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The reproductive biology of Prunus africana (Rosaceae) on Mount Cameroon and its implications for in situ conservation and management

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The reproductive biology of *Prunus africana* (Rosaceae) on Mount Cameroon and its implications for *in situ* conservation and management

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ABSTRACT

Prunus africana (Hook f.) Kalkman, a threatened medicinal tree of the Afromontane forest of Mount Cameroon, was studied with respect to population structure and aspects of the reproductive biology. Populations on Mount Oku and the Tchabal Mbabo areas were also characterised.

There was considerable variation with latitude in the size class distribution. The size class distribution was more "balanced" on Mount Cameroon, the most southerly population considered for the study of the flowering phenology and the pollination biology.

Prunus africana flowers are incompletely dichogamous, displaying an overlapping female – male sequence at anthesis. The longevity of a flower was 6-8 days and flowering within a raceme occurred acropetally.

The flowering and fruiting sequences of individual trees showed that *Prunus africana* flowered and fruited periodically on Mount Cameroon from December to May. Flowering was irregular, with most individual trees not reproductively active and with those, which were producing flowers and fruits in only one of the two years of the study. Flowering synchrony indices of individual trees were high (up to 0.83) and the mean synchrony indices ranged from 0.25 to 0.75.

Estimates of floral productivity per flowering tree ranged from 4402 (dbh = 27 cm) to 730765 (dbh = 82 cm) flowers. Fruit productivity followed the same trend and the estimates ranged from 891 to 80493 fruits per tree. The mean number of flowers per unit of crown shadow - from 100±144 m^{-2} to 2952±646 m^{-2} - and the number of fruit - from 16±11 m^{-2} to 261±76 m^{-2} - per unit of crown shadow increased significantly with the tree size.

Outcrossing was the predominant breeding mechanism, although flowers were self-compatible. The source of pollen had no significant impact on the germination parameters of the resulting seeds. Flowers were visited by a number of insects at anthesis, but only members of the Cerambicydae, Lycidae, Apidae and Megachilidae potentially effected pollination.

Dedication

To my daughter, Yakoue Pouakouyou Rosa Shelley, whose birth four years ago instigated radical decisions in my life that led to this thesis. Grand'-mère, I am dedicating this piece of work to you as a symbol of determination, hard work and trust in God. Might these ideals inspire you when time comes for you to make decisions for yourself.

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CHAPTER ONE:
INTRODUCTION

Cameroon was ranked as the fifth richest country in biological diversity in Africa about 10 years ago (WRI, 1990; Stuart *et al.*, 1991). This richness is attributable to large remaining tracts of relatively undisturbed lowland humid tropical forest, the broad range of ecological habitats produced by marked gradients in elevation and rainfall, and biogeographical affinities with both Western and Central Africa (Alpert, 1993). The extent of this richness was not fully acknowledged by government until 1985 when a joint FAO-UNDP initiative launched the Tropical Forest Action Plan that changed perceptions of forest worldwide. Yet, in Cameroon government reaction to this process was slow and only reinvigorated when World Bank pressure to include forest policy reform in the process of structural adjustment was applied, instigating changes that led to the revision of the forestry policy in Cameroon from 1994.

In a country where the forested area alone covers 19,598,000 ha (FAO, 1997) and where timber has long been considered as the only important forest product – contributing up to 6.7% to the country's GNP in 1995 (Ekoko, 2000) – there were good reasons to pay little attention to single and apparently poorly known bark producing species such as *Prunus africana*, *Pausinystalia johimbe* (Hauman) Kalkm. or other species commonly referred to as non timber product yielding forest species. As a result of the World Bank instigated forestry policy reform, there is a reorientation towards the efficient long term and sustainable utilisation and conservation of all available resources and ecosystems. *Prunus africana* has benefited from this reform and the allocation of a financial package worth Fcfa 821,750,000 (US$1.3 million) under project No 31 of the National Forestry Action Programme of Cameroon (MINEF, 1995) is testimony of this.

Prunus africana is an afromontane forest tree species attaining 30 m height or more (Letouzey, 1978) which, with the possible exception of *Prunus crassifolia* is the only *Prunus* species indigenous to mainland tropical Africa (Letouzey,

1978; Kalkman, 1988; Cunningham *et al.*, 1997). In the West African Afromontane system of White (1978), *Prunus africana* is present on Bioko, in Nigeria and Cameroon. The largest population is present in Cameroon where *Prunus africana* has been recorded in about 24 different sites, most of which fall within the Cameroon Volcanic Line that stretches from Mount Cameroon right in the Gulf of Guinea to Tchabal Mbabo area in the Adamaoua plateau. There is uncertainty about the source locality of a specimen (Mildbraed 9283, 1914 Kew), described as coming from Baboua (5°50' N – 14°40' E) which is far to the east of any other West African population.

Prunus africana is a well-known tree species throughout its natural distribution range. In local communities in Cameroon and elsewhere, the hard and durable wood of *Prunus africana* make it a favourite for domestic purposes and housewives prefer trees of smaller size for grinding pestles (ICRAF, 1994). Smaller trees are also source of axes and hoe handles (Nsom & Dick, 1992; Cunningham & Mbenkum, 1993) and dead wood of larger trees is exploited either for firewood or charcoal production (Sunderland & Nkefor, 1997). The tree bark, leaves and roots are traditionally used either singly or in association with other ingredients to tackle a number of ailments including malaria, chest infections, stomach ache, rheumatism and gonorrhoea (Nsom & Dick, 1992; Sunderland & Nkefor, 1997; Cunningham *et al.*, 1998). *Prunus africana* has been ranked as the fourth most popular medicinal plant species collected by 14% of households in the Mount Cameroon region (Jeanrenaud, 1991). The tree's bark has been used in the treatment of "old man's" diseases for centuries by the local Bakweri people on the slopes of Mount Cameroon (Mbai, 1998).

Prunus africana is a multipurpose forest tree species, which combines the international therapeutic properties of the bark with local uses. The international trade interest in *Prunus africana* bark extract as the basis of drugs for the treatment of benign prostatic hyperplasia and the closely related, but less severe prostate hypertrophy gained momentum in the 1960's. Pharmaceutical products were patented in 1965/1966 following research on materials from Cameroon.

Drugs were subsequently marketed under the trade names of Tadenan, Pygenil, Proscar or Finasteride (Cunningham & Mbenkum, 1993). Prostatic hyperplasia is the most common benign proliferative disorder of unknown etiology found in men (Boudon *et al.*, 1995) and associated with ageing (Weisser & Krieg, 1997). Symptoms include an increase in the frequency of urination, inability to empty the bladder, pain in passing urine and post urinary dribbling (ICRAF, 2001b).

Difficulties associated with the possibility of synthesising the bioactive compound as it is often the case with most pharmaceuticals developed from plants (Barker *et al.*, 1994), have imposed increasing pressure on natural populations of *Prunus africana*. There is no indication of bark collection from planted stands of *Prunus africana* more than 30 years after the discovery of the therapeutic properties and this international trade worth US$220 millions per annum (Cunningham *et al.*, 1997) is currently reliant on natural stocks. This situation has made the conservation of *Prunus africana* a priority.

Commercial exploitation of *Prunus africana* bark started effectively in Western and North-west provinces of Cameroon in 1972 and extended in less than half a decade to the Mount Cameroon region in the South-west province (Ngengwe, 1996; Ndibi & Kay, 1997). Attempts by the Forestry Department to regulate the exploitation of the bark from 1974 failed to ensure the sustainable harvesting of the bark. Early exploitation permits prescribed no technical debarking rules (Ndibi & Kay, 1997) and until very recently quotas offered by the Forestry Department had no scientific back up (Ewusi *et al.*, 1996; Acworth *et al.*, 1998). Nevertheless, the five-year exploitation permits of 1986 and 1992 included provisions allowing Plantecam, an exploitation company to fell 10,000 and 12,000 trees respectively (Asanga, 1993; Ndibi & Kay, 1997). This haphazard policy resulted in resource mining and by 1993 an estimated 80% of mature trees were dead on the Oku massif, a major exploitation locality (Asanga, 1993; Leakey, 1995).

The rapid depletion of the resource and the fear of a genetic erosion prompted the government to take action against illegal exploitation and in 1991, the Cameroon Forestry Department officially acknowledged the escalating destruction of wild populations of *Prunus africana* (see Besong *et al.,* 1991). Similar trends in other parts of the continent were brought to the attention of the international community and the call for action made by Kenya during the 9th CITES conference led to the inclusion of *Prunus africana* in Appendix II with effect from March 1995 (Cunningham *et al.,* 1997). Appendix II species are those not threatened with imminent extinction, but at risk unless trade in them or their product is regulated to avoid utilisation incompatible with their survival. Similarly, in recognition of its economic importance, the FAO Panel on Forest Genetic Resources identified *Prunus africana* as a top priority species for conservation and development (FAO, 1996). It is also on the list of high priority species for ICRAF programme in Humid West and East Africa, following the request by international development and conservation organisations - IPGRI, IUCN, UNESCO and WWF -, farmer's groups and Forestry Departments to initiate on-farm cultivation (Koffi-Tsekpo *et al.,* 1997).

At national level, state institutions, research organisations, pharmaceutical enterprises, conservation agencies, NGOs, farmers' groups and individuals are engaged in research on the species or in *Prunus africana* planting schemes. Efforts to safeguard the natural genepool include *in situ* appraisals of the natural stock nation-wide and the direct involvement of local communities in the bark harvesting process. It is anticipated that the ongoing national inventory of the resource will offer a clearer picture of the natural stock and enable appropriate harvesting quotas to be allocated to bark exploiters. Technical sampling difficulties associated with the occurrence of the trees, either as isolated individuals or aggregated sparse clusters of several individuals, are being addressed and this should resolve discrepancies in inventory returns that have been contradictory.

Cameroon thus enjoys the reputation of taking the lead in demonstrating the potential of the species as an important community resource (Hall *et al.*, in press). The direct involvement of local communities in bark exploitation, pioneered in the Mount Cameroon region, if legally reinforced and extended to other regions, could secure the natural resource genepool. Technical and logistical supports to local farmers would reinvigorate the regeneration process and the participation of 3500 farmers in *Prunus africana* tree planting schemes in the North-west province alone (Cunningham *et al.*, 1997) is evidence of farmers willingness to raise the species on their lands.

Work on the reproductive ecology of *Prunus africana* in West African populations has been scanty and unfocussed despite overwhelming evidence that effective breeding programmes, forest management and genetic conservation require detailed knowledge of the reproductive biology of the species concerned (Tufuor, 1977; Bawa & Krugman, 1991; Boshier & Lamb, 1997). Published information to date on *Prunus africana* in West Africa offers little more than a series of botanical descriptions (Hooker, 1864; Letouzey, 1978-1985; Vivien & Faure, 1985; Achoundong, 1995; Tchouto, 1996; Thomas & Thomas, 1996; Maisels & Forboseh, 1997) while data on flowering and fruiting phenology are restricted to collectors' notes. Herbarium specimen information indicates variations in the timing of the reproductive phenology of *Prunus africana* within its range in West Africa. The duration, intensity, frequency and sequence of events however, remain largely unexplored. For a hermaphrodite species that tends to have a low population density as revealed in several inventory reports (see Ewusi *et al.*, 1992; Tchouto, 1996; ONADEF, 1997; Underwood & Burn, 2000; Belinga, 2001), the level of inbreeding is likely to be high assuming self-pollination and a possible asynchronicity in the flowering process would further enhance this.

The fragmented West African distribution of *Prunus africana* (Figure 2.2) suggests geneflow is geographically restricted for a species in which anemophily is negligible (Hall *et al.*, in press) and the majority of seeds fall and lie beneath

the crown of the source tree (Sunderland & Nkefor, 1997). Such situation might lead to natural populations being genetically distinct throughout the afromontane regions of West Africa. Some indications of such a trend have been revealed by recent molecular characterisation of *Prunus africana* samples from Cameroon (see Barker *et al.*, 1994; Dawson & Powell, 1999). The management of the national genepool will require that areas are defined and given individual attention. In particular, for each population characterisation of stand structures with respect to age, and the spatial distribution of reproductively mature individuals, will be important.

Successful inclusion of *Prunus africana* in rural farming systems will demand wider and better understanding of its reproductive process. With regard to this, two constraints currently hamper progress with local farmer's initiatives.

The first constraint is the lack of seeds to support the husbandry of the tree as an economic resource. Uncertain fruiting intensities and frequencies imply shortages of seeds of high quality in some years. This problem is compounded by the recalcitrant nature of the seeds and their inability to retain viability for more than a year in storage. In a situation where seeds are sold in certain parts of Cameroon (Cunningham *et al.*, 1998), information on fruiting phenology is of primary importance. Such data as are available have been reviewed and summarised at the regional scale in this study.

The second constraint is that the success of tree planting schemes is disadvantaged by the poor and genetically unknown quality of planting materials collected from the wild. The low growth rates that are subsequently observed arise in part from ignorance of biological characteristics and ecological requirements, leading to inappropriate management actions. Disenchantment of farmers with domestication schemes threatens their success. Selecting improved materials for domestication will undoubtedly reinforce production systems and raise confidence in *ex situ* conservation strategies. This investigation is to contribute information relevant for such initiatives.

The present investigation sets one ecological objective and four objectives concerned with knowledge of the species reproductive biology:

1. Ecological
- to characterise the structure of *Prunus africana* populations in Cameroon;
2. Reproductive biology
- to investigate inflorescence characteristics and floral ontogeny;
- to investigate flowering and fruiting phenology within a *Prunus africana* population;
- to evaluate reproductive potential in terms of flower and fruit productivity of individual trees;
- to investigate the breeding mechanisms of *Prunus africana*, identify potential pollinators and evaluate the impact of each reproductive mode on seed germination.

