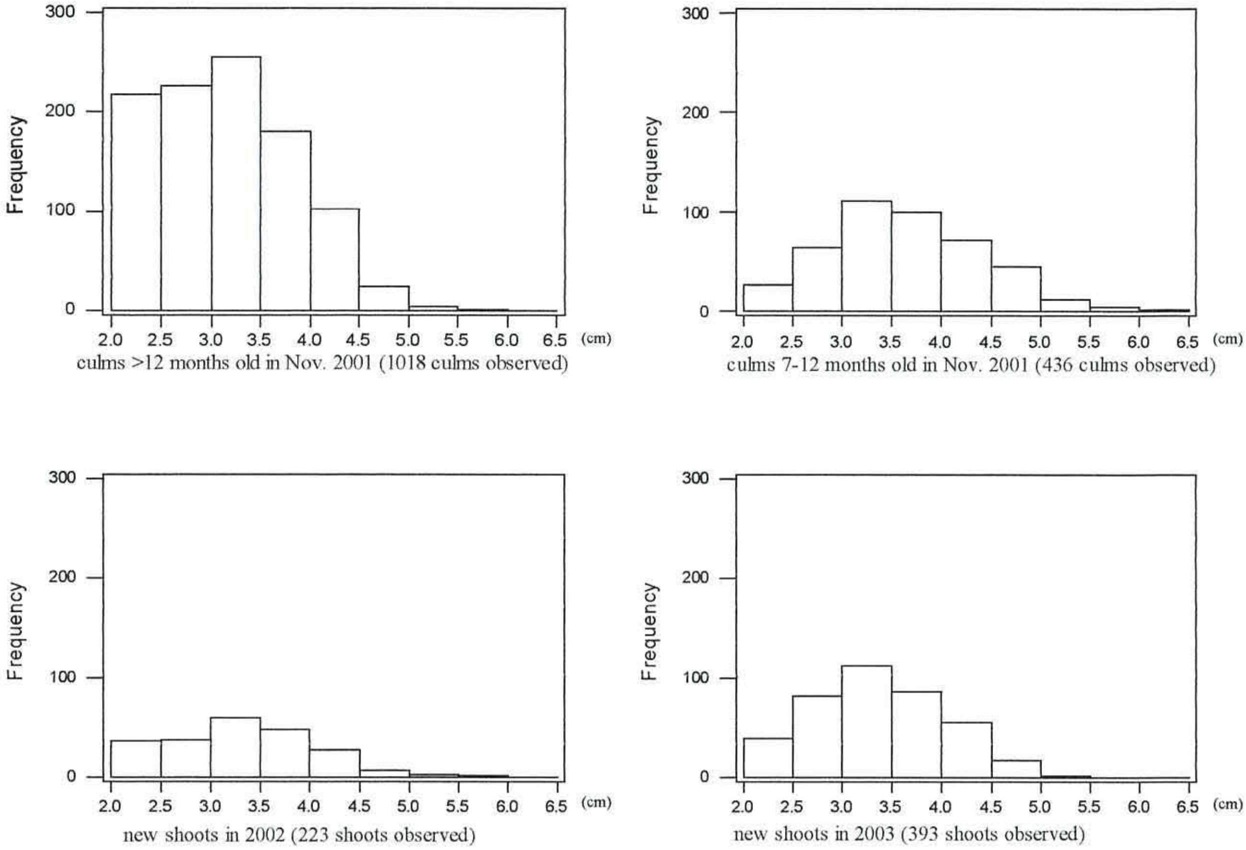


Figure 6.10: Frequency of culm diameters (cm) in each age category (culms 7-12 months old and more than 12 months old in November 2001, shoots produced in 2002 and in 2003)

In November 2001, the mean air dry-weight of young culms (7-12 months old) per meter was higher than that of mature culms (more than 12 months old): 0.55 kg/m *vs* 0.44 kg/m (Table 6.20). Young culms should have had high moisture content, and in two weeks had not been completely air-dried. Mean diameter (cm) at breast height of new shoots in 2002 and 2003 between clump categories was not significantly different (Figures 6.11 and 6.12) but it did appear that there was a trend of decreasing diameter with increasing harvest intensity applied in November 2001.

Table 6.20: Representative *Oxytenanthera abyssinica* culm parameters by age category (24 culms observed for each age)

	dbh (cm)			length (m)			dry weight (kg)			dry weight (kg)/m		
Culm age	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD	Min	Max	Mean ± SD
7-12 months	2.8	6.2	3.7 ± 0.82	6.2	16.8	10.3 ± 2.30	2.6	12.5	5.7 ± 2.53	0.29	1.33	0.55 ± 0.21
>12 months	2.0	4.5	3.1± 0.58	5.7	12.5	8.0 ± 1.62	1.1	9.1	3.7 ± 1.97	0.19	0.73	0.44 ± 0.15

Diameter (dbh) and length: measured immediately; dry weight: measured after 2 weeks air drying

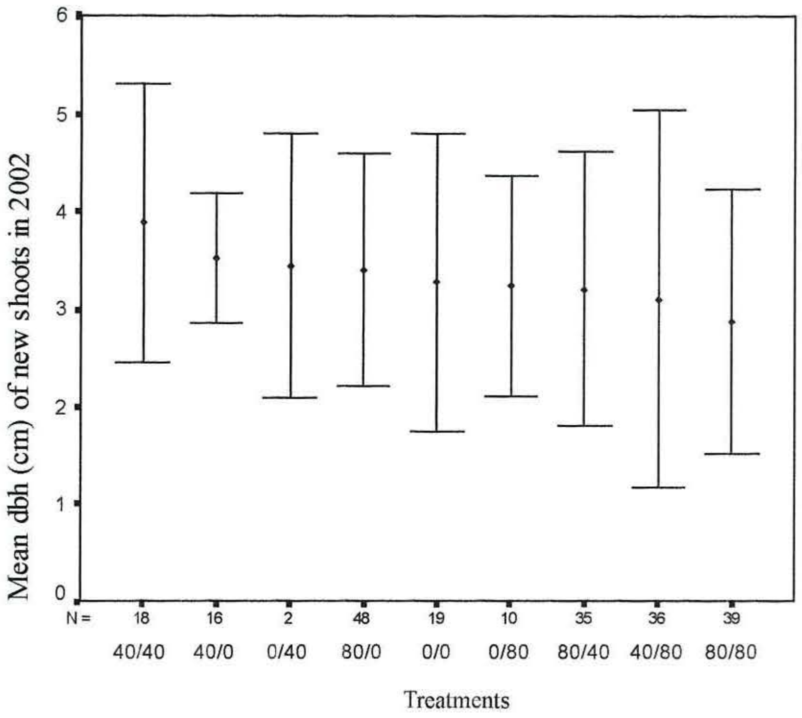


Figure 6.11: Mean diameter at breast height (cm) of new shoots in 2002 by clump harvest treatment category (Bars show standard deviations). Treatments are % of culms removed (young/mature).

Shoots 2002 Two way ANOVA:

felling (Y): n.s felling (M): n.s. interaction: n.s.

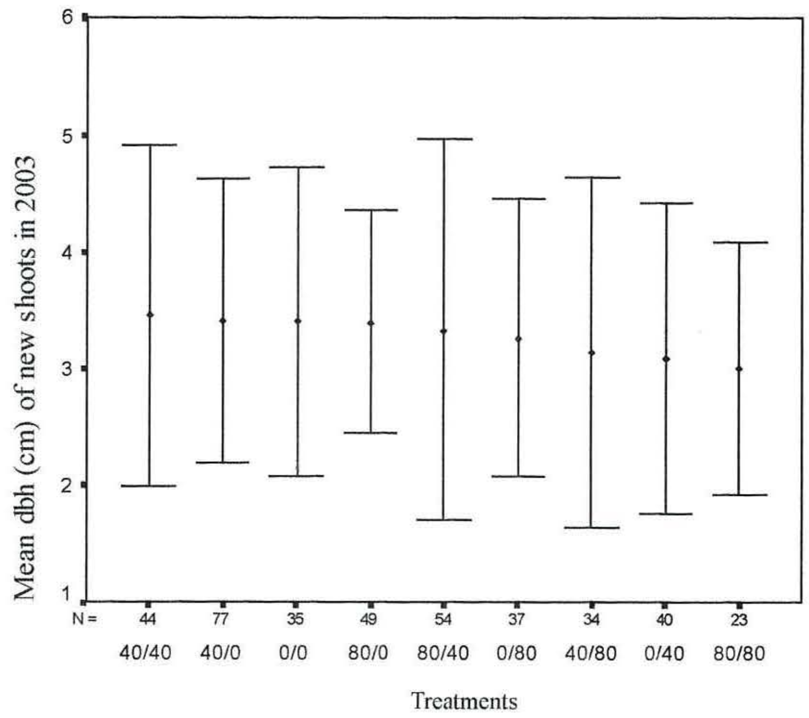


Figure 6.12: Mean diameter at breast height (cm) of new shoots in 2003 by clump harvest treatment category (Bars show standard deviations). Treatments are % of culms removed (young/mature).

Shoots 2003 Two way ANOVA:

felling (Y): n.s felling (M): n.s. interaction: n.s.

Shoot elongation

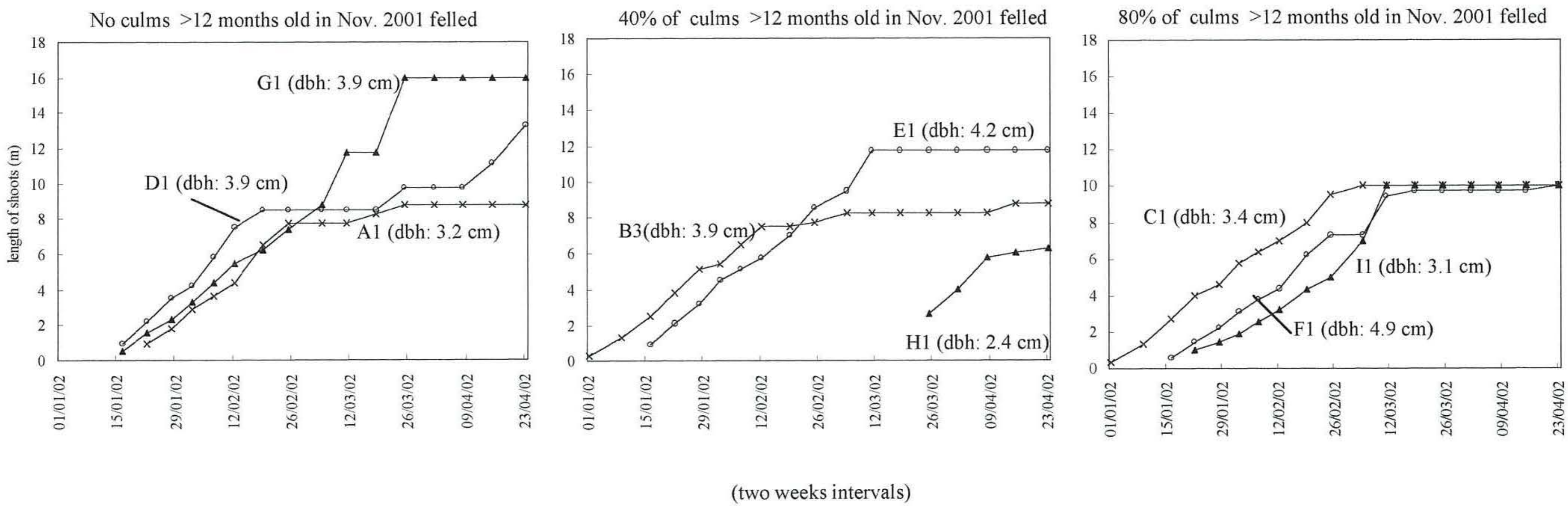
The process of shoot growth (2002 cohort) was graphed for one culm in each treatment (Figure 6.13). The first shoot appearing in any of the four replicate clumps of the treatment was monitored. Except in Treatment H (80% young culms harvested; 40% mature culms harvested), measurement of shoot length started when the first new culm appeared in the clump in January 2002. In Treatment H the measurement started on 26 March 2002 when the first shoot sprouted; in this case growth stopped within two weeks of sprouting (Figure 6.13). Disregarding the culm in Treatment H, maximum elongation of shoots per week was 1-3 m and extension growth continued for 6-10 weeks after initial sprouting. Maximum length attained by shoots was 16 m for the clump where 80% of young culms but no mature culms were harvested (Treatment G). Apart from Treatment H, the minimum was 8.8 m in the clumps where no culms (Treatment A) or no young culms and 40% of mature culms (Treatment B) were harvested in November 2001.

Restored ratios (post-harvest count/original count)

The unharvested control clumps (Treatment A) and Treatment G were fully restored or expanded in six months (Table 6.21). Control clumps (Treatment A) and clumps subject to low or moderate harvesting intensity (Treatment B, D, E and G) were fully restored or expanded in 19 months (Table 6.22). However, with excessive harvesting (Treatment C, F, H and I), the number of culms was not restored in 19 months.

Restored ratios (post-harvest cross sectional areas/original cross sectional areas)

Only unharvested control clumps (Treatment A) were expanded in six months (Table 6.23). Apart from clumps subject to excessive harvesting (Treatment F and I), all clumps were fully restored or expanded in 19 months (Table 6.24).



<u>**Note**</u>: observation: one shoot per treatment

Figure 6.13: Process of growth of *Oxytenanthera abyssinica* shoots: initial length observed from 1 January to 23 April 2002 in each harvesting category (A-I)

Table 6.21: Mean ratio of numbers of new shoots produced in 2002 plus retained culms (numerator) and numbers of culms before harvesting in November 2001 (denominator) (after 6 months, counted in April 2002)

harvesting intensity		mature culms					
		0%		40%		80%	
young culms	0%	A*: (135/116)	116	B: (90/121)	76	C: (73/132)	55
	40%	D: (187/196)	95	E: (97/132)	73	F: (95/205)	45
	80%	G: (187/183)	102	H: (143/208)	68	I: (71/161)	53

*A-I, treatment codes; figures in brackets, observations combined for four replicates; shadowed cells indicate fully restored or expanded clumps.

Table 6.22: Mean ratio of numbers of new shoots produced in 2002 and 2003 plus retained culms (numerator) and numbers of culms before harvesting in November 2001 (denominator) (after 19 months, counted in June 2003)

harvesting intensity		mature culms					
		0%		40%		80%	
young culms	0%	A*: (170/116)	145	B: (130/121)	110	C: (110/132)	83
	40%	D: (264/196)	138	E: (141/132)	109	F: (129/205)	63
	80%	G: (236/183)	129	H: (197/208)	94	I: (94/161)	66

*A-I, treatment codes; figures in brackets, observations combined for four replicates; shadowed cells indicate fully restored or expanded clumps.

Table 6.23: Mean ratio of cross sectional areas of new shoots produced in 2002 plus retained culms (numerator) and cross sectional areas of culms before harvesting in November 2001 (denominator) (after 6 months, counted in April 2002)

harvesting intensity		mature culms					
		0%		40%		80%	
young culms	0%	A*: (957/789)	120	B: (796/962)	85	C: (694/1028)	68
	40%	D: (1691/1800)	95	E: (1121/1449)	77	F: (933/1901)	49
	80%	G: (1804/1851)	97	H: (1304/1819)	74	I: (578/1324)	54

*A-I, treatment codes; figures in brackets, observations combined for four replicates; shadowed cells indicate fully restored or expanded clumps.

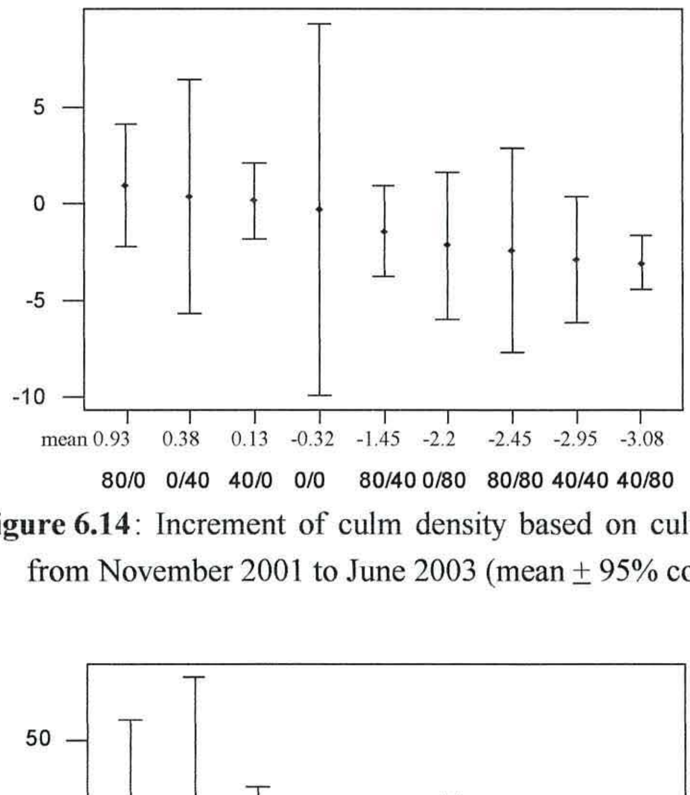
Table 6.24: Mean ratio of cross sectional areas of new shoots produced in 2002 and 2003 plus retained culms (numerator) and cross sectional areas of culms before harvesting in November 2001 (denominator) (after 19 months, counted in June 2003)

harvesting intensity		mature culms					
		0%		40%		80%	
young culms	0%	A*: (1288/789)	161	B: (1110/962)	123	C: (1014/1028)	103
	40%	D: (2418/1800)	136	E: (1552/1449)	113	F: (1213/1901)	65
	80%	G: (2259/1851)	125	H: (1804/1819)	103	I: (747/1324)	66

*A-I, treatment codes; figures in brackets, observations combined for four replicates; shadowed cells indicate fully restored or expanded clumps.

Culm density

Culm densities were calculated for November 2001 (pre-harvest), for April 2002 and for June 2003. Among restored clumps, the mean culm density of clumps decreased in Treatment E (40% of young culms 7-12 months old and 40% of culms more than 12 months old were harvested) from 14 culms/m^2 to 11 culms/m^2 and from 149 cm^2/m^2 to 119 cm^2/m^2 in 19 months (November 2002-June 2003). However, the mean culm density (number/m^2) of other restored clumps (Treatment A, B, D and G) increased (Figures 6.14 and 6.15, Tables 6.25 and 6.26).



Increment of culm number/clump area (no./ m^2) from Nov. 2001 to June 2003

Two way ANOVA:

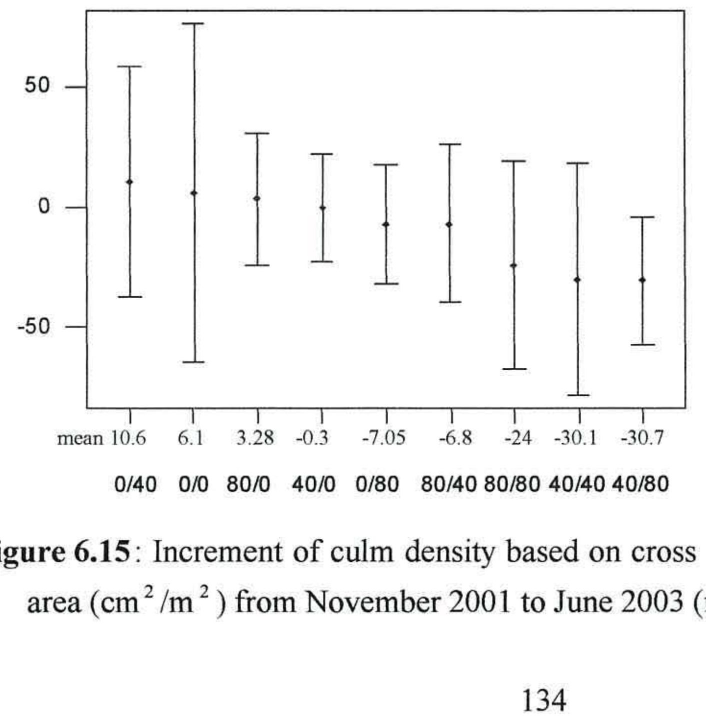
felling (Y): not significant

felling (M): not significant

interaction: not significant

harvesting intensity %: young/mature culms in November 2001

Figure 6.14: Increment of culm density based on culm number/clump area (no./m^2) from November 2001 to June 2003 (mean $\pm$ 95% confidence limits)



Increment of cross sectional areas of culms/ clump area (cm^2 / m^2) from Nov. 2001 to June 2003

Two way ANOVA:

felling (Y): not significant

felling (M): not significant

interaction: not significant

harvesting intensity %: young/mature culms in November 2001

Figure 6.15: Increment of culm density based on cross sectional areas of culms/clump area (cm^2/m^2) from November 2001 to June 2003 (mean $\pm$ 95% confidence limits)

Table 6.25: Culm density based on culm number/clump area (no./m ^{2}) from November 2001 to June 2003

	culm number/clump area (no/m²)			change relative to Nov. 2001 entry		
	Nov. 2001	Apr. 2002	June 2003	Nov. 01-Apr 02	Apr. 02-Jun. 03	Nov. 01-Jun. 03
A1	9.2	10.3	11.9	1.1	1.6	2.7
A2	16.4	18.8	*7.3*	2.4	-11.4	-9.0
A3	9.2	9.6	9.4	0.4	-0.2	0.3
A4	10.1	12.5	**14.8**	2.4	2.3	4.7
B1	9.1	6.1	7.5	-2.9	1.4	-1.6
B2	9.6	8.1	10.5	-1.4	2.3	0.9
B3	14.1	9.9	8.5	-4.3	0.9	-5.6
B4	11.2	8.6	**16.7**	-2.6	8.1	5.5
C1	7.8	3.6	*4.2*	-4.2	0.7	-3.5
C2	5.4	3.4	5.7	-2.1	2.3	0.3
C3	13.9	8.1	8.9	-5.8	0.8	-4.9
C4	6.1	3.9	5.4	-2.2	1.5	-0.7
D1	11.8	11.9	11.0	0.1	-0.9	-0.8
D2	15.4	15.8	14.3	0.4	-1.5	-1.1
D3	9.8	9.4	11.1	-0.5	1.7	1.3
D4	10.0	10.7	11.1	0.6	0.5	1.1
E1	15.7	10.8	13.8	-4.9	3.0	-1.9
E2	11.2	10.0	10.3	-1.2	0.3	-0.9
E3	16.1	10.5	10.5	-5.6	0.0	-5.6
E4	12.4	8.8	9.1	-3.7	0.3	-3.4
F1	7.2	2.2	*3.4*	-5.0	1.2	-3.8
F2	6.2	2.7	*3.1*	-3.5	0.4	-3.1
F3	11.6	6.8	8.0	-4.8	1.2	-3.6
F4	9.7	5.4	7.9	-4.4	2.6	-1.8
G1	7.3	5.5	6.6	-1.7	1.1	-0.7
G2	7.2	6.5	6.8	-0.7	0.2	-0.5
G3	13.6	12.8	15.0	-0.8	2.2	1.3
G4	11.5	11.9	15.1	0.4	3.2	3.6
H1	12.3	8.8	9.0	-3.5	0.3	-3.2
H2	6.9	5.3	4.9	-1.6	-0.4	-2.0
H3	18.6	19.0	18.8	0.4	-0.2	0.2
H4	15.1	11.1	14.3	-4.0	3.3	-0.8
I1	8.2	4.3	*4.8*	-4.0	0.5	-3.4
I2	5.6	6.9	7.8	1.3	1.0	2.3
I3	9.7	3.8	*4.1*	-5.9	0.4	-5.6
I4	9.2	4.0	6.1	-5.2	2.1	-3.1

Notes: Nov. 2001: total number of culms before harvesting were included. Apr. 2002: total number of retained culms in November 2001 and shoots produced in 2002 were included. June 2003: total number of retained culms in November 2001 and shoots produced in 2002 and in 2003 were included.

Clumps increasing in density by >40% between November 2001 and June 2003 are indicated in bold (2). Clumps decreasing in density by >40% between November 2001 and June 2003 are indicated in italics (6).

Table 6.26: Culm density based on cross sectional areas of culms/clump area (cm^2/m^2) from November 2001 to June 2003

	cross section areas of culms/clump area (㎠/㎡)			change relative to Nov. 2001 entry		
	Nov. 2001	Apr. 2002	June 2003	Nov. 01-Apr. 02	Apr. 02-Jun. 03	Nov. 01-Jun. 03
A1	52.1	58.6	**73.3**	6.5	14.7	21.2
A2	109.4	122.0	*53.6*	12.6	-68.4	-55.8
A3	59.9	66.6	71.0	6.6	4.4	11.1
A4	80.0	106.0	**127.7**	26.0	21.7	47.7
B1	89.3	67.1	76.1	-22.1	9.0	-13.1
B2	71.1	71.2	89.3	0.0	18.1	18.2
B3	91.0	71.2	61.5	-19.9	6.9	-29.5
B4	72.1	59.8	**122.3**	-12.3	62.5	50.2
C1	68.3	34.8	43.9	-33.5	9.2	-24.4
C2	26.1	21.2	**38.5**	-4.9	17.3	12.4
C3	92.1	75.4	80.2	-16.6	4.8	-11.8
C4	62.4	46.8	58.0	-15.6	11.2	-4.4
D1	92.4	97.8	96.5	5.4	-1.2	4.1
D2	128.5	131.0	114.3	2.5	-16.7	-14.2
D3	84.2	80.5	101.5	-3.7	21.0	17.3
D4	144.7	149.7	136.3	5.0	-13.4	-8.4
E1	154.9	120.2	146.3	-34.7	26.1	-8.6
E2	73.9	69.8	67.8	-4.1	-2.0	-6.1
E3	214.3	143.3	143.3	-71.0	0.0	-71.0
E4	152.8	111.5	118.1	-41.3	6.5	-34.8
F1	87.7	32.1	*45.0*	-55.6	13.0	-42.6
F2	96.0	49.4	*49.2*	-46.6	-0.3	-46.8
F3	73.9	45.5	53.5	-28.4	8.0	-20.4
F4	58.6	30.9	45.6	-27.6	14.7	-13.0
G1	84.2	59.6	71.0	-24.6	11.3	-13.2
G2	82.1	72.3	74.0	-9.8	1.7	-8.1
G3	119.5	110.0	129.7	-9.4	19.6	10.2
G4	93.2	88.8	117.4	-4.4	28.6	24.2
H1	113.6	81.4	84.3	-32.2	2.9	-29.3
H2	90.7	75.7	71.7	-15.0	-4.0	-19.1
H3	93.9	108.1	108.3	14.2	0.1	14.4
H4	115.1	94.7	121.8	-20.5	27.2	6.7
I1	70.4	36.2	*40.3*	-34.2	4.1	-30.1
I2	31.6	39.3	**45.7**	7.8	6.4	14.1
I3	96.3	41.5	*45.8*	-54.8	4.3	-50.5
I4	72.3	30.0	*42.9*	-42.4	13.0	-29.4

Notes: Nov. 2001: total cross sectional areas of culms before harvesting were included. Apr. 2002: total cross sectional areas of retained culms in November 2001 and shoots produced in 2002 were included. June 2003: total cross sectional areas of retained culms in November 2001 and shoots produced in 2002 and in 2003 were included.

Clumps increasing in density by >40% between November 2001 and June 2003 are indicated in bold (5). Clumps decreasing in density by >40% between November 2001 and June 2003 are indicated in italics (6).

6.3.5 Conclusions

Oxytenanthera abyssinica clumps in Lilongwe, Malawi were near-circular to broadly elliptic in shape, the longer axis always being less than 4 m (<80 culms). Culm densities in clumps reaching 4-6 culms/25 cm × 25 cm grid unit where congestion was greatest. Young culms (7-12 months old) were present not only at peripheries of clumps but also in the clump interior. Typical clumps, before treatments were applied, consisted of one-third young culms 7-12 months old and two-thirds mature culms more than twelve months old.

Most culms and shoots were less than 5 cm in diameter at breast height and less than 10 m in length. Maximum elongation of shoots per week was 1-3 m. Extension growth continued for 6-10 weeks after initial sprouting.

More intense harvesting of culms 7-12 months old in November 2001 appeared to have a positive effect on new shoot production in 2002. Harvesting young culms had a significantly positive effect on new shoot production in 2002, on the basis of numbers of new shoots produced per initial culm in November 2001 (both young and mature culms). There was also evidence that clump size (initial and retained number of culms) positively affected total shoot production in 2002-2003.

In terms of the number and the cross sectional areas, with harvesting intensity limited to 40% of young or mature culms, or both, clumps were fully restored or expanded in 19 months. Where all mature culms were retained, restoration was achieved even if 80% of the young culms had been harvested. Otherwise, any 80% harvesting prevented restoration in 19 months. Among restored clumps, the mean culm density of clumps decreased only in Treatment E (40% of young culms 7-12 months old and 40% of culms more than 12 months old were harvested).

Plates of *Oxytenanthera abyssinica* in Lilongwe, Malawi

Plate 1: Rhizome system (3/11/2001)

Plate 2: New shoots and mature culms (June 2003)

Plate 3: Clump where 80% of young and mature culms were harvested (I3 clump, November 2001)

Chapter 7

Propagation studies

In this chapter investigations into potential propagation methods are reported. Following a background section (7.1), the chapter is organised on the basis of two component studies (7.2 Detached cuttings; 7.3 Seeds) carried out. A protocol approach has been adopted to describe each of the experiments/trials. Experimental material, treatments, experimental layout, investigation period and maintenance are described through protocols. For each experiment, data processing, results and conclusions are summarised in further subsections.

7.1 Bamboo propagation experience

Where scarcity of bamboos is severe, domestication by planting around homesteads is a sound option to improve the situation. Since flowering of bamboos is irregular and the interval is very long from - seven years (*Ochlandra travancorica* (Bedd.) Benth. in India; Varmah and Bahadur, 1980) to 67 years (*Phyllostachys edulis* (Carrière) J. Houz. in Japan; Shibata, 1999) propagation by seeds is impractical (Liese, 1985; McClure, 1966; Suzuki and Ordinario, 1980). Vegetative propagation is, therefore, commonly employed for bamboo propagation. Five methods of vegetative propagation have been practised for bamboos: rhizome planting, culm cuttings, branch cuttings, layering and marcotting. Branch cuttings, layering and marcotting were successful for certain species but not for many others (Dransfield and Widjaja, 1995). Rhizome planting and culm cuttings are the most common propagation techniques (Uchimura, 1980).