CHAPTER TWO:
PRUNUS AFRICANA IN WEST AFRICA WITH EMPHASIS ON CAMEROON: A REVIEW OF THE STATE OF KNOWLEDGE

This chapter organises the existing knowledge on *Prunus africana* in West Africa into four sections. Section 2.1 offers a brief account of the taxonomic characteristics, drawing on materials from Cameroon and elsewhere. Section 2.2 addresses the ecology of the species at the regional level. Biological information on the species is presented under section 2.3 with as much emphasis on the Cameroon situation as possible. The fourth section (2.4) deals with conservation and management efforts within the existing legal framework in Cameroon. This section interprets and explains the current status and summarises the measures management is considering to improve resource sustainability. Sections are subdivided as appropriate.

2.1 Taxonomic characteristics

2.1.1 Systematic position

Current views on the systematic position of the Rosaceae place this family in the order Rosales, together with the monophyletic complex of Rhamnaceae, Ulmaceae, Celtidaceae, Urticaeae and Moraceae (Morgan *et al.*, 1994; Judd *et al.*, 1999). The family is diverse and cosmopolitan, comprising more than 3000 herbaceous and woody species in *ca.* 100 genera and apparently originated in West Gondwana (South America and Africa) migrating northwards along three routes (Kalkman, 1988), although other authors have favoured a Laurasian origin.

The phylogenetic analysis of the Rosaceae has generated much debate, as this family poses a number of systematic and evolutionary questions. The current state of knowledge indicates that the major traits used for defining groups of genera in Rosaceae are chromosome numbers and fruit types, but Morgan *et al.* (1994) argue that these two characters often conflict in the relationships they support, and give unclear relative predictive values. With traditional systematic approaches, and using

fruit type as the primary criterion, the family has been divided into four major subfamilies: Spiraeoideae, Rosoideae, Maloideae and Amygdaloideae. In a recent review, Judd *et al.* (1999) briefly discuss these groups on the basis of the study of Morgan *et al.* (1994). With minor expansion to include some additional genera, the recent work supports the Rosoideae, Maloideae and Amygdaloideae as major groupings within the family, but the Spiraeoideae is interpreted as polyphyletic and not of comparable status. Table 2.1 offers a key to the major subfamilies of Rosaceae.

Table 2.1: Key to major groups of Rosaceae

Descriptive features	Major subfamilies
Woody plants with simple leaves; flowers usually with a single carpel (but rarely as many as 5); fruit is a drupe (rarely a capsule); X = 8; sorbitol, cyanogenic glycosides, and flavones present; ellagic acid absent	Amygdaloideae
Woody plants; leaves simple, rarely pinnate; flowers with 2-5 carpels ± connate, and/or adnate to hypanthium; fruit is a pome (infrequently a capsule or follicle); X = 17 (infrequently 15 or 16); sorbitol, cyanogenic glycosides, and flavones present; ellagic acid absent.	Maloideae
Woody or herbaceous plants; leaves simple, pinnate or palmate, or trifoliate; flowers rarely unisexual; carpels usually numerous; fruit is a drupe or achene; X = 7 or rarely 8; sorbitol, cyanogenic glycosides, and flavones absent; ellargic acid present	Rosoideae
Unarmed shrubs, erect, scandent or creeping; leaves simple, lobed and dentated or not; stipule present or not; flowers in terminal or axillary racemes, panicles, umbels, corymbs, 5-numerous, bixesual; fruit is a dry follicle, dehiscent, sometimes protruding from the enlarged hypanthium; X = 9; sorbitol, cyanogenic glycosides, and flavones present; ellagic acid absent	Spiraeoideae

Sources: Hutchinson & Daziel, 1958; Mendes, 1978; Kalkman, 1993; Morgan *et al.*, 1994; Judd *et al.*, 1999; X= chromosome base number.

Despite the considerable diversity in anatomy, vegetative features, and fruit morphology, the family Rosaceae has long been considered monophyletic and Morgan *et al.* (1994), reporting *rbcL* sequences, strongly support this view. Floral similarities – with a well-developed hypanthium and a probably axial outgrowth from the top of the pedicel surrounding the pistils (Kalkman, 1988, 1993) - are apparently the only unifying factors in this family although diversity in vegetative and fruit characteristics is increasingly subjected to attention.

While the Maloideae and Prunoideae are two end-branches on the phylogenetic tree with distinct and natural (halophyletic) taxa (Kalkman, 1988, 1993), the Spiraeoideae and Rosoideae exhibit degrees of similarity and heterogeneity. According to Kalkman's (1993) work on the Malaysian Rosaceae, the likeness of the flowers of some Spiraeoideae and those of some Maloideae - notably *Cotoneaster* and *Pyracantha* - supports enlargement of the subfamily Maloideae with at least part of the Spiraeoideae. Similarly, the level of heterogeneity displayed by members of the Rosoideae suggests supports with other Spiraeoid genera to form another holophyletic branch in which some subdivision may be possible.

Division within the Amygdaloideae is subject to debates, but members of this subfamily are apparently distinct from groupings. The Amygdaloideae subfamily consists of four genera: *Prunus* L., *Prinsepia* Royle, *Exochorda* Lindl. and *Oemleria* Rchb. (Morgan *et al.*, 1994). Evans & Dickinson (1999) recently confirmed this view in a phylogenetic analysis of the group using a combination of scanning electron micrographs and section materials. Members of this subfamily in the strictest sense are simple-leaved trees and shrubs that produce single-seeded drupaceous fruits from a perigynous ovary (Evans & Dickinson, 1999). A key to the four genera within the Amygdaloideae is provided (Table 2.2), using information from floras. Phytochemical characteristics are also indicated.

Table 2.2: Key to the four genera in the Amygdaloideae

Descriptions	Genera
Woody plants with simple leaves, alternate; white flowers borne in terminal racemes; hypanthium enlarged; 5 sepals and 5 petals; 15-30 stamens; two ovules per carpel; fruit is a five carpellate capsule; X = 8; cyanogenic glycosides present in leaves; unidentified cynogenic glycoside (not prunasin) present in twigs	*Exochorda* Lindl.
Woody plants with simple leaves, entire; flowers racemose; 5 free carpels; ovule is epitropic; fruit is a cluster of 1-5 drupes; X = 8; cyanogenic glycosides present in leaves; unidentified cynogenic glycoside (not prunasin) present in twigs	*Oemleria* Rchb.
Woody plants with simple leaves, alternate, often clustered; flowers racemose or 1 to 4; hypanthium enlarged; 5 petals; one carpel per flower; ovule is pleurotropic; ovary is fused; fruit is an indehiscent drupe; X = 8; cyanogenic glycosides present in leaves; unidentified cynogenic glycoside (not prunasin) present in twigs	*Prinsepia* Royle
Woody plants with simple leaves, alternate, nerves pinnate, margin incised or entire, glands present in the margin and/or on the underside or on the petiole; 5-numerous solitary flowers usually bisexual and borne in groups or on a raceme; sepals and petals 5; hypanthium enlarged; stamens numerous and perigynous; one carpel per flower; epitropic ovule; ovary is fused; fruit is an indehiscent drupe, usually 1-seeded; X = 8; amygdalin present in seeds of many species; prunasin present in the vegetative parts; phenolic, acidic and tannin constituents also present	*Prunus* L.

Sources: Synge, 1977; Letouzey, 1978; Kalkman, 1988; Kalkman, 1965 - 1988 - 1993; Morgan *et al.*, 1994; Stace, 1997; Evans & Dickinson, 1999; X = chromosome base number.

2.1.2 Phylogenetic history of the genus *Prunus*

Prunus is the major genus in the Amygdaloideae and comprises at least 200 species of trees or shrubs rarely with thorns (Synge, 1977; Kalkman, 1993; Evans & Dickinson, 1999; Judd *et al.*, 1999). The genus was long treated differently from *Pygeum*, although both genera were considered closely related. However, Kalkman's (1965) revision sank *Pygeum* into *Prunus* assigning what had been species of *Pygeum* to section Laurocerasus (about 14 species in tropical Africa and tropical Asia, and adjoining subtropical to cool-temperate regions - Kalkman, 1993). Kalkman (1993)

recognises five distinct subgenera within the genus *Prunus*: *Amygdalus*, *Cerasus*, *Padus*, *Laurocerasus* and *Prunus*.

2.1.3 Description of *Prunus africana*

Material from Cameroon is described in detail by Letouzey (1978) and a recent review of published information by Hall *et al.* (in press) suggests little morphological variation in *Prunus africana* through the distribution range in Africa and Madagascar. Unless *Prunus crassifolia* is recognised as a different species, *Prunus africana* is the only *Prunus* species indigenous to tropical Africa and Madagascar (Letouzey, 1978; Kalkman, 1988; Cunningham *et al.*, 1997).

2.1.3.1 Seedling

The descriptive features of *Prunus africana* seedlings (Fraser *et al.*, 1996) indicate that the young parts are often tinged red. The leaves are simple, ovate/broadly elliptic, 2-7 cm long, with pinnate venation. Initially they are opposite, but leaves expanding later are in a spiral phyllotaxy. The leaf margin is serrate with small, forward-facing teeth. The young leaves are apparently scentless, but a slightly scratched stem exhales a strong and bitter smell that becomes stronger with deeper scratches. The stipules are paired, triangular, more or less apiculate and 1.0 – 1.5 cm long.

2.1.3.2 Mature tree

Prunus africana is a large evergreen Afromontane tree species attaining 30 m or more in height (Letouzey, 1978), but sometimes a large shrub. The plants are entirely glabrous, except for the flowers (Kalkman, 1965). In the forest, the crown is open with pendulous branches, but in grassland the crown is more rounded and compact (Bekele-Tesemma *et al.*, 1993; Mbuya *et al.*, 1994).

Younger trees have fairly smooth bark, but older trees develop bark with a characteristically blocky texture noticeable even when bark is collected in commercial bundles (Cunningham *et al.*, 1997). On mature trees, the bark is rough and dark in colour, scaling irregularly. The branches are corky, the branchlets being dotted with lenticels (Bekele-Tesemma *et al.*, 1993). Smell produced when stem is scratched is bitter, and stronger with deeper scratches. It has been described as like that of bitter

almonds or cyanide due to the presence of hydrocyanic acid or prussic acid (Fraser *et al.*, 1996). The rough, blocky outer bark is sometimes almost black in colour.

The leaves are simple, coriaceous, elliptic-oblong, 3-6 x 6-15 cm long and acute or shortly subacute or obtusely acuminate. The base is rounded or broadly cuneate and the margins are crenate-serrate or subentire. The texture is thinly coriaceous (Letouzey, 1978). The margins are finely to coarsely crenate, dark glandular-pointed in the incisions. There are 9-12 (-15) pairs of nerves (Kalkman, 1965). Crushed leaves have the same bitter almond smell as the cut stem (Bekene-Tesemma *et al.*, 1993; Mbuya *et al.*, 1994).

Prunus africana produces flowers in simple solitary or fascicled racemes, 10 cm long or shorter, very close to each other and emerging from the lower scale-axils of shoots, which produce normal leaves more distally. The number is variable but generally there are ten to twenty bisexual flowers per raceme, carried by the pedicels subtended from secondary bracts (Kalkman, 1965; Letouzey, 1978). The flowers are small, fragrant, greenish-white or yellowish. There are 24-35 stamens in each flower, with glabrous filaments up to 1.5 (2.5) mm long, supporting anthers 0.5-1 mm long. The ovary is sparsely long-hairy, the hypanthium being 1.25-2 mm long, glabrous outside and hairy inside, especially in the lower half. The perianth is usually regularly 5-merous and biseriate (rarely 4- or 6-merous or irregular). The sepals are 1-1.5 mm long and greenish in colour, forming a turbinate-campanulate calyx, with 5 short deltoid teeth. The petals are small (1-2 cm long), white in colour, and ovate in shape. The stipules are 2-2.5 by 0.3-0.4 mm. The style is up to 1.5 mm long and sparsely hairy (Kalkman, 1965; Letouzey, 1978; Bekele-Tesemma *et al*, 1993; Mbuya *et al.*, 1994).

Morphological descriptions of the flower at anthesis (Munjuga *et al.*, 2001), indicate that anthers of *Prunus africana* are cream in colour and form three circular rows attached to the corolla tube. The stigma is raised above the anthers and notched on one side. It is yellow in colour.

The mature fruit is a purple drupe, depressed-globose or transversely ellipsoid in shape, and 5-8 x 10-12 mm long; glabrous or with some persisting hairs. The seedcoat is glabrous or with a few hairs (Kalkman, 1965; Letouzey, 1978).

2.2 ECOLOGY

2.2.1 Geographical distribution

Despite the increasing interest in *Prunus africana* as an economic resource, the distribution map offering a nation-wide picture of the species was not made available until 1985 when Vivien & Faure (1985) produced a list of the major forest timber species of the moist Central African forest including *Prunus africana*. This map originally prepared by R. Letouzey within the framework of a FAO/UNEP project 1108-75-05 (FAO, 1984), covers Cameroon south of 7° N only and shows just four areas of occurrence. Individual localities are not indicated. Achoundong (1995) later reproduced this map. Collector's notes and information from the literature indicate that *Prunus africana* is not a rare species in Cameroon and has been reported from numerous localities in the Afromontane region. A recent collaborative project between the Limbe Botanic Garden/Mount Cameroon Project and the Centre for the Environment and Rural Transformation, Limbe (LBG/MCP – CERUT, 2001) indicates the presence of *Prunus africana* in over seventy localities in six out of 10 provinces in Cameroon (Table 2.3).