Propagation by rhizome cuttings is not recommended for clump-forming bamboos, because there is no clear distinction between the rhizome and the mother bamboo (Uchimura, 1979). In rhizome planting, culms attached to rhizomes are cut about 30 cm off the ground and separated from the mother clump (Vongvijitra, 1990). The rhizome of the mother bamboo is damaged when the cutting is removed (Uchimura, 1979). Accordingly, rhizome planting is widely used for the propagation of non-clump forming bamboos (leptomorph rhizome type) of temperate regions which have longer rhizomes and clear distinction from the body of the mother bamboos. (Dransfield and Widjaja, 1995; Farrelly, 1996; Uchimura, 1980). Two common bamboos in Japan *Phyllostachys edulis* and *Phyllostachys bambusoides* Siebold & Zucc. have for many years been successfully planted by rhizome planting (Ueda, 1960).

The culm cutting technique takes advantage of the rapid and considerable resource gain from rhizome planting and breeding activities, leading to uniform stands, because many propagation units can be obtained from a single culm which is cut into sections. Although propagation with culm cuttings is successful for clump forming bamboos (pachymorph rhizome type) in the tropics, it is not successful for the non-clump forming bamboos (leptomorph rhizome type) of temperate regions (Uchimura, 1980 - Japan). Successful experiments involving culm cuttings have been reported for *Bambusa vulgaris* 'Striata' and *Dendrocalamus asper* (Schult. f.) K. Heyne in Indonesia (Sutiyono, 1999), *Bambusa vulgaris* J. C. Wendl. in India (Sharma, 1980), *Bambusa vulgaris* in Malaysia (Abd. Razak and Hashim, 1992), *Bambusa vulgaris* (Suzuki and Ordinario, 1980; Uchimura, 1979), *Bambusa blumeana* Schult. f., *Dendrocalamus merrillianus* Elm (Suzuki and Ordinario, 1980) and *Dendrocalamus strictus* (Roxb.) Nees (Uchimura, 1979) in the Philippines and *Dendrocalamus asper* in Thailand (Patrakosol, 1992).

Propagation by branch cuttings is useful and seems to be promising for mass propagation. Large plantations of *Dendrocalamus asper* in Thailand were successfully established with this method (Vongvijitra, 1990).

In layering, either whole culms or a part of the culm bearing branches is bent down to a shallow trench in the ground and secured in place with hooked or crossed stakes. When roots and shoots develop at the nodes, the buried parts are separated from the mother plant (Dransfield and Widjaja, 1995; McClure, 1966). This method is suitable for small bamboos. The low success is, however, disadvantageous (Dransfield and Widjaja, 1995). Layering of *Bambusa vulgaris* and *Dendrocalamus giganteus* Munro showed only 10% success (Banik, 1987b - Bangladesh; Lantican *et al.*, 1987 - Philippines; Sharma, 1982 - India). *Melocanna baccifera* (Roxb.) Skeels did not respond to this method (Banik, 1987b). *Dendrocalamus asper*, however, appeared amenable to layering with a 50% success rate in Indonesia (Dransfield and Widjaja, 1995). No maintenance is required for layered culms, because they are left alive, being attached to the clump.

Marcotting is practised for *Dendrocalamus membranaceus* Munro in Phu Tho, Vietnam

(Shibata, 2000). Branches are kept on culms which remain erect and connected with clumps. The base of a branch complement is notched with knives and the complement is enclosed within a mixture of cow dung and dried straws, and wrapped in plastic to maintain a moist state and promote rooting. Thirty to forty cm of the branch near the culm is left and other parts are removed. About 10 units of this type can be made on each culm. Rooting usually starts within three weeks.

No successful vegetative propagation has been reported for *Oxytenanthera abyssinica*. The objective of this study was, therefore, to investigate possible nursery techniques for the vegetative propagation of *Oxytenanthera abyssinica*. Consulting the reports mentioned above, propagation by culm cuttings was the main focus in this study but other vegetative propagation techniques were also attempted (Appendix XIII, Plates 4-8: p.174).

7.2 Vegetative propagation using detached cuttings

There are two reports of attempted vegetative propagation by culm cuttings for *Oxytenanthera abyssinica* (Abeels, 1961; Khan, 1966), but neither was successful despite inferences to the contrary by Fanshawe (1972) in the case of Abeels's study. However, the researchers made suggestions and left room for improvements to this approach, which was modified and adapted for this Malawi study.

Abeels (1961) tried vegetative propagation for *Oxytenanthera abyssinica*, using four types of nursery bed. These were soil, stagnant water over sand in tubs, floating beds and the sandy bed of a stream. *Oxytenanthera abyssinica* produced young leaves in floating beds but the cuttings gradually died. Khan (1966) tried several vegetative propagation methods for *Oxytenanthera abyssinica*, using three source positions from the primary culm axis (lower 1/3, middle 1/3 and upper 1/3). The cuttings were planted in the media silt-sand or clay and had 1-3 nodes. Planting was in a slanting position. Two-nodes cuttings from the lower one third of culms planted in the mixture of silt and sand survived for 92 days but none of them survived beyond 242 days. Khan (1966) has given several suggestions for his failure of propagation (Chapter 2). From his suggestions, branch material is retained at the node keeping at least the base of the branch and placement of cuttings (vertical) in the soil, irrigation in the dry season, and provision of light shade over the nursery were modified for this experiment. In addition, a growth regulator (NAA, naphthaleneacetic acid) was applied to facilitate rooting from the nodes.

Growth regulators IBA (indole-butyric acid) and NAA (naphthaleneacetic acid) have commonly been used to facilitate rooting from the nodes of bamboo cuttings. There were three methods of application of growth regulators to bamboo cuttings: soaking in dilute solution (<500 ppm), injection of a dilute solution into the cavity of the internodes and quick-dipping in concentrated solution (>500 ppm). More successful rooting responses have generally been reported with quick-dipping in concentrated solution than with soaking in diluted solution (Dirr, 1983; Loach, 1988).

In Malaysia, the lower 5 cm of culm cuttings of *Dendrocalamus strictus* was stood in 100 ppm IBA for 24 hours and resulted in a higher percentage of rooting (70%) than a lower concentration of 10 ppm IBA or 10 ppm and 100 ppm IAA (indole-acetic acid) and NAA (20-60%) (Surendran *et al.*, 1986). Delgado (1949) and White (1947) reported no effect of IAA, IBA and NAA on rooting of branch cuttings at low concentrations (<50 ppm). With regard to the type of growth regulator, in the Philippines, Uchimura (1977) reported that standing the base of culm cuttings of *Bambusa vulgaris* in 100 ppm IBA for 24 hours before planting resulted in higher rooting rates and longer roots than did standing in NAA and IAA.

In Kenya, the number and the height of sprouts of *Ochlandra travancorica* were higher for culm cuttings injected with 100 ml of 100 ppm NAA into the cavity of the internodes (Seethalakshmi *et al.*, 1990). There were, however, no difference of the rooting percentage of the cuttings to the total planted between the lower (10 ppm) and the higher solution (100 ppm), and among the growth regulators applied (IAA, IBA, NAA). Rooting reached 40% in all of the applications in the summer (February to June). Branch cuttings of several bamboo species were immersed in 100 ppm IBA for 24 hours and in 550 ppm and 1000 ppm IBA for 5 seconds in the Philippines (Castillo, 1990). No significant effect was found between treatments. In this Malawi study, higher solution (500 ppm) of NAA was applied for 5 seconds on the bases of culm cuttings before planting.

The first experiment was carried out to compare cuttings from the primary culm axis harvested in three different seasons (before and after rain started, and in the dry season). The next experiment involved comparing the fate of cuttings collected from the different populations and of the application of growth regulator hormone (NAA).

The clump environment was standardised, unless otherwise stated, in terms of exposure (mid slope sampling only), aspect (level, gradient <10%), and topographic position (within 30 m of a watercourse). Only large clumps of more than 20 culms more than one year (>2 seasons) old were considered. Clumps which had been exploited were not sampled. Within clump categories suitable culms were at least 3 cm diameter at breast height, composed of at least 20 internodes ≥5 cm long, straight (no curve), and with no evidence of leaf disease, stem discoloration or injurious organisms.

For the first experiment, without growth regulator hormone, cuttings were harvested in Lilongwe Nature Sanctuary (13°57'S, 33°47'E; 1060 m) and planted in a nursery by the Sanctuary office. For the next experiment, with growth regulator hormone, clumps were selected from two populations, Lilongwe Nature Sanctuary and Mua-Livulezi Forest Reserve (14°36'S, 34°51'E; 719 m) for comparative purposes. Cuttings were planted in the nursery of Lilongwe National Botanic Garden.

In Mua, a place for the collection of culms was recommended by a local forest guard, taking account of the selection standard. Lilongwe Nature Sanctuary was selected because it was close to Lilongwe National Botanic Garden, and had many natural clumps of *Oxytenanthera abyssinica* and the Ministry of Tourism, Parks and Wildlife and Lilongwe Nature Sanctuary gave approval for harvesting culms for research purposes.

7.2.1 Detached cuttings without hormone application

7.2.1.1 Protocol

Experimental material

At first, two areas were chosen in the Sanctuary, one in the north of Zone A (Map 6.2) and one in the south. Clumps that departed from the standard criteria (7.2) were disregarded. From the remaining clumps, one was selected at the centre in each area and the ten clumps nearest to the centre were identified. From these, five were randomly sampled in each area.

In addition to the standard criteria mentioned above (7.2), culm selection took account of age, with inclusion of culms <1 year old (young) and 1-4 years old (mature) but not those more than four years old. Cuttings with buds which were nearly bursting were selected.

After culms which did not conform to the standard had been excluded, a young culm and an old culm were sampled from each clump. The culms selected were cut into sections of an internode with a node at each end (Figure 7.1). The length of an internode was less than 50 cm. Beyond the node, 5 cm of culm was included at each end of the cutting. Branches were cut 2-4 cm from the nodes. All leaves were trimmed from the cuttings. Felling of bamboos for cuttings was carried out early in the morning, in misty weather or just after rain. Twenty culms of *Oxytenanthera abyssinica* were firstly harvested with saws from 10 clumps. Secondly, leaves were trimmed off to reduce evaporation. Culms were cut into proximal and distal halves, ensuring identical numbers of culms in each half portion.

Topsoil taken near the nursery in the Sanctuary was mixed with sand taken from the woodland of the Sanctuary to improve drainage.

Treatments

Three cuttings were taken from each of three positions on each culm. The positions were: top 1/3, middle 1/3, lower 1/3 (Figure 7.1). Sections less than 1 cm in distal diameter were rejected.

Thirty cuttings were laid horizontally at 10 cm depth. Another thirty portions were set vertically, with one quarter of the length exposed above ground (Figure 7.2, Plate 4). There were twelve combinations of planting orientation, culm age and source position and each had five culm cuttings (Table 7.1).

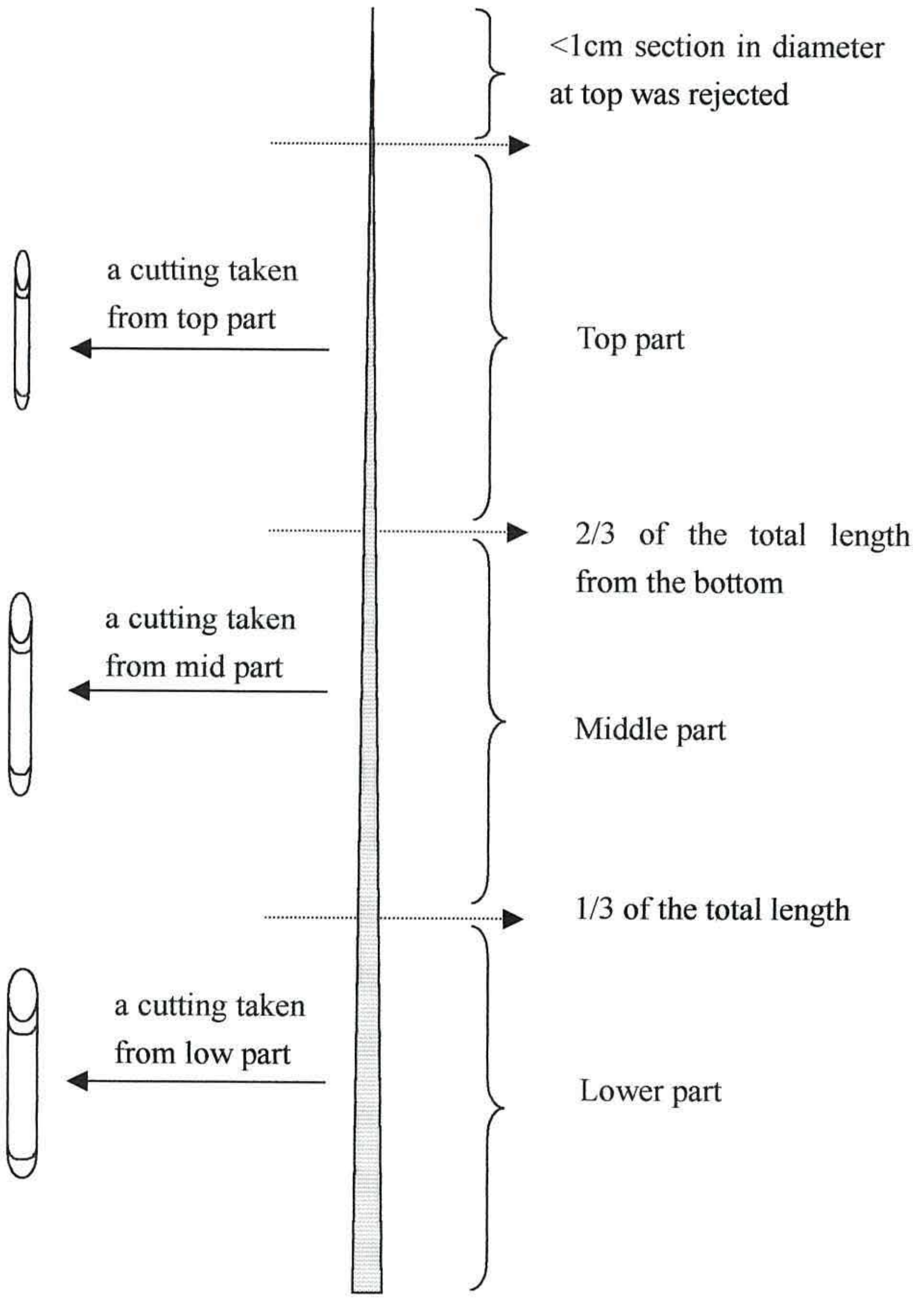


Figure 7.1 : Cuttings from a culm

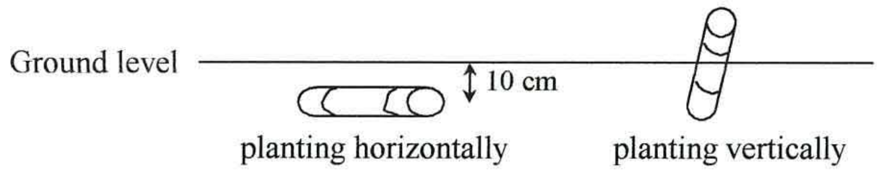


Figure 7.2 : Planting methods of culm cuttings

Table 7.1: Number of portions in combination with several kinds of cuttings and planting methods

	Vertical planting			Horizontal planting		
Parts of culms	Low	Mid	Top	Low	Mid	Top
Young	5	5	5	5	5	5
Mature	5	5	5	5	5	5

Experimental layout

Six ridges were made straight from the south to the north and 10 cuttings were planted in each ridge (Figure 7.3). Cuttings were planted 10 cm from each other. Cuttings were covered with 10 cm of medium. Each row was labelled.

HLM	VMM	VTY	HTM	VLY	HMM
HLM	VMM	VTY	HTM	VLY	HMM
HLM	VMM	VTY	HTM	VLY	HMM
HLM	VMM	VTY	HTM	VLY	HMM
HLM	VMM	VTY	HTM	VLY	HMM
HTY	VLM	HMY	HLY	VMY	VTM
HTY	VLM	HMY	HLY	VMY	VTM
HTY	VLM	HMY	HLY	VMY	VTM
HTY	VLM	HMY	HLY	VMY	VTM
HTY	VLM	HMY	HLY	VMY	VTM

5 m

7 m

First field: horizontal (H) or vertical (V) planting; second field: collection position in source culm, top (T), Mid (M), Low (L); third field: culm age, >1 year old (Y), 1 - <4 years old (M); a single cutting for each box.

Figure 7.3 :Actual layout of culm cuttings on the ground without growth regulator

Investigation period

Collection and planting of cuttings were done on 8 November 2001, and repeated on 11 April 2002, and on 31 July 2002 for comparison of seasonal alternatives (Table 7.2). In total 60 cuttings were planted on each seasonal planting date: (10 clumps × 2 culms/clump × 3 cuttings/culm = 60 cuttings, Table 7.1). Duration of recording was five months for the propagation experiments initiated in November 2001, three months for the propagation experiments initiated in April 2002 and two months for the last experiment, initiated in July 2002.

Table 7.2: Dates of planting and assessment activities for culm cuttings in three seasons

	Dates of activities		
Harvesting & Planting	8 Nov. 2001	11 Apr. 2002	31 July 2002
Final assessment	9 Apr. 2002	15 July 2002	23 Sep. 2002

Maintenance

Unless there was rain, cuttings were watered every two days, early in the day or late in the afternoon. No watering was done if the soil was already moist. Weeding was carried out when necessary. Cuttings attacked by termites and by disease were removed.

Parameters recorded

Presence of leaves, shoots, rhizomes and roots was regarded as survival. Their survival was recorded for every cutting at the end of each experiment (9 April 2002, 15 July 2002 and 23 September 2002, Table 7.2).

7.2.1.2 Data processing

Survival of cuttings was recorded at the end of each assessment period. A tabular summary of survival of cuttings was drawn up by planting orientation (vertical and horizontal), age of culms (young and mature) and position in culms (top, mid and low).

Chi-square tests of association were carried out for each category of treatments. Survival/non-survival frequencies for each treatment (age of culms and position in culms) were summarised in contingency tables [2 × 2] for the age of culms and [3 × 2] for position in culms. Values for χ^2 were calculated:

$$\chi^2 = \Sigma \frac{(O-E)^2}{E}$$

where:
O is observed frequency and E is expected frequency.

Yate's correction was applied to the table [2 × 2] of culm ages where there was only one degree of freedom. The Minitab statistical package was used, row × column contingency tables being entered on the appropriate Minitab worksheet.

7.2.1.3 Results

There was no survival of cuttings in vertical planting at the end of the observation period (Table 7.3) regardless of the origin in culm of material used. In horizontal planting, cuttings planted in July 2002 and recorded until September in 2002 were more successful than those in the trials at different seasons. Also, cuttings from middle and lower position of mature culms resulted in higher survival rate than those from top position of young culms (Table 7.4).

In the first trial, only five of 30 cuttings horizontally planted were alive on 9 April 2002 and by this time no vertically planted cuttings (out of 30) and no cuttings secured from the top part of a culm remained alive. Roots were detected only for a single cutting taken from the middle part of a culm and horizontally planted. In the second trial, there was no vertically planted cutting surviving by 15 July 2002. No cuttings from the lower part of culms remained alive, either. Eight cuttings out of 30 cuttings planted horizontally remained alive. One of the three surviving cuttings from the mid part of a mature culm had roots. In the third trial, fourteen cuttings were alive out of the 30 cuttings planted horizontally but in no case were roots initiated. There was only a single cutting from the top part of a mature culm alive (Table 7.3).

Table 7.3: *Oxytenanthera abyssinica*: survival of cuttings from different culm sources planted in different seasons and at different orientation (5 per culm age per season)

Date of planting	Date of observation	Culm age	Planted no. of cuttings	Vertical Low	Vertical Mid	Vertical Top	Horizontal Low	Horizontal Mid	Horizontal Top
8 Nov. 01	9 April 02	Young	5	0	0	0	1 (0)	0	0
		Mature	5	0	0	0	2 (0)	2 (1)	0
11 Apr. 02	15 July 02	Young	5	0	0	0	0	2 (0)	0
		Mature	5	0	0	0	0	3 (1)	3 (0)
31 July 02	23 Sep 02	Young	5	0	0	0	3 (0)	3 (0)	0
		Mature	5	0	0	0	3 (0)	4 (0)	1 (0)

Figures in brackets: number with roots

Table 7.4 : *Oxytenanthera abyssinica*: association between horizontally-planted cutting survival and culm age and source position of collection

	Treatment	df	χ^2 value	probability	Indication	Remarks
April	Age of culms	1	–	Fisher: 0.33	n.s.	–
	Position in culms	2	3.36	0.19	n.s.	–
July	Age of culms	1	–	Fisher: 0.109	n.s.	–
	Position in culms	2	6.48	0.04	5%	+
September	Age of culms	1	0	1	n.s.	–
	Position in culms	2	8.30	0.02	5%	++
Total	Age of culms	1	3.39	0.07	n.s.	–
	Position in culms	2	7.94	0.02	5%	++

N = 30 in each test; assessed in April 2002 (November 2001 planting), July 2002 (April 2002 planting) and September 2002 (July 2002 planting); continuity correction was applied where there was only with 1 degree of freedom; when expected frequencies in any cell of a 2×2 table were lower than 5, Fisher's exact test was carried out and the value indicates exact level of significance. +: middle culm, ++: middle and lower culm regions yield better cutting material.

In vertical planting, exposure of upper parts of cuttings in the air may have accelerated the reduction of moisture content in the cuttings and hence the lower survival. In the third trial from July to September, there was little rain and few insects, and fewer cuttings were insect damaged or diseased, which may explain the higher survival. It would, however, be difficult for these cuttings to survive further without roots.

7.2.1.4 Conclusions

There was no survival of culm cuttings with vertical planting. Horizontal planting of culm cuttings gave some success. Cuttings secured from the distal end 1/3 of culms were not satisfactory for propagation. Those from the middle and lower parts of culms had better survival. Although cuttings from mature culms (>1 year old) gave higher survival than those from young culms (<1 year), the difference of survival rates between them was not statistically significant.

7.2.2 Detached cuttings with hormone application

7.2.2.1 Protocol

Experimental material

In each location, clumps lacking the standard specification (7.2) were excluded from consideration. Among suitable clumps, a clump was selected as the centre and the 30 clumps nearest to this centre were identified. From these, 15 clumps were sampled at random. Within categories, four suitable culms (7.2) 1-2 years old were sampled from each of the 15 clumps but culms of other ages were not sampled. Cuttings with buds or a swollen part at the base of branchlets were taken. Two of the four culms sampled from each clump were cut into single internode sections and the remaining two culms were cut into sections with two internodes (Figure 7.4). Single internode cuttings were consistently less than 50 cm long and two-internodes cuttings were less than 1 m long. Beyond the nodes at the ends of the cuttings, 5 cm of culm was included. Central branches were cut 15-25 cm from the nodes and other branches were cut 2-4 cm from the nodes. All leaves on the branches of the cuttings were trimmed off when culms were harvested.

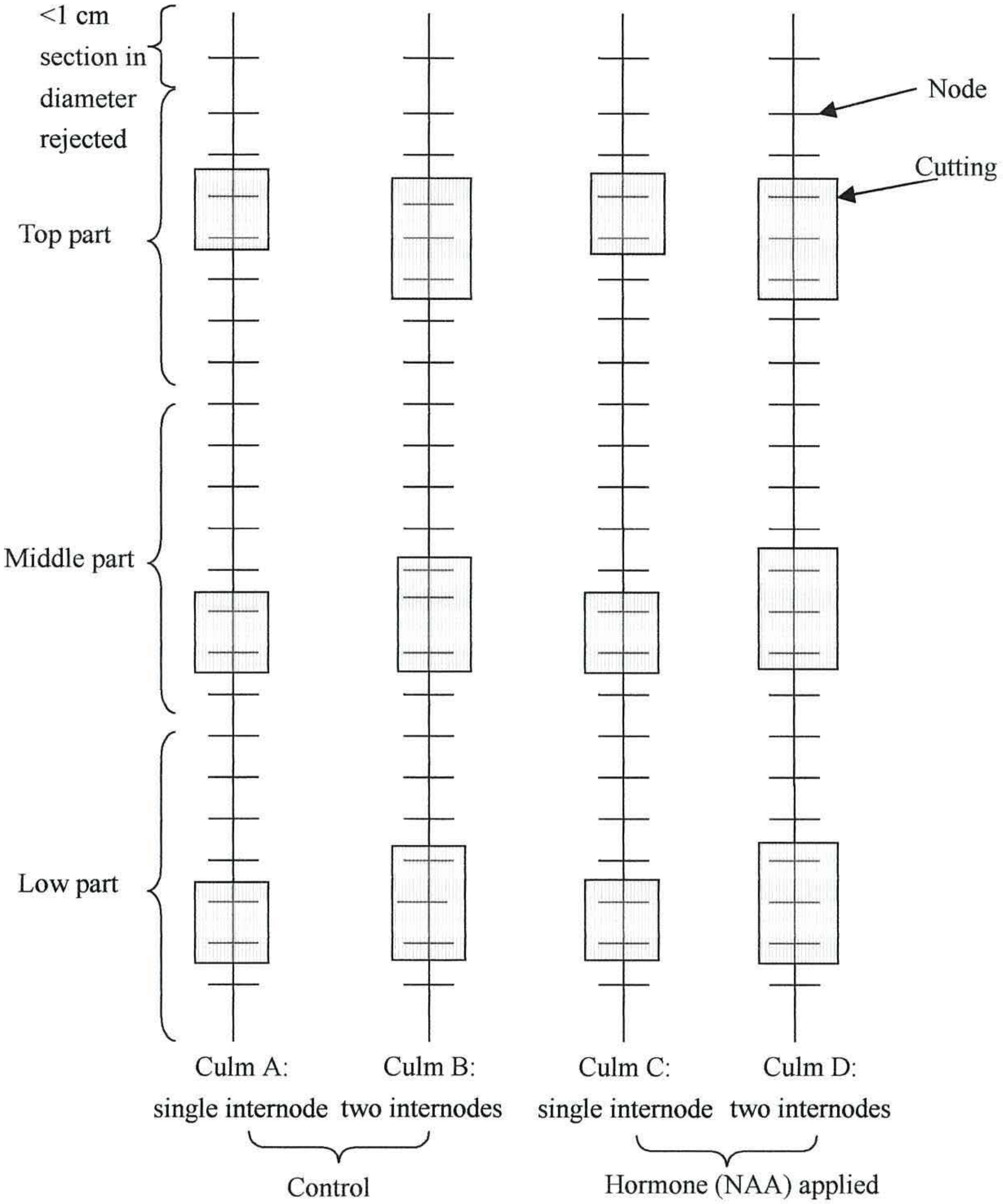


Figure 7.4 : Diagram of making cuttings for treatment with NAA at each selected clump

Felling of bamboos for cuttings was carried out with saws early in the morning, in misty weather or just after rain. Then, leaves were trimmed off to reduce water loss through transpiration. Culms were cut into proximal and distal halves with identical numbers in each half portion. They were then covered with detached leaves and transported to Lilongwe Botanic Garden, where the experiment was established, on the same day.

To make 500 ppm of auxin, 0.5 g of auxin was dissolved in 20 ml of methyl alcohol. Then, this volume was diluted to 1000 ml by adding 50 percent methyl alcohol. Following harvesting, the half-culm units were cut into the sections to be used as individual cuttings. Rooting hormone was applied immediately after this. Both ends of cuttings were dipped in rooting hormone (500 ppm NAA) for five seconds just before planting.

The nursery medium was 50% sand from the Lingazi river mixed with 50% topsoil from the Botanic Garden. All cuttings were planted horizontally because of the failure of vertically planted cuttings to survive in the preceding experiment.

Treatments

Three cuttings were secured from each culm. The positions were: top (top 1/3 part), middle (1/3-2/3 part), low (low 1/3 part) in a whole culm. Sections distally less than 1 cm in diameter were rejected. There were 360 cuttings planted, of which 180 were taken from each location. The total number of culms was: 2 locations × 15 clumps × 4 culms/clump × 3 cuttings/culm = 360 cuttings (180 cuttings/location, Table 7.5).

Table 7.5: Number of culm portions per location × internode size × culm position × hormone treatment combination

Location	Position in culms	hormone dipped		no hormone	
		No. of internodes per cutting			
		One	Two	One	Two
Lilongwe	Top	15	15	15	15
	Mid	15	15	15	15
	Low	15	15	15	15
Mua	Top	15	15	15	15
	Mid	15	15	15	15
	Low	15	15	15	15

Experimental layout

Cuttings were planted not touching each other and each cuttings was covered with 10 cm of soil and labelled. Ten ridges were made straight from south to north in the nursery, five of which were for single internode cuttings and five of which were for two-internode cuttings. Allocation of ridges to single or two-internodes cuttings was at random. On each ridge 36 holes for cuttings were made. In the first 18 holes from the south, 18 cuttings from the same location, either from Mua or Lilongwe, were planted. In the first row, cuttings from Lilongwe were planted since this was the starting line of the nursery and it was convenient to plant cuttings from Lilongwe which were harvested two days earlier than those in Mua. In the second 18 holes on the ridge, cuttings from the other location from the first 18 cuttings were planted. Of the 180 cuttings dipped in growth regulator hormone, half (90 cuttings) were planted in the east half of the nursery and the other half (90 cuttings) in the west half of the nursery (Figure 7.5).

Investigation period

For the experiment with growth regulator hormone, cuttings were harvested in Lilongwe Nature Sanctuary on 27 January 2003 and planted on the following day, 28th of January. Cuttings were harvested in Mua forest reserve on 29 January 2003 and were planted on the following day, 30th of January (Table 7.6). Duration of recording was four months. Basic parameters were recorded every two months.

Maintenance

Cuttings were watered every two days unless there was rain, early in the day or late in the afternoon. There was no watering if the soil was already moist. Weeding was carried out when necessary. Cuttings attacked by termites or by any disease were removed.