Table 2.3: Localities of occurrence of *Prunus africana* in Cameroon (LBG & CERUT, 2001)

Province	Divisions	Localities
South-West	Fako	Mt Cameroon
	Meme	Mt Cameroon
	Kupe Muanengouba	Mt Kupe, Mt Muanangaouba
	Lebialem	Mt Bamboutos (Bamumbu, Fossimondi, Finaua m'mouck), Wabane
	Manyu	Akwaya (Amassi, Mbassa, Tchinatchom)
North-West	Bui	Nbiame, Kumbo, Jakiri, Oku, Kom, Kilum Ijim massif, Nvem, Vekovi
	Boyo	Fundong, Njinikom, Belo, Ngeni Kigem
	Ngoketunjia	Sabga
	Momo	Njikwa Achatugi, Menka, Oshey, Gouzang, Ngui
	Mezam	Bafouchu, Medankwe, Santa, Awing, Njong Kidjiogam, Mbot, Adon
	Menchum	Abizenaku, Abor, Adou
	Donga Mantung	Furawa, Akweto, Tabenkem
Western	Menoua	Santchou, Gwata
	Noun	Malantouen, Bangourain, Nkoutoutpit, Mbam massif
	Bamboutos	Mt Bamboutos: Babadjou…
	Haut Kam	Mt Bana, Bafang…
	Nde	Banganté (Balembo, Bangaloup, Bassamba)
	Haut Plateau	Baham, Bapa, Badenkop
Littoral	Moungo	Mt Muanengouba and Kupe, Barouka area, Mt Lonako (village Barondo)
Central	Mbam et Kim	Mt Ngora, Mt Yangba, Mt Golep
	Mefou et Akono	Mt Eloumdem
Adamaoua	Mayo-Banyo	Tchabal Mbabo (Gandwa, Niamsounre, Sambo Labo, Mayokelélé..)
	Faro et Deo	Galim Tignere

The LBG/MCP – CERUT (2001) report extends the list of sites of occurrence to localities not known to host *Prunus africana* prior to the compilation of two accounts produced by Ndam & Nkuinkeu (1999) and Ndam *et al.* (2000). It is however not clear whether this list represents only areas of natural occurrence of *Prunus africana* or also includes localities where domestication is taking place or is intended to take place, in Cameroon. None of the three reports provides indications on the source of data used in compiling the list. Nevertheless, the distribution range through Cameroon stretches from Mount Cameroon in the Gulf of Guinea to the Bamenda highlands and

further north to Tchabal Mbabo and Tchabal Ouadde (Letouzey, 1978, 1985; Vivien & Faure, 1985; Achoundong, 1995). A significant proportion of this areas lies at the junction of the West African and Congo continental plates where tectonic stresses and instabilities have resulted in a line of volcanoes, of which Mount Cameroon is the largest (ERM, 1998).

In the wider context of the whole West African Mountain System of White (1978), note should be taken also of occurrences in Nigeria, Equatorial Guinea (Bioko) and São Tomé. *Prunus africana* herbarium specimens have been collected from four localities within Nigeria, all close to the border with Cameroon. The most northern limit of the distribution range in West Africa is apparently among these, at latitude 8°44' N in Gangoro Forest Reserve. There are occurrences on two of the volcanic islands (part of the line along the Congo/West African plate junction) in the Gulf of Guinea. Some 60 km south from Mount Cameroon is the nearest of the populations of *Prunus africana* in Equatorial Guinea, Bioko. Sunderland & Tako (1999) mention eight sites on this island. The only record seen of the species on São Tomé is a flowering specimen (Monod 11977) from Pico Pequeno (0°15' N; 6°35'E). East of Cameroon is the Baboua region within German administered "Kamerun" prior to World War I. A specimen (Mildbraed 9283) may have originated from this area, but there is doubt about the precise source locality. Mildbraed undertook long itineraries in Cameroon and the Cameroon/Central African Republic border area between 1895 and 1915 (Letouzey, 1968). His collection could have been made as far west as Mount Nganba (7°22' N, 14°01' E), only 50 km east of Ngaoundere and much nearer several known *Prunus africana* localities. Figure 2.1 depicts the distribution of *Prunus africana* in West Africa. Voucher specimen data and literature information have been used to generate this map, part of a full range map compiled in a recent project (Hall *et al.*, in press).

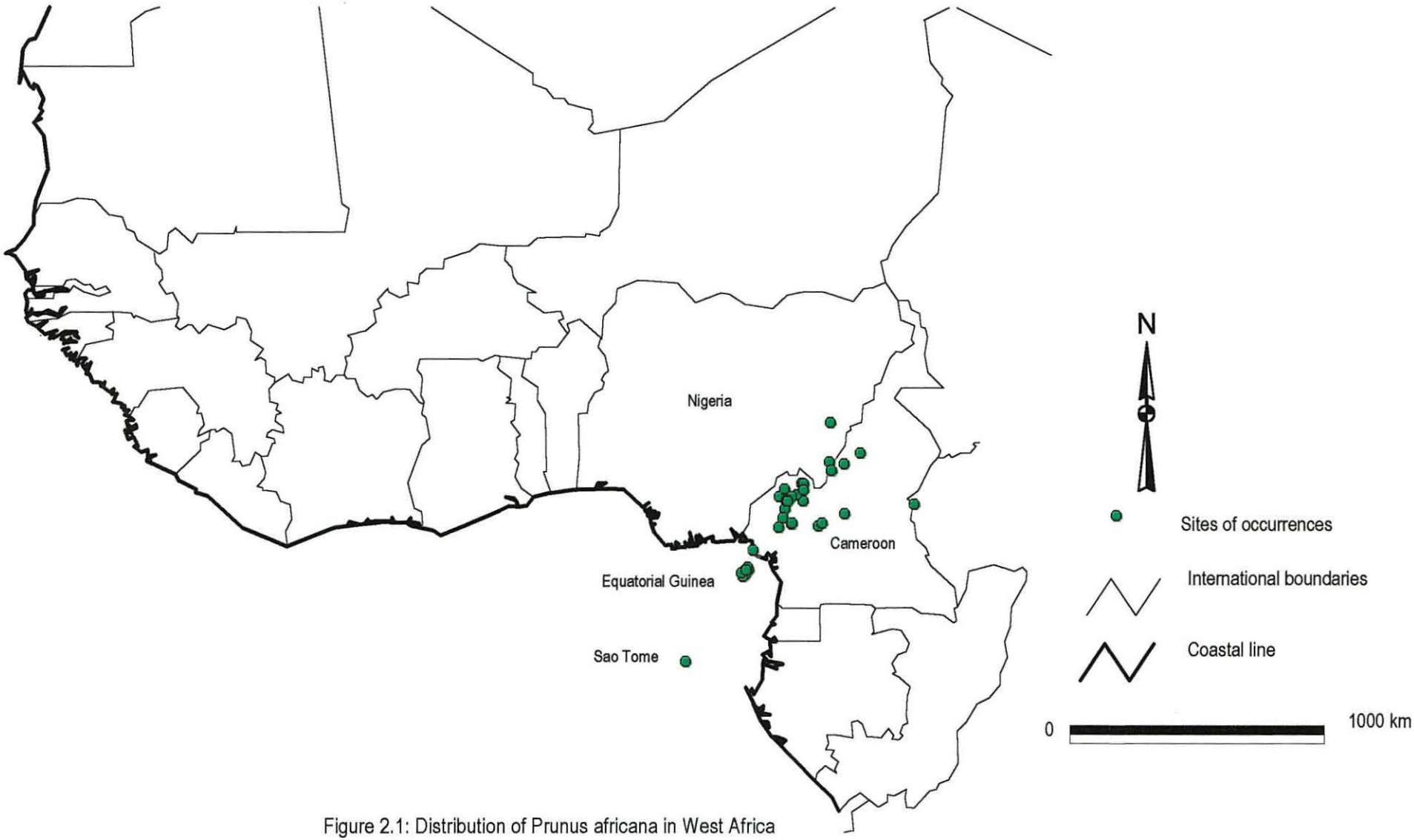

Figure 2.1: Distribution of Prunus africana in West Africa

2.2.2 Environmental factors in distribution

2.2.2.1 Topography

Areas of high terrain are few in West Africa and most land lies below 850 m elevation (Figure 2.2). The few peaks rising higher are generally distantly separated. Mount Cameroon is the highest mountain in this region and culminates at 4070 m. Although it is established that elevation *per se* is not a limiting factor in the distribution of *Prunus africana* (Hall *et al.*, in press), the species shows some altitudinal preference in the Cameroon Mountain system of West Africa where it occurs. From the Baboua region in the east to the most westerly region of Pico Pequeno in São Tomé, *Prunus africana* occurs in the altitudinal range 750 - 3000 m. It is widely reported in Cameroon in Afromontane regions above 1500 m, but extends down to 1000 m (Achoundong, 1995).

Information on elevations from which *Prunus africana* has been reported in West Africa is tabulated by locality (Appendix 2.1). Six other localities with geographical co-ordinates and specimen identity are omitted, owing to the lack of information on the elevation.

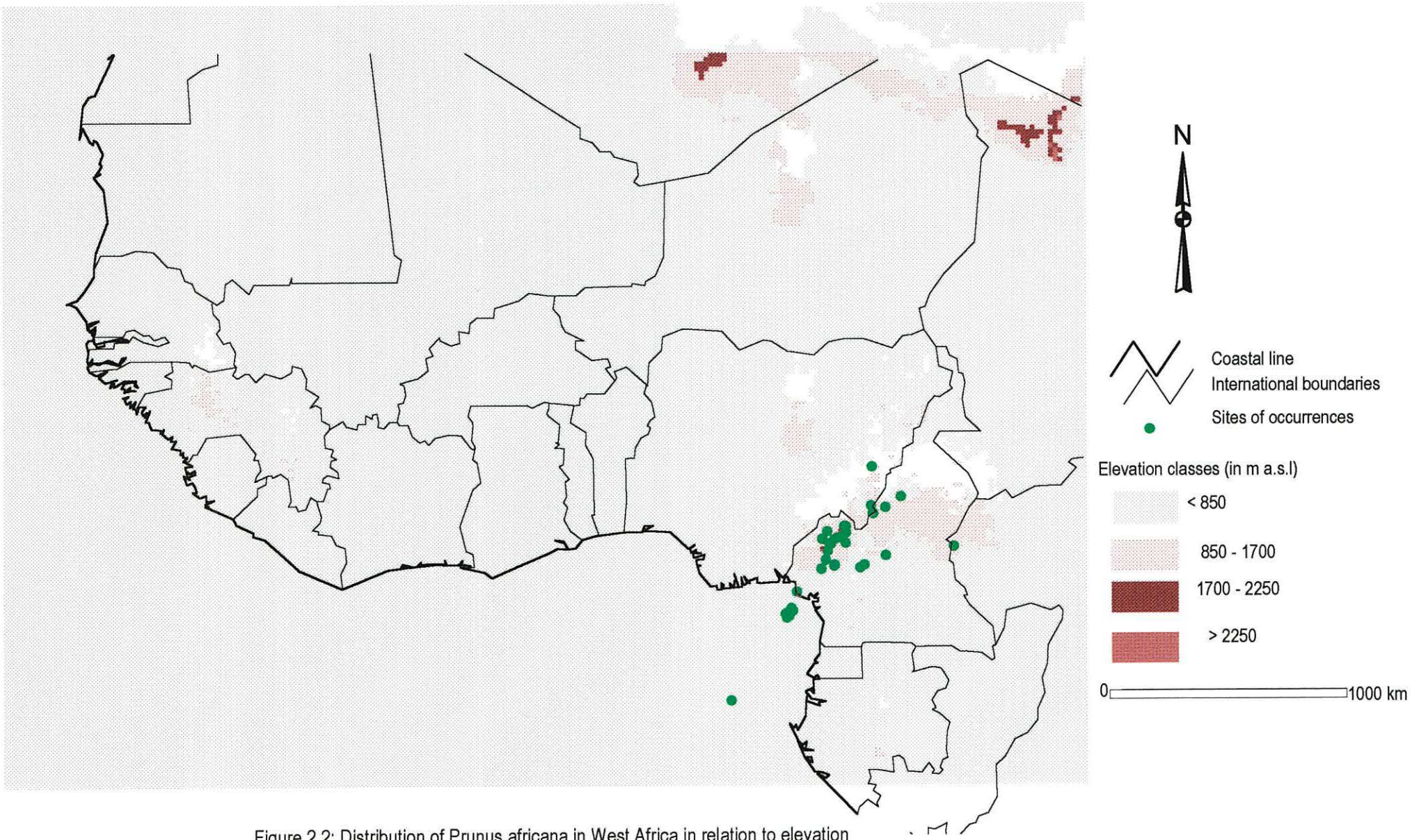

Figure 2.2: Distribution of Prunus africana in West Africa in relation to elevation

Elevation classes on Mount Cameroon (> 2250 m) and Bamenda highlands (1700-2250 m) are shadowed by the distribution dots in green

2.2.2.2 Geology and soils

There is a general paucity of knowledge directly relating geological formations and soil types to *Prunus africana* occurrences on West Africa Mountains. There is nevertheless, incontestable evidence associating the natural distribution with areas subjected to stresses and instabilities over several millennia. From the Gulf of Guinea to the most northerly occurrence zone, there is a succession of major tectonic fractures aligned in an ENE-ESW direction, covered for most of its length by volcanic rocks, forming the continental sector of the Cameroon Volcanic Line (Ubangoh *et al.*, 1998). This is a 1600 km long Y-shaped chain of tertiary to recent, generally alkaline, volcanoes that extends more than 900 km through Cameroon from the Adamaoua plateau to the Mount Cameroon region in the south and beyond, to the Gulf of Guinea Islands.

In the broad sense, andosols, leptosols, ferralsols, acrisols, alisols and plinthosols are the major soil categories indicated for the area on the FAO-UNESCO soil map of the world (FAO, 1977). Soil types range on Mount Cameroon from andosols on sloping ground formed of derived basaltic lava and associated igneous rocks to various subdivisions of fluvisols, cambisols and patches of leptosols overlying sedimentary rocks in small areas that have escaped lava on Mount Cameroon (ERM, 1998). On the Bamenda highlands and on sections of the Bamboutos Mountains, Ngala (1988) and Maisels & Forboseh (1997) describe the soils as humic ferrasols, characterised by high organic matter content and high permeability. These soils are finely structured loams, and silty clay loams containing 45-70% clay. On the Tchabal Mbabo plateau, infertile ferrasols are present at mid-elevations, while at higher elevations on the mountain, the soils are immature, and often dark because of the accumulation of organic matter, or are thin, dry, rocky leptosols (Thomas & Thomas, 1996; Belinga, 2001).

2.2.2.3 Climate

The refinement of meteorological information (Legates & Willmott, 1992) and relating them to the distribution data provide insights into the rainfall and temperatures associated with *Prunus africana* distribution in West Africa.

The natural distribution of *Prunus africana* in West Africa coincides with areas that generally experience mean annual rainfall in the range of 1000 mm to 3000 mm (Figure 2.3). There are two prominent situations with respect to the amount of rainfall. One is the area bounded by latitudes 3°16' N and 6°34' N and longitudes 8°34 E and 10°45' E. Almost 66% of the *Prunus africana* occurrence sites are in this area, which extends from Bioko, Equatorial Guinea to the Bamenda highlands, Cameroon. Mean annual rainfall is depicted as 2000-3000 mm. In fact, there is a major exception in the extremely wet locality of Debundscha on Mount Cameroon (mean annual rainfall 9086 mm - Fraser *et al.*, 1998), which is too localised to be revealed in the "Legates & Willmoot" Africa GIS data, but which supports Morton's (1986) view on the influence of mountains on rainfall in West Africa. The collection site of Theodore Monod's specimen from Pico Pequeno, São Tome is at the southern limit of this area which is also wetter in reality than shown, receiving 3000-4000 mm of mean annual rainfall. The second area is bounded by latitudes 5°04' N and 8°44' N and longitudes 11°17' E and 12°45' E. This area is much drier and is mapped as receiving mean annual rainfall in the range 1000 – 2000 mm. It contains the remaining sites in Cameroon, the Nigeria populations, and the Baboua population at 5°50' N, 14°40' E.

The mean monthly temperature associated with *Prunus africana* distribution in Africa from the equator to 9° N is within the range 11-25°C (Hall *et al.*, in press). Almost all the occurrence sites of *Prunus africana* in West Africa fall within this range. The difference in average temperature of the warmest and the coldest month is generally small - only between 4°C and 6°C. The average temperature of the warmest months is in the range of 16 – 24 °C (Figure 2.4), except in Gangoro Forest Reserve, Nigeria and Pico Pequeno, São Tome, where it is hotter and reaches 24-32°C. A similar pattern emerges with respect to the average temperature of the coldest months. The bulk of the occurrence sites are in areas where this is within the range 10 – 20°C, except in Gangoro Forest Reserve and Pico Pequeno where it exceeds 20°C (Figure 2.5). These temperatures are certainly much lower at altitudes at which *Prunus africana* occurs. It is generally believed that for each 100 m ascent, there is a drop by approximately 0.6°C (Morton, 1986). The average temperature of the coldest month is less than 10°C on Mount Cameroon and Mount Oku.

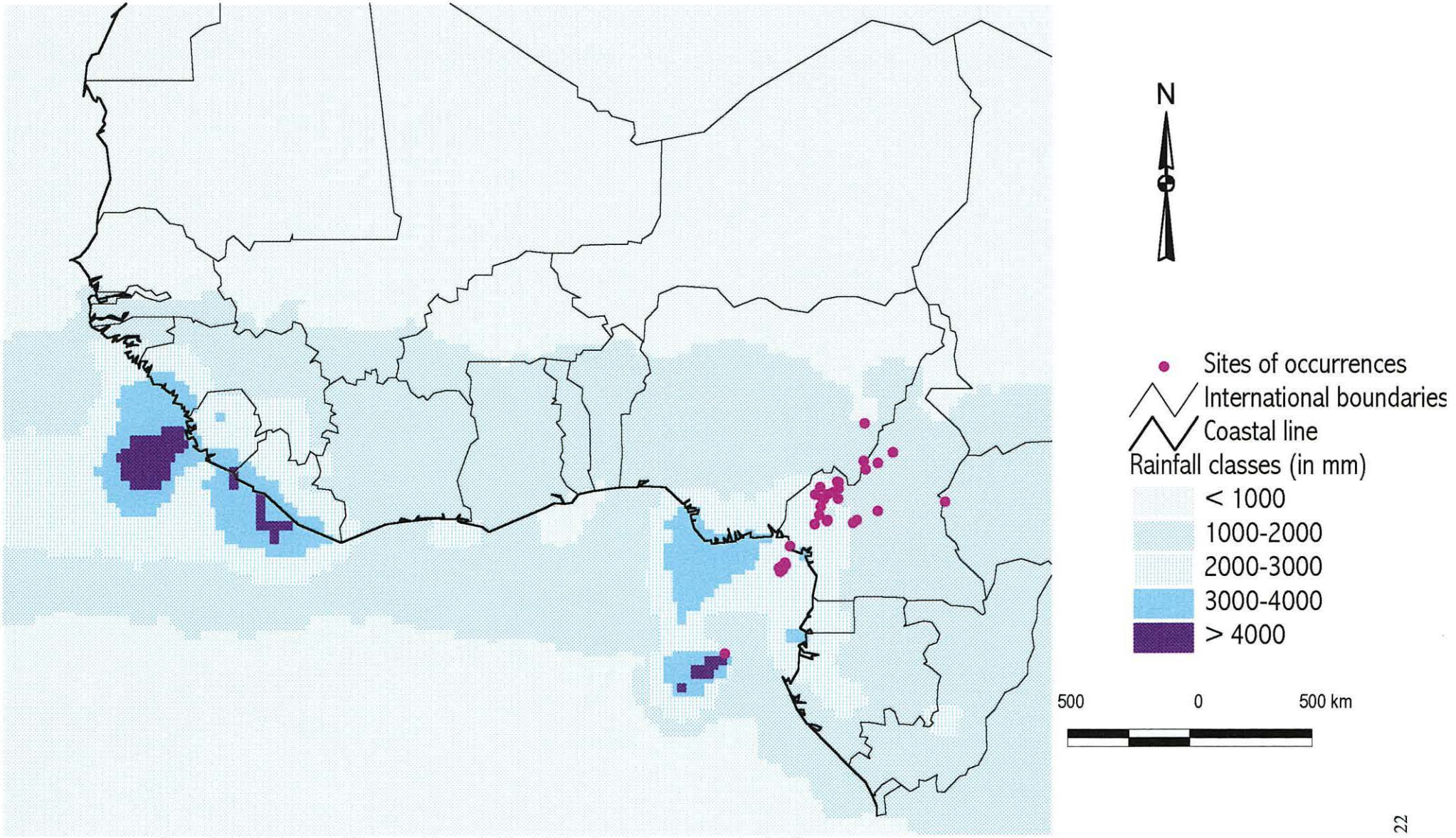

Figure 2.3: Distribution of Prunus africana in West Africa in relation to annual rainfall

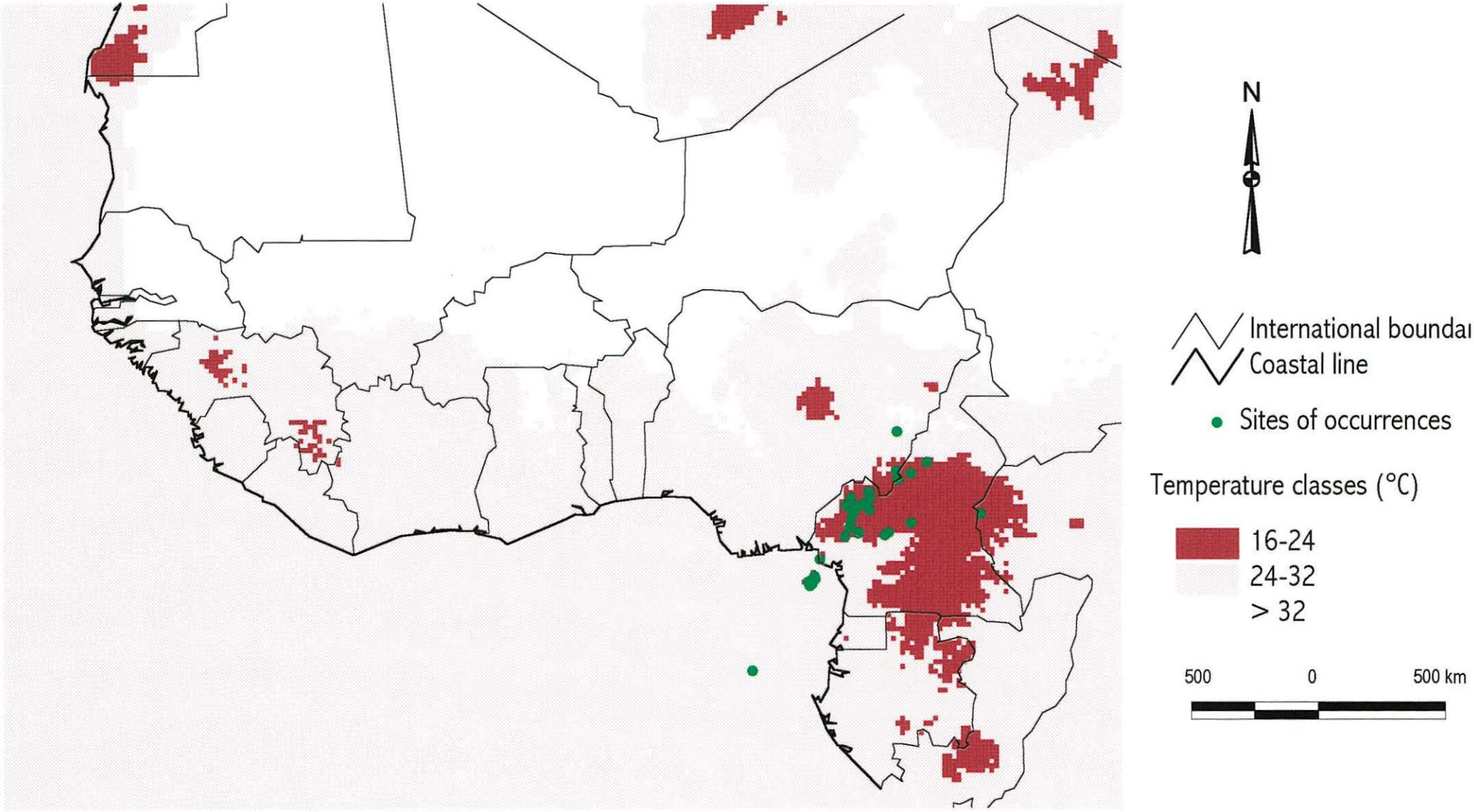

Figure 2.4: Distribution of Prunus africana in West Africa in relation to the average temperature of the warmest months

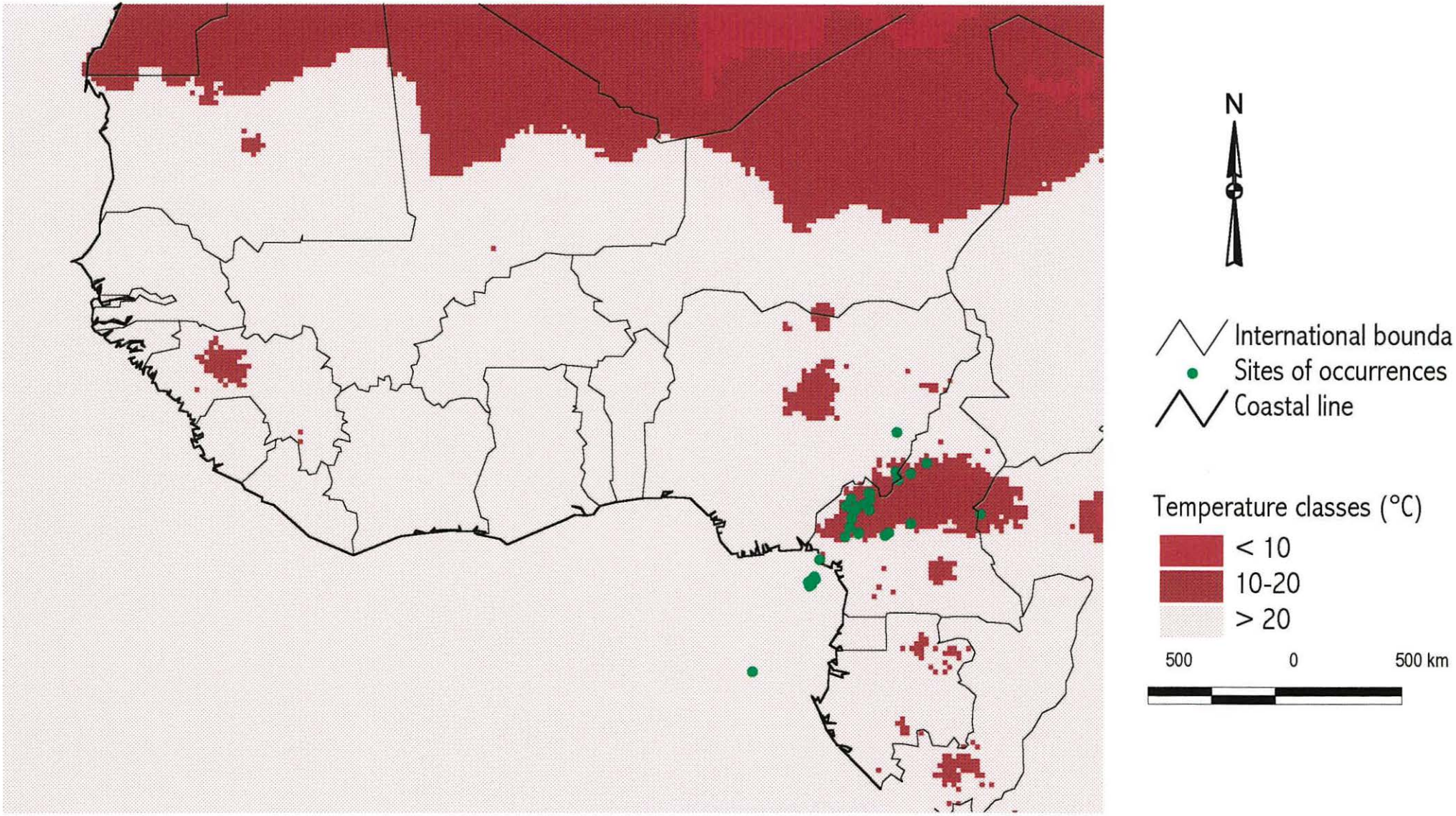

Figure 2.5: Distribution of Prunus africana in West Africa in relation to the average temperature of the coldest months

Note: Cooler temperatures are experienced on Mount Cameroon and Mount Oku (< 10°C). This trend is shadowed on the map by the green dots

2.2.3 *Prunus africana* as a vegetation component

2.2.3.1 Chorology

Hall *et al.* (in press) note that *Prunus africana* belongs to a group of approximately 20 tree species typifying White's (1983) Afromontane Centre of Endemism at the continental scale. Members of this group are reported in all seven of White's regional Afromontane systems and are only exceptionally found in other phytochoria. In West Africa, *Prunus africana* has been indicated below 1200 m altitude in lowland phytochoria in several situations in Cameroon and Bioko, but occurs mainly in Afromontane vegetation. *Prunus africana* possesses no relative in African tropical lowland forest, but there are other species of *Prunus* in the North Temperate zone, a situation that prompted Chapman & White (1970) to refer *Prunus africana* to the category of "eu-Afromontane" genetical elements.