N

10.7 m

3.8 m

row no.	①	②	③	④	⑤	⑥	⑦	⑧	⑨	⑩
	one -	two +	one +	two -	one +-	one -	two +-	two -	one +	two +
1	L3M-	D1L+	L2T+	D1L-	D14T-	L14L-	D5M+	L5M-	D4T+	L5M+
2	L2L-	D6M+	L3M+	D14T-	D11L-	L1M-	D15T+	L7T-	D9M+	L7T+
3	L2M-	D2T+	L3L+	D6M-	D2L-	L1L-	D13L+	L5L-	D15T+	L5T+
4	L3T-	D14T+	L2M+	D8L-	D2M-	L1T-	D5L+	L7M-	D6M+	L7L+
5	L2T-	D9L+	L2L+	D9T-	D14M-	L14T-	D5T+	L7L-	D9L+	L7M+
6	L3L-	D8M+	L3T+	D2M-	D11M-	L14M-	D15L+	L5T-	D10M+	L5L+
7	L12M-	D1M+	L12L+	D1M-	D14L-	L8M-	D13T+	L11L-	D7L+	L11M+
8	L6M-	D1T+	L6L+	D2L-	D2T-	L7L-	D13M+	L9M-	D9T+	L11T+
9	L6L-	D8L+	L12T+	D6T-	D11T-	L8L-	D15M+	L9T-	D15M+	L9T+
10	L6T-	D6L+	L6M+	D8M-	D14M+	L7M-	D5T-	L11M-	D6L+	L9M+
11	L12T-	D9T+	L12M+	D8T-	D2T+	L7T-	D13M-	L9L-	D4M+	L9L+
12	L12L-	D14L+	L6T+	D14L-	D11L+	L8T-	D15L-	L11T-	D10T+	L11L+
13	L15L-	D2M+	L10T+	D1T-	D11M+	L13M-	D5L-	L15L-	D10L+	L4T+
14	L15T-	D2L+	L15T+	D2T-	D2M+	L4L-	D13L-	L15M-	D7M+	L15L+
15	L10M-	D6T+	L15M+	D9L-	D11T+	L13T-	D15T-	L4M-	D15L+	L15T+
16	L10T-	D8T+	L10L+	D6L-	D14L+	L4T-	D5M-	L4T-	D6T+	L15M+
17	L10L-	D9M+	L10M+	D9M-	D2L+	L13L-	D13T-	L15T-	D7T+	L4L+
18	L15M-	D14M+	L15L+	D14M-	D14T+	L4M-	D15M-	L4L-	D4L+	L4M+
1	D3M-	L3M+	D5T+	L10T-	L11L-	D4L-	L2L+	D3T-	L1L+	D10M+
2	D3L-	L3T+	D8M+	L3M-	L11M-	D10L-	L6M+	D4M-	L14M+	D4L+
3	D5T-	L10T+	D8L+	L3L-	L9M-	D15T-	L12L+	D7T-	L14L+	D7T+
4	D8L-	L3L+	D13L+	L10L-	L9T-	D4M-	L2T+	D10L-	L1M+	D3T+
5	D8T-	L10M+	D1T+	L3T-	L5M-	D15M-	L12M+	D10M-	L1T+	D12M+
6	D12M-	L10L+	D1L+	L10M-	L11T-	D6T-	L2M+	D12L-	L14T+	D11L+
7	D12L-	L1L+	D3M+	L8T-	L9L-	D9M-	L12T+	D3L-	L7M+	D3L+
8	D13M-	L8M+	D12T+	L1T-	L5T-	D7T-	L6L+	D4T-	L8L+	D4T+
9	D1T-	L8T+	D12L+	L1M-	L5L-	D6L-	L6T+	D7L-	L8T+	D3M+
10	D13L-	L1M+	D5M+	L8L-	L9L+	D10M-	L6L-	D3M-	L7T+	D10T+
11	D8M-	L8L+	D13T+	L8M-	L11L+	D10T-	L6T-	D11T-	L8M+	D11M+
12	D12T-	L1T+	D1M+	L1L-	L11T+	D9L-	L2M-	D12M-	L7L+	D12L+
13	D13T-	L13T+	D12M+	L14L-	L11M+	D7M-	L12L-	D11L-	L13T+	D7M+
14	D1M-	L14M+	D5L+	L13M-	L5M+	D4T-	L2L-	D4L-	L4M+	D4M+
15	D1L-	L13M+	D3T+	L13L-	L5L+	D9T-	L2T-	D12T-	L4L+	D7L+
16	D3T-	L14L+	D3L+	L14T-	L9M+	D7L-	L12T-	D10T-	L13M+	D10L+
17	D5M-	L14T+	D13M+	L14M-	L9T+	D15L-	L6M-	D11M-	L4T+	D12T+
18	D5L-	L13L+	D8T+	L13T-	L5T+	D6M-	L12M-	D7M-	L13L+	D11T+

Cutting identification

First field: location of collected cuttings, L = Lilongwe, D = Mua; second field: clump; number at the location (1-15 clumps numbered); third field: collection position in source culm, T = top, M = Mid, L = Low; fourth field: treatment, + = auxin (NAA) applied, - = auxin not applied; a single cutting in each box.

Figure 7.5: Layout of experiment to investigate influence on survival of hormone-treated cuttings of *Oxytenanthera abyssinica* from two localities in Malawi

Table 7.6: Dates of planting at Lilongwe, Malawi and assessment of culm cuttings of *Oxytenanthera abyssinica*

	Date of activities carried out	
	Cuttings from Lilongwe	Cuttings from Mua
Harvesting	27 January 2003	29 January 2003
Planting	28 January 2003	30 January 2003
First assessment	1-2 April 2003	1-2 April 2003
Second assessment	30 May 2003	30 May 2003

Parameters recorded

The number of shoots per cutting and the length of longest shoot per cutting (rounded to nearest cm) were recorded on 1-2 April, 2003 (two months after planting) by staff of the Lilongwe National Botanic Garden. The number of shoots, rhizomes and roots per cutting and length of all shoots, rhizomes and roots (rounded to nearest cm) was recorded by the writer on 30 May, 2003 (four months after planting).

7.2.2.2 Data processing

Survival (presence of leaves, shoots, rhizomes and roots) of cuttings was recorded and a tabular summary by original location of cuttings, source positions in culms, hormone application and number of internodes was drawn up.

Chi-square tests of association were carried out for each category of treatments. Survival/non-survival frequencies for each treatment (original locations of cuttings, positions in culms, hormone application and number of internodes) were summarised in contingency tables [2 × 2] for the locations, hormone application, and the number of internodes and [3 × 2] for positions in culms. Values for χ^2 were calculated:

$$\chi^2 = \Sigma \frac{(O-E)^2}{E}$$

where:

O is observed frequency and E is expected frequency.

Yate's correction was applied to the table [2 × 2] where there was only one degree of freedom. The Minitab statistical package was used, row × column contingency tables being entered on the appropriate Minitab worksheet.

Mann-Whitney *U* tests were carried out to examine whether medians of total rhizome length and total shoot length of each cutting on two populations (NAA applied or not) were different. Observations from both populations were ranked from 1 to the appropriate maximum number. The ranks of each population was summed and *U* values were determined, from:

$$U_1 = n_1 n_2 + \frac{n_2 (n_2 + 1)}{2} - R_2, U_1 = n_1 n_2 + \frac{n_1 (n_1 + 1)}{2} - R_1,$$

R_1 is the sum of the ranks of sample 1 and R_2 is the sum of the ranks of sample 2. The smaller of the two *U* values was compared with the critical value.

7.2.2.3 Results

Effect of NAA on growth behaviour

No effect of growth regulator hormone (NAA) was detected on the survival rate of cuttings (Tables 7-7-7.9). Roots and rhizomes were found on survival cuttings. Roots were detected on a single cutting on 30 May 2003, (a single internode cutting from the low part of a culm from Mua, dipped in NAA); there were three roots, 9 cm, 5 cm and 4 cm in length, respectively (Plate 5). According to a report from the botanist of the Garden, on 21 July 2003, a second cutting had produced two roots (2.5 cm, 1.8 cm) - this was a two-internode cutting taken from the mid part of a culm from Mua, to which hormone had been applied.

Table 7.7: *Oxytenanthera abyssinica*: cutting survival at Lilongwe, Malawi, after 2 months (1 April 2003) in relation to source position in culm, number of internodes, source locality and application of hormone

Original source of cuttings	Position in culms	hormone applied No. of internodes per cutting One	Two	Total	no hormone One	Two	Total	Grand total
Lilongwe (Σ = 180)	Top (n = 60)	–	1	1	–	–	–	1
	Mid (n = 60)	–	2	2	1	3	4	6
	Low (n = 60)	–	–	–	1	4	5	5
	Total	0	3	3	2	7	9	12
Mua (Σ = 180)	Top (n = 60)	1	1	2	3	2	5	7
	Mid (n = 60)	7	7	14	2	6	8	22
	Low (n = 60)	6	6	12	3	6	9	21
	Total	14	14	28	8	14	22	50
Grand total		14	17	31	10	21	31	62

–: no survival

Table 7.8: *Oxytenanthera abyssinica*: survival (30 May 2003) of cuttings planted in January 2003 in relation source position in culm, number of internodes, source locality and application of hormone

Original source of cuttings	Position in culms	hormone applied No. of internodes per cutting One	Two	Total	no hormone One	Two	Total	Grand total
Lilongwe (Σ = 180)	Top (n = 60)	–	–	0	–	–	0	0
	Mid (n = 60)	–	2	2	–	–	0	2
	Low (n = 60)	–	–	0	–	3	3	3
	Total	0	2	2	0	3	3	5
Mua (Σ = 180)	Top (n = 60)	–	–	0	–	–	0	0
	Mid (n = 60)	2	4	6	2	3	5	11
	Low (n = 60)	4 (1)	5	9	4	3	7	16
	Total	6	9	15	6	6	12	27
Grand total		6	11	17	6	9	15	32

Figures in brackets: number of roots. –: no survival

Table 7.9: *Oxytenanthera abyssinica*: association between survival (April and May 2003) of cuttings planted in January 2003 in relation source position in culm, number of internodes, source locality and application of hormone

Date	Treatment	df	χ^2 value	probability	Indication
April 1	Hormone	1	0	1	n.s.
	Number of internodes	1	3.29	0.70	n.s.
	Original location of cuttings	1	26.68	0.00	0.1%
	Position in culms	2	14.19	0.001	0.1%
May 30	Hormone	1	0.03	0.85	n.s.
	Number of internodes	1	1.68	0.195	n.s.
	Original location of cuttings	1	15.13	0.00	0.1%
	Position in culms	2	19.413	0.00	0.1%

Continuity correction was applied where there was only one degree of freedom.

The mean numbers of rhizomes were higher on the cuttings to which NAA was applied (0.36 rhizomes/cutting) than those NAA was not applied (0.12 rhizomes/cutting) (Table 7.10). It was unclear whether NAA had affected the number of rhizomes produced. For cuttings to which NAA was applied and which sprouted rhizomes, rhizome numbers ranged from 1 to 18. The mean of total rhizome length per regenerating cutting, to which NAA was applied, was longer (17.4 cm) than the corresponding mean for those to which no NAA was applied (9.3 cm). However, the means of the rhizome length of two populations (NAA applied or not) were not significantly different (Mann-Whitney *U* test). Nor did growth regulator hormone (NAA) affect the growth of shoots (Table 7.11, Appendix XII).

The number of internodes

The number of internodes, one or two, did not affect the survival of cuttings (Table 7.9).

Table 7.10: Effect of NAA on growth behaviour (numbers) of *Oxytenanthera abyssinica* cuttings observed on 30 May 2003 (360 cuttings divided into two groups, NAA applied or not)

	NAA applied	NAA not applied
No. of cuttings with rhizomes	10/180	8/180
mean rhizome no./cutting	0.36	0.12
mean rhizome no./sprouted cutting	6.40	2.75
No. of cuttings with shoots	11/180	12/180
mean shoot no. /cutting	0.14	0.22
mean shoot no./sprouted cutting	2.40	3.30

Notes: 9 cuttings had both shoots and rhizomes which were included in both counts.

Table 7.11: Effect of NAA on rhizome and shoot recorded (length) for *Oxytenanthera abyssinica* cuttings observed on 30 May 2003 (360 cuttings divided into two groups, NAA applied or not)

	rhizomes		shoots	
Hormone (NAA)	applied	not applied	applied	not applied
Mean of total length/sprouted cutting (cm)	17.4	9.3	41.6	60.6
U test	n.s.	n.s.	n.s.	n.s.
U value	41	39	75	57

Notes: 9 cuttings had both shoots and rhizomes which were included in both counts.

U test: Mann-Whitney *U* test

Relationship between survival and collecting location

A chi-squared test showed a highly significant association between original location of cuttings and survival number (Table 7.9). In total, 50 cuttings from Mua survived while only 12 cuttings from Lilongwe had survived until 1 April 2003 (Table 7.7). Twenty seven cuttings from Mua survived, but only five cuttings from Lilongwe, until 30 May 2003 (Table 7.8).

Relationship between survival and positions in culms

There was a highly significant association between culm position and survival number (Table 7.9). The middle and low parts of culms appear more suitable than the top part for propagation by cuttings of *Oxytenanthera abyssinica*, which is consistent with

Khan's (1966) conclusion.

7.2.2.4 Conclusions

More cuttings from middle and low parts of culms collected in Mua survived than those from top parts of culms collected in Lilongwe. Locations of material and positions in culms significantly affected the survival rate. There was no effect of rooting hormone (NAA) or the number of internodes in the cutting on survival, although the number of rhizomes and the total rhizome length of cuttings to which NAA was applied were higher than for those where NAA was not applied.

7.3 Seeds as potential propagation material

Flowering of *Oxytenanthera abyssinica* occurs very rarely. Eggeling (1951) defined the flowering cycle as seven years but Istas and Raekelboom (1962) noted the cycle was 25-40 years. The typical flowering interval of *Oxytenanthera abyssinica* is still unclear and it has been claimed that it occurs irregularly and the cycle is long (Fanshawe, 1972; Innes, 1977; Williamson, 1975).

Fanshawe (1972) reported a nursery seed germination rate at 5-30% in 11 days in Malawi but without detailing the circumstances. Embaye (2003) conducted germination tests on *Oxytenanthera abyssinica* seeds planted with different orientation and at various sowing depths. Seed "lay flat" orientation and 2.5 mm sowing depth gave the highest germination rate at 80% respectively. Seeds were not pre-treated (e.g. soaked in water) in his method.

There is no reliable treatment method reported for propagation of general bamboo and *Oxytenanthera abyssinica* seeds. Rice (*Oryza sativa* L.) seeds are generally soaked in water before planting, because the embryo resumes activity when the moisture content of seeds exceeds 15% (Goto and Kanahama, 1995). Bamboo seeds have some similarity to rice seeds, so the propagation method of rice seeds was modified for this study and seeds were soaked in water before planting in Lilongwe, Malawi, expecting higher germination rate than non-soaked seeds.

According to Anon. (1954a), seeds of *Oxytenanthera abyssinica* sown in the warm season (November in Malawi) take 11 days to germinate, while those sown in the cold weather have taken 2-4 months. Therefore, avoidance of distinctly cool periods appears appropriate, but precise temperature recommendations are lacking. It is desirable to investigate suitable techniques for nursery propagation of seeds, because rarely obtainable seed should be efficiently used.

The writer found flowers of *Oxytenanthera abyssinica* with seeds in 2001-2003 in Lilongwe, Malawi (Frontispiece). This made it possible to assess the seed germination rate under various conditions.

7.3.1 In Malawi

Initial seed germination testing was carried out in Malawi.

7.3.1.1 Protocol

Flowering of *Oxytenanthera abyssinica* was seen in Lilongwe Nature Sanctuary in December 2001 (Plate 9). However, only eight developed seeds of *Oxytenanthera abyssinica* could be found, out of thousands of spikelets investigated. After husks were removed, the seeds were directly sown in a tray of sand-soil mixture immediately after collection. Seven (88%) germinated 13 days later.

Flowering occurred again in the Sanctuary in May 2003 and about 200 developed seeds were collected. Using these seeds, a test was carried out to investigate whether seeds pre-soaked in water gave a higher germination rate than seeds which had not been pre-soaked.

Experimental material

Seeds were sampled from five out of ten flowering clumps on the east bank of the Lingazi river in Zone A in Lilongwe Nature Sanctuary (13°57'S, 33°47'E; 1060 m) on 11 May 2003. Of the 200 fertile seeds (Plate 10) sampled, 50 were used for this test. Seeds were dehusked before treatment.

Treatment

Of 50 seeds, 25 were soaked in water in petri dishes for 10 hours before sowing and the other 25 were not soaked. Tap water from Lilongwe town was used. This water was reasonably free from organic or inorganic impurities. Tubes were filled with a mixture of topsoil and leaf manure in the Lilongwe Botanic Garden. Seeds were sown in the tubes in embryo-down orientation.

Experimental layout

Thirteen tubes, in which unsoaked seeds were planted, were laid in a line (Line 1) from the south to the north (Figure 7.6). In successive parallel lines to the east, there were 13 tubes with soaked seeds (Line 2), 12 tubes with unsoaked seeds (Line 3) and 12 tubes with soaked seeds (Line 4). The distance separating the seeds within lines was 5 cm and between lines was 15 cm, and around the plot a buffer zone 2 m wide free of vegetation was created.

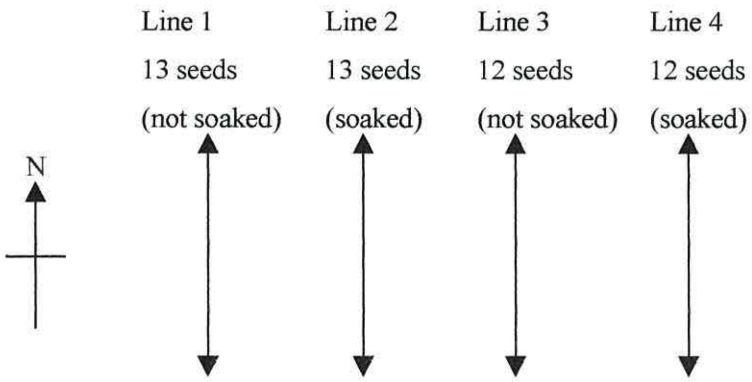


Figure 7.6: Spatial arrangement of seed tubes for germination test of *Oxytenanthera abyssinica* in Lilongwe, Malawi

Note: Seeds planted in tubes were laid on the ground, being covered by light shade.

Investigation period

Seeds were sown in polythene tubes on 12 June 2003 and kept at the nursery of the Lilongwe Botanical Garden for four and a half months, until 30 October 2003.

Maintenance

To keep the soil moist, seed tubes were watered every day, early in the day or late in the afternoon unless there was rain. Weeding was carried out when necessary. Tubes were covered by a roof of straws.

Parameters recorded

The emergence of a plumule above the sand surface was defined as germination. The number of germinated seeds was counted every month for four months (July to October in 2003).

7.3.1.2 Data processing

A tabular summary of germination success by treatment (soaked in water or not) was drawn up. Chi-square tests were carried out to test whether the soaking method affected the final germination rate of seeds. Survival/non-survival frequencies for treatments, soaked and not soaked, were summarised in contingency tables [2 × 2]. Yate's correction was applied. The Minitab statistical package was used, row × column contingency tables being entered on the appropriate Minitab worksheet.

7.3.1.3 Results

None of the seeds had germinated one month after planting. By October (four months after planting) 16 of the seeds soaked in water had germinated and eight seeds which were not soaked had germinated. Soaking treatment promoted germination at 4 months (Table 7.12).

Table 7.12: Total number of germinated seeds in Lilongwe (planted on 12 June 2003), Malawi

assessment	12 July 03	15 Aug 03	17 Sep 03	30 Oct 03
month (s)	1	2	3	4
Treatment				
soaked in water	0/25	2/25	10/25	16/25
control	0/25	1/25	7/25	8/25
χ^2 test	n.s.	n.s.	n.s.	*
df	1	1	1	1

Note: *: significant at 5% level.

7.3.1.4 Conclusions

Soaking in water for 10 hours before sowing had a positive effect on germination of *Oxytenanthera abyssinica* seeds although this did not become clear for four months. Most seeds germinated in September (mean daily temperature 20.9°C) and October (mean daily temperature 22.4°C). Few seeds germinated in July-August (mean daily temperature <20°C).

7.3.2 Tetrazolium test in UK

The tetrazolium test is commonly used to make quick estimates of the viability of seed samples (Hartman *et al.*, 1990; International Seed Testing Association, 1996). However, no tetrazolium test procedure specifically for bamboos was prescribed in international rules for seed testing or in the literature. The test procedure for *Oryza sativa* in International Seed Testing Association (1996) was adopted for *Oxytenanthera abyssinica* seeds in a modified form. Such a test was carried out before direct germination tests in cabinets were performed.

7.3.2.1 Protocol

Experimental material

Of 200 seeds collected on the east bank of the Lingazi river in Lilongwe Nature

Sanctuary (13°57'S, 33°47'E; 1060 m) on 11 May 2003, 125 were available. These had been kept for about three months, from the beginning of May to the beginning of August in Lilongwe, Malawi and in Bangor, UK at ambient temperatures. Of the 125, 23 seeds were sampled at random for the tetrazolium test.

Treatment

First, 23 dehusked seeds were soaked in distilled water and left in a dark cabinet maintained at 22°C for two hours to soften the seed coat. Next, the seed coat was abraded with sandpaper to facilitate water penetration into the seeds. Finally, the seeds were again soaked in distilled water and then left in a dark cabinet at a temperature of 27°C for 18 hours.

Evaluation process

After soaking in water for 18 hours, seeds were longitudinally bisected along the embryonic axis. One seed was found to be in a decayed state and one found to lack an embryo. These two seeds were excluded and the test carried out on the remaining 21 seeds. The cut seeds were soaked in a 1% solution of tetrazolium aqueous solution for two hours. Evaluation of staining was made immediately after this.

Investigation period

The tetrazolium test was carried out under the laboratory condition in the School of Agricultural and Forest Sciences in Bangor, 4-5 August 2003.

7.3.2.2 Results/conclusion

All 21 seeds (100%) were viable in the tetrazolium test.

7.3.3 Direct germination test in controlled conditions in UK

For investigation of thermal effects on germination, a direct germination test in controlled conditions was carried out in Bangor, UK, at the Pen-y-Ffridd experimental site.

7.3.3.1 Protocol

Experimental material

Seeds were sampled on the east bank of the Lingazi river in Lilongwe Nature Sanctuary (13°57'S, 33°47'E; 1060 m) on 11 May 2003. Of 100 seeds remaining after the tetrazolium test (7.3.2), 90 were sampled at random and 76 were used for the test. Seeds were dehusked before the treatment was applied.

Treatments

To break any seed dormancy, all sampled seeds for the test were soaked in water on 11 August 2003 before sowing on 12 August 2003. First, 90 seeds were soaked in tap water in a beaker and left in a greenhouse maintained at a temperature of 20°C for two hours to soften the seed coat. The beaker was covered with a black plastic sheet during this time. Secondly, the seed coat was abraded with sandpaper to facilitate water penetration into the seed. Then, the seeds were again soaked in tap water and left in a dark cabinet at 20°C for 24 hours (Figure 7.7). In this process, 14 seeds were excluded from the test because embryos were collapsed or seeds were decayed. Consequently 76 seeds were vertically sown, embryo end upwards.

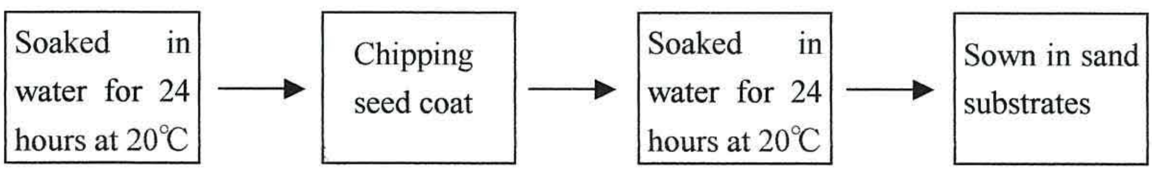


Figure 7.7: Procedure of pre-treatment of seeds for direct germination test in Bangor, UK

For investigation of thermal effects on germination, seeds were kept in cabinets in which temperatures alternated between 32°C and 22°C (Cabinet 1), and 36°C and 26°C (Cabinet 2). The higher temperatures applied for eight hours and the lower temperatures for 16 hours (Table 7.13). Variation due to the apparatus was no more than ± 1°C. The germination test started with a phase of the lower temperature.

Table 7.13: *Oxytenanthera abyssinica*: germination conditions imposed in growth cabinets at the Pen-y-Ffridd research facility, Bangor

	Cabinet 1 (38 seeds)		Cabinet 2 (38 seeds)	
Temperature	32°C, 8 h	22°C, 16 h	36°C, 8 h	26°C, 16 h
Light	Light, 8 h	Dark, 16 h	Light, 8 h	Dark, 16 h
Humidity	90% at all times		90% at all times	

Experimental layout

The test was performed in cabinet equipped with sodium lamps (400W × 5) and metal halide lamps (250W × 4). Seed trays were illuminated with these lamps for 8 hours at the higher temperature and were kept in darkness for 16 hours at the lower temperature.

In each of two seed trays filled with sand, 38 seeds were planted. The sand had a pH value 6.5. The bottom layer of sand was loosened by raking before sowing. The seeds were covered with about 2 mm of uncompressed sand and planted 3.5 cm from each other.

Investigation period

Germination of seeds in cabinets was monitored for a month from 12 August 2003 to 11 September 2003. Germinated seeds were transplanted into pots on 11 September 2003 then monitored for three months until 10 December 2003.

Maintenance

Water was sprayed on the sand before sowing the seeds. The sand was continually kept moist, but moisture content was not excessive. Tap water was used. This water was reasonably free from organic or inorganic impurities. The pH of the water was 7.7. Relative humidity in the air was kept at 90% or more. To ensure there was sufficient air around the seeds, the sand was not compressed.

Pots were kept at 25/20°C (day/night) in the greenhouse. Soil-based compost (product name: Humax John Innes) was used as the substrate. Watering was carried out to keep the substrate continually moist. Relative humidity in the air was kept at 90% or more.

Parameters recorded

The weight of seeds was recorded when harvested (fresh weight) and after they had been kept at room temperature for three months (weight before use in the growth cabinets). Only developed seeds were taken into account.

Germination of seeds was defined as the emergence of the plumule above the sand surface. The number of germinated seeds (out of 76 observed) was counted daily.

After germination, the growth of seedlings was monitored. To minimise disturbance, essential structures for further development were observed when transplanted to pots:

- root system (primary root)
- shoot axes
- cotyledons
- coleoptile

The following parameters were determined:

- Imbibition period: the number of days from sowing to the first recorded germination
- Total germination period: the number of days from sowing to the last rise in the percentage of seeds germination
- Cumulative germination percentage: the final level of germination recorded
- Mean daily germination percentage: this is calculated by dividing the cumulative percentage by the number of days for each of the time period

- Final daily speed of germination: the mean daily germination percentage for the duration of the test period

From the parameters above, the following additional values were derived:

- Germination energy: the highest of the calculated mean daily germination percentages
- Energy period: the interval in days from sowing to reaching the highest mean daily germination
- Germination value: the germination energy multiplied by the final daily speed of germination

7.3.3.2 Data processing

Seed weight (fresh and before use in the growth cabinets) was expressed as the number per kilogram.

Chi-square tests were carried out to ascertain the effect of temperature regime on germination rate. The frequencies of germinated and non-germinated seeds for each treatment (32/22°C and 36/26°C) were arranged in a contingency table. Yate's correction for continuity was applied. The Minitab statistical package was used, row × column contingency tables being entered on the appropriate Minitab worksheet.

7.3.3.3 Results

Seed weight

The weight of 100 seeds was recorded when harvested and after they had been kept at ambient temperatures for three months, and converted to the seed number per kilogram:

Table 7.14: Seed number per kilogram of *Oxytenanthera abyssinica* with and without husks

	with husks	dehusked
fresh	9000	13000
before use in the growth cabinets (after 3 months)	11000	16300

Cumulative germination percentage

The cumulative germination percentage under the 32/22°C regime was higher than the 36/26°C regime (Tables 7.15, 7.16 and 7.17, Plates 11-13).

Table 7.15: Results of direct germination test of *Oxytenanthera abyssinica* seeds under growth cabinet condition in Bangor, UK (seeds collected in Lilongwe, Malawi)

Treatment 1: 32/22°C (day 8h/night 16h; 38 seeds planted on 12 August 2003)

August 03	13	14	15	16	17	18	19	20	21	22	23	24	25
days	1	2	3	4	5	6	7	8	9	10	11	12	13
no. of germinated seeds	0	0	0	0	0	1	4	9	2	1	1	1	1
total germinated seeds	0	0	0	0	0	1	5	14	16	17	18	19	20
cumulative germination (%)	0.0	0.0	0.0	0.0	0.0	2.6	13.2	36.8	42.1	44.7	47.4	50.0	52.6
mean daily germination (%)	0.0	0.0	0.0	0.0	0.0	0.4	1.9	4.6	4.7	4.5	4.3	4.2	4.0

Treatment 2: 36/26°C (day 8h/night 16h; 38 seeds planted on 12 August 2003)

August 03	13	14	15	16	17	18	19	20	21	22	23	24	25
days	1	2	3	4	5	6	7	8	9	10	11	12	13
no. of germinated seeds	0	0	0	0	0	3	2	2	1	1	3	1	2
total germinated seeds	0	0	0	0	0	3	5	7	8	9	12	13	15
cumulative germination (%)	0.0	0.0	0.0	0.0	0.0	7.9	13.2	18.4	21.1	23.7	31.6	34.2	39.5
mean daily germination (%)	0.0	0.0	0.0	0.0	0.0	1.3	1.9	2.3	2.3	2.4	2.9	2.9	3.0

Table 7.16: *Oxytenanthera abyssinica*: numbers of seeds germinating and failing to germinate over 30 days under growth cabinet condition in Bangor, UK

Treatment (alternating °C)	germinated*	not germinated	total
32/22	20	18	38
36/26	15	23	38

*: includes seeds which germinated but decayed after transplanted in pots in greenhouse.

Table 7.17: Derived parameters of germination test in Bangor, UK

Parameters	Treatment (alternating °C)	
	32/22	36/26
Imbibition period (days)	6	6
Total germination period (days)	13	13
Cumulative germination (%)	53	40
Final daily speed of germination	4.0	3.0
Energy period	9	13
Germination energy (%)	4.7	3.0
Germination value (no units)	18.8	9.0

There was no significant difference between the number of germinated seeds in 32/22°C regime and in 36/26°C regime.

$\chi^2 = 0.847$; n.s. ($p = 0.35$)

Derived germination parameters

Observation period was 30 days after sowing but the total germination period was 13 days in both treatments. Energy period of the temperature regime of 36/26°C is longer than that of the regime of 32/22°C. The peak of mean daily germination percent of the 32/22°C regime was 4.7% (germination energy) and the energy period was 9 days. The peak of mean daily germination percent of the 36/26°C regime was 3.0% and the energy period was 13 days. The germination value of the 32/22°C regime was much higher than that of the 36/26°C regime because both two factors (final daily speed of germination and germination energy) of the 32/22°C regime was higher (Table 7.17).