2.2.3.2 Vegetation types

In the broad sense, the distribution of *Prunus africana* in West Africa corresponds to the West African Mountain system of White (1978) and the Cameroon Mountains System of Morton (1972, 1986). The vegetation occurring on the Cameroon Mountain System forms an archipelago floristically allied to the mountain archipelagos of East Africa, all of which are in the Afromontane regional centre of endemism of White (1983). White (1983) indicates the presence of Afromontane forest and Afromontane bamboo in the Cameroon Mountain System. Within the Afromontane forest category, Afromontane rain forest and undifferentiated Afromontane forest are present in this part of the continent (Table 2.4). White, however, mentions very superficially the presence of a further category, the Guineo-Congolian Afromontane transitional forest in the Guinean subsystem. Single-dominant Afromontane forest and the dry transitional montane forest are not reported from West Africa.

While Afromontane rain forests are present within the altitudinal range 1200–2500 m and receive an annual rainfall in the range 1250–2500 mm, conditions associated with White's (1983), "undifferentiated" Afromontane forests are less narrowly defined. White (1983) notes, nevertheless, a tendency for undifferentiated Afromontane forest

to replace Afromontane rain forest at higher altitudes on wetter slopes and to occur at comparable altitudes on drier slopes or below areas of Afromontane rainforest.

Prunus africana has been reported in three different situations in Cameroon. The first and most prominent one is indicated in the montane forest of Letouzey (1985) – 1800-2000 m to 2460 m on Tchabal Mbabo; 1800-2200 m to 2800-3200 m on Mount Cameroon - where together with associated species of both drier and wetter affinities, *Prunus africana* is a member of a well-developed montane forest. Fifteen of the twenty-four sites (63%) where *Prunus africana* has been indicated are found in this category, qualifying *Prunus africana* as a "very good mountain biotope indicator" (Achoundong, 1995). The second situation is in Afro-subalpine shrubland above 2800 m altitude, which Letouzey (1985) compares to high altitude scenarios of East and Southern Africa, or temperate regions. This situation appears to be exclusive to Mount Oku, Bamenda, where at high altitude (i.e > 2800 m), in addition to past volcanic activities, the vegetation is shaped by grazing and frequent fires. *Prunus africana* has been found in this situation, together with such associates as *Podocarpus latifolius, Nuxia congesta, Rapanea melanophloeos,* and *Syzygium staudtii*. The third condition is also indicated on Mount Oku, where at 2530 – 2830 m altitude, *Prunus africana* is scattered in Afromontane bamboo (*Sinarundinaria alpina*) communities, together with *Podocarpus latifolius, Maesa lanceolata* and *Rapanea melanophloeos* (Maisels & Forbeseh, 1997). On Mount Cameroon *Sinarundinaria alpina* is absent (White, 1983; Cable & Cheek, 1998). Both *Prunus africana* and *Sinarundinaria alpina* have been reported on Mount Bamboutos and Mount Mba Kokeka (Letouzey, 1968; Ngala, 1988), but not in the context of extensive bamboo stands.

Table 2.4: Provisional vegetation categories and vegetation types occurring on the Cameroon Mountain system of Morton (1986)

Highlands	Afromontane vegetation categories	Afromontane vegetation types	Surrounding lowland vegetation
Adamaoua	- Afromontane rain forest - Afromontane mixed with Afro-alpine grassland	- Afromontane rain forest - Undifferentiated Afromontane forest	Sudanian woodland with abundant *Isoberlinia*. Guineo-Congolian mosaic of lowland rain forest and secondary grassland
Bamboutos	- Afromontane forest - Afromontane mixed with Afro-alpine grassland - Afromontane bamboo	- Afromontane rain forest - Undifferentiated Afromontane forest	Guineo-Congolian lowland rain forest (wetter types). Guineo-Congolian mosaic of lowland rain forest and secondary grassland
Bamenda	- Afromontane forest - Afromontane mixed with Afro-alpine grassland - Afromontane bamboo	- Afromontane rain forest - Undifferentiated Afromontane forest	Guineo-Congolian mosaic of lowland rain forest and secondary grassland
Mt Cameroon	- Afromontane forest - Afromontane mixed Afro-alpine shrubland - Afromontane mixed with Afro-alpine	- Afromontane rain forest - Undifferentiated Afromontane forest	Guineo-Congolian lowland rain forest (wetter types)
Mambila plateau	- Afromontane forest - Afromontane mixed with Afro-alpine grassland	Undifferentiated Afromontane forest	Guineo-Congolian mosaic of lowland rain forest and secondary grassland. Mosaic of lowland rain forest, *Isoberlinia* woodland and secondary grassland
Vogel peak	- Afromontane forest - Afromontane mixed with Afro-alpine grassland	Undifferentiated Afromontane forest	Mosaic of lowland rain forest, *Isoberlinia* woodland and secondary grassland
Obudu plateau	- Afromontane forest - Afromontane mixed with Afro-alpine grassland	Afromontane rain forest	Guineo-Congolian lowland rain forest (wetter types). Guineo-Congolian mosaic of lowland rain forest and secondary grassland
Bioko Islands	- Afromontane forest - Afromontane mixed Afro-alpine shrubland - Afromontane mixed with Afro-alpine grassland	- Afromontane rain forest - Undifferentiated Afromontane forest	Guineo-Congolian lowland rain forest (wetter types)
Sao Tome Islands	- Afromontane forest	- Afromontane rainforest - Undifferentiated Afromontane forest	Lower rainforest zone from 0-800 m now almost completely under cultivation.

2.2.3.3 Associated species

Prunus africana occurs at a wide range of elevations (700–3000 m) in the Afromontane regions of West Africa. Its presence over such an extended altitudinal range implies an association with a number of species of both Afromontane and lowland affinities. Consideration of phytogeographical information and descriptive data from floras has allowed the compilation of a provisional list of species associated with *Prunus africana* in six localities in West Africa (Table 2.5). This list includes erect woody species within the Afromontane phytochorion, which usually exceed 8 m in height at maturity.

Various species are characteristic of peripheral and outlying phytochoria, but 14 are listed as Afromontane taxa that occur in at least 4 of the 7 regional mountain systems of White (1978). They are *Agauria salicifolia, Sinarundinaria alpina, Cassipourea gummiflua, Gnidia glauca, Hypericum revolutum, Ilex mitis, Maesa lanceolata, Nuxia congesta, Podocarpus latifolius, Rapanea melanophloeos, Ritchiea albersii, Schefflera abyssinica, Strombosia scheffleri* and *Xymalos monospora.* Five associates of *Prunus africana* are endemic to the Cameroon Afromontane Archipelago, including the nearby Bioko and possibly other West African Mountains (Letouzey, 1985). This group comprises *Allophylus bullatus, Dalbergia oligophylla, Pavetta hookeriana, Pittosporum viridiflorum* and *Schefflera mannii*. Two species strictly endemic to Mount Cameroon, *Oncoba lophocarpa* and *Oncoba ovalis* are listed as Afromontane species by Cable & Cheek (1998) and occur within the altitudinal limits of *Prunus africana* on Mount Cameroon. Similarly, *Peddiea thomensis* and *Podocarpus mannii* are endemic to Sao Tome (White, 1983) and are reported from the undifferentiated Afromontane forest community where *Prunus africana* occurs on the island.

Ecological transgressors in the sense of White (1978) – species which occur in two or more major phytochoria and also occur in at least two major vegetation types – include *Albizia gummifera, Olea capensis, Parinari excelsa, Pittosporum viridiflorum, Polyscias fulva* and *Syzygium guineense*. *Albizia gummifera* is also listed as a pioneer Afromontane connecting species, endemic or near-endemic to the Afromontane phytochorion and absent from, or very rare in the lowlands, together

with *Maesa lanceolata*. *Albizia gummifera* is present on the Bamenda highlands, Mount Cameroon, the Obudu plateau and the Tchabal Mbabo plateau. *Maesa lanceolata* occurs within Afromontane rainforest on all the six mountains indicated, but not on Sao Tome.

Xymalos is the only genus endemic to the Afromontane Archipelago-like Regional Centre of Endemism of White (1983) and occurs both as Afromontane rain forest and undifferentiated Afromontane species. A single representative, *Xymalos monospora* is present on Mount Cameroon and the Bamenda highlands. With *Olea capensis, Parinari excelsa, Podocarpus latifolius, Strombosia scheffleri* and *Syzygium guineense*, this forms a group that is represented in White's (1983) list of species characteristics of Afromontane rain forest and which occur in West Africa. Other species of undifferentiated Afromontane forest are *Ilex mitis, Nuxia congesta, Podocarpus latifolius* and *Rapanea melanophloeos. Hypericum revolutum* and *Hypericum roeperanum* are indicated as Afromontane species having no affinities with lower altitude phytochoria, but they are related to genera on other tropical mountains or in the temperate regions (Schnell, 1970).

Table 2.5: Provisional list of associated species of *Prunus africana* in the Cameroon Mountain system of Morton (1986)

Species	Chorology	Mt Bamboutos	Bamenda highlands	Mt Cameroon	Obudu plateau	Sao Tome	Tchabal Mbabo
Agauria salicifolia (Comm.) Hook.f. – Ericaceae	✪	1	1	1	0	0	1
Alangium chinense (Lour.) Harms – Alangiaceae	❀	0	0	1	0	0	1
Albizia gummifera J.F. Gmel. – Leg./Papilionaceae	✪	0	1	1	1	0	1
Albizia zygia (DC.) J.F. Gmel. – Leg./Papilionoideae	✪	1	1	0	1	0	0
Allophyllus bullatus Radlk. – Sapindaceae	❀	1	1	1	1	0	1
Aningeria altissima (A. Chev.) Aubr. & Pellegr. – Sapotaceae	❀	0	1	0	0	0	0
Aningeria robusta (A. Chev.) Aubr. & Pellegr. – Sapotaceae	❀	0	0	1	0	0	0
Bridelia micrantha (Hochst.) Baill. – Euphorbiaceae	✪	0	1	0	0	0	0
Bridelia speciosa Mull.Arg. – Euphorbiaceae	❀	0	1	1	1	0	0
Carapa grandifolia DC. – Meliaceae	✪	0	1	0	0	0	1
Cassipourea gummiflua (Hook.f. ex Oliv.) J. Lewis – Rhizophoraceae	❀	0	0	0	0	1	0
Cephaelis mannii (Hook.f.) Hiern – Rubiaceae	✪	0	0	1	1	0	1
Cephaelis peduncularis Salisb. – Rubiaceae	✪	0	0	1	1	0	1
Croton macrostachyus Hochst. – Euphorbiaceae	✪	0	1	1	0	0	0
Cyathea manniana Hook.f. – Cyatheaceae	✪	1	1	1	1	0	0
Dalbergia oligophylla Bak. Leg./Caesalpinioideae	❀	0	0	1	1	0	0
Dasylepis racemosa Oliv. – Flacourtiaceae	❀	0	0	1	1	0	0
Discopodium penninervium Hochst. – Solanaceae	❀	0	1	1	0	0	1
Dombeya buettneri K. Schum. – Sterculiaceae	✪	1	0	0	0	0	0
Eriocoelum macrocarpum Gilg – Sapindaceae	✪	0	0	0	1	0	0
Eugenia gilgii Engl. & V. Brehm. – Myrtaceae	❀	0	0	0	0	0	1
Gaertnera paniculata Benth. – Rubiaceae	❀	0	0	0	1	0	0
Garcinia punctata Oliv. – Guttiferae	✪	0	0	0	1	0	0
Garcinia smeathmannii (Planch. & Triana) Oliv. – Guttiferae	✪	0	0	0	1	0	0
Gnidia glauca (Fres.) Gilg – Thymelaeaceae	✪	0	1	1	1	0	0
Harungana madagascariensis Lam ex Poir. – Guttiferae	✪	0	1	0	1	0	0
Hypericum revolutum Vahl – Guttiferae	❀	0	1	1	0	0	1

Table 2.5 (continued): Provisional list of associated species of *Prunus africana* in the Cameroon Mountain system of Morton (1986)

Species	Chorology	Mt Bamboutos	Bamenda highlands	Mt Cameroon	Obudu plateau	Sao Tome	Tchabal Mbabo
Hypericum roeperanum Schimp. ex A.Rich. – Guttiferae	⊛	0	0	1	0	0	1
Ilex mitis (Linn.) Radlk. – Aquifoliaceae	⊛	0	0	1	1	0	1
Macaranga occidentalis (Müll. Arg.) Müll. Arg. – Euphorbiaceae	⊛	0	0	1	1	0	0
Maesa kamerunensis Mez – Myrsinaceae	⊛	1	0	0	0	0	0
Maesa lanceolata Forsk. – Myrsinaceae	⊛	1	1	1	1	0	1
Margaritaria discoidea (Baill.) Webster. – Euphorbiaceae	⊛	1	1	1	0	0	0
Myrica arborea Hutch. – Myricaceae	✪	0	1	1	0	0	0
Newtonia buchananii (Bak.) Gilbert & Boutique – Leg./Mimosoideae	✪	0	1	0	0	0	0
Nuxia congesta R. Br. ex.Fres. – Buddlejaceae	⊛	1	1	1	1	1	1
Olea capensis L. – Oleaceae	✪	0	1	1	0	0	0
Oncoba lophocarpa – Oliv. – Flacourtiaceae	⊛	0	0	1	0	0	0
Oncoba ovalis - Oliv. – Flacourtiaceae	⊛	0	0	1	0	0	0
Parinaria excelsa Sab. – Chrysobalanaceae	⊛	0	0	1	0	0	0
Pavetta hookeriana Hiern – Rubiaceae	✪	0	0	1	0	0	0
Peddiea thomensis Exell – Thymelaeaceae	⊛	0	0	0	0	1	0
Pittosporum mannii Hook.f. – Pittosporaceae	⊛	0	0	1	0	0	0
Pittosporum viridiflorum (Hutch.) – Pittosporaceae	⊛	1	1	1	0	0	1
Podocarpus melanjianus Rendle – Podocarpaceae	✪	0	1	1	1	0	1
Podocarpus mannii Hook.f. – Podocarpaceae	⊛/✪	0	0	0	0	1	0
Polyscias fulva (Hiern) Harms– Araliaceae	✪	1	1	1	1	0	0
Pseudagrostachyus africana (Müll. Arg.) Pax & K. Hoffm. – Euphorb.	⊛	0	0	1	1	0	0
Psorospermum aurantiacum Engl. – Guttiferae	⊛	0	0	0	1	0	1
Psydrax dunlapii (Hutch. & Daziel) Bridson – Rubiaceae	✪	0	1	1	0	0	0
Rapanea melanophloeos (Linn.) Mez – Myrsinaceae	✪	1	1	1	0	0	0
Rhamnus prinoides L'Hérit. – Rhamnaceae	✪	0	0	0	0	0	0
Rinorea keayi Brenan – Violaceae	✪	0	0	0	1	0	0
Rytigynia umbellulata (Hiern) Robyns – Rubiaceae	⊛	0	0	1	0	0	1
Ritchiea albersii Gilg – Capparaceae	⊛	0	0	0	1	0	1

Table 2.5 (continued): Provisional list of associated species of *Prunus africana* in the Cameroon Mountain system of Morton (1986)

Species	Chorology	Mt Bamboutos	Bamenda highlands	Mt Cameroon	Obudu plateau	Sao Tome	Tchabal Mbabo
Sapium ellipticum (Hochst.) Pax. – Euphorbiaceae	✪	0	0	1	1	0	0
Schefflera abyssinica(Hochst. ex. Rich.) Harms – Araliaceae	✪	1	1	1	0	0	1
Schefflera mannii (Hook. f.) Harms – Araliaceae	❀/✪	1	1	1	1	1	1
Sinarundinaria alpina (K. Schum.) C.S Chao & S.A. Renv. – Gramineae	✪	1	1	0	0	0	0
Strombosia scheffleri Engl. – Olacaceae	❀/✪	0	0	1	0	0	0
Symphonia globulifera L.f. – Guttiferae	❀	0	0	0	1	0	0
Syzygium guineense (Willd.) DC. – Myrtaceae	❀	0	0	0	0	1	0
Syzygium staudtii (Engl.) Mildbr. – Myrtaceae	✪	1	1	1	0	0	1
Tabernaemontana vientricosa Hochst. ex. A.DC. – Apocynaceae	❀	0	1	1	0	0	0
Xylopia africana (Benth.) Oliv. – Annonaceae	❀	0	1	1	1	0	0
Xymalos monospora (Harv.) Baill. ex. Warb. – Annonaceae	❀/✪	0	1	1	0	0	0
Zenkerella citrina Taub. – Leg./Caesalpinoideae	❀	0	0	0	1	0	0

❀ = Afromontane rain forest; ✪ = Undifferentiated Afromontane forest; ✪ = Ecological Transgressor - 1 = present; 0 = absent – References: Hutchinson & Dalziel (1958); Richards (1963), Letouzey (1968 – 1985); Schnell (1970); White (1978-1983); ENGEF (1987); Ngala (1988); Tchatat (1988); Achoundong (1995); Tame & Asonganya (1995); Thomas & Thomas (1996); Tchouto (1996); Maisels & Forboseh (1997); Cable & Cheek (1998); Belinga (2001).

2.2.3.4 Natural regeneration

Relatively few thorough studies have been undertaken in relation to the natural regeneration of *Prunus africana*. However, there are published/documented comments on *Prunus africana* regeneration for Cameroon and Equatorial Guinea in West Africa and for Kenya, South Africa and Madagascar in other parts of the range.

Prunus africana seeds apparently germinate well under the crown of or in the vicinity of, the parent trees some few months following fruit maturation. Geldenhuys' (1981) observations in the Bloukrans River Gorge, Southern Cape, Ndam's (1998) investigation on Mount Cameroon, and recently Dailey & Fernandes' (2001) in Madagascar confirm this. Seeds germinate well regardless of the prevailing environmental conditions in the forest, but exposure to direct light inhibits germination (Geldenhuys, 1981). Observations of thousands of seedlings on the forest floor in Kakamega and South Nandi forest in Kenya (Were & Munjuga, undated), on Pico Basilé, Bioko (Sunderland & Tako, 1999) and recently on Tchabal Mbabo, Cameroon (Belinga, 2001) reinforce this view.

Available information recognises unambiguously the importance of light in seedling establishment and survival and this view is shared in observations from Cameroon, Kenya, South Africa and Madagascar. When the first enumeration of *Prunus africana* saplings in 2 x 2 m sub-sample plots was conducted on the slopes of Mount Cameroon by Ewusi *et al.* (1992), they found a density of 5 saplings per m^2 with patches up to 50 saplings per m^2 in areas with good light penetration. Similarly, in the same ecosystem half a decade later, during a two-year regeneration study in sets of 1 x 2 m subplots, Ndam (1998) found only a mean number of seedlings (up to 25 cm height) per m^2 increasing with disturbance: 1.31±0.72; 0.32±0.17; 0.17±0.08 in 1994 and 1.45±0.67; 0.70±0.20; 0.52±0.20 in 1995 in fallow land, secondary and primary forest respectively. Recruitment in fallow lands in this study was more than twice the amount recorded in secondary forest which in turn was 18% higher in comparison to undisturbed primary forest.

The conclusion drawn from these studies, and from other opportunistic remarks, points to *Prunus africana* as a light demanding species that requires habitat

disturbance for seedling establishment. Geldenhuys (1981) supports this view and further concludes that *Prunus africana* is becoming involved early in secondary succession. Sunderland & Nkefor's (1997) observations on Mount Oku, Cameroon support this argument. The high mortality rate of regenerating seedlings indicated by Ndam (1998) on Mount Cameroon (90%) regardless of the level of disturbance and implicitly mentioned in Bioko (Sunderland & Tako, 1999) is imputable to insect attacks or mould development on seedling leaves (Geldenhuys, 1981; Ndam, 1998). A high level of seedling herbivory in open canopy forest and heavy seedling predation in a more shaded forest environment is also mentioned for Kakamega forest, Kenya (Tsingalia, 1989).

2.2.3.5 Population level

Available information on the numerical importance of *Prunus africana* in natural communities in the Cameroon Mountain system through forest inventories is restricted to Mount Cameroon, Mount Manengouba, Tchabal Mbabo, Tchabal Gang Daba, and Bioko Island (Figure 2.6).

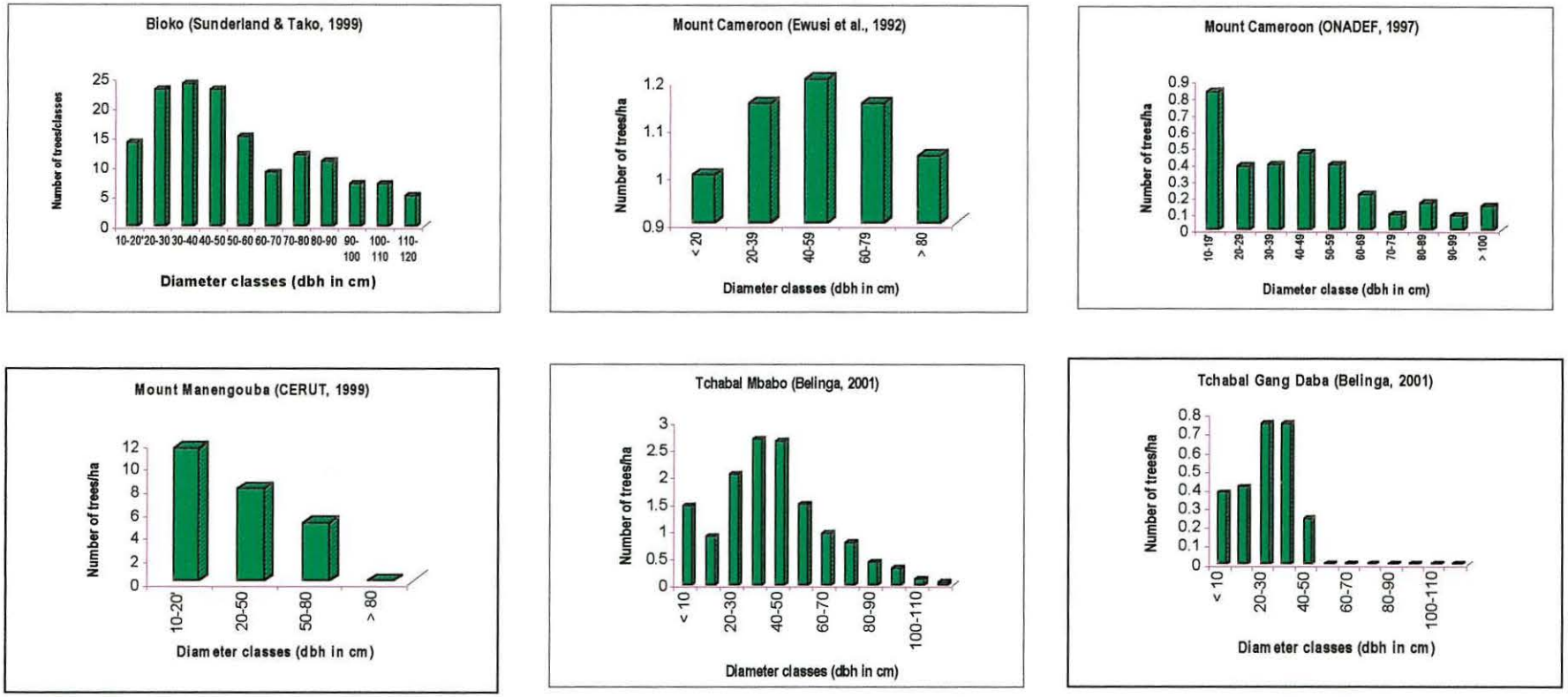

Figure 2.6: Numerical importance of *Prunus africana* in selected sites within the Cameroon Mountain system.

The vegetation types and areas sampled in Bioko are not indicated in Sunderland & Tako (1999) report. 150 trees with dbh ≥ 10 cm were tallied from 5 populations on the island. - Ewusi *et al.* (1992) set samples in all Afromontane rain forests and undifferentiated Afromontane forests from the village to the savanna boundaries. 45 ha were sampled in total and 249 trees of all diameter classes were tallied – ONADEF (1997) established plots in different vegetation strata: 26.5 ha were sampled and 28 trees with dbh ≥ 10 cm were tallied in farming areas within the Afromontane forest range. 244.5 ha were sampled and 215 trees tallied in the Afromontane rain forest. In the undifferentiated Afromontane forest, 73.5 ha were sampled and 91 trees tallied. – CERUT (1999) makes no mention of the vegetation types covered and the areas sampled on Manengouba Mountain. - Belinga (2001) inventories in Tchabal Mbabo and Tchabal Gang Daba were concentrated in undifferentiated Afromontane forests and trees tallied included those with dbh < 10 cm. 101.4 ha were sampled and 1392 trees tallied on the Tchabal Mbabo plateau. 74 trees were tallied in an area of 29.25 ha on Tchabal Gang Daba.

There is considerable variation regarding the numerical importance of *Prunus africana* from one locality to another within the Cameroon Mountain system. Comparison between sites is difficult. The different studies use different sampling strategies and more importantly, the minimum diameter recorded is not harmonised, although dbh 10 cm has been used as the basis for most studies. Ewusi *et al.* (1992), in their inventory on Mount Cameroon adopted an unspecified lower limit of dbh < 20 cm. Similarly, Belinga (2001) reports from Tchabal Mbabo and Tchabal Gang Daba, adopted a diameter class of less than 10 cm dbh with no further details.