Survival after transplantation

All seedlings resulting from germination (35) were transplanted into pots on 11 September 2003. All 15 plants transplanted of the germinating in the cabinet of the higher temperature regime (36/26°C) had died two months after transplanting (by 10 November 2003) (Table 7.18, Plate 14). In contrast, all 20 plants transplanted from the lower temperature regime were still alive after three months (by 10 December 2003). Plants from the higher temperature cabinet were probably unable to withstand the 10°C reduction in temperature involved (greenhouse temperature was 25/20°C). Number of stems, diameter of the widest stems and length of longest stems were measured for each of the 20 plants from the cabinet of 32/22°C on 10 December 2003.

Table 7.18: *Oxytenanthera abyssinica*: survival of plants transplanted from growth cabinets to pots in a greenhouse (day 25°C /night 20°C) after 3 months

	day and night temperature (d/n) regime in cabinets	
	32/22°C	36/26°C
surviving plants/transplanted plants	20/20	0/15

Descriptive statistics (Table 7.19) were calculated for the 20 transplanted plants after three months in the greenhouse (25/20°C, day and night):

Table 7.19: *Oxytenanthera abyssinica*: stem numbers, length and diameters three months after transplanting* to greenhouse pots from growth cabinets

	number of stems (stems)	diameter of widest stems (mm)	length of longest stems (cm)
mean (± 95% CI)	3.79 ± 0.44	3.68 ± 0.48	44.84 ± 5.59
standard deviation	0.92	1.00	11.60
minimum	2	1.5	20
maximum	5	5	60

*seed was sown one month before transplanting date.

Most leaves were similar in size (3-4 cm × 15-17 cm) to those of mature culms.

7.3.3.4 Conclusions

Of the two regimes compared, the temperature regime 32/22°C (day 8 hours/night 16 hours) was more suitable for the germination of *Oxytenanthera abyssinica* seeds than the 36/26°C regime. In the direct germination test, cumulative germination percentage in one month after sowing was 53% (20/38 seeds) under the 32/22°C regime and 40% (15/38 seeds) under the 36/26°C regime. The peak of mean daily germination percent of the 32/22°C regime came in 9 days while that of the 36/26°C regime did in 13 days. Plants transplanted from the higher temperature regime (36/26°C) were unable to survive in a new environment 10°C cooler. In contrast, plants germinated under a temperature regime of 32°C (day) and 22°C (night) survived well, and grew.

Plates of *Oxytenanthera abyssinica* in Lilongwe, Malawi

Plate 4: Culm cuttings in vertical and horizontal planting (November 2001)

Plate 5: Roots from the cutting to which NAA applied (June 2003)

Plate 6: Cuttings in a pond (12/11/2001)

Plate 7: Marcotting (2/1/02)

Plate 8: Air layering of a new shoot (12/4/02)

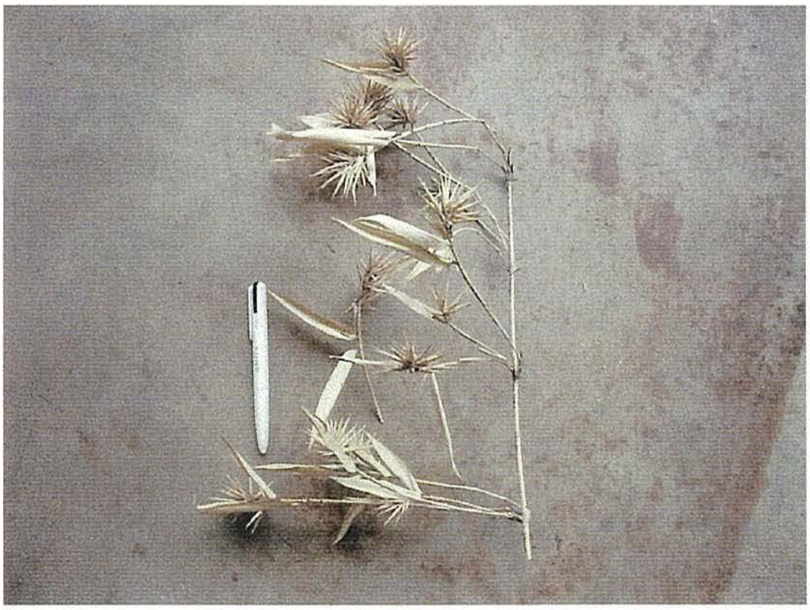
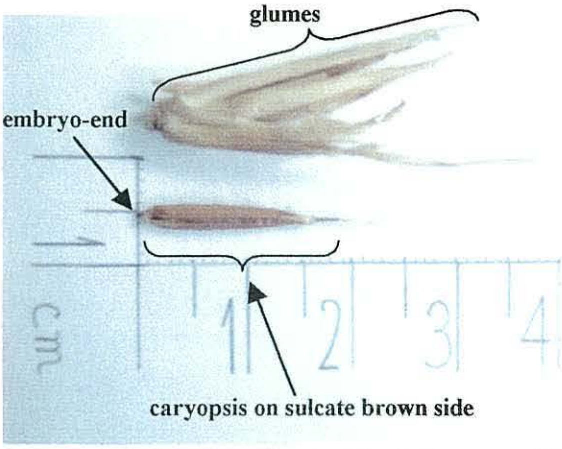


Plate 9: Inflorescences



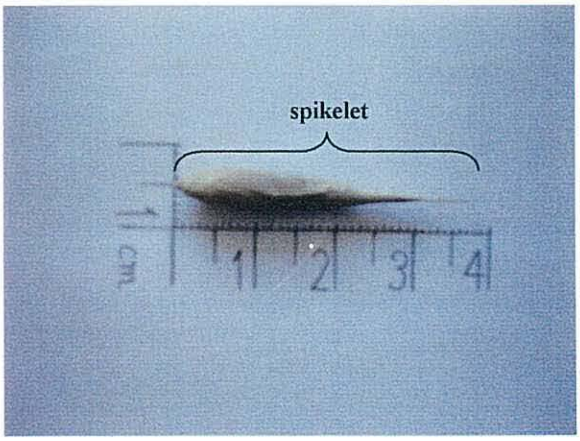


Plate 10: Seeds collected in Lilongwe (July 2003)

Oxytenanthera abyssinica: germination tests in Bangor, UK

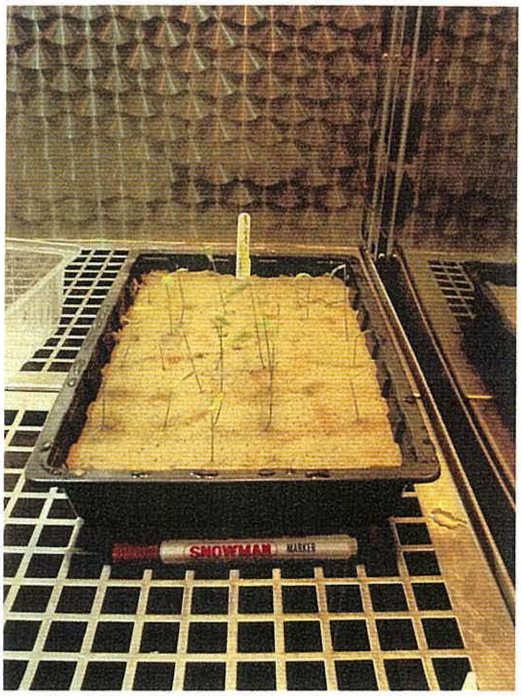


Plate 11: Direct germination test: seeds planted in 32/22°C regime (23 days after)

Plate 12: Direct germination test: seeds planted in 36/26°C regime (23 days after)

Plate 13: Seedling grown in 32/22°C regime (one month after sowing)

Plate 14: Seedlings from 32/22°C regime (left) and from 36/26°C regime (right) three months after transplanted (seed sown one month before transplanting)

Chapter 8

Discussion

This study was carried out with a specific aim of characterising the *Oxytenanthera abyssinica* clump as a management unit, in terms of size composition and potential to produce annual cohorts of new culms. A second specific aim was to explore possible approaches (mainly vegetative) to nursery propagation. Both aims were pursued through practical fieldwork and involved setting and testing three basic hypotheses. In this chapter, these issues are discussed and management strategy is considered.

Hypothesis 1 – there are no differences in clump characteristics between populations of *Oxytenanthera abyssinica* in different regions of Malawi

This hypothesis is rejected. Differences between the numbers of new culms recruited, expressed as a percentage increase in the number of culms per clump, were noted between unharvested populations from Nsawagi (85%), Lilongwe (28%) and Zomba (20%). Differing mortality rates of pre-existing culms in the three populations, or particularly favourable conditions for new culm development, may have accounted for the findings. Kigomo and Kamiri (1985) stated annual production for *Oxytenanthera abyssinica* depends on rainfall in the previous year. Nsawagi may have received more rainfall in the previous year than years before. To explain higher production (on-year) and lower production (off-year) of leptomorph bamboos occurring in alternate years (Smitinand and Ramyarangsi, 1980; Ueda, 1960), Li *et al.* (1998) attributed the life span of leaves which have high photosynthetic capacity when they are less than one year old. In the second year, leaves of leptomorph bamboos are shed, therefore they produce little photosynthates and few shoots. Because almost all leaves of *Oxytenanthera abyssinica* are shed every dry season, Li's theory may not be appropriate for *Oxytenanthera abyssinica*. It suggests, however, the number of productive leaves affects new culm production. Some leaves persisted throughout the year in Lilongwe in 2001-2002. In Nsawagi, many new leaves may have persisted longer in 2001, perhaps a consequence of a longer period of rain than in previous seasons. This may have contributed to the higher production of new shoots against existing culms in 2002. Confirmation of this phenomenon requires further research about the association of climate with the life cycle of leaves and with new culm production.

For *Oxytenanthera abyssinica*, new culm production relative to existing culms was at least 20-28% in Malawi. This figure is similar to that of past reports for *Oxytenanthera abyssinica* (17-20% - Henkel, 1927) and for tropical Asian bamboos (30-40%) and temperate bamboos (6-10%). For *Yushania alpina*, new shoots less than one year old against older culms was 13-17% in Ethiopia (Embaye *et al.*, 2003; LUSO CONSULT, 1997a). New culms are generally produced from new rhizomes produced from old rhizomes in the previous year (Chaturvedi, 1988; McClure, 1966). Rhizome form is unique for each bamboo species, being thick or thin and branching frequently or infrequently (McClure, 1966). Pachymorph rhizomes branch more frequently than leptomorph rhizomes. The distinctiveness of the rhizome system in each species may explain reports that new culm production relative to numbers of old culms varies with species (Kleinhenz, and Midmore, 2001; Manthauda, 1960; Tomar, 1963; Ueda, 1960). Rhizomes of *Oxytenanthera abyssinica* may be less branched than those of tropical Asian bamboos, because there are fewer new culms relative to the number of existing culms. Rhizomes excavated in Zomba and Lilongwe showed that 1-2 new rhizomes were produced annually from each existing rhizome (personal observation), but these observations refer only to one year. Excavating several clumps and counting the number of rhizomes produced from each rhizome for *Oxytenanthera abyssinica* along with some other bamboos should be carried out in future to clarify how the rhizome branching pattern differs between species and reveal more precisely the relation between new culm production and existing culms.

Hypothesis 2 – harvesting culms does not reduce or increase new shoot production in clumps of *Oxytenanthera abyssinica* in Malawi

This hypothesis is rejected. More intense harvesting of young (7-12 months old) culms in November 2001 appeared to have a positive effect on new shoot production in 2002 in Lilongwe Nature Sanctuary, Malawi. If young culms of *Oxytenanthera abyssinica* are needed, modest harvesting intensity 40% of young and mature culms every two years is suitable for clump management. Even if only young culms are needed, mature culms should also be harvested to ease culm density and prevent congestion. If only mature culms are exploited, the harvesting intensity should be limited to 40% every two years to sustain clumps.

No past study carried out research into the impact of harvesting young culms on new culm production, although young culms are highly valued in the local economy (Inada, 2000). Harvesting 40% of *Gigantochloa scortechinii* culms more than three years old ultimately gave higher yields than harvesting intensities of 0%, 20% and 80% according to Azmy (1996). Overall harvesting intensity applied in his method was lower than that used with *Oxytenanthera abyssinica* in Malawi, because culms less than 3 years old were retained. Both methods, however, suggest that a certain proportion of mature culms should be removed to eliminate risks of suppression of new shoots in congested sections of a clump (Chaturvedi, 1988; Deogun, 1937; Ueda and Numata, 1961), and a certain proportion should be kept for the production of photosynthates.

Culms less than one year old have few branches and leaves and less capacity for photosynthetic activity than culms more than one year old (Uchimura, 1999). Young culms may use more photosynthates from clumps than they produce. Harvesting young culms may be followed by increased allocation of photosynthates to the rhizomes, resulting in increased shoot growth. In Japan, it is said that the growth of new shoots is facilitated by harvesting shoots in the rainy season and harvesting shoots eventually increases the production (Muroi, 1987). Clumps of *Oxytenanthera abyssinica* may have responded similarly to the harvesting of young culms in Malawi, as harvesting young culms did not have an adverse effect on new shoot production. Growth of stems is generally stimulated by auxins (Kozlowski *et al.*, 1991). As well as the movement of photosynthates within rhizomes, differences of levels of auxins before and after harvesting young culms should be observed in the future.

Because more shoots were produced in 2003, the second year after harvest, it is not advisable to shorten the harvesting cycle (one year) and apply a lower harvesting intensity (20%). Past reports (Anon., 1962; Mooney, 1959) recommend 25-33% harvesting intensity of mature culms of *Oxytenanthera abyssinica* every year. A longer (two years) cycle of harvesting can overcome variations in production reflecting a year deficient in rainfall. Also, villagers tend to harvest more culms than planned in Malawi, because resource decline forces them to rely less and less on finding other harvestable sources. It is more realistic to regulate the interval but accept a higher harvesting intensity than to limit the intensity and apply a shorter cycle.

The reduction of culm density within clumps with 40% harvesting intensity is explained by the fact the clump area gradually increases. Definition of congestion is varied. Deogun

(1937) simply defined congestion as an overcrowded condition with culms, branches and leaves. Before the experimental monitoring of new culm production under various harvesting intensities started in Lilongwe, it was thought that higher harvesting intensity might increase the number of thin culms (Dransfield and Widjaja, 1995) and increase overcrowded conditions (Deogun, 1937). Neither outcome occurred, however, although there was a marginal tendency of decreasing diameter of new shoots in 2002 and 2003 with increasing harvesting intensity. If clumps are already congested, culms at the centre and dead culms should be cut out leaving culms at the clump periphery, as practiced in India (Deogun, 1937). An appropriately manageable size of clump is probably 20-50 culms. It is laborious to reach culms in the interior if clumps are large and such culms tend to be left until they die. For larger clumps with 100-200 culms, it may be necessary to clear culms at the centre leaving culms on the clump periphery as practiced for congested clumps.

No felling in the growing season should be carried out as it may damage the newly emerging shoots (Liese, 1985). Harvesting at the end of the dry season is suitable for *Oxytenanthera abyssinica*, because it is not the growing season of new shoots and culms are conveniently dry as material for weaving and construction products. It also favours new shoot production to leave clumps unharvested until leaves are shed in the dry season to maximise annual gains from photosynthetic activity. Assessment of the age of culms for harvesting should be stressed for the clump management. New shoots of *Oxytenanthera abyssinica* generally appear from the clump periphery in Zambia (Fanshawe, 1972). However, new shoots did not necessarily arise at the clump periphery in Lilongwe, Malawi. Therefore, careful observation both on the location of culms in clumps and the condition of the culms should be made.

Hypothesis 3 – vegetative propagation using culm cuttings from any part of a culm of any age is a feasible option for nursery use with *Oxytenanthera abyssinica*

This hypothesis is rejected. No promising vegetative propagation method was identified in the course of this study. Propagation by detached cuttings was unsuccessful for *Oxytenanthera abyssinica*, which is consistent with the past reports (Abeels, 1961; Khan, 1966; Kigomo and Kamiri, 1987). It is said that thick-walled bamboos can be propagated with culm cuttings because of high nutrient content (Liese, 1985) and clump forming bamboos in Asia are usually propagated with the culm cutting method (Abd. Razak and

Hashim 1992; Patrakosol, 1992; Sharma, 1980; Sutiyono, 1999; Suzuki, and Ordinario 1980; Uchimura, 1979) but it is not the case for *Oxytenanthera abyssinica* although it is a clump forming bamboo with a pachymorph rhizome system.

There were some indications of prospects for propagating cuttings of *Oxytenanthera abyssinica* but, at best, successes were very limited. All cuttings vertically planted died. Thirty percent (27/90) of cuttings horizontally planted survived - but only for a few months. All culm cuttings vertically planted in Kenya (Kigomo and Kamiri, 1987) died within five months which is consistent with the results in Malawi. More culm cuttings planted in June 2003 in Malawi survived than those planted in November 2001 and in April 2002. After the rainy season started in December 2001 leaves were produced. Culms used for planting in June 2002 should have stored more photosynthates than did others. For *Dendrocalamus strictus* in India, culm cuttings collected before the initiation of growth gave a higher shooting rate (Gupta and Pattanath, 1976). There was less insect damage on cuttings planted in June 2002. The late dry season before leaves are shed would be suitable for harvesting culms of *Oxytenanthera abyssinica*.

Locations of material and positions in culms also affected the survival rate. The soil of Mua should be more fertile than Lilongwe, accumulating nutrient from the forests of the Mua mountain. The middle and low parts of culms appeared more suitable than the top part for viable cuttings, consistent with Khan's (1966) results. There was no effect of age of culms, rooting hormone or the number of internodes in the cutting on survival. It can be considered that rooting hormone may not be absorbed into the cuttings of *Oxytenanthera abyssinica* with the quick-dip method (5 seconds). In Asia, the cavity of internodes of cuttings is filled with water or a dilute solution of rooting hormone before planting of cuttings (Abd. Razak and Hashim, 1992; Kumar *et al.*, 1988; Sutiyono, 1999). *Oxytenanthera abyssinica* culms are solid or thick-walled in lower parts but there is a cavity in middle parts (Inada *et al.*, 2003). Another rooting hormone, IBA, worked more effectively than NAA for culm cuttings of *Bambusa vulgaris* and *Dendrocalamus strictus* (Surendran *et al.*, 1986; Uchimura, 1977). In future propagation experiments for *Oxytenanthera abyssinica*, cuttings from middle parts of culms should be used, the internode cavity being filled with water or a dilute solution of rooting hormone. Alternative rooting hormones should also be tested.

Rhizome fragments (offsets) are a possible source for *Oxytenanthera abyssinica* (Anon., 1944, 1954a; Eggeling and Dale, 1951; Kigomo and Kamiri, 1987; Mgeni, 1983; von

Breitenbach, 1961). Although removing rhizomes with culms from clumps may damage source clumps (Khan, 1966; Uchimura, 1979), this commonly has to be accepted because there is no other option where no seed is available. Rhizome planting with culms has a long tradition (Peal, 1882) and is a successful technique for *Gigantochloa nigrociliata* (33% success rate), *Dendrocalamus longisipathus* (Kurz) Kurz (40% success rate - Hassan, 1977) and *Bambusa vulgaris* (100%) (Banik, 1984). Micropropagation has also been found successful for several bamboos in Asia. Hundreds of plants can be produced from the tissues of mother bamboos (Rao *et al.*, 1992). Thus, this technique is suitable for mass propagation. For future plantation work of *Oxytenanthera abyssinica*, research of micropropagation is needed.

Raising plants from seeds of *Oxytenanthera abyssinica* was more successful than vegetative propagation, again consistent with past reports (FAO, 1974; Kigomo and Kamiri, 1987). Soaking in water for 10 hours before sowing was effective for the germination of *Oxytenanthera abyssinica* seeds in the open in Lilongwe Botanical Garden but seedling emerged only from three months after sowing when the daily mean temperatures were more than 20°C. Soaking in water is usually carried out to break seed coat and embryo dormancy so that seeds can be germinated (Willan, 1985). It is unclear whether the soaking treatment increased the germination rate of *Oxytenanthera abyssinica* seeds, because most seeds germinated so long (3-4 months) afterwards. Sur *et al.* (1988) reports that a soaking-drying treatment was not effective for *Dendrocalamus strictus* seeds. In soaking-drying, after soaking for 6 hours in water, seeds were dried back to the original weight in a cabinet (Sur *et al.*, 1988). However, rice (*Olyza sativa*) seeds, which have some similarity to bamboo seeds, are generally soaked in water at 10°C for one week or at 20°C for three days (Goto and Kanahama, 1995). Germination rates of pre-soaked rice seeds are 2-3% higher than those of unsoaked rice seeds (Kim *et al.*, 2001). The soaking period (10 hours) used in this experiment in Malawi is shorter than that for rice seeds to avoid the risk of seeds germinating before the intended sowing date.

This study showed that *Oxytenanthera abyssinica* seeds could be stored at least three months at the ambient temperatures without losing viability (100% viable in the tetrazolium test). Embaye (2003) indicates seeds of *Oxytenanthera abyssinica* can be stored at least seven months. For most bamboos in Bangladesh, viability lasts only for 2 months (Banik, 1987a). Fresh seeds germinated better (germination rate 50% of sown seeds within 10 days after collection) than stored seeds (2%, 1-2 months after collection) for *Bambusa tulda*, *Bambusa multiplex*, *Bambusa bambos*, *Gigantochloa nigrociliata*, *Dendrocalamus longispathus* in Bangladesh (Banik, 1987a). Seeds can be stored longer if stored in silica gel in a desiccator (18 months, 2% of germination rate for *Bambusa tulda* - Banik, 1987a) and their moisture content reduced to 7% (12 months, 70% of germination rate for *Bambusa tulda* - Thapliyal *et al.*, 1991). Generally viability of seeds in the grass family can be maintained better in dry cold conditions than in moist warm conditions (Chapman, 1996). *Oxytenanthera abyssinica* seeds used in Bangor and in Embaye's study may have been dried sufficiently. *Oxytenanthera abyssinica* seeds may need some period to ripen so that they are adapted to remain ungerminated but viable for 3-7 months after flowering occurs. Anon. (1954a) also suggests *Oxytenanthera abyssinica* seeds need some months to germinate before sowing in Malawi. For some varieties of rice, months of ripening after harvesting are necessary to germinate (Grist, 1975). Perhaps because of such a ripening period, soaked and unsoaked seeds in Lilongwe did not germinate for four months. Genetic variations within populations likely increase when seed dormancy is present, since plants' progeny continue to enter the population after the parent's death (Loveless and Hamrick, 1984). There may be genetic variations for *Oxytenanthera abyssinica* because of the dormancy. It is worth exploring whether *Oxytenanthera abyssinica* seeds immediately after collection can germinate on an extensive scale. If not, suitable treatments to shorten the ripening period (Goto and Kanahama, 1995; Grist, 1975) should be investigated.

Embaye (2003) obtained a similar germination rate to that recorded here for *Oxytenanthera abyssinica* seeds from Ethiopia (50%) with embryo-end up orientation in 32 days after sowing but 60% in 45 days. He conducted propagation tests in a greenhouse where temperatures ranged from 11°C to 24°C. The temperatures varied widely and were lower than those in the experiments in Bangor (32/22°C). It is considered that *Oxytenanthera abyssinica* seeds from Ethiopia are adapted to lower temperatures than those from Malawi. Genetic variation of *Oxytenanthera abyssinica* may exist, because selfing of hermaphroditic plants generally promotes divergence (Loveless and Hamrick, 1984). In the experiment in Bangor, only two temperature regimes were applied, because only two cabinets equipped with the same facility were available. Although 100% of seeds were viable in the tetrazolium test, only 53% of seeds germinated in the direct germination test of the 32/22°C treatment in Bangor. Taking this fact into account, temperatures need to be modified, probably 1-2 degrees lower, to minimise the loss of seed viability.

Coleoptiles (primary shoots) without roots below the sand surface were observed in 13 out of the 18 ungerminated seeds grown in the temperatures 32/22°C regime in Bangor one month after sowing. When oxygen is deficient in the substrate, emergence of roots is prevented (Kome, 2003; Kozlowski *et al.*, 1991). Water may have been excessive in the substrates so that there was depletion of soil oxygen (Willan, 1985), although precautions were taken not to water excessively. Excessive water in the substrate should be carefully avoided in nursery practice. Anon. (1954) recommends seeds to be sown vertically with embryo-down orientation in Malawi. Higher germination rates were obtained, however, with lay-flat orientation than with embryo-up and embryo-down orientations in Ethiopia (Embaye, 2003). No record of the seed orientation in any other bamboos is available. For other plant families, seeds sown in embryo-up orientation consistently showed higher germination rates than those in embryo-down and lay-flat orientations (Krishnasamy, 1992; Pandey and Khatoon, 1999; Prasad and Nautiyal, 2003). The embryo is located near the face away from the sulcate brown side of the caryopsis of *Oxytenanthera abyssinica* (personal observation in the tetrazolium test). The depth from the soil surface to an embryo sown with the embryo-down orientation of lay-flat orientation could be 4 mm while that for an embryo sown with embryo-up orientation could be 2 mm. This was not considered by Embaye (2003). It would be premature to conclude that lay-flat orientation is superior to embryo-up and down orientations. Since it took four months for germination with embryo-down orientation in Malawi and the difference in germination rate between embryo-up (60%) and down (65%) orientations was marginal in Embaye's (2003) experiments, embryo-up orientation can be recommended as suitable for *Oxytenanthera abyssinica* seeds.

The mean height of seedlings was 45 cm four months after sowing in the greenhouse, Bangor. Temperatures in the greenhouse were 25/20°C (day/night). The mean height of seedlings was 17 cm two months after sowing in Embaye's (2003) experiments, where temperatures were kept from 11°C to 24°C. It should be noted that his seedlings grew well in the cooler conditions and suggests his plants from Ethiopia were associated with cooler conditions than those from Malawi.

All seven successfully raised plants of *Oxytenanthera abyssinica* in Lilongwe (mean annual rainfall 837 mm and mean annual temperature 20°C) were growing vigorously (tallest culm 120 cm, 6.1 mm culm diameter with 11 culms/plant) in June, nine months after transplantation in October 2002. Plants transplanted had more than two culms and the tallest culm was 30 cm in length in each plant. Transplantation was apparently carried out at an appropriate time. Anon. (1962a) recommends transplantation from seed beds is done between eight months and one year after germination, when the seedlings reach one meter in height. All seedlings one year old of *Oxytenanthera abyssinica* transplanted in the ground in Kenya survived for the next year (Kigomo and Kamiri, 1987). Mortality for *Oxytenanthera abyssinica* seedlings one year after sowing should be very low. In Lilongwe, additional watering was not carried out for the seedlings. Being dry tolerant and fast growing, and suffering low mortality, transplanted seedlings of *Oxytenanthera abyssinica* should be a good basis for plantation establishment.

Collecting seeds from different sources will be necessary to find out if suitable temperatures for germination can be generalised, and if genetic variation associated with geographical source affect the germination rate. Seed collection should be carried out on a continental scale to confirm suitable techniques for seed propagation and characterise genetic differences among populations.

For the distinctive biological features and associated environmental conditions of other African bamboos from *Oxytenanthera abyssinica,* studies for their propagation and management practices are required.

The future management and conservation of *Oxytenanthera abyssinica*

Management

Capacity to manage an undomesticated or semi-domesticated woody plant resource has to be based on an understanding of its ecology (Appendix XIV is an ecological profile). With *Oxytenanthera abyssinica* this understanding has reached a level sufficient for a number of key management challenges and options to be identified and, to some extent, elaborated. The comments that follow relate to these.

Suitable environmental conditions for *Oxytenanthera abyssinica* found in a GIS study should be considered to explore areas where this species grows well. Giffard (1974) remarked that the production of culms of *Oxytenanthera abyssinica* was significantly affected by the type of soils. The suitable site conditions to obtain better culm quality are along watercourses with good drainage and the bottom of the valley where moisture is retained in the soil. Sites exposing to the sun are favoured. From the indication on other bamboos in Asia (Suwannapinunt and Thaiutsa, 1990; Ueda, 1960), basic elements of fertiliser (NPK) are considered to be effective to increase yield and produce better quality of culms of *Oxytenanthera abyssinica*. Investigation on suitable amount of fertiliser for *Oxytenanthera abyssinica* is needed.

With recommended harvesting intensity (40% of young and mature culms) every two years, production for typical clumps composed of 10 young and 20 mature culms is estimated to be 4 young culms and 8 mature culms at the beginning of the cycle and 4 young culms and 9 mature culms at the end. In addition to the harvesting intensity found in this study, following harvesting routines can be recommended for *Oxytenanthera abyssinica* clumps to maintain quality of culms, consulting past reports on other bamboos in Asia (Deogun, 1936; Dransfield and Widjaja, 1995; Varalakshmi, 1992). Culms should be felled close to the ground to prevent the remaining stumps congesting the clumps. Dead culms should be cut out whenever found to prevent clump congestion. Culms older than two years should be left throughout the clump to support the growth of shoots.

Oxytenanthera abyssinica has suitable characters for plantation, being dry tolerant and fast growing, and suffering low mortality. It can be used for plantation establishment for soil erosion control and government forests that have become unproductive. Also, it is suitable for the plantations of community woodland for sources of daily products. Agroforestry actions can be made with dispersed plantings through farmlands as individual clumps. In Sudan, interplantation of *Eucalyptus* with *Oxytenanthera* was unsuccessful because *Eucalyptus* was attacked by termite (Anon., 1958). Although it was unclear if *Oxytenanthera abyssinica* attracted termite, precautions are needed for interplantation. If *Oxytenanthera abyssinica* is closely interplanted with the other plants, those plants may be suppressed by extension of *Oxytenanthera* clumps. Further research is needed to confirm the interplantation has no adverse effect and to identify suitable spacing.

Forest guards and extension workers should promote harvesting practices to the communities. Because most households are engaged in harvesting activities (Inada, 2000), those professionals are expected to visit communities to carry out this task. Handbooks of management guidelines in the local languages should be provided by the governments to facilitate the promotion. Permanent research plots should be constructed in Malawi and/or in other parts of Africa by them to extend silvicultural experiences.

Conservation

Where important plant resources are concerned, it is desirable to develop conservation guidelines in parallel with developing any management framework. This is a distinctly different approach from the more widely publicised efforts made to rescue or revive threatened species or populations but a fundamental element of good management provision. Appendix XV is a conservation profile of *Oxytenanthera abyssinica*, highlighting aspects of the present state-of-knowledge which have a bearing on management options for dealing with threats to resource integrity, and taking positive actions to enhance resource status and maintain genepool diversity.

Repeated fire prevents rejuvenation of *Oxytenanthera abyssinica* (Snowden, 1953). Fire could have a serious and adverse impact on the present resource base if nothing is done to control them. In southern Africa, vegetation is largely burnt by people to stimulate the growth of grasses for cattle grazing and hunting. In populated areas, vegetation is frequently burnt (Werger and Coetzee, 1978). In those areas, it is desirable to protect *Oxytenanthera abyssinica* from fire by constructing fire breaks.

Long interval of flowering is typical for bamboos. The reported flowering cycle for *Oxytenanthera abyssinica* is varied from seven years (Uganda) to 40 years (Democratic Republic of Congo). The reasons for flowering and the death of culms including rhizomes (monocarpy) is unknown for any bamboos (Liese, 1985). Drastic changes of climate may stimulate flowering of *Oxytenanthera abyssinica* (Anon., 1949). Past reports (Anon., 1944; Shibata, 1999) for *Oxytenanthera abyssinica* and other bamboos inferred after developed seeds are produced, culms and rhizomes die but when undeveloped seeds are produced, mother plants would survive. If this is the fact, conservation strategies would not be seriously prevented by flowering events.

No framework for the conservation of *Oxytenanthera abyssinica* has been made by international organisations - CITES, FAO and WCMC. International Network for Bamboo and Rattan (INBAR) published a few reports on *Oxytenanthera abyssinica* (Chihongo *et al.*, 2000; Kelbessa *et al.*, 2000) but has given no strategies for the conservation. International initiatives should be taken by these organisations to encourage awareness of the potential value of the *Oxytenanthera* resource, and encourage the adoption of appropriate management practices.

Chapter 9

General conclusions and recommendations

In this chapter, general conclusions drawn from the study are presented and specific recommendations for management and research activities are made.

Conclusions

Differences in clump characteristics were observed between unharvested populations of *Oxytenanthera abyssinica* in different regions of Malawi. The studies determined optimum harvesting intensities of culms for the sustainable management of *Oxytenanthera* clumps. No promising vegetative propagation method was identified. Seed propagation was more successful and promising.

Recommendations

Management recommendations

The following five specific recommendations are made for management and propagation of *Oxytenanthera abyssinica*:

- Suitable harvesting intensities should be applied for the sustainable production of new shoots in clumps. Harvesting 40% of the number of young (7-12 months) and 40% of mature (>12 months) culms per clump every two years is recommended. Harvesting should be carried out late in the dry season before the leaves are shed.

- An appropriately manageable size of clump is 20-50 culms. For clumps with more than 100 culms and congested clumps, it is necessary to clear culms at the centre leaving culms on the clump periphery. Culm ages should carefully be observed.

- Other management guidelines for harvesting are adopted from past reports on other bamboos in Asia. Culms should be felled close to the ground. Dead culms should be cut out whenever found. Culms older than two years should be left throughout the clump to support the growth of shoots.

- Seed collection should be carried out whenever flowering is found across the continent. Seeds should be pre-soaked in water of 20°C for 3 days before sowing. Seeds should be sown vertically, keeping embryo side up to the soil surface. Seeds should be sown in pots in the open when the mean daily temperature is more than 20°C.

- In controlled conditions for seed propagation, the higher temperature should be kept at 30°C (8 hours) and the lower temperature at 20°C (16 hours). Humidity should be kept at 90% or more. Excessive water supply to the substrate should be avoided. Seedlings can be transplanted in the ground when more than two culms are produced in each plant and the tallest culm is >30 cm.

Research recommendations to strengthen understanding of the biological potential of *Oxytenanthera abyssinica*

Five key areas of research activities for *Oxytenanthera abyssinica* are recommended:

- Studies should be conducted to reveal the relation between new culm production and existing culms more precisely. The association of climate with the life cycle of leaves and with new culm production should be studied. Branching pattern of rhizomes should be observed by excavating clumps. The movement of photosynthates within rhizomes, and levels of auxins before and after harvesting young culms should be observed.

- Little information is available for biology of *Oxytenanthera* seeds. Germination rate of seeds immediately after collection should be observed on an extensive scale whether seed dormancy exists. Environmental conditions and monocarpy relating to seed viability should be observed.

- Propagation using detached culm sections should be studied in improved conditions. Cuttings of culms should be planted in the greenhouse, keeping the temperature 20°C or more and more than 90% of humidity. Cuttings from middle parts of healthy culms growing in the suitable environmental conditions (fertile soils with good drainage, appropriate water supply and temperature) should be harvested late in the dry season before the leaves are shed. The internode cavity should be filled with water or diluted rooting hormone. Suitable rooting hormone for cuttings should be investigated.

- For future plantation work, studies on an alternative method for propagation, micropropagation, are needed. Suitable amount of fertiliser (NPK) should be investigated to increase the production and produce better quality of culms. Association of other plants with *Oxytenanthera abyssinica* should be studied for interplantation work.

- To extend silvicultural experiences there should be permanent research plots established and maintained by forest research institutions in Malawi and/or in other parts of Africa.

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Appendices

Appendix I: Vernacular names of *Oxytenanthera abyssinica* in Africa

Country	Name	Language	Reference
Benin	téma	Baatonun	Burkill (1994)
Burkina Faso	báalé	Samo	Burkill (1994)
	buna	Bobo	Burkill (1994)
	lebooji	Fulfulde	Burkill (1994)
	mia	Gurma	Burkill (1994)
	tanhuisi	Moore	Burkill (1994)
Cameroon	lekwê	Ngyemboon	Burkill (1994)
	ndyung	Ngyemboon	Burkill (1994)
	nkâ (split bamboo)	Ngyemboon	Burkill (1994)
	shyu (pole)	Ngyemboon	Burkill (1994)
Ethiopia	shemel	Agewgna	Bekele-Tesemma *et al.* (1993)
	shmel	Amhara	Bekele-Tesemma *et al.* (1993)
Eritrea	arkai	Tigrenia	Bein *et al.* (1996)
	hil	Tigre	Bein *et al.* (1996)
	hila	Bilen	Bein *et al.* (1996)
Gambia	bo (cut culms)	Manding-mandinka	Burkill (1994)
	boho	Manding-mandinka	Burkill (1994)
	bongo	Manding-mandinka	Burkill (1994)
	kebe	Fula-pulaar	Burkill (1994)
	kewal	Fula-pulaar	Burkill (1994)
	wah	Wolof	Burkill (1994)
Ghana	anohwere	Anyi-anufo	Burkill (1994)
	anohwere	Aowin	Burkill (1994)
	anohwere	Brosa	Irvine (1961)
	gora	Hausa	Burkill (1994)
	gora	Hausa	Irvine (1961)
	kremponyi	Aowin	Burkill (1994)
	kremponyi	Brosa	Irvine (1961)
	kyemponyi	Anyi-anufo	Burkill (1994)
	mbaramboro	Anyi-anufo	Burkill (1994)
	mbaramboro	Sehwi	Burkill (1994)
	mbaramboro	Brosa	Irvine (1961)
	mbaramboro	Esa	Irvine (1961)
	miu	Grusi	Burkill (1994)
	miu	Grunsi	Irvine (1961)
	mpampro	Twi	Burkill (1994)
	mpampro	Aowin	Burkill (1994)
	mpàmpró	Lefana	Burkill (1994)
	mpampuro	Twi	Irvine (1961)

Country	Name	Language	Reference
Ghana	mprampuro	Twi	Burkill (1994)
	mprampuro	Twi	Irvine (1961)
	nkampon	Akanfante	Burkill (1994)
	nkampon	Fante	Irvine (1961)
	nkampro	Guang-anum	Burkill (1994)
	nkampro	Gonja	Burkill (1994)
	nkampro	Guang	Irvine (1961)
	nyoringa	Mampruli	Burkill (1994)
	o-bébéi (*pl.* sî-)	Akrafu	Burkill (1994)
	pamplo	GBE-VHE	Burkill (1994)
	pamplo	Ewe	Irvine (1961)
	pampló	Ga	Burkill (1994)
	pamploo	Adangme	Burkill (1994)
	pamploo	Adagme-krobo	Burkill (1994)
	pamploo	Ga	Burkill (1994)
	pamploo	Ga	Irvine (1961)
	pamploo	Adangme	Irvine (1961)
	pámpró	Avatime	Burkill (1994)
	pampru	VHE	Burkill (1994)
	pampru	Ewe	Irvine (1961)
	pãplo	Adagme-krobo	Burkill (1994)
	pãplo	Ga	Burkill (1994)
	pãplo	Ga	Irvine (1961)
	pãplo	Adangme	Irvine (1961)
	prampru	Akanfante	Burkill (1994)
Guinea	c-xàtyɛ́	Basari	Burkill (1994)
	kô-tamami	Baga	Burkill (1994)
	tatami	susu	Burkill (1994)
	u-ryag	Konyagi	Burkill (1994)
	wa-diag	Konyagi	Burkill (1994)
Guinea-Bissau	bamú	Crioulo	Burkill (1994)
	bô	Mandin-mandinka	Burkill (1994)
	djambarlam	Pulaar	Burkill (1994)
	djambátam-ô	Mandin-mandinka	Burkill (1994)
	djame	Biafada	Burkill (1994)
	djame	Mankanya	
	edjô	Bidyogo	Burkill (1994)
	nahjane	Mandyak	Burkill (1994)
	pepel djamá	Mankanya	Burkill (1994)
	québè	Fula-pulaar	Burkill (1994)
	quénè	Fula-pulaar	Burkill (1994)
	sougué	Balanta	Burkill (1994)
	udjame	Mandyak	Burkill (1994)
Ivory coast	kole	Kru-bete	Burkill (1994)
Liberia	temui	Loma	Burkill (1994)

Country	Name	Language	Reference
Malawi	lulasi	Ngonde (Karonga)	author's interviews (2002)
	milasi	Yao	Williamson (1975)
	mshombe	Phoka	author's interviews (2002)
	musyombe	Henga	Williamson (1975)
	nsungwi	Chewa	Williamson (1975)
	nsungwi	Kunda	author's interviews (2002)
	nsungwi	Ngoni	author's interviews (2002)
	nsungwi	Tunbuka	author's interviews (2002)
	sungwe	Tumbuka	author's interviews (2002)
Mali	bo	Manding-bambara	Burkill (1994)
	dianacaré	Songhai	Burkill (1994)
	koré	Soninke-sarakole	Burkill (1994)
Niger	káálá	Dendi	Burkill (1994)
Nigeria	àchàlà oyìbo (European achara)	Igbo	Burkill (1994)
	aco	Idoma	Burkill (1994)
	aligua	Odual	Burkill (1994)
	apàko	Yoruba	Burkill (1994)
	aparun	Yoruba	Burkill (1994)
	àtàng	Yala	Burkill (1994)
	bálbàl	Pero	Burkill (1994)
	bomoun	Ijo-izon	Burkill (1994)
	eman	Loke	Burkill (1994)
	gàmáré	Kanuri	Burkill (1994)
	gana	Arabic-Shuwa	Burkill (1994)
	gónrò (a bamboo pole)	Pero	Burkill (1994)
	góora (large pole)	Hausa	Burkill (1994)
	halwa	Kanuri	Burkill (1994)
	kava	Kanuri	Burkill (1994)
	kawu	Gwari	Burkill (1994)
	ketitahng	Loke	Burkill (1994)
	kewal (*pl.* kewe)	Fula-fulfulde	Burkill (1994)
	kida	Bura	Burkill (1994)
	mbàkárá	Efik	Burkill (1994)
	mkpo àchàlà (the bamboo pole)	Igbo	Burkill (1994)
	nnyányánga	Efik	Burkill (1994)
	ocaco	Idoma	Burkill (1994)
	ocáco	Idoma	Burkill (1994)
	òcyácyo	Akpa	Burkill (1994)
	oholoibo	Igbo	Burkill (1994)
	okpokpo	Yala	Burkill (1994)
	opa (a pole)	Yoruba	Burkill (1994)
	oparun (canes or giant grasses)	Yoruba	Burkill (1994)
	otosi	Igbo	Burkill (1994)

Country	Name	Language	Reference
Nigeria	oyo	Edo	Burkill (1994)
	pàko	Yoruba	Burkill (1994)
	ràas	Sura	Burkill (1994)
	syè	Birom	Burkill (1994)
	tákárwá (*pl.* - áwín)	Ngizim	Burkill (1994)
Senegal	bo	Bambaras	Berhaut (1967)
	bó	Mandin-bambara	Burkill (1994)
	bó	Manika	Burkill (1994)
	bu bul	Diolas	Berhaut (1967)
	bubul	Diola	Burkill (1994)
	fu gil	Diolas	Berhaut (1967)
	gol	Sérèves	Berhaut (1967)
	ingol (a fishing bow)	Serer giol	Burkill (1994)
	kévé	Mandin-bambara	Burkill (1994)
	kévé	Bambaras	Berhaut (1967)
	kéwé	Fula-pulaar	Burkill (1994)
	ma- kátyè	Bedik	Burkill (1994)
	o-kadjié	Basari	Burkill (1994)
	soce bó	Manika	Burkill (1994)
	u-hátyè	Bedik	Burkill (1994)
	vah	Volfs	Berhaut (1967)
	wa	Wolof	Burkill (1994)
Sierra Leone	baa	Manding-Mandinka	Burkill (1994)
	barang	Limba (Tonko)	Burkill (1994)
	bo	Kcranko	Burkill (1994)
	bomi (a pole)	Susu	Burkill (1994)
	ka-sul (a cut pole)	Temne	Burkill (1994)
	ka-thong	Temne	Burkill (1994)
	ka-ton	Temne	Burkill (1994)
	kana- le	Bulom	Burkill (1994)
	ken	Krio	Burkill (1994)
	kenye	Vai	Burkill (1994)
	keve	Fula-pulaar	Burkill (1994)
	kissi boho	Gola sen	Burkill (1994)
	ko-ai	Limba	Burkill (1994)
	pilanda	Gola sen	Burkill (1994)
	semi	Mende	Burkill (1994)
	seni	Gola sen	Burkill (1994)
	seni	Vai	Burkill (1994)
	senye	Vai	Burkill (1994)
	sii	Loko	Burkill (1994)
	siminɛ	Kono	Burkill (1994)
	tatami	Susu	Burkill (1994)
	tatamina	Yalunka	Burkill (1994)
	thong	Bulom	Burkill (1994)
	wus-le	Bulom	Burkill (1994)

Country	Name	Language	Reference
Sudan	gana	Arabic	Vogt (1995)
	tal	Arabic	Vogt (1995)
Tanzania	mwanzi	Swahili	Mbuya *et al.* (1994)
	kitindi, mulanzi	Hehe	Mbuya *et al.* (1994)
	lasi	Bondei	Mbuya *et al.* (1994)
	lasi	Sambaa	
	lazi	Zigua	Mbuya *et al.* (1994)
	mlanzi	Kinga	
	mlanzi	Lunguru	
	mlanzi	Nyamwezi	Mbuya *et al.* (1994)
Uganda	keo	Ateso	Eggeling and Dale (1951), Katende *et al.* (1995)
	koo	Luo	Eggeling and Dale (1951), Katende *et al.* (1995)
	odra	Lugbara	Eggeling and Dale (1951), Katende *et al.* (1995)
	ordra	Madi	Eggeling and Dale (1951), Katende *et al.* (1995)
Zambia	nkosa	Lunda	Fanshawe (1972)
	nkosa	Ndembu	Fanshawe (1972)
	chi waya	Ngoni	Fanshawe (1972)
	lu seng, nsengu	Bemba	Fanshawe (1972)
	lu seng, nsengu	Bisa	Fanshawe (1972)
	lu seng, nsengu	Chishinga	Fanshawe (1972)
	lu seng, nsengu	Kabenda	Fanshawe (1972)
	lu seng, nsengu	Lala	Fanshawe (1972)
	lu seng, nsengu	Mambwe	Fanshawe (1972)
	lu seng, nsengu	Swaka	Fanshawe (1972)
	lu seng, nsengu	Ushi	Fanshawe (1972)
	ma sumpo	Tonga	Fanshawe (1972)
	n sununu	Kaonde	Fanshawe (1972)
	n thele	Ngoni	author's interviews (2002)
	n thele	Nyanja	author's interviews (2002)
	n thele	Swaka	Fanshawe (1972)
	n thele	Ila	Fanshawe (1972)
	n thele	Lala	Fanshawe (1972)
	sasu	Kunda	Fanshawe (1972)
	sasu	Nsenga	Fanshawe (1972)
Zimbabwe	bindura bamboo,	Manyika	FAO (2001b)
	musengere	Manyika	FAO (2001b)
	muchenjere	Zezuru	FAO (2001b)

Appendix II : Countries of distribution of six African bamboos

Countries of distribution	*Hickelia africana* (1)	*Olyra latifolia* (27)	*Oreobambos buchwaldii* (7)	*Oxytenanthera abyssinica* (28)	*Thamnocalamus tessellatus* (4)	*Yushania alpina* (10)
Angola		+		+		
Benin				+		
Burundi		+		+		+
Burkina Faso				+		
Cameroon		+		+		+
CAR		+		+		
Chad				+		
Comoro		+				
Congo (DRC)		+	+	+		+
Eq. Guinea		+				
Eritrea				+		
Ethiopia		+		+		+
Gabon		+				
Gambia				+		
Ghana		+		+		
Guinea		+		+		
Guinea Bissau				+		
Ivory coast		+		+		
Kenya		+	+			+
Lesotho					+	
Liberia		+				
Madagascar		+			(+)	
Malawi		+	+	+		(+)
Mauritius					(+)	
Mozambique		+		+		
Niger				+		
Nigeria		+		+		
Rwanda						+
Senegal		+		+		
Sierra Leone		+		+		
South Africa		+		(+)	+	
Sudan		+		+		+
Tanzania	+	+	+	+		+
Togo		+		+		
Uganda		+	+	+		+
Zambia		+	+	+		
Zimbabwe		+	+	+		

*( ), there is some taxonomic uncertainty in these cases

Appendix III: Planted species with *Oxytenanthera abyssinica* in Sudan from 1951 to 1970

Year and references	Location	Nearest met. station: annual rain, mean temp. (max. mean. of hottest month, min. mean of coldest month)	Areas: feddan (420 ha)	Species
1951-52 Anon. (1952)	Nyala mahogany provincial reserve (4°55'N, 30°21'E, 745 m)	Maridi (4°35'N, 29°28'E, 750 m): 1411 mm, 24.8℃(34.5℃, 15.8℃)	3	*Albizia procera* *Cordia africana* *Eucalyptus microtheca* *Khaya senegalensis* *Oxytenanthera abyssinica*
1952-53 Anon. (1953c)	Tasomi (10°37'N, 30°22'E, 467 m)	Kadugli (11°00'N, 29°43'E, 499 m): 764 mm, 26.9℃(40℃, 15℃)	5	*Azadirachta indica* *Khaya senegalensis,* *Oxytenanthera abyssinica*
	Kundua	n.a.	6	*Albizia procera* *Azadirachta indica* *Cassia siamea* *Cordia africana* *Eucalyptus sp.* *Khaya senegalensis,* *Oxytenanthera abyssinica* *Prosopis juliflora*
1954-55 Anon. (1955b)	Um Gutoud, Sadalla	n.a.	1	*Oxytenanthera abyssinica*
	Gezair, Singa (13°11'N, 33°55E, 618 m)	Singa (13°09'N, 33°57'E, 430 m): 618 mm, 28.6℃ (41.1℃, 16.5℃)	4	*Eucalyptus microtheca* *Azadirachta indica* *Oxytenanthera abyssinica*
	Um Zibil, Hawata	n.a.	3	*Eucalyptus microtheca* *Oxytenanthera abyssinica*

Year and references	Location	Nearest met. station: annual rain, mean temp. (max. mean. of hottest month, min. mean of coldest month)	Areas: feddan (420 ha)	Species
1954-55 Anon. (1955b)	Tasomi (Talodi) (10°37'N, 30°22'E, 467 m)	Kadugli (11°00'N, 29°43'E, 499 m): 764 mm, 26.9℃ (40℃, 15℃)	5.5	*Azadirachta indica* *Cordia africana* *Eucalyptus sp.* *Khaya senegalensis,* *Tectona grandis* *Oxytenanthera abyssinica*
	El Obeid El Ain Banno (13°10'N, 30°13'E, 609 m)	El Obeid (13°10N, 30°14ºE, 570 m): 386 mm, 26.9℃ (39℃, 13.5℃)	5 (single line planting)	*Albizia sp.* *Azadirachta indica* *Cassia siamea* *Cordia africana* *Eucalyptus sp.* *Khaya senegalensis,* *Tamarix aphylla* *Oxytenanthera abyssinica*
	Korate	n.a.	40	*Acacia niloticai* *Albizia sp.* *Azadirachta indica* *Cordia africana* *Khaya senegalensis,* *Oxytenanthera abyssinica*
1955-56 Anon. (1956)	Gezair, Singa (13°11'N, 33°55E, 618 m)	Singa (13°09'N, 33°57'E, 430 m): 618 mm, 28.6℃ (41.1℃, 16.5℃)	1.5	*Oxytenanthera abyssinica*
	Um Zibil, Hawata		1.5	*Eucalyptus microtheca* *Oxytenanthera abyssinica*

Year and references	Location	Nearest met. station: annual rain, mean temp. (max. mean. of hottest month, min. mean of coldest month)	Areas: feddan (420 ha)	Species
1955-56 Anon. (1956)	Tasomi, Talodi (10°37'N, 30°22'E, 467 m)	Kadugli (11°00'N, 29°43'E, 499 m): 764 mm, 26.9℃ (40℃, 15℃)	3	*Azadirachta indica* *Cordia africana* *Eucalyptus sp.* *Khaya senegalensis* *Tectona grandis* *Oxytenanthera abyssinica*
	East circle	n.a.	1	*Oxytenanthera abyssinica*
1957-58 Anon. (1958)	Hedibat, Bunzoga (12°30'N, 34°10', 440 m)	Abu Na'ama (12°44'N, 34°08'E, 445 m): 576 mm, 28℃ (41℃, 15℃)	12	*Eucalyptus microtheca* *Oxytenanthera abyssinica*
	Um Zibil, Hawata	n.a.	5	*Eucalyptus sp* *Oxytenanthera abyssinica*
	Farajok, Torit (3°51'N, 32°30'E, 982 m)	Katrie (4°02'N, 32°47'E, 1000 m): 1541 mm, 24.8 ℃ (33.5℃, 18℃)	1	*Oxytenanthera abyssinica*
1958-59 Anon. (1959b)	Hdeibat, Bunzoga (12°30'N, 34°10', 440 m)	Abu Na'ama (12°44'N, 34°08'E, 445 m): 576 mm, 28℃ (41℃, 15℃)	10	*Eucalyptus umbellata* *Oxytenanthera abyssinica*
	Mandi (5°07'N, 30°13'E, 609 m)	Maridi (4°35'N, 29°28'E, 750 m): 1411 mm, 24.8℃(34.5℃, 15.8℃)	1	*Oxytenanthera abyssinica*
1959-60 Anon. (1960)	Bau	n.a.	10	*Oxytenanthera abyssinica*
1960-61 Anon. (1961)	Fung	n.a.	18.5	*Albizia aylmeri* *Eucalyptus camaldulensis* *Eucalyptus trabuti* *Oxytenanthera abyssinica*

Year and references	Location	Nearest met. station: annual rain, mean temp. (max. mean. of hottest month, min. mean of coldest month)	Areas: feddan (420 ha)	Species
1960-61 Anon. (1961)	Kassala (15°28'N, 36°23'E, 518 m)	Kassala (15°28'N, 36°24'E, 500 m): 321 mm, 29.2℃ (41.6℃, 16℃)	2.5	*Azadirachta indica* *Casuarina cunninghamania* *Eucalyptus sp.* *Khaya senegalensis* *Oxytenanthera abyssinica*
1961-62 Anon. (1962b)	Fung	n.a.	139.25	*Boswelia sp.* *Cordia africana* *Eucalyptus microtheca* *Eucalyptus umbellata* *Khaya senegalensis* *Oxytenanthera abyssinica*
1962-63 Anon. (1963)	Northern Fung	n.a.	3.5	*Oxytenanthera abyssinica*
	Central circle	n.a.	1	*Oxytenanthera abyssinica*
1963-64 Anon. (1964)	Southern Fung	n.a.	3	*Oxytenanthera abyssinica*
1965-66 Anon. (1966)	Gezira circle	n.a.	1	*Oxytenanthera abyssinica*
1969-70 Anon. (1971)	Southern Fung	n.a.	6	*Oxytenanthera abyssinica*

Note:

Climate data from FAO (1984)

Mean temp: mean of average daily temperatures throughout the year for a certain period (usually 30 years)

Appendix IV: Resource roles of *Oxytenanthera abyssinica* in Africa

Entry	Category	Country	References
Structural use	Boundary marker	Tanzania	Mbuya *et al.* (1994)
	Buildings	Cameroon, Malawi, Sudan, Uganda	Katende *et al.* (1995) Wickens (1976) van der Zon (1992) Williamson (1975)
	Door	Zambia	Fanshawe (1972)
	Dune control	Sudan	Vogt (1995)
	Fences	Ethiopia and Eritrea, Ghana, Senegal, Sudan, Tanzania, Zambia, Zimbabwe	Bégué (1958) Bein *et al.* (1996) Bekele-Tesemma *et al.* (1993) Fanshawe (1972) FAO (2001b) Giffard (1974) Henkel (1927) Irvine (1961) LUSO CONSULT, 1997a Mbuya *et al.* (1994) Pardy (1954) Sommerlatte and Sommerlatte (1990)
	Frames of mortal cement	Ghana, Senegal, Zimbabwe	Giffard (1974) Irvine (1961)
	Granaries	Malawi, Zimbabwe	FAO (2001b) Inada (2000, 2001a, 2001b) Ngulube (1999)
	Hedges	Ghana	Irvine (1961)
	Houses	Ethiopia and Eritrea, Sudan, Zimbabwe	Badi *et al.* (1989) FAO (2001b) Henkel (1927) LUSO CONSULT, 1997a
	Huts	Malawi, Tanzania, Senegal, Zimbabwe	Greenway (1940) Giffard (1974) Henkel (1927) Masamba and Bwanali (2000) Pardy (1954)
	Pipes	Ethiopia and Eritrea, Sudan, Uganda	Bein *et al.* (1996) Bekele-Tesemma *et al.* (1993) Irvine (1961) Katende *et al.* (1995) Sommerlatte and Sommerlatte (1990)
	Screens	Ghana, Zambia	Fanshawe (1972) Irvine (1961)
	Poles	Ethiopia and Eritrea, Tanzania, Uganda	Bein *et al.* (1996) Bekele-Tesemma *et al.* (1993) Katende *et al.* (1995) Mbuya *et al.* (1994) Snowden (1945)
	Protection of water and soils	Ethiopia and Eritrea	Henkel (1927)
	Rafters for huts and granaries	Ghana	Irvine (1961)
	Roof	Ghana, Malawi, Senegal, Sudan, Zambia, Zimbabwe	Anon. (1954a) Bégué (1958) Fanshawe (1972) FAO (2001b) Giffard (1974) Irvine (1961)

Entry	Category	Country	References
Structural use	Shade	Sudan	Vogt (1995)
	Shelter belt	Sudan	Bayoumi (1977) Vogt (1995)
	Stakes	Zimbabwe	Irvine (1961)
	Temporal shelters	Zambia	Fanshawe (1972)
	Tobacco crates	Zimbabwe	Irvine (1961)
	Tobacco sticks	Malawi, Zambia, Zimbabwe	Anon. (1954) Fanshawe (1972) Pardy (1954)
	Trellises	Zimbabwe	Irvine (1961)
	Windbreaks	Ghana, Sudan, Zimbabwe	Anon. (1956) FAO (2001b) Irvine (1961) Pardy (1954) Wickens (1976)
	Window	Zambia	Fanshawe (1972)
Artificial use	Arrow shafts	Ethiopia and Eritrea, Sudan, Uganda	Bein *et al.* (1996) Bekele-Tesemma *et al.* (1993) Irvine (1961) Katende *et al.* (1995) Sommerlatte and Sommerlatte (1990)
	Baskets	Ethiopia and Eritrea, Ghana, Malawi, Sudan, Tanzania, Uganda, Zambia, Zimbabwe	Anon. (1954a) Bein *et al.* (1996) Bekele *et al.* (1993) Fanshawe (1972) FAO (2001b) Greenway (1940) Henkel (1927) Irvine (1961) Katende *et al.* (1995) Masamba and Bwanali (2000) Mbuya *et al.* (1994) Ngulube (1999) Pardy (1954) Sommerlatte and Sommerlatte (1990) Williamson (1975)
	Canoe	Zambia	Fanshawe (1972)
	Chairs	Malawi	Ngulube (1999)
	Cooking utensils	Malawi	Masamba and Bwanali (2000)
	Cups	Sudan	Irvine (1961)
	Dust bins	Malawi	Masamba and Bwanali (2000)
	Flute	South Africa	Gibbs-Russell *et al.* (1990)
	Fish traps	Malawi Zambia	Inada (2000, 2001a, 2001b) Fanshawe (1972) Masamba and Bwanali (2000)
	Food container	Malawi	Masamba and Bwanali (2000)

Entry	Category	Country	References
Artificial use	Furniture	Ethiopia and Eritrea, Ghana, Malawi, Sudan, Uganda Zimbabwe	Anon. (1954a)
			Bein *et al.* (1996)
			Bekele-Tesemma *et al.* (1993)
			FAO (2001b)
			Henkel (1927)
			Irvine (1961)
			Katende *et al.* (1995)
			Masamba and Bwanali (2000)
			Sommerlatte and Sommerlatte (1990)
			Wickens (1976)
	Mats	Ethiopia and Eritrea, Malawi, Zambia	Fanshawe (1972)
			Henkel (1927)
			Ngulube (1999)
	Racks	Malawi	Masamba and Bwanali (2000)
	Shelves	Malawi	Ngulube (1999)
	Store bins	Zimbabwe	Henkel (1927)
	Tea and tobacco baskets	Malawi	Anon. (1954a)
	Trays	Tanzania	Mbuya *et al.* (1994)
	Plant pots	Sudan	Irvine (1961)
	Punt poles	Zambia	Fanshawe (1972)
	Spears	Sudan	Wickens (1976)
	Traps	Senegal	Giffard (1974)
	Walking sticks	Ethiopia and Eritrea, Malawi, Sudan, Uganda	Bein *et al.* (1996)
			Bekele-Tesemma *et al.* (1993)
			Burkill (1994)
			Katende *et al.* (1995)
			Masamba and Bwanali (2000)
Beverage & food	Fodder	Ethiopia and Eritrea, Gambia, Senegal, Tanzania, Uganda	Bein *et al.* (1996)
			Bekele-Tesemma *et al.* (1993)
			von Breitanbach (1961)
			Burkill (1994)
			Innes *et al.* (1977)
			Irvine (1961)
			Katende *et al.* (1995)
			Mbuya *et al.* (1994)
	Seeds eaten in famine	Malawi, Sudan, Uganda	Burkill (1994)
			Irvine (1961)
			Sommerlatte and Sommerlatte (1990)
			Williamson (1975)
	Seeds for tonic for children and alcohol	Tanzania	Burkill (1994)
			Irvine (1961)
	Shoots eaten in famine	Uganda	Burkill (1994)
			Irvine (1961)
	Young shoots sap for beer	Tanzania	Mbuya *et al.* (1994)
			Mgeni (1983)
			Takara Shuzo (2001)

Entry	Category	Country	References
Medicine	Leaf decoction for urine problem	Senegal	Burkill (1994)
	Medicine	Sudan	Vogt (1995)
	Rhizome for dysentery	Burkina Faso	Burkill (1994)
	Leaves to keep away lice	Ghana	Burkill (1994) Irvine (1961)
	Pesticide	Sudan	Vogt (1995)
Other uses	Agriculture implements	Malawi	Masamba and Bwanali (2000)
	Agroforestry hedging	Sudan	Vogt (1995)
	Amenity	Sudan	Vogt (1995)
	Basin	Sudan	Irvine (1961)
	Bombing sticks	Zambia	Fanshawe (1972) FAO (1974)
	Canoe poles and spare shafts	Nigeria	Irvine (1961)
	Charcoal	Sudan, Ghana	Burkill (1994) Irvine (1961) Vogt (1995)
	Droppers	Zimbabwe	Pardy (1954)
	Drying racks	Zambia	Fanshawe (1972)
	Erosion control	Sudan	Vogt (1995)
	Fuel	Ethiopia Malawi	LUSO CONSULT (1997a) Masamba and Bwanali (2000)
	Ladder	Malawi	Masamba and Bwanali (2000)
	Ornamental plants	Cameroon, Ghana, Malawi, Zimbabwe	van der Zon (1992) Irvine (1961) Masamba and Bwanali (2000) Pardy (1954)
	Soil erosion control	Malawi	Masamba and Bwanali (2000)
	Tobacco boxes	Malawi	Masamba and Bwanali (2000)
	Tool handles	Malawi, Uganda, Zimbabwe	Katende *et al.* (1995) Irvine (1961) Masamba and Bwanali (2000)
	Tools	Uganda	Katende *et al.* (1995)

Appendix V : Vector and raster files

Vector

With vector representation, the boundaries or the course of features are defined by a series of points that, when jointed with straight lines, form the graphic representation of that feature. The points themselves are encoded with a pair of numbers giving the X and Y coordinates in systems such as latitude/longitude or Universal Transverse Macerator grid coordinates.