The highest density is indicated for the Manengouba Mountain. At 24.4 trees/ha (dbh ≥ 10 cm), this density is almost five times higher than the most optimistic situation on Mount Cameroon indicated by Ewusi *et al.* (1992) - 5.5 trees/ha, enumerated trees including those with dbh < 20 cm - and twenty five times the density indicated during the ONADEF (1997) inventory (0.95 tree/ha, dbh ≥ 10 cm). The sampling strategy adopted during the CERUT (1999) survey was not indicated and *Prunus africana* was apparently not the only targeted species during this work. The area effectively sampled is unspecified. It is probable that a limited number of plots were established in forest patches rich in *Prunus africana*. Counts of trees with dbh ≥ 10 cm in such circumstances inflate the potential and realistic comments on the numerical importance of *Prunus africana* at this site require extra attention.

There is also a high population density of *Prunus africana* on Tchabal Mbabo. Belinga's (2001) recent inventory indicates 13.73 trees/ha. All trees including those with dbh < 10 cm were apparently enumerated in an area of 101.4 ha consisting of undifferentiated Afromontane forest patches. There is no other study quantifying the numerical importance of *Prunus africana* on this mountain. The enumeration of all trees including those with dbh < 10 cm and the lack of an accurate map to guide sampling strategy is acknowledged by Belinga himself, and make comparison with other areas difficult. Nevertheless, the *Prunus africana* per hectare value from the Tchabal Mbabo plateau is five times higher than the situation on the nearby Tchabal Gang Daba, where *Prunus africana* density is 2.53 trees/ha (including smaller trees with dbh < 10 cm).

In the Mount Cameroon region, the numerical importance of *Prunus africana* is subject to increasing speculation and the four inventories undertaken in the last 10 years provide conflicting results. Two main methodological approaches have been used in the different inventories: strip transects methods and adaptive cluster sampling (Table 2.6).

Forest inventory work reported by Tchouto (1996) and Acworth *et al.* (1996) was unfocused, apparently designed to enumerate all forest tree species with a dbh greater than 10 cm within sampled plots. The primary aim of this survey was to provide a broad indication of the forest quality on the east and west-facing slopes of Mount Cameroon. Selected areas were located in the then proposed Etinde Forest Reserve. *Prunus africana* was only one of the species encountered during this work and apparently not a targeted species. The estimation of *Prunus africana* density based only on those inventory plots containing the species biases the estimate upwards and extrapolation of the findings to the entire mountain would be misleading.

Table 2.6: Summary of inventory methods of *Prunus africana* on Mount Cameroon
Estimated population sizes are based on the following specified areas: 28980 ha (Ewusi *et al.*, 1992), 49848.32 ha (ONADEF, 1997), 12152 ha (Underwood & Burn, 2000). Tchouto (1996) and Acworth *et al.*(1996) estimates were based on the area covered by 20 x 0.25 ha plots established on the east and west-facing slopes of Mount Cameroon – the tree size in the density column is indicated in "data collected" column). There is no indication of the minimum diameter recorded in Ewusi *et al.* (1992)

Inventory methods	Sample size (ha)	Area represented (ha)	Sampling intensity (%)	Recording units	Data collected	Density (tree/ha)	Estimate of population size for whole mountain	References
Strip transect around the mountain in representative areas from the village to the savanna boundaries using local knowledge in site selection	45	28,980	0.15	18 x 2.5 ha (50 m x 500 m) temporary plots along transects	All *Prunus africana* trees including those with dbh < 20 cm	5.5	160356 in 29155.6 ha	Ewusi *et al.* (1992)
Plots systematically located in 15 stratified strip transects on the east and west-facing	5	5	?	20 x 0.25 ha (50 m x 50 m) plots along transects	All trees with dbh ≥ 10 cm dbh	11.8	59 in 5 ha	Tchouto (1996); Acworth *et al.* (1996)
Plots systematically located in 40 stratified strip transects	345	48,632	1.0	1000 x 0.5 ha (250 m x 20 m) along transects	All selected with dbh ≥ 10 cm dbh	0.95	46191 in 48622.1 ha	ONADEF (1997)
Adaptive Cluster Sampling based on randomly selected transects	197.8	12,152	1.6	989 circular plots of 25 m radius (0.2 ha)	All trees with dbh ≥ 10 cm dbh	4.27 with 95% confidence limits of 2.89, 5.66 trees/ha	51912, with 95% confidence limits 35,085 – 68739 in 12157.4 ha	Underwood & Burn (2000)

The discrepancies between the results of Ewusi *et al.* (1992), ONADEF (1997), and Underwood & Burn (2000) are considerable. For the Ewusi report sampling was not random, but based on sites where *Prunus africana* occurred (Cunningham & Mbenkum, 1993). The Adaptive Cluster Sampling approach on Mount Cameroon tends to succumb to this apparent weakness. The adding rule in the Adaptive Cluster Sampling technique requires a threshold value to be set prior to sampling in the field (Underwood & Burn, 2000). A preliminary exploratory inspection of the main plots in the field to guide the definition of the threshold value on Mount Cameroon implies that sampling intensity fluctuates from one area to another. Consequently, richer areas would receive more attention than poorer ones, a scenario not fundamentally different from using knowledge of local bark harvesters to guide transect locations. Nonetheless, for a species that tends to be found aggregated into relatively sparse clusters, the Adaptive Cluster Sampling technique is praised for enabling entire clusters to be covered in the sample when they are located and offers an unbiased estimate of the density and its sampling error (Underwood & Burn, 2000).

The overall picture of the population structure shows trees in all diameter classes, with a possible exception in Tchabal Gang Daba in the Adamaoua plateau (Cameroon) where the population appears relatively young. An inventory of *Prunus africana* on this mountain was conducted very recently (Belinga, 2001) and there was no indication of *Prunus africana* in this mountain prior to this investigation. All recorded trees are less than 60 cm dbh and *Prunus africana* density amounts to 2.53 trees per hectare (including trees with dbh < 10 cm). There is no documented evidence of *Prunus africana* bark exploitation in this region and the absence of larger trees is unusual. A similar trend, but less pronounced is observed further south on the wetter Manengouba Mountain. Trees above 80 cm diameter are completely absent from this forest though it is situated south of Tchabal Gang Daba. A recent participatory biodiversity survey investigation (CERUT, 1999) highlights unsustainable bark harvesting of *Prunus africana* in this region and harvesters may have felled larger trees. There is a reasonable number of young trees on this mountain and the density of 11.5 trees/hectare in the diameter class 10-20 cm testifies this.

There is a resemblance in stem distribution per diameter class on Mount Cameroon, Tchabal Mbabo and possibly Bioko. Despite a large discrepancy between the tree density reported on Mount Cameroon and that for Tchabal Mbabo, there are individuals in all the diameter classes. The majority of trees are in the diameter class below 80 cm, but larger trees are also present. This situation was also noted on Bioko forest and on Mount Cameroon (Sunderland & Tako, 1999).

2.3 BIOLOGY

2.3.1 Flowering and fruiting phenology

2.3.1.1 Flowering and fruiting seasonality

The reproductive phenology of *Prunus africana* in West Africa is poorly documented. Available information is restricted to herbarium specimen records and information in floras. Consideration of dated records from different localities where botanical collections have taken place (Figure 2.7) indicates that flowering is aseasonal at the regional level and occurs almost throughout the year in West Africa. This trend is also apparent at the same latitude in East Africa (Hall *et al.*, in press).

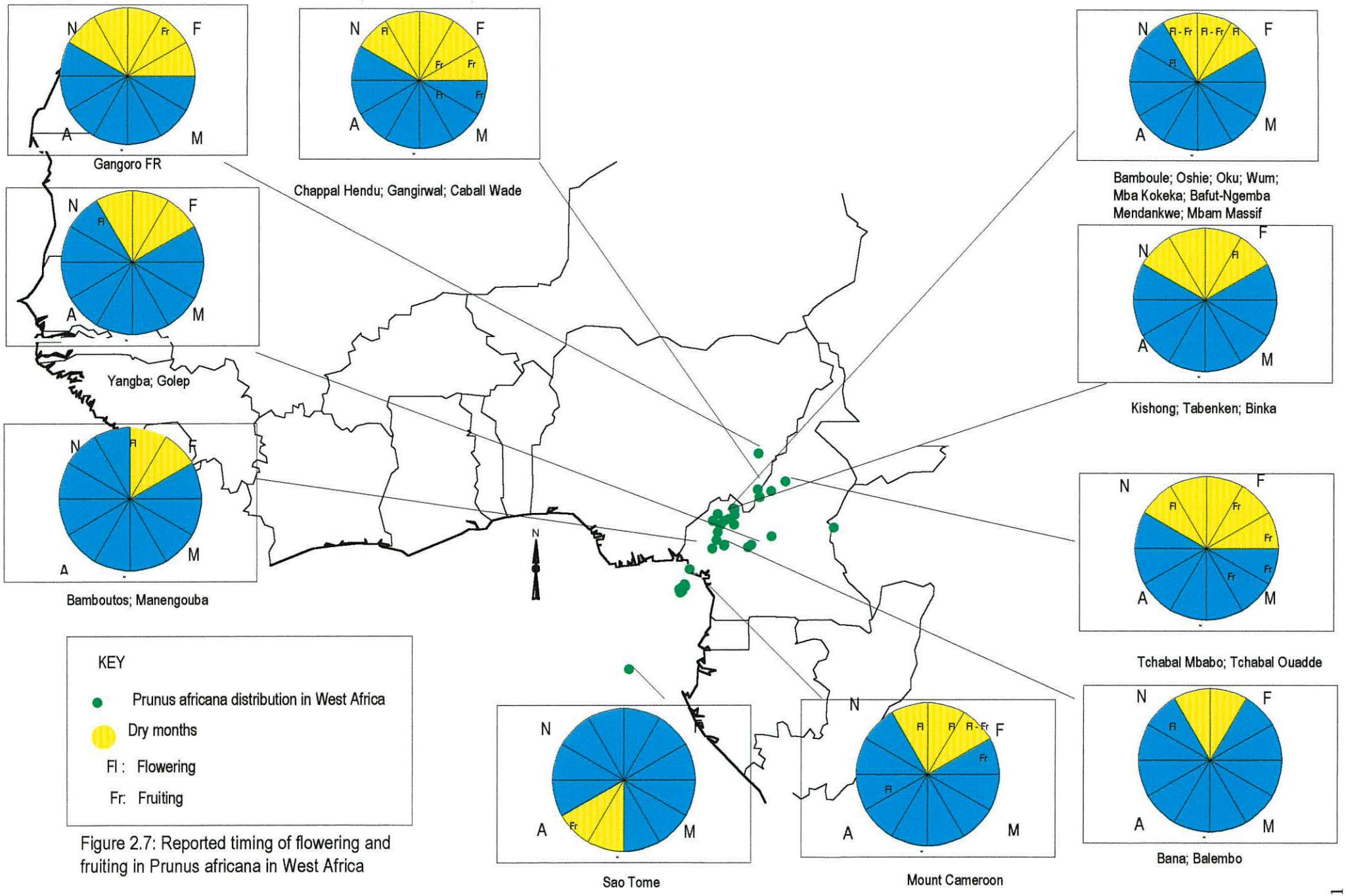

Figure 2.7: Reported timing of flowering and fruiting in Prunus africana in West Africa

Populations in Nigeria and Cameroon show some similarities in relation to the timing. The broader picture indicates that flowering does not start until November in most localities and extends to February. Exceptions have been indicated however, for Mount Cameroon where there are indications of flowering in June in areas around latitude 4°08'- 4°10' N and in September in the region south of 4°08' N. Further south on Pico Pequeno, São Tome, flowering apparently occurs late in August. There is no information for the Bioko populations.

With the possible exception of the west-facing slope of Mount Cameroon, flowering in *Prunus africana* in West Africa is a dry season event. From the Gangoro Forest Reserve, Nigeria, at 8°44'N to Bioko around 3° N, dry months are reported at some time within the November to March period and flowering episodes in *Prunus africana* coincide with this period. On Pico Pequeno, São Tome, fruiting in *Prunus africana* is reported in August, suggesting a possible late flowering in July, a period that also coincides with the dry season (July-August).

Fruiting episodes follow the flowering trend with respect to the seasonality and happen immediately after flowering. Early fruits are indicated in December in the Bamenda highlands in Cameroon and in February in the Nigerian Mountains. The fruiting phase extends to May or June in the Bamboutos and Manengouba mountains in Cameroon. With fruiting starting late in August on Pico Pequeno, this can be expected to extend to November or December, but there is no specimen information to support this view.

2.3.1.2 Flowering and fruiting frequency

Information on the flowering and fruiting frequency of *Prunus africana* in West Africa is scanty and speculative. Nonetheless, it appears that flowering and fruiting in *Prunus africana* this region is somewhat erratic, the timing of fruiting and fruit set varying from year to year (Sunderland and Nkefor, 1997). Good production is reported to occur at 2-3 years intervals (Z. Tchoundjeu, pers. communication), paralleling the situation reported in parts of the natural range in East and South Africa (Hall *et al.*, in press). Early fruiting is also indicated on individuals that have recently been subjected to bark removal. With respect to this, Sunderland & Nkefor (1997)

suggest the stress created by debarking acts as a trigger to promote seed production as in domesticated taxa such as *Persea americana* Mill. (Lauraceae).

2.3.2 Breeding system

2.3.2.1 Floral structure

The small, fragrant flowers produced by *Prunus africana* (2.1.3.2) bear both pistillate and staminate organs. This bisexuality predisposes both endogamy and allogamy as breeding systems in this species.