Raster

With raster systems, the graphic representation of features and the attributes they possess are merged into unified data files. Each cell is given a numeric value which may then represent either a feature identifier, a qualitative attribute code or a quantitative attribute value.

Appendix VI : Macro statements for IDRISI

Apart from manual techniques, there is an automatic mode (macro command) to make new images in IDRISI. Explanation of macro commands:

Overlay

Overlay produces a new image from the data on two input images. The module can add, subtract, multiply, ratio, normalised ratio, exponentiate, cover, minimise and maximise the data set of two input images.

Macro file command line:

1. x (indicate that batch mode is being used)
2. operation number (overlay operation as below)
3. first input image (the first image in the overlay)
4. second input image (second image in the overlay)
5. output file name (the created new image file)

Operation options: 1: add, 2: subtract, 3: multiply, 4: ratio (first/second), 5: normalised ratio ((first-second)/(first+second)), 6: exponentiate (first to the power of the second), 7: cover (first covers second unless zero), 8: minimum, 9: maximum

Reclass

Reclass classifies or reclassifies the data stored in images or attribute values files into new integer categories.

Macro command line:

1. x: indicate that batch mode is being used
2. file type (i=image, a= value file)
3. input file name (the file to be reclassified)
4. output file name (the new file to be created)
5. classification type (1=equal interval, 2=uner defined, 3=file mode)

if classification type is 1,

6. minimum (specify "min" to use actual min or enter new min)
7. maximum (specify "max" to use actual min or enter new max)

8. number of classes (specify integer number or real num. class width)

If classification type is 2

6. new value (assign a new integer class value of)

7. old start value (for the old values ranging from)

8. old end value (to those just less than)

n. -9999 (end of sequence code: same as "q" in manual mode)

If classification type is 3,

6. ".rcl" text file name (text file name, without the extension)

Macro statements for:

Hickelia africana

```
reclass x i dem-m demhi 2 0 0 1700 1 1700 9999 -9999
reclass x i annprec annhi 2 0 0 900 1 900 1500 0 1500 9999 -9999
reclass x i fao-soil soilhi 2 0 0 7 1 7 17 0 17 69 1 69 73 0 73 9999 -9999
overlay x 3 demhi annhi hisuit
overlay x 3 hisuit soilhi hisuit2
overlay x 1 hisuit2 land hisuit3
reclass x i annprec annhi2 2 0 0 900 1 900 1500 2 1500 9999 -9999
overlay x 3 annhi2 land annhi3
```

Olyra latifolia

```
reclass x i dem-m demol 2 1 0 1000 0 1000 9999 -9999
reclass x i annprec annol 2 0 0 1000 1 1000 9999 -9999
reclass x i fao-soil olsoil 2 0 0 27 1 27 34 0 34 47 1 47 48 0 48 57 1 57 66 0 66 69 1 69 73
0 73 9999 -9999
overlay x 3 demol annol olsuit
overlay x 3 olsuit olsoil olsuit2
overlay x 1 olsuit2 land olsuit3
overlay x 3 olsuit3 land olsuit4
reclass x i dem-m demol2 2 0 0 1000 1 1000 9999 -9999
overlay x 1 demol2 land demol3
reclass x i annprec annol2 2 0 0 1000 1 1000 9999 -9999
overlay x 3 annol2 land annol3
```

Oreobambos buchwaldii

```
reclass x i dem-m demore 2 0 0 600 1 600 1400 0 1400 9999 -9999
reclass x i annprec annore2 2 0 0 750 1 750 9999 -9999
reclass x i fao-soil orsoil 2 0 0 27 1 27 34 0 34 47 1 47 48 0 48 57 1 57 66 0 66 69 1 69 73
0 73 9999 -9999
overlay x 3 annore2 demore oresuit
overlay x 3 oresuit orsoil oresuit2
overlay x 1 oresuit land oresuit3
reclass x i annprec annore3 2 0 0 750 1 750 9999 -9999
```

```
overlay x 3 annore3 land annore4
reclass x i dem-m demore2 2 0 0 600 1 600 1400 2 1400 9999 -9999
```

Oxytenanthera abyssinica

```
reclass x i janprec janprecr 2 1 0 50 0 50 9999 -9999
reclass x i febprec febprecr 2 1 0 50 0 50 9999 -9999
reclass x i marprec marprecr 2 1 0 50 0 50 9999 -9999
reclass x i aprprec aprprecr 2 1 0 50 0 50 9999 -9999
reclass x i mayprec mayprecr 2 1 0 50 0 50 9999 -9999
reclass x i junprec junprecr 2 1 0 50 0 50 9999 -9999
reclass x i julprec julprecr 2 1 0 50 0 50 9999 -9999
reclass x i augprec augprecr 2 1 0 50 0 50 9999 -9999
reclass x i sepprec sepprecr 2 1 0 50 0 50 9999 -9999
reclass x i octprec octprecr 2 1 0 50 0 50 9999 -9999
reclass x i novprec novprecr 2 1 0 50 0 50 9999 -9999
reclass x i decprec decprecr 2 1 0 50 0 50 9999 -9999
overlay x 1 janprecr febprecr temp1
overlay x 1 temp1 marprecr temp2
overlay x 1 temp2 aprprecr temp3
overlay x 1 temp3 mayprecr temp4
overlay x 1 temp4 junprecr temp5
overlay x 1 temp5 julprecr temp6
overlay x 1 temp6 augprecr temp7
overlay x 1 temp7 sepprecr temp8
overlay x 1 temp8 octprecr temp9
overlay x 1 temp9 novprecr temp10
overlay x 1 temp10 decprecr drymoth
reclass x i annprec annprect 2 0 0 800 1 800 9999 -9999
reclass x i dem-m dem2 2 0 0 300 1 300 1500 0 1500 9999 -9999
reclass x i drymoth drymot 2 0 0 3 1 3 8 0 8 9999 -9999
reclass x i fao-soil soil2 2 0 0 1 1 1 17 0 17 27 1 27 34 0 34 57 1 57 66 0 66 69 1 69 73 0
73 9999 -9999
overlay x 1 annprect dem2 temp11
overlay x 1 temp11 drymot temp12
overlay x 1 temp12 soil2 suitq
reclass x i suitq suitqr 2 0 0 4 1 4 9999 -9999
overlay x 1 suitqr land suitqrr
```

Thamnocalamus tessellatus

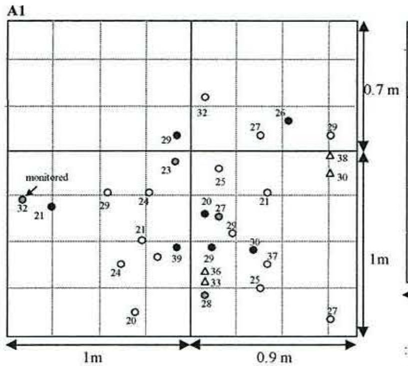
```
reclass x i dem-m demth 2 0 0 1500 1 1500 2500 0 2500 9999 -9999
reclass x i annprec annth 2 0 0 600 1 600 800 0 800 9999 -9999
reclass x i fao-soil soilth 2 0 0 47 1 47 48 0 48 57 1 57 66 0 66 9999 -9999
overlay x 3 demth annth tempth
overlay x 3 tempth soilth thsuit
overlay x 1 thsuit land thsuit2
reclass x i annprec annth2 2 0 0 600 1 600 800 2 800 9999 -9999
overlay x 3 annth2 land annth3
reclass x i dem-m demth2 2 0 0 1500 1 1500 2500 2 2500 9999 -9999
```

Yushania alpina

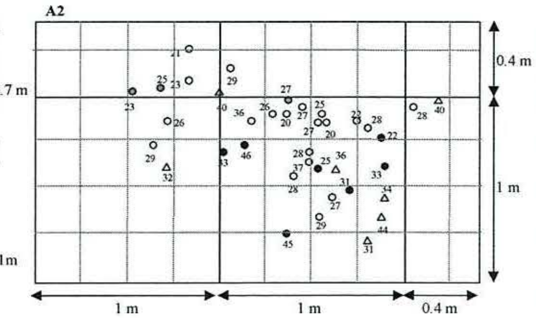
```
reclass x i janprec janprecr 2 1 0 50 0 50 9999 -9999
reclass x i febprec febprecr 2 1 0 50 0 50 9999 -9999
reclass x i marprec marprecr 2 1 0 50 0 50 9999 -9999
reclass x i aprprec aprprecr 2 1 0 50 0 50 9999 -9999
reclass x i mayprec mayprecr 2 1 0 50 0 50 9999 -9999
reclass x i junprec junprecr 2 1 0 50 0 50 9999 -9999
reclass x i julprec julprecr 2 1 0 50 0 50 9999 -9999
reclass x i augprec augprecr 2 1 0 50 0 50 9999 -9999
reclass x i sepprec sepprecr 2 1 0 50 0 50 9999 -9999
reclass x i octprec octprecr 2 1 0 50 0 50 9999 -9999
reclass x i novprec novprecr 2 1 0 50 0 50 9999 -9999
reclass x i decprec decprecr 2 1 0 50 0 50 9999 -9999
overlay x 1 janprecr febprecr temp1
overlay x 1 temp1 marprecr temp2
overlay x 1 temp2 aprprecr temp3
overlay x 1 temp3 mayprecr temp4
overlay x 1 temp4 junprecr temp5
overlay x 1 temp5 julprecr temp6
overlay x 1 temp6 augprecr temp7
overlay x 1 temp7 sepprecr temp8
overlay x 1 temp8 octprecr temp9
overlay x 1 temp9 novprecr temp10
overlay x 1 temp10 decprecr drymoth
reclass x i drymoth drymoty 2 0 0 3 1 3 7 0 7 9999 -9999
reclass x i dem-m demyu 2 0 0 2000 1 2000 9999 -9999
reclass x i annprec annyu 2 0 0 900 1 900 9999 -9999
reclass x i fao-soil yusoil 2 0 0 7 1 7 17 0 17 27 1 27 34 0 34 69 1 69 73 0 73 98 1 98 103 0
103 9999 -9999
overlay x 3 demyu annyu yusuit
overlay x 3 yusuit yusoil yusuit2
overlay x 3 yusuit2 drymoty yusuit3
overlay x 1 yusuit3 land yusuit4
reclass x i annprec annyu2 2 0 0 900 1 900 9999 -9999
overlay x 3 annyu2 land annyu3
reclass x i drymoth drymot2 2 0 0 3 1 3 7 0 7 9999 -9999
overlay x 3 drymot2 land drymot3
```

Appendix VII

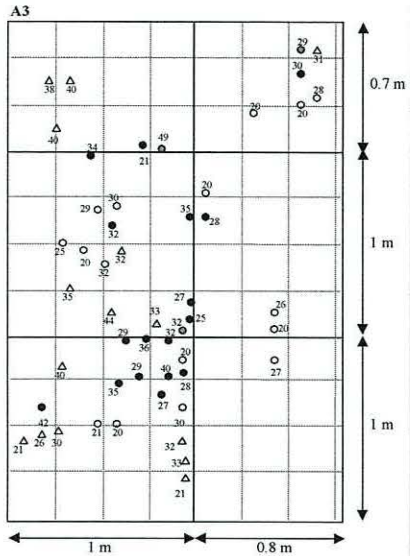
Location of culms within clumps of *Oxytenanthera abyssinica* at Lilongwe, Malawi



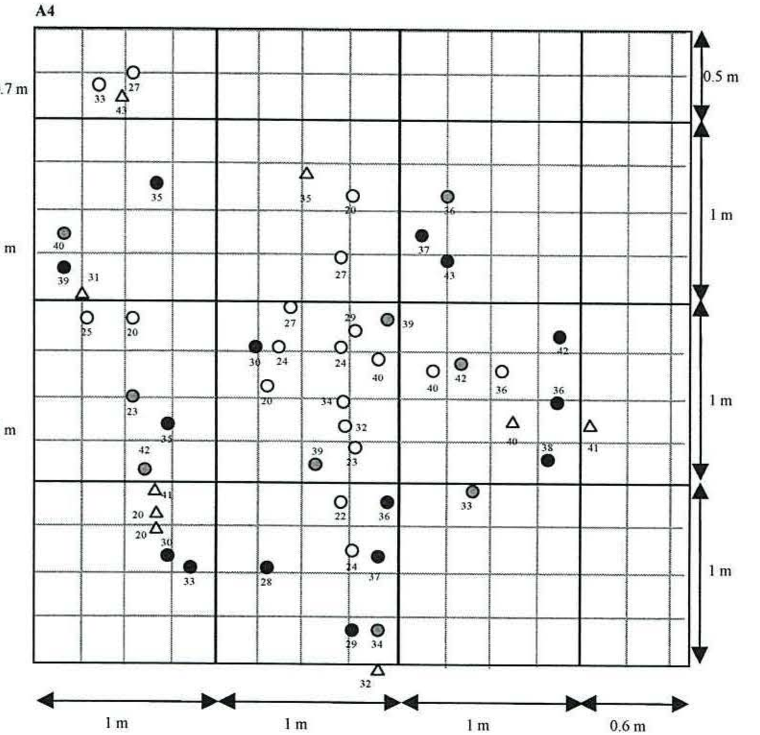
● : Young culms in November 2001 (7)
○ : Mature culms in November 2001 (15)
◉ : Shoots sprouted from November 2001 to April 2002 (4)
△ : Shoots sprouted from May 2002 to June 2003 (4)
Unit: mm in diameter



: Young culms in November 2001 (7)
: Mature culms in November 2001 (20)
: Shoots sprouted from November 2001 to April 2002 (3)
: Shoots sprouted from May 2002 to June 2003 (7)

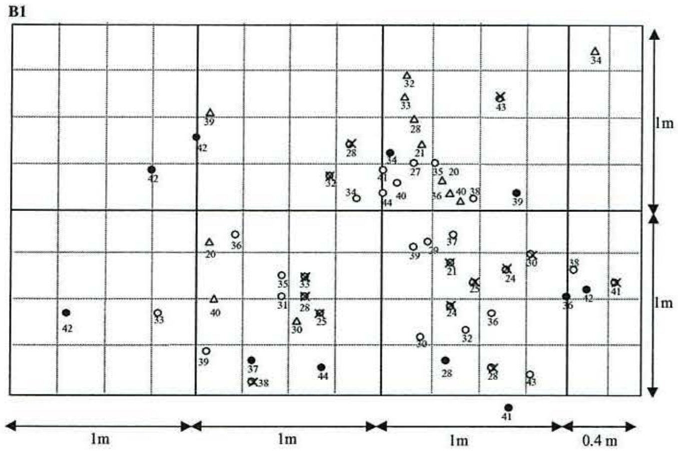


: Young culms in November 2001 (17)
: Mature culms in November 2001 (16)
: Shoots sprouted from November 2001 to April 2002 (3)
: Shoots sprouted from May 2002 to June 2003 (15)

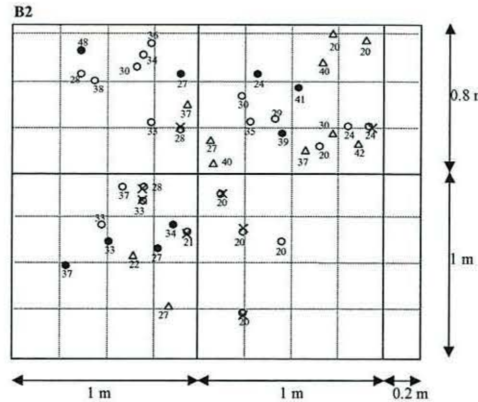


: Young culms inNovember2001 (15)
: Mature culms inNovember2001 (19)
: Shoots sprouted fromNovember2001 to April 2002 (9)
: Shoots sprouted from May 2002 to June 2003 (9)

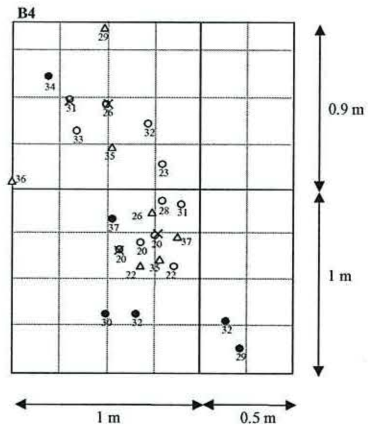
A1-A4 clumps (harvesting intensity 0% of young culms 7-12 months old /0% of mature >12 months old culms)



● : Young culms in November 2001 (11)
○ : Mature culms in November 2001 (34)
⊙ : Shoots sprouted from November 2001 to April 2002 (0)
△ : Shoots sprouted from May 2002 to June 2003 (12)
✕ : Culms harvested in November 2001 (14 mature)
Unit: mm in diameter

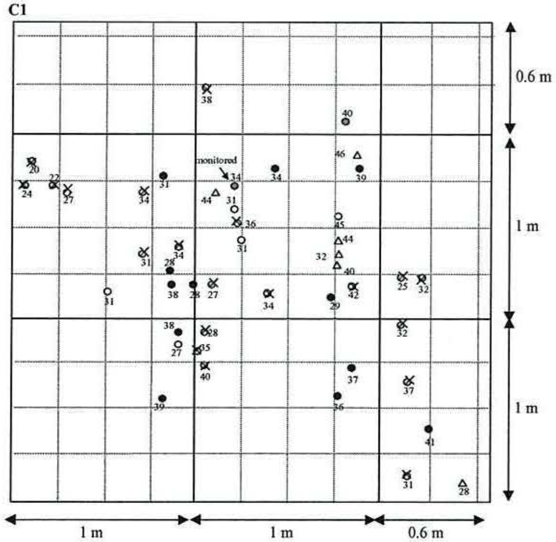


: Young culms in November 2001 (9)
: Mature culms in November 2001 (22)
: Shoots sprouted from November 2001 to April 2002 (0)
: Shoots sprouted from May to June 2003 (11)
: Culms harvested in November 2001 (8 mature)

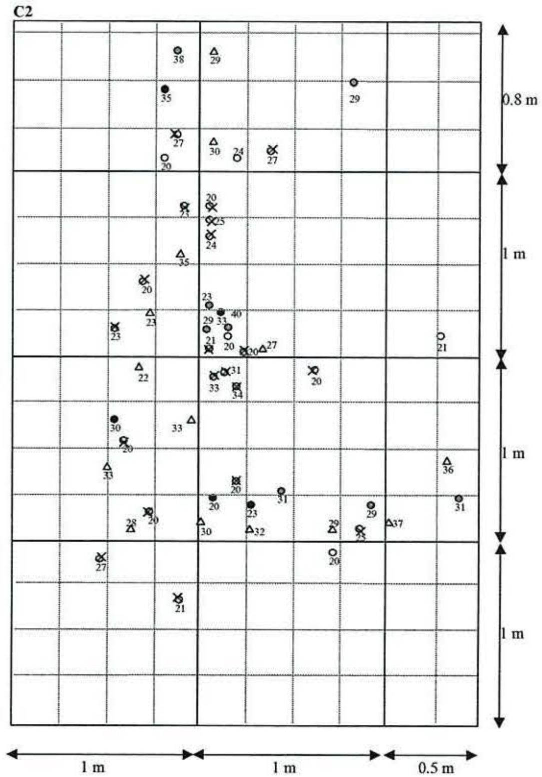


: Young culms in November 2001 (6)
: Mature culms in November 2001 (11)
: Shoots sprouted from November 2001 to April 2002 (0)
: Shoots sprouted from May 2002 to June 2003 (7)
: Culms harvested in November 2001 (4 mature)

B1, B2, B4 clumps (harvesting intensity 0% of young culms/40% of mature culms)



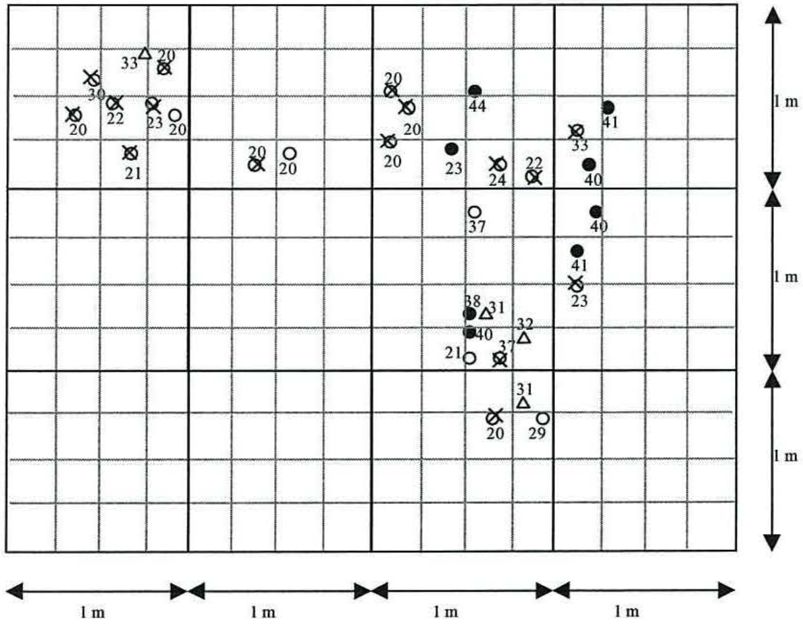
● : Young culms in November 2001 (12)
○ : Mature culms in November 2001 (25)
◉ : Shoots sprouted from November 2001 to April 2002 (2)
△ : Shoots sprouted from May 2002 to June 2003 (6)
✕ : Culms harvested in November 2001 (20 mature)
Unit: mm in diameter



: Young culms in November 2001 (5)
: Mature culms in November 2001 (25)
: Shoots sprouted from November 2001 to April 2002 (8)
: Shoots sprouted from May 2002 to June 2003 (14)
: Culms harvested in November 2001 (20 mature)

C1 and C2 clumps (harvesting intensity 0% of young culms/80% of mature culms)

C3



● : Young culms in November 2001 (8)

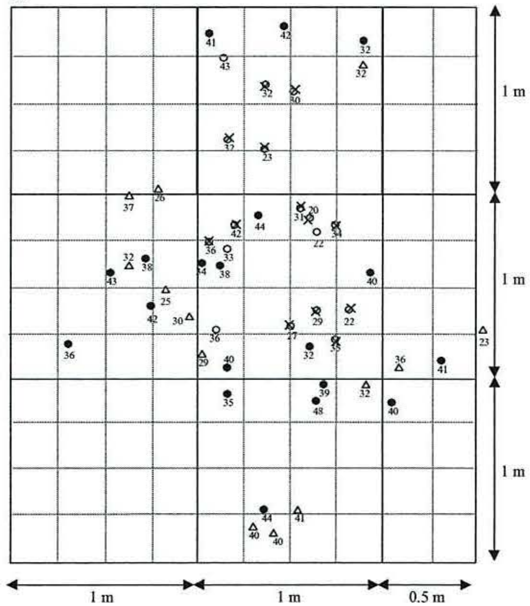
○ : Mature culms in November 2001 (21)

⊙ : Shoots sprouted from November 2001 to April 2002 (0)

Δ : New shoots sprouted from May 2002 to June 2003 (4)

× : Culms harvested in November 2001 (16 mature)

C4



: Young culms in November 2001 (19)

: Mature culms in November 2001 (17)

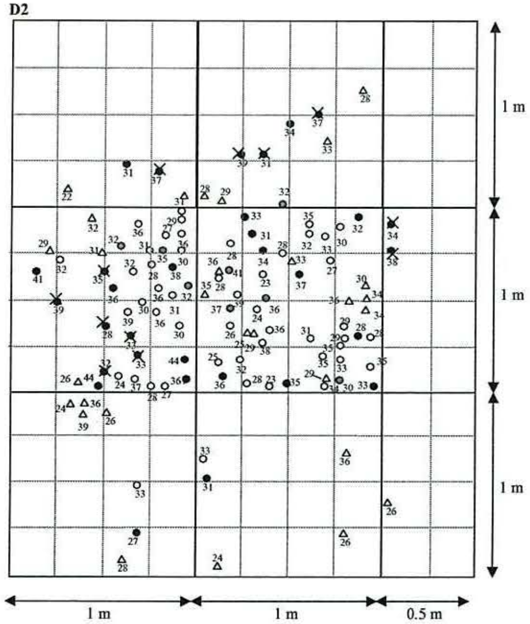
: Shoots sprouted from November 2001 to April 2002 (0)

: Shoots sprouted from May 2002 to June 2003 (13)

: Culms harvested in November 2001 (13 mature)

C3-C4 clumps (harvesting intensity 0% of young culms/80% of mature culms)

D2



● : Young culms in November 2001 (31)

○ : Mature culms in November 2001 (49)

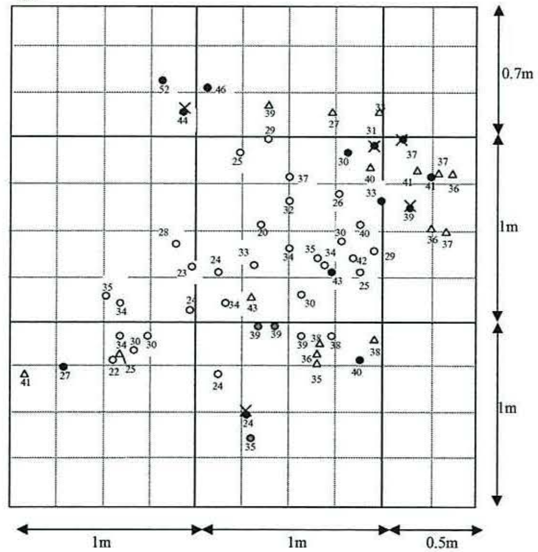
◉ : Shoots sprouted from November 2001 to April 2002 (8)

△ : Shoots sprouted from May 2002 to June 2003 (29)

× : Culms harvested in November 2001 (12 young)

Unit: mm in diameter

D3



: Young culms in November 2001 (13)

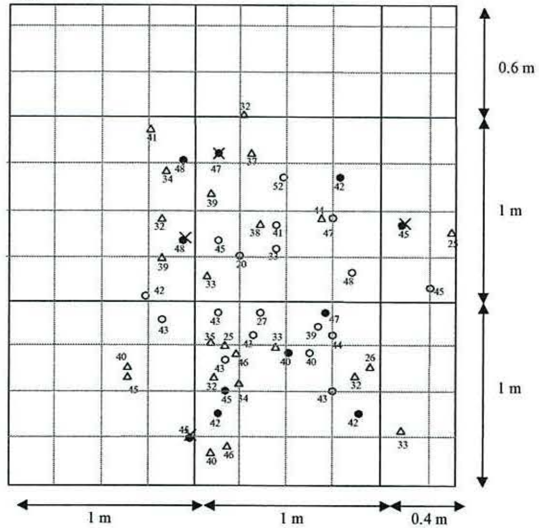
: Mature culms in November 2001 (30)

: Shoots sprouted from November 2001 to April 2002 (3)

: Shoots sprouted from May 2002 to June 2003 (16)

: Culms harvested in November 2001 (5 young)

D4



: Young culms in November 2001 (11)

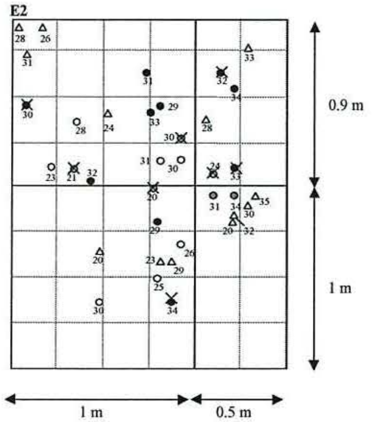
: Mature culms in November 2001 (18)

: Shoots sprouted from November 2001 to April 2002 (0)

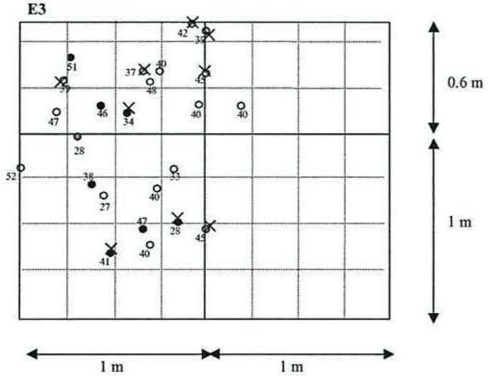
: Shoots sprouted from May 2002 to June 2003 (24)

: Culms harvested in November 2001 (4 young)

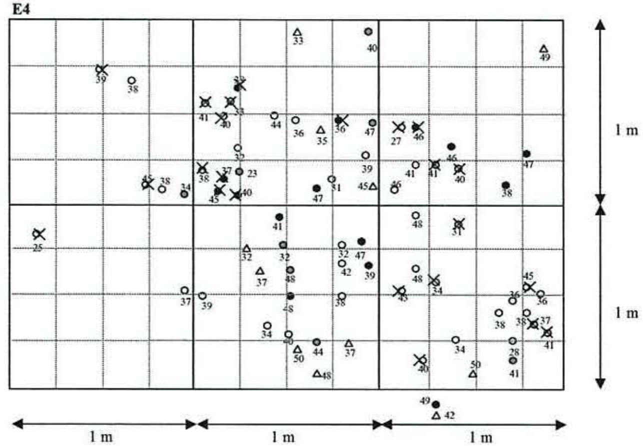
D2-C4 clumps (harvesting intensity 40% of young culms/0% of mature culms)



● : Young culms in November 2001 (10)
○ : Mature culms in November 2001 (11)
◉ : Shoots sprouted from November 2001 to April 2002 (2)
△ : Shoots sprouted from May 2002 to June 2003 (13)
✕ : Culms harvested in November 2001 (4 young, 4 mature)
Unit: mm in diameter

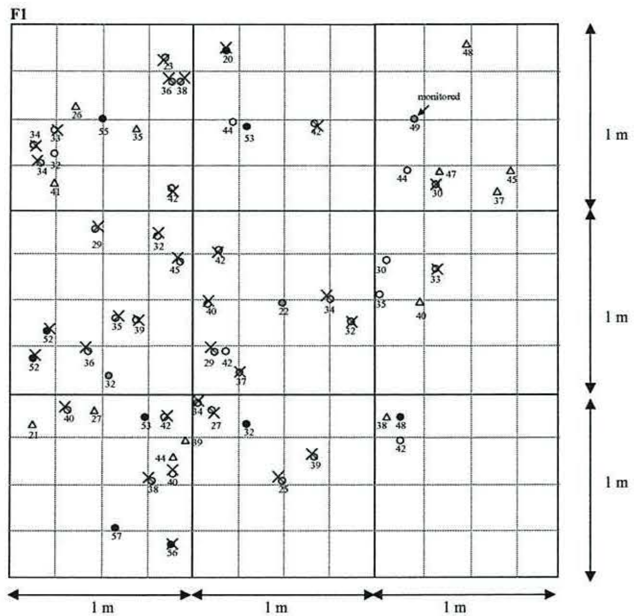


: Young culms in November 2001 (7)
: Mature culms in November 2001 (16)
: Shoots sprouted from November 2001 to April 2002 (1)
: Shoots sprouted from May to June 2003 (0)
: Culms harvested in November 2001 (3 young, 6 mature)

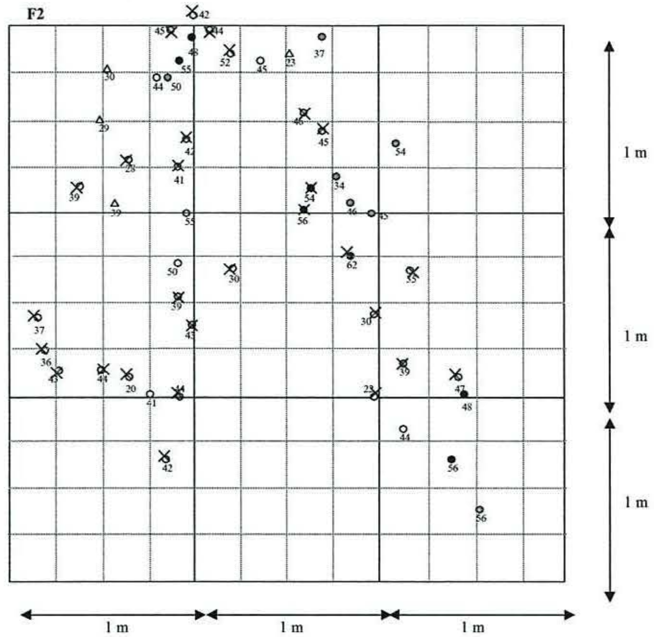


: Young culms in November 2001 (15)
: Mature culms in November 2001 (41)
: Shoots sprouted from November 2001 to April 2002 (8)
: Shoots sprouted from May June 2003 (11)
: Culms harvested in November 2001 (6 young, 17 mature)

E2-E4 clumps (harvesting intensity 40% of young culms/40% of mature culms)

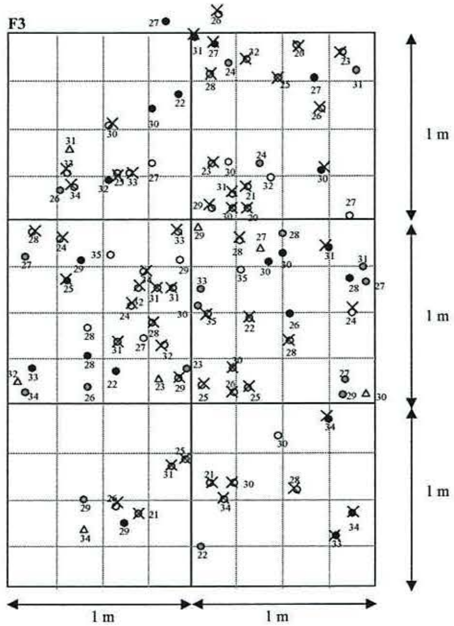


●: Young culms in November 2001 (10)
○: Mature culms in November 2001 (36)
⊙: Shoots sprouted from November 2001 to April 2002 (3)
△: Shoots sprouted from May 2002 to June 2003 (13)
✕: Culms harvested in November 2001 (4 young, 29 mature)
Unit: mm in diameter

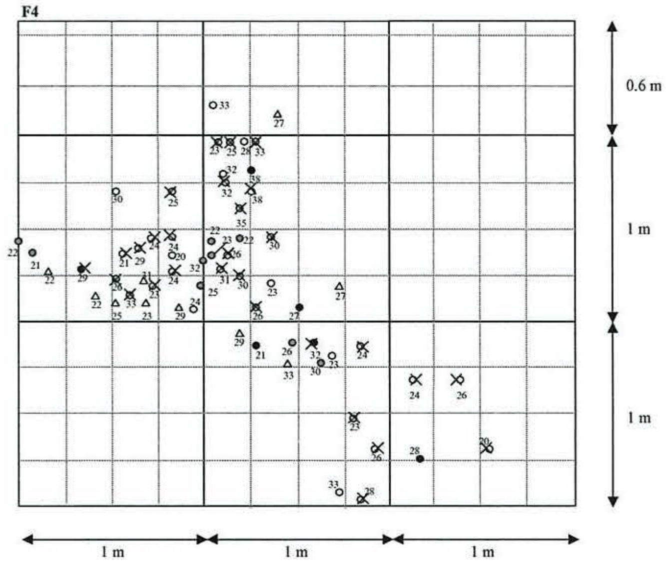


: Young culms in November 2001 (7)
: Mature culms in November 2001 (31)
: Shoots sprouted from November 2001 to April 2002 (7)
: Shoots sprouted from May 2002 to June 2003 (4)
: Culms harvested in November 2001 (3 young, 25 mature)

F1 and F2 clumps (harvesting intensity 40% of young culms/80% of mature culms)

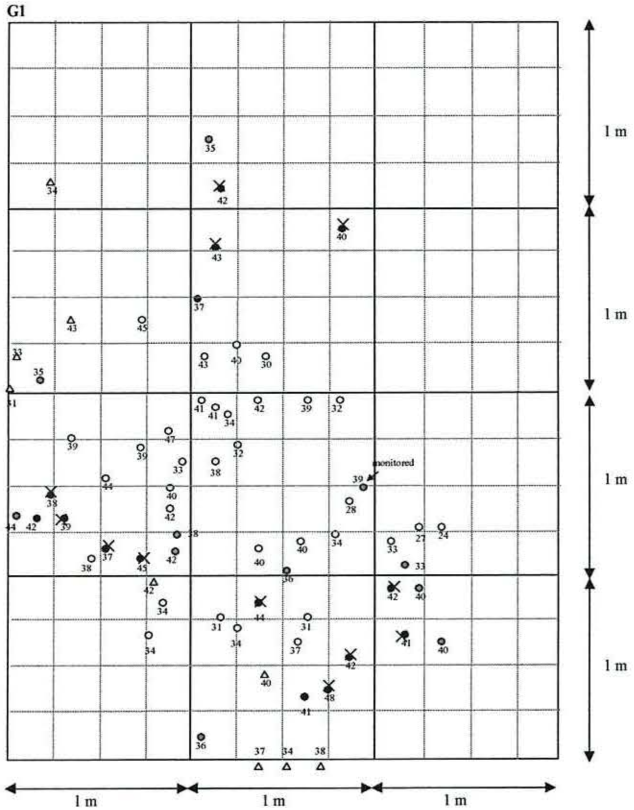


● : Young culms in November 2001 (22)
○ : Mature culms in November 2001 (57)
◉ : Shoots sprouted from November 2001 to April 2002 (17)
△ : Shoots sprouted from May 2002 to June 2003 (7)
✕ : Culms harvested in November 2001 (8 young, 47 mature)
Unit: mm in diameter

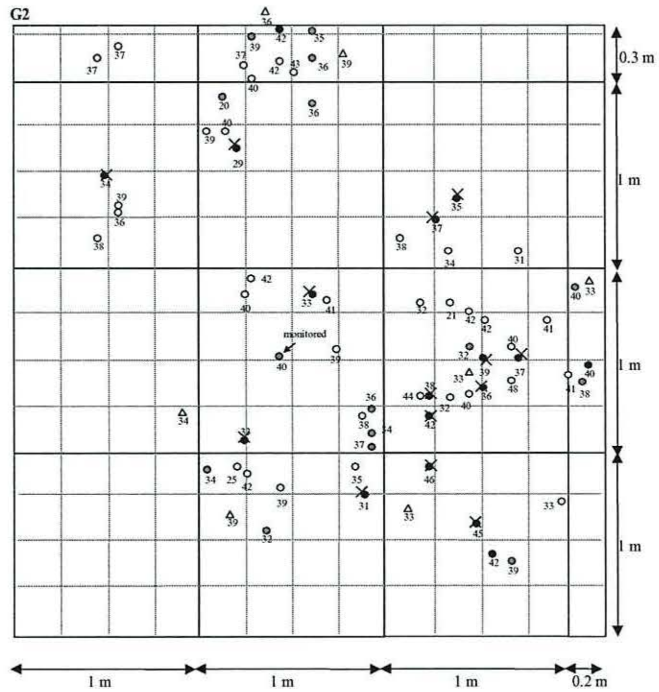


: Young culms in November 2001 (6)
: Mature culms in November 2001 (36)
: Shoots sprouted from November 2001 to April 2002 (9)
: Shoots sprouted from May 2002 to June 2003 (10)
: Culms harvested in November 2001 (2 young, 28 mature)

F3 and F4 clumps (harvesting intensity 40% of young culms/80% of mature culms)

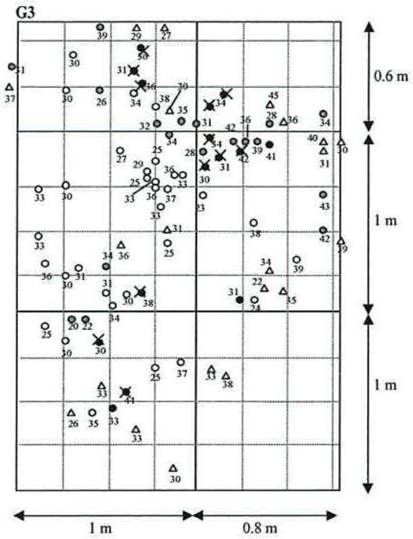


●: Young culms in November 2001 (15)
○: Mature culms in November 2001 (33)
◉: Shoots sprouted from November 2001 to April 2002 (11)
△: Shoots sprouted from May 2002 to June 2003 (9)
×: Culms harvested in November 2001 (12 young)
Unit: mm in diameter

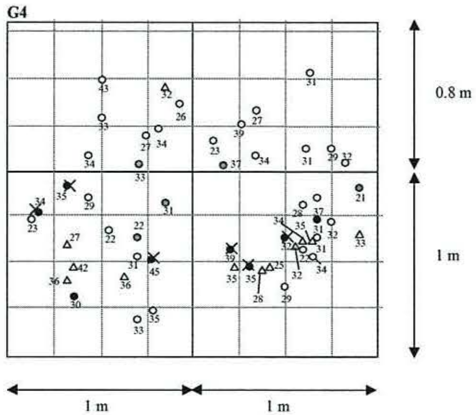


: Young culms in November 2001 (17)
: Mature culms in November 2001 (35)
: Shoots sprouted from November 2001 to April 2002 (15)
: Shoots sprouted from May 2002 to June 2003 (7)
: Culms harvested in November 2001 (14 young)

G1 and G2 clumps (harvesting intensity 80% of young culms/0% of mature culms)

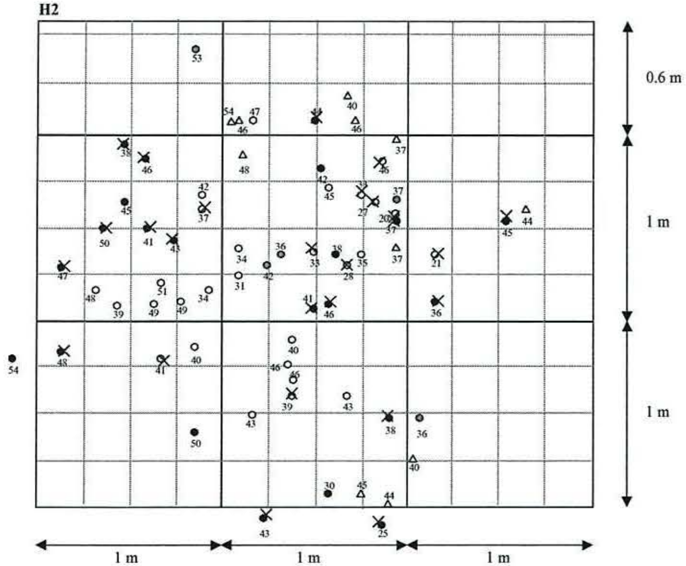


●: Young culms in November 2001 (15)
○: Mature culms in November 2001 (33)
◉: Shoots sprouted from November 2001 to April 2002 (17)
△: Shoots sprouted from May 2002 to June 2003 (21)
×: Culms harvested in November 2001 (12 young)
Unit: mm in diameter

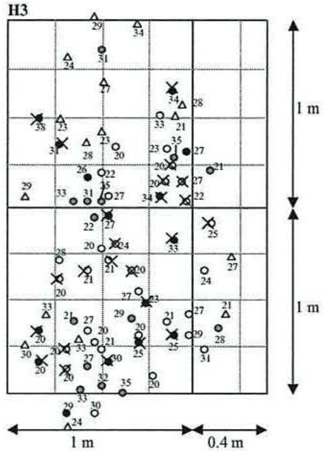


: Young culms in November 2001 (8)
: Mature culms in November 2001 (27)
: Shoots sprouted from November 2001 to April 2002 (5)
: Shoots sprouted from May 2002 to June 2003 (12)
: Culms harvested in November 2001 (6 young)

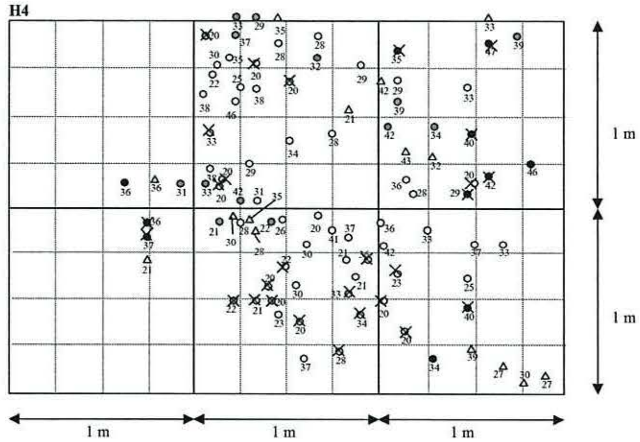
G3 and G4 clumps (harvesting intensity 80% of young culms/0% of mature culms)



●: Young culms in November 2001 (22)
○: Mature culms in November 2001 (28)
◉: Shoots sprouted from November 2001 to April 2002 (5)
△: Shoots sprouted from May 2002 to June 2003 (11)
✕: Culms harvested in November 2001 (16 young, 10 mature)
Unit: mm in diameter

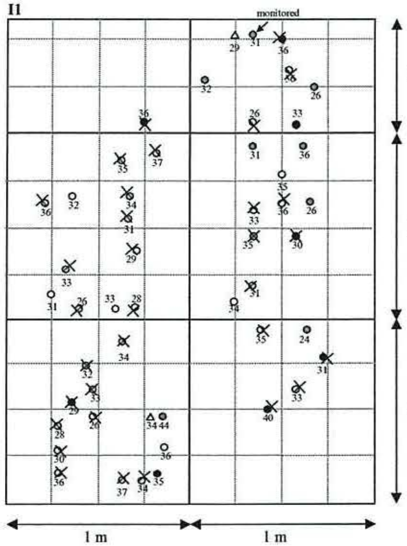


: Young culms in November 2001 (15)
: Mature culms in November 2001 (31)
: Shoots sprouted from November 2001 to April 2002 (14)
: Shoots sprouted from May 2002 to June 2003 (16)
: Culms harvested in November 2001 (12 young, 12 mature)

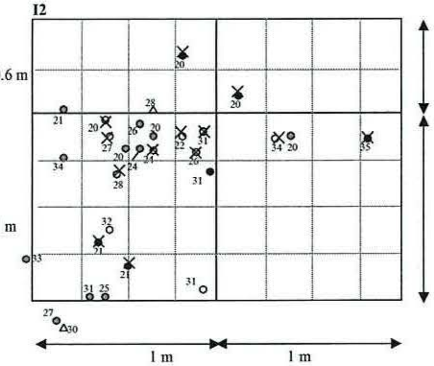


: Young culms in November 2001 (11)
: Mature culms in November 2001 (55)
: Shoots sprouted from November 2001 to April 2002 (13)
: Shoots sprouted from May 2002 to June 2003 (15)
: Culms harvested in November 2001 (8 young, 20 mature)

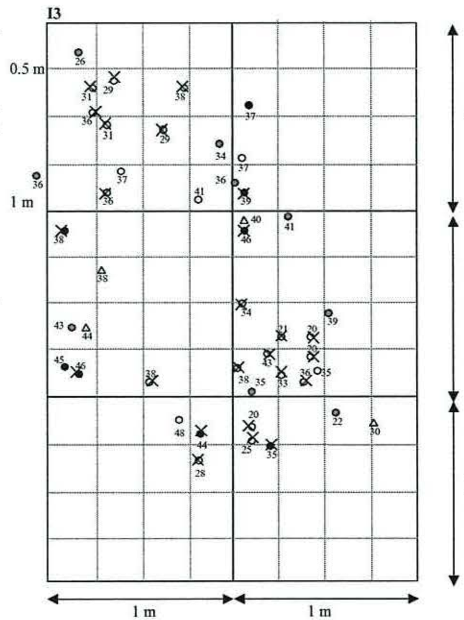
H2-H4 clumps (harvesting intensity 80% of young culms/40% of mature culms)



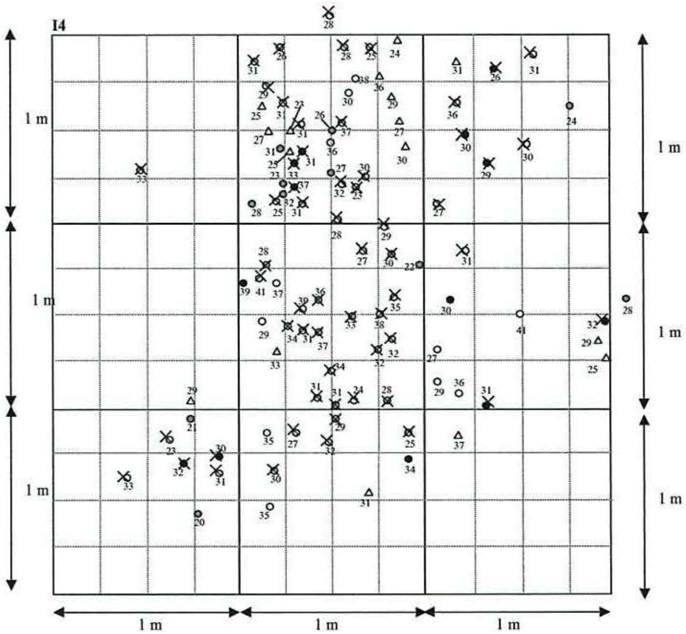
● : Young culms in November 2001 (8)
○ : Mature culms in November 2001 (32)
⊙ : New shoots sprouted by April 2002 (8)
△ : New shoots sprouted by June 2003 (2)
✕ : Culms harvested in November 2001 (6 young, 26 mature)
Unit: mm in diameter



: Young culms in November 2001 (6)
: Mature culms in November 2001 (10)
: Shoots sprouted from November 2001 to April 2002 (11)
: Shoots sprouted from May 2002 to June 2003 (2)
: Culms harvested in November 2001 (5 young, 8 mature)



: Young culms in November 2001 (8)
: Mature culms in November 2001 (24)
: Shoots sprouted from November 2001 to April 2002 (9)
: Shoots sprouted from May 2002 to June 2003 (4)
: Culms harvested in November 2001 (6 young, 19 mature)



: Young culms in November 2001 (13)
: Mature culms in November 2001 (60)
: Shoots sprouted from November 2001 to April 2002 (11)
: Shoots sprouted from May 2002 to June 2003 (15)
: Culms harvested in November 2001 (10 young, 49 mature)

I1-I4 clumps (harvesting intensity 80% of young culms/80% of mature culms)

Appendix VIII: *Oxytenanthera abyssinica*: actual numbers of culms and shoots for each of 36 clumps in Lilongwe, Malawi

	sum of original culms	young	mature	sum of retained culms	young	mature	new shoots Apr. 2002	new shoots June 2003
A 1	22	7	15	22	7	15	4	4
2	27	7	20	27	7	20	3	7
3	33	17	16	33	17	16	3	15
4	34	15	19	34	15	19	9	9
B 1	45	11	34	31	11	20	0	12
2	31	9	22	22	9	13	0	11
3	28	13	15	22	13	9	2	10
4	17	6	11	13	6	7	0	7
C 1	37	12	25	17	12	5	2	6
2	30	5	25	10	5	5	8	14
3	29	8	21	13	8	5	0	4
4	36	19	17	23	19	4	0	13
D 1	44	11	33	40	7	33	5	8
2	80	31	49	68	19	49	8	29
3	43	13	30	38	8	30	3	16
4	29	11	18	25	7	18	0	24
E 1	32	12	20	19	7	12	7	20
2	21	10	11	13	6	7	2	13
3	23	7	16	14	4	10	1	0
4	56	15	41	33	9	24	8	11
F 1	46	10	36	13	6	7	3	13
2	38	7	31	10	4	6	7	4
3	79	22	57	24	14	10	17	7
4	42	6	36	12	4	8	9	10
G 1	48	15	33	36	3	33	11	9
2	52	17	35	38	3	35	15	7
3	48	15	33	36	3	33	17	21
4	35	8	27	29	2	27	5	12
H 1	46	14	32	24	3	21	3	12
2	50	22	28	24	6	18	5	11
3	46	15	31	22	3	19	14	16
4	66	11	55	38	3	35	13	15
I 1	40	8	32	8	2	6	8	2
2	16	6	10	3	1	2	11	2
3	32	8	24	7	2	5	9	4
4	73	13	60	14	3	11	11	15

Appendix IX: *Oxytenanthera abyssinica*: summed cross sectional areas (cm^2) of culms and shoots for each of 36 clumps in Lilongwe, Malawi

	sum for original culms (Nov. 2001)	young	mature	sum for retained culms (post-harvest)	young	mature	new shoots Apr. 2002	new shoots June 2003
A 1	124.0	44.2	79.8	124.0	44.2	79.8	23.7	37.1
2	180.5	65.5	115.0	180.5	65.5	115.0	14.7	75.1
3	215.7	139.3	76.4	215.7	139.3	76.4	33.9	133.8
4	268.7	148.4	120.3	268.7	148.4	120.3	95.9	84.9
B 1	442.7	134.9	307.8	339.6	134.9	204.8	0.0	95.9
2	229.8	87.5	142.4	192.2	87.5	104.7	0.0	89.1
3	180.2	96.5	83.7	154.0	96.5	57.5	18.9	73.1
4	109.6	49.6	60.0	90.9	49.6	41.3	0.0	55.9
C 1	325.2	116.5	208.6	163.1	116.5	46.6	21.9	73.8
2	144.0	32.5	111.5	50.2	32.5	17.7	62.6	102.9
3	192.4	93.5	98.9	120.7	93.5	27.2	0.0	31.7
4	366.9	233.4	133.5	275.4	233.4	42.0	0.0	111.4
D 1	345.5	86.5	258.9	319.3	60.4	258.9	50.2	96.7
2	668.0	296.0	372.0	554.2	182.2	372.0	74.4	211.5
3	368.1	140.6	227.5	318.4	90.9	227.5	33.4	169.1
4	418.2	173.4	244.8	350.4	105.6	244.8	0.0	249.3
E 1	316.0	156.4	159.7	189.3	88.3	101.0	99.9	198.1
2	138.6	79.2	59.4	88.0	46.5	41.6	16.7	79.8
3	306.5	94.0	212.5	199.0	65.5	133.5	5.9	0.0
4	687.8	218.7	469.0	424.0	141.9	282.1	97.9	153.4
F 1	559.3	189.1	370.2	202.1	119.5	82.5	30.4	150.4
2	584.6	161.0	423.6	186.4	83.6	102.8	119.9	24.0
3	504.2	140.4	363.8	169.3	85.4	83.9	103.7	48.2
4	253.0	40.9	212.1	77.3	26.3	51.0	43.6	57.4
G 1	555.9	203.7	352.2	389.1	36.9	352.2	117.9	97.1
2	591.3	190.8	400.5	440.3	39.8	400.5	148.4	68.5
3	420.5	144.7	275.8	305.3	29.5	275.8	150.3	185.1
4	283.2	79.2	204.0	219.0	14.9	204.0	34.1	103.8
H 1	426.0	163.3	262.8	232.6	43.2	189.4	18.1	113.6
2	657.9	313.9	344.0	346.8	90.2	256.6	66.6	167.1
3	232.0	93.6	138.4	110.9	17.5	93.3	93.5	94.5
4	503.2	129.3	373.8	317.2	35.6	281.6	118.3	124.9
I 1	342.1	71.6	270.5	71.5	18.1	53.4	64.2	15.3
2	90.9	30.5	60.4	22.9	7.4	15.5	57.3	13.0
3	317.9	108.2	209.7	88.4	26.7	61.7	88.1	46.2
4	572.8	105.8	467.0	128.0	28.3	99.8	57.7	93.9

Appendix X: Clump restoration of *Oxytenanthera abyssinica* after culms were harvested in November 2001 in Lilongwe, Malawi

	number						cross sectional areas (cm^2)					
	sum of original culms	sum of retained culms	new shoots Apr. 2002	new shoots June 2003	Restored ratio April 2002	Restored ratio June 2003	sum of original culms	sum of retained culms	new shoots Apr. 2002	new shoots June 2003	Restored ratio April 2002	Restored ratio June 2003
	A	B	C	D	(B+C)/A	(B+C+D)/A	E	F	G	H	(F+G)/E	(F+G+H)/E
A 1	22	22	4	4	1.18	1.36	124	124	24	37	1.19	1.49
2	27	27	3	7	1.11	1.37	181	181	15	75	1.08	1.50
3	33	33	3	15	1.09	1.55	216	216	34	134	1.16	1.78
4	34	34	9	9	1.26	1.53	269	269	96	85	1.36	1.67
B 1	45	31	0	12	0.69	0.96	443	340	0	96	0.77	0.98
2	31	22	0	11	0.71	1.06	230	192	0	89	0.84	1.22
3	28	22	2	10	0.86	1.21	180	154	19	73	0.96	1.37
4	17	13	0	7	0.76	1.18	110	91	0	56	0.83	1.34
C 1	37	17	2	6	0.51	0.68	325	163	22	74	0.57	0.80
2	30	10	8	14	0.60	1.07	144	50	63	103	0.78	1.50
3	29	13	0	4	0.45	0.59	192	121	0	32	0.63	0.79
4	36	23	0	13	0.64	1.00	367	275	0	111	0.75	1.05
D 1	44	40	5	8	1.02	1.20	346	319	50	97	1.07	1.35
2	80	68	8	29	0.95	1.31	668	554	74	212	0.94	1.26
3	43	38	3	16	0.95	1.33	368	318	33	169	0.96	1.42
4	29	25	0	24	0.86	1.69	418	350	0	249	0.84	1.43
E 1	32	19	7	20	0.81	1.44	316	189	100	198	0.92	1.54
2	21	13	2	13	0.71	1.33	139	88	17	80	0.76	1.33
3	23	14	1	0	0.65	0.65	307	199	6	0	0.67	0.67
4	56	33	8	11	0.73	0.93	688	424	98	153	0.76	0.98
F 1	46	13	3	13	0.35	0.63	559	202	30	150	0.42	0.68
2	38	10	7	4	0.45	0.55	585	186	120	24	0.52	0.57
3	79	24	17	7	0.52	0.61	504	169	104	48	0.54	0.64
4	42	12	9	10	0.50	0.74	253	77	44	57	0.48	0.70
G 1	48	36	11	9	0.98	1.17	556	389	118	97	0.91	1.09
2	52	38	15	7	1.02	1.15	591	440	148	69	1.00	1.11
3	48	36	17	21	1.10	1.54	421	305	150	185	1.08	1.52
4	35	29	5	12	0.97	1.31	283	219	34	104	0.89	1.26
H 1	46	24	3	12	0.59	0.85	426	233	18	114	0.59	0.86
2	50	24	5	11	0.58	0.80	658	347	67	167	0.63	0.88
3	46	22	14	16	0.78	1.13	232	111	94	95	0.88	1.29
4	66	38	13	15	0.77	1.00	503	317	118	125	0.87	1.11
I 1	40	8	8	2	0.40	0.45	342	72	64	15	0.40	0.44
2	16	3	11	2	0.88	1.00	91	23	57	13	0.88	1.03
3	32	7	9	4	0.50	0.63	318	88	88	46	0.56	0.70
4	73	14	11	15	0.34	0.55	573	128	58	94	0.32	0.49

Appendix XI: Tree species ≥ 2 cm dbh within 3 m of research clumps of *Oxytenanthera abyssinica* (A. Rich.) Munro in Lilongwe, Malawi

	Species within 3 m from clump periphery	Dbh (cm)
A1	*Vernonia amygdalina* Del.	4
A2	*Flueggea virosa* (Willd.) Voigt	6
A3	*none*	
A4	*none*	
B1	*Albizia versicolor* Welw.	35
B2	*Albizia harveyi* Fourn.	44
B3	*Friesodielsia obovata* (Benth.) Vedc.	4
B4	*Combretum molle* R. Br.	31
C1	*none*	
C2	*Rauvolfia caffra* Sond.	13
C3	*Combretum zeyheri* Sond.	15
	Combretum zeyheri Sond.	10
	Vernonia amygdalina Del.	3.5
	Markhamia acuminata (Klotz.) K. Schum.	5
	Markhamia acuminata (Klotz.) K. Schum.	6
C4	*Ziziphus abyssinica* Hochst.	19
D1	*Acacia xanthophloea* Benth.	45
	Strychnos potatorum L. f.	2.7
D2	*none*	
D3	*none*	
D4	*Grewia flavescens* Juss.	7
	Pterocarpus rotundifolius (Sond.) Druce.	50
E1	*none*	
E2	*Diospyros lycioides* Desf.	2.7
E3	*none*	
E4	*Bauhinia thonningii* Schumach.	46
F1	*Acacia polycantha* Willd.	35
	Albizia harveyi Fourn.	21
F2	*none*	
F3	*none*	
F4	*Rauvolfia caffra* Sond.	5
G1	*Pterocarpus rotundifolius* (Sond.) Druce.	30
G2	*none*	
G3	*Diospyros lycioides* Desf.	4
G4	*none*	
H1	*none*	
H2	*none*	
H3	*none*	
H4	*none*	
I1	*none*	
I2	*Terminalia sericea* Burch.	51
	Diospyros lycioides Desf.	7
I3	*none*	
I4	*none*	

Appendix XII: Number and length of rhizomes and shoots for cuttings which sprouted shoots and/or rhizomes *Oxytenanthera abyssinica* in Malawi

unit of length: cm

NAA applied					NAA not applied				
cutting ID	total length of rhizomes	no. of rhizomes	total length of shoots	no. of shoots	cutting ID	total length of rhizomes	no. of rhizomes	total length of shoots	no. of shoots
one D3L	n.a.	n.a.	62	8	one D1L	11	3	19	4
one D5L	23	6	n.a.	n.a.	one D1M	16	4	n.a.	n.a.
one D5M	n.a.	n.a.	25	1	one D3L	6	1	n.a.	n.a.
one D10L	n.a.	n.a.	50	2	one D12L	5	2	n.a.	n.a.
one D12L	n.a.	n.a.	40	1	one D12M	7	4	42	1
one D14M	4	2	n.a.	n.a.	one D13L	n.a.	n.a.	8	1
two D3L	58	15	n.a.	n.a.	two L4L	5	1	168	3
two D3M	39	18	40	1	two D4M	14	3	10	1
two L4M	n.a.	n.a.	7	1	two D5L	n.a.	n.a.	13	1
two D4L	n.a.	n.a.	25	1	two D5M	n.a.	n.a.	72	3
two D4M	6	3	n.a.	n.a.	two D9L	10	4	20	1
two D5L	4	1	n.a.	n.a.	two D11L	n.a.	n.a.	20	1
two D5M	4.4	1	80	1	two D12M	n.a.	n.a.	90	2
two D12L	n.a.	n.a.	30	1	two L13L	n.a.	n.a.	250	18
two L13M	20	13	62	4	two L14L	n.a.	n.a.	15	3
two D13L	2	2	n.a.	n.a.	—	—	—	—	—
two D13M	14	3	37	5	—	—	—	—	—
mean	17.4	6.4	41.6	2.4	mean	9.3	2.8	60.6	3.3
observ.	10	10	11	11	observ.	8	8	12	12

Averages were calculated only for cuttings which sprouted shoots and/or rhizomes; n.a.: no rhizomes nor shoots were observed; culms 1-2 years old were sampled at Lilongwe and Mua, cut into sections (360 cuttings) and planted one day after in Lilongwe; of the 360 cuttings, 180 were dipped in 500 ppm NAA for 5 seconds before planting.

Cutting identification

First filed: number of internodes per cutting

Second filed: location of collected cuttings, L = Lilongwe, D = Mua

Third filed: clump number at the location (1-15 clumps numbered)

Fourth filed: collection position in source culm, T = top, M = Mid, L = Low

Appendix XIII

Unsuccessful experiments of propagation

In this appendix, unsuccessful experiments and trials of propagation of *Oxytenanthera abyssinica* are reported. The methods are cuttings using sections of lateral branches (2) and planting in saturated medium (3), marcotting (4) and layering (5).

1 Resume of relevant propagation work

Branch cuttings, marcotting and layering propagation have been practised for Asiatic bamboos (see Chapter 7). Branch cuttings and marcotting would be suitable for mass plantation, since many propagation units can be obtained from a single culm. Layering is maintenance free technique, because culms are layered being attached to the mother clump. Even though these advantages, they should have never been applied for *Oxytenanthera abyssinica*. Propagation in these methods was, therefore, carried out for *Oxytenanthera abyssinica* in this study.

Abeels (1961) carried out vegetative propagation for *Oxytenanthera abyssinica,* using four types of nursery bed. These were soil, stagnant water over sand in tubs, floating beds and the sandy bed of a stream. *Oxytenanthera abyssinica* produced young leaves five to six weeks after propagation in floating beds, but it did not produce roots and gradually dried. Cuttings used for this propagation were three culm nodes. In his method, poor nutrition in the water may have restricted rooting. In this experiment in Malawi, topsoil was mixed in the water to keep higher nutrition in medium for cuttings.

Sources of material

Cuttings were harvested in Zone A of the Lilongwe Nature Sanctuary (13°57'S, 33°47'E; 1060 m) and planted in the nursery near the Sanctuary office. Marcotting and layering were conducted in the Zone A.

2 Sections of lateral branches

2.1 Protocol

Experimental material

The same culms for culm cuttings were used for branch cuttings to minimise the reduction of resource. The process of selecting clumps, therefore, followed that of culm cuttings. Five clumps were sampled from the ten clumps of culm cuttings at random in the Sanctuary.

Following culm standard was added to the standard mentioned before:

- age of culms
  - < 1 year old (young)
  - 1 - < 4 years old (mature)
  - 4 years old (NOT SAMPLED)
- cuttings with buds which were nearly bursting.

First, culms which did not conform the standard were eliminated. Then, a young culm and a mature culm were randomly sampled from each clump.

Treatments

Three branch cuttings were taken from three positions of each culm. The positions were: top (top 1/3 part), middle (1/3-2/3 part), low (low 1/3 part). In each position, a single branch was sampled, confirming their condition which had no disease and cracking. Main branches were cut at the bottom just near culms. In total 30 branch cuttings were planted each time: 5 clumps × 2 culms/clump × 3 cuttings/culm = 30 cuttings (Table 1).

Table 1 : Number of branch cuttings each time of experiments

Culm age	Position in culms		
	Low	Mid	Top
Young	5	5	5
Mature	5	5	5

Branches were cut into sections of two internodes with a node at each end. Beyond the node, 2 cm of branch was included in each cutting. All leaves were trimmed to reduce evaporation when harvested.

Experimental layout

Top soils from the Sanctuary were mixed with the sand from the trails. Plastic tubes (14 cm × 7 cm) were filled with the soils. Branch cuttings were then planted in the tubes. All branch cuttings were planted vertically.

Two blocks were made on the ground. Ten branch cuttings in the plastic tubes from the same position in culms were distributed in the two blocks, each having five branch cuttings. This was repeated for branch cuttings of three positions of culms (Table 2). Tree shades covered these cuttings.

Table 2 : Actual layout of branch cuttings on the ground

BT	BL	BM	BL	BT	BM
BT	BL	BM	BL	BT	BM
BT	BL	BM	BL	BT	BM
BT	BL	BM	BL	BT	BM
BT	BL	BM	BL	BT	BM

Keys: BT = branch cutting in a tube from the top part of culm
BM = branch cutting in a tube from the mid part of culm
BL = branch cutting in a tube from the low part of culm

Investigation period

Branch cuttings were planted on 8 November 2001 (just before the rainy season), and repeated on 11 April 2002 (after the rainy season) and on 31 July 2002 (in the dry season, Table 3). Duration of recording was two months for all the propagation of branch cuttings.

Table 3 : Dates of planting and assessment activities of branch cuttings

	Date of activities		
Planting	8 Nov. 2001	11 Apr. 2002	31 July 2002
Final assessment	11 Jan. 2002	5 June 2002	23 Sep. 2002

Maintenance

Following care was taken:

- watering: every two days unless there was rain, early in the day or late in the afternoon. No watering if the soil was already moist.
- weeding: when necessary

Parameters recorded

Broken stems were employed as the indication of dead branches. Presence of leaves and roots was regarded as survival. Survival/mortality of cuttings was monitored every two days as watering was carried out. Presence of leaves and roots was recorded for every cutting at the end of each experiment (11 January 2002, 5 June 2002, 23 September 2002).

2.2 Data processing

Recorded parameters were tabulated for each category of ages, positions in culms and trial periods.

2.3 Results

All branch cuttings were dying two months after the first trial of planting in January 2002. Young branches started dying earlier than mature ones. It seemed that young branches were spoiled shortly due to their higher proportion of unlignified tissue. Two months after the second and the third trials, all branches also died (Table 4). Exposure of branches in the air would have accelerated the reduction of water, by which branches may have died.

Table 4 : Number of surviving branch cuttings which had leaves and roots

Assessment date	Culm age	Position in culms		
		Low	Mid	Top
11 Jan. 2002	Young	0	0	0
	Mature	0	0	0
5 June 2002	Young	0	0	0
	Mature	0	0	0
23 Sep. 2002	Young	0	0	0
	Mature	0	0	0

2.4 Conclusions

Propagation using branch cuttings was not successful for *Oxytenanthera abyssinica*. It would not be suitable for *Oxytenanthera abyssinica*.

3 Saturated medium

3.1 Protocol

Experimental material

At first, two areas were selected, one in the north and one in the south of Zone A in the Sanctuary. Clumps that departed from the standard (Subsection 7.2) were disregarded. From remaining clumps, three clumps were selected in the north and two clumps were selected in the south randomly. In addition to the standard criteria mentioned before (Subsection 7.2), culm selection took account of age and condition.

- age of culms
  - < 1 year old (young)
  - 1 - < 4 years old (mature)
  - 4 years old (NOT SAMPLED)
- cuttings with buds which were nearly bursting.

Treatments

First, culms which did not conform to the standard were eliminated. Then, a young culm and a mature culm were randomly sampled from each clump. Three cuttings were secured from each culm. The positions were: top (top 1/3 part), middle (1/3-2/3 part), low (low 1/3 part). Culms less than 1 cm in diameter at top were rejected.

There were 30 cuttings planted, of which 18 cuttings were taken in the north and 12 cuttings were taken in the south of Zone A:

- in the north; 3 clumps × 2 culms/clump × 3 cuttings/culm = 18 cuttings
- in the south; 2 clumps × 2 culms/clump × 3 cuttings/culm = 12 cuttings (Table 5).

Table 5 : Number of cuttings for floating bed

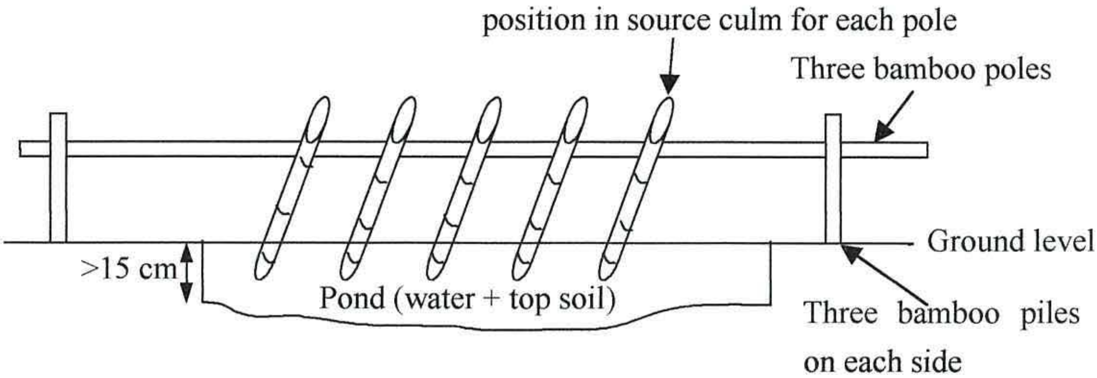
Culm age	Position in culms		
	Low	Mid	Top
Young	5	5	5
Mature	5	5	5

All cuttings cut into sections of two internodes. The upper ends were cut just below the node and lower ends were cut above the node. Cuttings were less than 1 m long. Beyond the node, 5 cm of culm was included in each cutting. All branches were cut 2-4 cm from the nodes. All leaves on branches of cuttings were trimmed off when culms were harvested.

Experimental layout

Cuttings were planted in a pond near the Sanctuary office. Culms tied to bamboo poles to float in the pond (3 m length × 3 m wide × 0.15 m in depth, Figure 1). The pond was roofed with plastic sheets to reduce evaporation. The bottom was covered with plastic sheets to reduce leakage of water (Plate 6). Top soils from the Sanctuary was mixed in the water. Cuttings were positioned vertically in a pond.

Figure 1 : Floating bed for cuttings



Cuttings from the same position of culm were tied to a pole due to the similar length of the cuttings. Accordingly, three poles were made, each pole having ten cuttings taken from the top, the middle or the low parts of culms.

Investigation period

Cuttings were planted in a pond on 12 November 2001. Cuttings were kept in a pond for recording for five months until 15 April 2002.

Maintenance

Water was added when the depth became less than 15 cm. The lowest node was always kept in the water.

Parameters recorded

Presence of leaves, shoots, rhizomes and roots was regarded as survival. Survival of cuttings was monitored every week. Presence of leaves and roots was recorded for every cutting on 6 December 2001 and 15 April 2002.

3.2 Data processing

Recorded parameters were tabulated for each category of ages and positions in culms.

3.3 Results

Only two young cuttings from the mid parts of culms out of five cuttings in this category had leaves one month after planting (6 December 2001). Other cuttings from the top and low parts of culms had no leaves (Table 6). The two young cuttings lost their leaves until 1st of April 2002. No root has been detected for all cuttings in this experiment until 15 April 2002. This method of cuttings seemed unsuitable for propagation of *Oxytenanthera abyssinica.*

Table 6 : Number of survival cuttings for floating bed which had leaves

Culm age	Position in culms	Date of observation	
		6 December 2001	15 April 2002
Young	Low	0/5	0/5
	Mid	2/5 (R = 0)	0/5
	Top	0/5	0/5
Mature	Low	0/5	0/5
	Mid	0/5	0/5
	Top	0/5	0/5

Keys: Number of observations for each category = 5; R = Roots on culms

3.4 Conclusions

Propagation of cuttings in saturated medium was not successful for *Oxytenanthera abyssinica.* Propagation of cuttings in saturated medium would not be suitable for *Oxytenanthera abyssinica.*

4 Marcotting

4.1 Protocol

Experimental material

An area in the north of Zone A and another area in the south were randomly sampled from where *Oxytenanthera abyssinica* clumps were present. At each area two clumps were sampled randomly from those which conformed the standard mentioned in Subsection 7.2. Five branchlets were randomly sampled for marcotting in each clump.

Only mature culms were regarded as the source for marcotting due to the availability of branches at the lower part of culms where the author could reach. Young culms had no branches at the lower part where the author could reach. Two mature culms were sampled at random from each clump within the culm categories (Subsection 7.2). The culms were kept alive (Plate 7).

Treatments

Branchlets for this method were at the lower part of each culm within the height where the author could work (<1.8 m from the ground). Leaves were left on branches.

One or two branchlets were used at each culm. Ten sets of marcotting were made in two clumps at each area. In total twenty sets of marcotting were made (Table 7):

2 location × 2 clump/location × 2 culms/clump × 2-3 branchlets/culm = 20

Table 7 : Number of marcottings

	Location in Zone A	
Culm age	South	North
Mature	10	10

Experimental layout

Branches were kept on culms which remained connecting with clumps. The bark of the base of branch complement was cut, and it was rounded by the mixture of cow dung and dried straws. It was then wrapped with plastic paper. Thirty cm of the branch near the culm was left and other parts were removed.

Investigation period

Marcottings were established on 2 and 3 January 2002. This experiment was kept for recording for nine months until 23 September 2002. Survival was assessed on 15 April and on 23 September 2002

Maintenance

Branching was left in the natural environment.

Parameters recorded

Broken stems were employed as the indication of dead branches. Presence of leaves and roots was regarded as survival. It was recorded for every cutting on 15 April and 23 September 2002. The observation of survival/mortality was carried out fortnightly.

4.2 Data processing

Recorded parameters were tabulated for survival and non-survival of marcotting.

4.3 Results

No roots were found in April 2002. In September 2002, all the sets were dead (Table 8). Manure rounded base of branch complement might have lost their moisture content rapidly in the dry season before roots were produced.

Table 8 : Number of surviving marcotting on culms

Culm age	15 April 2002		23 September 2002	
	Location in Zone A			
	South	North	South	North
Mature	10	10	0	0

4.4 Conclusions

Propagation of marcotting was not successful for *Oxytenanthera abyssinica*. Marcotting would not be suitable for *Oxytenanthera abyssinica*.

5 Layering

5.1 Protocol

Experimental material

Clump selection standard was applied to this propagation. Ten clumps were sampled along footpaths across the Zone A (Map 6.1), which were located near the clumps for new culm production to identify the location of layering without difficulty. Taking account of the standard criteria (Subsection 7.2), a young culm, a mature culm and a new culm were sampled at random at each clump. Ten young, mature culms, and ten new culms were in total used for layering.

Treatments

Leaves and branches were kept on the culms. Culms were kept alive for air layering. Culms were bent down into a shallow trench (1 m length × 0.3 m wide × 0.3 m depth) of the ground and covered with topsoil. Nodes bearing branches were buried with culms (Plate 8).

Experimental layout

The soil was topsoil existed in the place where culms were buried.

Investigation period

Layering of young and mature culms was made on 13 November 2001, because the rain was expected to start soon after this in November. Layering of new culms was made on 12 April 2002 when the shoots were available (Table 9).

Table 9 : Location, age and planting date of culms for air layering

	Culm age		
Initiation	New	Young	Mature
November 2001		+	+
April 2002	+		

This experiment was kept for recording for 10 months for young (< 1 year) and mature (1-4 years) culms and for five months for new culms (new in April 2002) until 18 September 2002.

Maintenance

Culms for layering were left in the natural environment without any control.

Parameters recorded

Cracking was employed as the indication of dead culms. Presence of leaves and roots was regarded as survival. It was recorded for young and mature culms on 10 December 2001, on 12 April and on 18 September 2002. The observation of survival/mortality was carried out fortnightly.

5.2 Data processing

Recorded parameters were tabulated for each age class of culms and observation date.

5.3 Results

Three young culms cracked a month after planting. A single mature culm (Location L8) in all experimental culms for air layering rooted four months after planing in April 2002 but this culm died in September 2002. Three young culms out of ten young culms planted and six mature culms out of ten mature culms planted remained alive in September 2002 (10 months after planting). Five new culms out of ten planted in April 2002 remained alive in September 2002 (Table 10). Cracking occurred probably due to the solid walls of culms and high tensile structure. The large diameter of the culms should also be one of the reasons for cracking. It was observed by the author not for experimental culms but for naturally bending culms that shoots came upwards from the nodes. These culms were not covered with soils. These shoots seemed to become culms. Culms in this method of layering may have cracked for high pressure of bending, being buried in the ground. Naturally decumbent culms could be used for layering.

5.4 Conclusions

Propagation of layering was not successful for *Oxytenanthera abyssinica*. Layering would not be suitable for *Oxytenanthera abyssinica*.

Table 10 : Observation of culms for air layering

Location (Map 6.1)	Culm age	Date of observation		
		10 December 2001	12 April 2002	18 September 2002
L1	Young	+	+	—
	Mature	+	+	+
	New	n.a.	n.a.	+
L2	Young	+	+	+
	Mature	+	+	+
	New	n.a.	n.a.	+
L3	Young	+	+	+
	Mature	+	+	—
	New	n.a.	n.a.	+
L4	Young	+	+	+
	Mature	+	+	+
	New	n.a.	n.a.	+
L5	Young	+	+	—
	Mature	+	+	+
	New	n.a.	n.a.	+
L6	Young	—	—	—
	Mature	+	+	+
	New	n.a.	n.a.	—
L7	Young	—	—	cut by human
	Mature	+	+	+
	New	n.a.	n.a.	—
L8	Young	+	+	—
	Mature	+	rooting (very small)	—
	New	n.a.	n.a.	—
L9	Young	—	—	—
	Mature	+	+	—
	New	n.a.	n.a.	—
L10	Young	+	+	—
	Mature	+	—	—
	New	n.a.	n.a.	—
Total alive	Young	7/10*	7/10*	3/10*
	Mature	10/10*	9/10*	6/10*
	New	n.a.	n.a.	5/10*

Keys: —: dying with cracks on the culm

+: surviving with leaves but without new roots and shoots

n.a.: not applicable for new shoots because they were planted in April 2002

*: total number of observations was 10 culms.

Appendix XIV

An ecological profile for *Oxytenanthera abyssinica* (Poaceae)

The mature plant

A caespitose bamboo with a pachymorphic rhizome system and solid or thick-walled outwardly-spreading culms typically to about 10 m in length and to 5-8 cm in diameter at the base. There is a dominant central branch at each of the nodes distal to the lowest 6-8.

Distribution

Widely distributed through the Zambezian and Sudanian phytochoria of Africa, and extending into neighbouring dryland phytochoria. Present in 28 countries, from Senegal and Zambia east to Eritrea and Ethiopia, south to Mozambique and across south-central Africa from Malawi to Angola.

Field identity

There is no risk of confusion with any other indigenous woody African bamboo as no others share the savanna habitat. Among the indigenous large woody African bamboos, *Oxytenanthera* is the only one with thick culm walls. Distinction from the other large indigenous African bamboos is also possible on foliar features. The leaf blades of *Yushania alpina* end in a filiform tip 10 mm long, while those of *Oxytenanthera* end in stiff tip 5 mm long. In *Oreobambos buchwaldii* the leaf blades tend to be wider (30-60 mm wide) than in *Oxytenanthera* (10-30 mm wide). Further, at the mouth of the leaf sheath cilia are present on the young leaves of *Oxytenanthera* but not on those of *Oreobambos*. The most widespread introduced large bamboo in Africa, *Bambusa vulgaris*, differs in having auricles present at the shoulders of the leaf sheath.

Flowering cycle

Flowering is sometimes gregarious and synchronous on long cycles, but there may be isolated individuals flowering in most years, at least in some areas. For some parts of the range, however, there have been no records of flowering for very long periods. Mass flowerings at intervals of 7 years, approximately 14 years and approximately 20 years have been reported. A triggering effect of a very wet season followed by an unusually intense dry season has been suggested to cause gregarious flowering.

Phenology/dispersal

Oxytenanthera is evergreen in continually warm and humid conditions but sheds an increasing proportion of its foliage if there are severe seasonal soil water deficits or periods of low temperature. Where the dry season is long (7 months) leaves turn from green to yellow 1-2 months after the dry season begins and are shed in the mid-dry season. Flowering is a dry season event with mature seed being present about 6 months later, at the end of the following rainy season.

Phenology/dispersal

Dispersal by water has been suggested, as has dispersal by animals – presumably when contact detaches spikelets that become lodged in the animal's hair. The bird, *Lonchura fringilloides*, a specialised seed predator, may contribute to dispersal if viable seeds are dropped before ingestion. In general, seed dispersal beyond the vicinity of a fruiting clump is rare.

Regeneration

Post-flowering observations in parts of the natural range indicate monocarpy, the total death of clumps. In other areas, flowering shoots have been observed to die but not the rhizome system. A year after flowering, new shoots develop from the same rhizomes.

Seeds germinate during the rainy season following dispersal, or a year later. In natural conditions, seedlings appearing are concentrated among and near the parent clumps. Early growth is relatively slow in natural stands, seedlings reaching 30 cm in height one year after germination. Growth accelerates later. From seedling origin, clumps may take up to eight years to mature. Within clumps, new shoots are produced in the rainy season. In established clumps, individual culms mature in 3-4 years.

Growth

Initially, after progressing from the seedling stage, culms do not attain the lengths or diameters reached in mature clumps. Shoots attain full length during a single rainy season's growth (typically 4-5 months). Culms produced in the second year after germination may reach a length of only 3 m; in the fourth year they can reach 4.5 m but are thin (diameter less than 2 cm). Full-sized culms usually first develop when clumps reach an age of 5-8 years, depending on the favourability of the site..

Inventory

Clump density varies widely but where *Oxytenanthera* brakes form a more or less pure thicket there may be several hundred clumps per hectare, each with 20-80 culms.

Appendix XV

A conservation profile for *Oxytenanthera abyssinica* (Poaceae)

Population status and structure

Oxytenanthera in little-disturbed or undisturbed populations is gregarious and may form extensive brakes of thousands of clumps, among which other woody species are poorly represented. Individual clumps reach diameters as great as 6 m at ground level. In per hectare terms, there may be 100-750 clumps (4000-30 000 culms), depending on whether occurrence is in pure stands or as a minor element of a mixture.

A clump longevity of 30 years for populations thought to flower sporadically rather than gregariously, has been suggested for Sudan. Where synchronous flowering occurs, this often limits clump life span to around 14-20 years, although there are instances recorded of short-term (7 years) synchronous flowering which is not associated with rhizome death. Older, larger clumps may contain as many as 80 living culms, the oldest of which may be 7-8 years old.

Resilience

The vigorous rhizome system ensures capacity to rapidly resume shoot production after a quiescent period associated with drought. The species is deciduous where extended intense droughts are annual events, with new leaf production taking place with the onset of the next rainy season. At least towards the southern limits of the distribution, *Oxytenanthera* is tolerant of mild frosts. Clumps usually survive ground fires, although in severe late dry season events young and thin culms may be killed. Nevertheless, annually repeated intense fires adversely affect mature culms and progressively weaken the capacity of the rhizome system to produce new shoots. Short, newly emerged shoots are vulnerable to predation by animals, notably pigs, but such losses are usually minor.

Level of exploitation

On the national scale, there have been reports of major reductions in the resource base, as in the first decades of the 20th Century in Senegal and in the mid-20th Century in Uganda. Throughout the range of the species, easily accessible populations are often heavily exploited for building poles and weaving material. Both young and mature culms are harvested and, locally, young shoots may be decapitated for wine tapping.

Level of rehabilitation

In many rural areas through the range of the species, conveniently located clumps owe their origin to transplanting initiatives, rhizome portions with culms attached being excavated in natural stands and replanted in new sites. Some professional experience with formal bambusiculture has been gained – mainly from experimental initiatives using seed (Congo, Kenya, Malawi) and on a plantation scale in Sudan (also from seed). Stands in Uganda were established from rhizome and shoot units in the 1950s.

Genetic variability

The wide range, and disjunctions within it, suggest there is appreciable genetic variation within the species but this has apparently never been formally investigated through any form of provenance trial. There appears to be an equatorial disjunction within the range and the Ethiopian/Eritrean and Angolan populations appear isolated. Reports of annual flowering cycles in places and, elsewhere, conflicting reports of whether clumps flowering at long intervals are monocarpic (south central Africa) or not (Uganda) could reflect genetic differences. However, ontogenetic and environmental factors might also explain this contrast. Equally, differences recorded in clump and culm characteristics in different localities may have a genetic or an environmental basis, or a combination of the two.

Site

Key site factors are good drainage combined with access to a reliable water supply. *Oxytenanthera* habitats very frequently recorded are areas beside rivers and along drainage lines, termite mounds and rocky slopes. In the latter case gully areas protected from exposure, with pockets of deep soil accumulated between boulders and weathering rock within rooting depth, are a typical microhabitat.

Breeding system and reproductive biology

There has been no specific examination of the pollination process, nor any experimental pollination study in *Oxytenanthera*. Individuals are, however, hermaphrodite and presumably wind-pollinated. The terminal and near-terminal positions of inflorescences on the culms and branches, and the ciliate stigmatic branches, would be consistent with wind pollination. These positions also make them more accessible to flying pollen-collecting insects but it is unlikely that these effect pollination.

Dispersal by water has been suggested, as has dispersal by animals – presumably when contact detaches spikelets that become lodged in the animal's hair. The bird, *Lonchura fringilloides*, a specialised seed predator, may contribute to dispersal if viable seeds are dropped before ingestion.

Seed biology

Seed crops in *Oxytenanthera* have not been estimated but there are around 9000-11 000 seeds, with husks, per kilogram, and around 13 000-16 000 seeds without husks. Unlike most bamboos the seed retains viability from when dispersed until the following, or even the subsequent, rainy season (6-18 months). Prior to use for artificial regeneration, a period of several months storage "to allow it to mature" has been recommended. Germination of good seed in favourable conditions takes around 11 days; under sub-optimal conditions germination may take as long as 4 months.

Nursery technology

Nursery production of seedlings is preferred to direct sowing as the latter may be limited by rodent predation. Seed availability for nursery work varies through the natural range – in Sudan seed appears to be available in most years but in many places there is little or no seed except after infrequent gregarious flowering events. In some instances, very high proportions of inflorescences fail to yield viable seeds. Limited experience suggests low germination success (30% or lower).

In parts of the range where flowering is infrequent, division of rhizomes is a realistic option for establishing new clumps, and this method would also be appropriate if clonal material was desired.

Policy to curb threats

In some countries, concern over exploitation levels has prompted protection measures and the distribution of planting materials. Bamboo reserves have been gazetted in Uganda, and in Nigeria forestry services have actively undertaking direct sowing to rehabilitate degraded areas when seed has been available.

In general, however, *Oxytenanthera* as a resource has not received the conservation attention its economic importance merits. This neglect apparently arises from a combination of complacency (as it is known that local societies take positive actions to create new stands), and the poor state of knowledge typical of wild-collected non-timber resources. Leading conservation organisations concerned with woody plants have only recently extended attention to bamboos while organisations with a more general biodiversity conservation remit have omitted *Oxytenanthera* from "red data" lists because concerns about its status have not been publicised.