2.3.2.2 Anthesis and sexuality

Maturation of female and male organs occurs sequentially at anthesis and there are indications that *Prunus africana* flowers are protogynous (Hall *et al.*, in press). The stigma is apparently receptive immediately after flower opening and receptivity lasts for a short period (Munjuga *et al.*, 2001). Pollen maturation and exposure is delayed and occurs in phases, starting with the outermost ring and progressively extending to adjacent stamens in the inner whorls (Munjuga *et al.*, 2001). Hall *et al.* (in press) identify this temporal separation between the female-male sequence of function as a possible barrier to selfing in *Prunus africana*, but also indicate herkogamy. Selfing is possible, following assisted pollination (Munjunga *et al.*, 2001).

Assuming protogyny operates and limits selfing, it remains unclear whether the separation between this female-male sequence of function is complete or not in nature. Equally, the bisexual nature of *Prunus africana* flowers and the lack of evidence suggesting heterostyly in this species indicate that homomorphic herkogamy is likely to be responsible for the spatial separation of the anthers from the stigma. It is not clear whether "approach" herkogamy or "movement" herkogamy applies.

The experimental work in Kiambu District, Kenya (Munjuga *et al.*, 2001), is one indication of allogamy as the predominant breeding mechanism in *Prunus africana*. A high percentage fruit set was recorded with assisted cross-pollination. Endogamy is also possible, if there is a pollen vector.

2.3.2.3 Pollination mode

The study (Munjuga *et al.*, 2001) of the pollination mode in Kenya suggests that entomophily is the main pollen transfer mechanism, taking the sticky nature of pollen grain as an indication of this. Anemophily is also possible given the light weight of the pollen grain, but there is speculative evidence suggesting that the role of wind in effecting pollination is, in fact negligible (Hall *et al.*, in press).

2.3.3 Seed biology and management

Unlike many other tropical forest tree species where *ex situ* conservation efforts are lessened through the creation of seed banks, there is no evidence for the presence of seed banks with *Prunus africana*. On the contrary, research reports indicate that *Prunus africana* seeds are highly recalcitrant, losing their viability very quickly during storage (Sunderland & Nkefor, 1997; Were & Munjuga, undated). The main causes of this recalcitrance are subject to debate, but there are indications that it can be lessened if the pericarp is removed from the mature seed immediately after collection (Geldenhuys, 1981; Albrecht, 1993; Sunderland & Nkefor, 1997). Seed collection and sowing apparently without storage indicate a 52% germination rate in seeds with pericarp intact, against 90% and 92.5% germination rate following pericarp removal and pre-treatment with cold water for 7 days and 1 day respectively (Geldenhuys, 1981). Geldenhuys' (1981) experiment further indicates that the germination rate is 92% and 94% following pre-treatment for 1 day with HCl at pH 3 and pH 1 respectively. Available information on *Prunus africana* seed biology indicates three possible causes of *Prunus africana* seed recalcitrancy: the level of seed maturity, the moisture content and the temperature of storage.

2.3.3.1 Level of seed maturity.

Seed from mature purple fruits can germinate well: a 96% germination rate has been achieved with depulped seeds sown immediately after collection (Sunderland & Nkefor, 1997). This trend is confirmed by Were & Munjuga (undated) in the study of the impact of different levels of seed maturity and moisture content. A 72% germination rate for depulped seeds with 15% moisture content (from purple fruits) was recorded, against less than 5% in all other seed state categories at the same moisture content. This finding is, however, not consistent with the results of a recent

joint IPGRI/ICRAF (ICRAF, 2001a) study aiming to extend the period of seed viability by manipulating factors such as the timing of seed collection, the moisture content of the seed and the temperature of storage. This study achieved a 90% germination rate for *Prunus africana* seeds extracted from green fruits after a year of storage at 10°C with 15% moisture content. Thus, the main factor in seed recalcitrancy may not be the level of fruit maturity, but the combination of seed moisture content and storage temperature, and perhaps the embryo condition.

2.3.3.2 Seed moisture content and temperature of storage.

The seed moisture content and the temperature of storage thus seem to have an impact on seed viability, but the incidence of each factor on its own cannot be clearly differentiated from available literature. *Prunus africana* seeds are sensitive to desiccation. The 4% germination rate after extraction and shade drying (Schaefer, 1990) and the drop in germination rate from 96% to 15% reported by Sunderland & Nkefor (1997) after three weeks exposure to ambient conditions support this view. There is however, still confusion regarding suitable levels of moisture content and storage temperature (Table 2.7; Figure 2.8).

Table 2.7: Germination rates reported for *Prunus africana* seeds (mature depulped seeds) in laboratory/nurseries studies

Germination rate (%)	Moisture content of seeds (%)	Storage atmospheric humidity (%)	Duration of storage	Temperature of storage (°C)	References
96	Unspecified	Unspecified	No storage	-	Sunderland & Nkefor (1997)
74b	50 (peat)	95	5 months	+ 3	Schaefer (1990)
72	15	Unspecified	No storage	-	Were & Munjuga (undated)
72	8	Unspecified	> 2 months	+ 5	Were & Munjuga (undated)
60-70	Unspecified	60	≥ 8 weeks	+ 4	Sunderland & Nkefor (1997)
67	8	Unspecified	No storage	-	Were & Munjuga (undated)
62b	50 (sawdust)	95	5 months	+ 3	Schaefer (1990)
52	25	Unspecified	> 2 months	+ 5	Were & Munjuga (undated)
49	25	Unspecified	No storage	Unspecified	Were & Munjuga (undated)
48	15	Unspecified -	> 2 months	+ 5	Were & Munjuga (undated)
38	15	Unspecified	> 1 year	+ 5	Were & Munjuga (undated)
37	8	Unspecified	> 1 year	+ 5	Were & Munjuga (undated)
35c	48 (peat)	95	2 months	+ 3	Schaefer (1990)
33c	48 (sawdust)	95	2 months	+ 3	Schaefer (1990)
15	Unspecified	Unspecified	3 weeks	Unspecified	Sunderland & Nkefor (1997)
13b	48 (sand)	95	2 months	+ 3	Schaefer (1990)
12	25	Unspecified	> 1 year	+ 5	Were & Munjuga (undated)
8a	18 (control)	95	5 months	+ 3	Schaefer (1990)
4	15	-	No storage	-	Schaefer (1990)
3a	18 (control)	95	2 months	+ 3	Schaefer (1990)
0	Unspecified	60	> 18 weeks	+ 4	Sunderland & Nkefor (1997)

a-c refer to storage conditions: a = open plastic box or drum; b = perforated polythene bag; c = open plastic box (or perforated polythene bag) and seed mixed with damp sawdust (twice the seed volume).

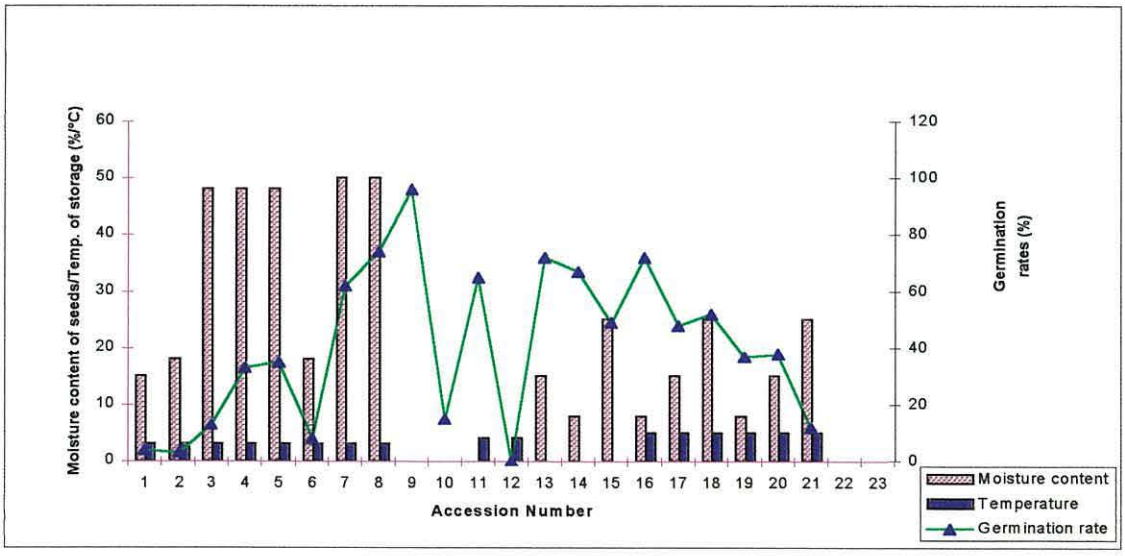

Figure 2.8: Indicated germination rates of *Prunus africana* seeds in relation to seed moisture content and temperature of storage

The highest germination rates have been achieved with fresh seed sown immediately after collection (96%) regardless of the level of moisture content (Sunderland & Nkefor, 1997). Seeds are sensitive to desiccation and excessive drying reduces the germination capacity considerably. In the experiment of Were & Munjuga (undated), a 72% germination rate for seed dried to 15% moisture content, against a 67% germination rate for seeds dried to 8 % moisture content were recorded. However, Schaefer (1990) recorded only a 4% germination rate after drying seeds to 15% moisture content and sowing immediately.

Excessive moisture content reduces the germination capacity at any given temperature of storage, or duration of storage. Were & Munjuga (undated) determined that a satisfactory level of seed moisture content is around 15%. A germination rate of 72% is indicated for such seeds against those dried to 25% moisture content and 8% moisture content: 49% and 67% germination rate respectively. Seeds were sown immediately after drying to the desired level of moisture content without storage.

The germination capacity drops considerably after two months of storage if seed moisture content level is high. Seeds dried to 8% moisture content germinate better than those dried to 15% and 25% moisture content. Were & Munjuga (undated) achieved a 72% germination rate with the driest seeds (8% moisture content), against 48% and 52% germination rates for seed dried to 15% and 25% moisture content, respectively. Additional treatment is required in the case of high initial moisture content of seed to maintain viability. Schaefer (1990) has indicated that seeds with a high initial moisture content (48%) are better preserved mixed with damp sawdust or peat than if they are stored in sand or left in an open plastic box or drum. His work indicated germination rates of 33 % and 35% for seed preserved for two months under 95% storage atmospheric humidity at 3°C storage temperature in damp sawdust and peat, respectively. The germination rate was only 13% for seeds preserved in sand and only 3% for seeds left unmixed in an open plastic box or drum (control). This trend persisted after five months of storage under 95% atmospheric humidity and 3°C. Better germination rates were achieved if mixed seeds are preserved in perforated polythene bags: germination rates of 62% and 74% are indicated for seeds mixed with damp sawdust and peat, respectively. The germination rate was only 8% for seeds

mixed with sand and kept in open plastic box or drum. The work of Sunderland & Nkefor (1997) supports this: 60-70% germination rates were recorded for seed kept in 60% relative humidity storage conditions for at least 8 weeks. Sunderland & Nkefor did not report the initial level of seed moisture content.

The situation after a year of storage is unclear. There are mixed indications regarding the desirable initial moisture content. Seeds with 8% and 15% moisture content exhibited similar germination (37% and 38% success, respectively) (Were & Munjuga, undated). Higher moisture content appears inimical after this time, and seeds with 25% moisture showed a poor germination rate (12% success). A recent publication from the International Centre for Research in Agroforestry (ICRAF, 2001b) suggests a possible improvement to this situation, but expresses the moisture content level in % millicycles, an unusual unit that makes comparison difficult. According to ICRAF publication, a reduction of the temperature of storage to 1°C and a seed moisture content level of 37% millicycles induce a 42% germination rate after a year of storage. At 20% millicycles moisture content however, the germination rate drops to 39% after nine months storage at 4°C. Further desiccation to 15% millicycles apparently induces dormancy, which is broken by pre-chilling seeds at 3°C for five months.

2.3.4 Seed dispersal

Information on *Prunus africana* seed dispersal is poorly documented. The one-seeded *Prunus africana* drupe is favoured by frugivorous birds and mammals, but recent observations on fruiting populations on Mount Cameroon indicate that dispersal from the parent tree is negligible, and the majority of seeds reach the ground beneath the crown and remain there (Sunderland & Nkefor, 1997).

Suspected seed dispersers reported for Mount Cameroon are the endemic greenbul (*Andropagus montanus*), the rare primate Preuss' Guenon (*Cercopithecus preussii*) and Bannerman's Turaco (*Tauraco bannermani*) (Ndam, 1996).

2.3.5 Pests and diseases

Information regarding pests and diseases attacking *Prunus africana* has been compiled by Hall *et al.* (in press), but no references to observations in West Africa are included. Nonetheless, attacks by predators such as insects and caterpillars have been reported on naturally growing seedling leaves on the slopes of Mount Cameroon (Ndam, 1996; B. Ewusi. Ken. wkps), although without indication of the extent of the damage caused. A lepidopteran caterpillar, which then pupates on the plant itself, extensively eats *Prunus africana* leaves on Mount Cameroon (Sunderland & Nkefor, 1997). Aphid attacks on developing buds are common at lower altitudes on Mount Cameroon (Sunderland & Nkefor, 1997). It seems that damage caused by such attacks is severe and results in considerable deformation of growing shoots, with implications for early growth rate. Developing young leaves on Mount Oku suffer fungal infections of unknown nature (C. Asanga, Ken. wkps). In East Africa, in Kenya, Tsingalia (1989) mentions a high level of seedling herbivory in opened canopy forest and heavy seedling predation in a more shaded forest environment at Kakamega forest.

Debarked trees are also prone to wood-borer attacks: this situation has been consistently reported on Mount Cameroon and on Mount Oku (Cunningham & Mbenkum, 1993; B. Ewusi, Ken. wkps). In some cases, these attacks are associated with crown die-back or even tree death. On four-year old *Prunus africana* trees at the Limbe Botanic Garden at the foothills of Mount Cameroon, the presence of stem borer attacks was indicated by localised resin exudation through small borer holes (Sunderland & Nkefor, 1997).

In nursery conditions also, *Prunus africana* is affected by pests and diseases (Sunderland & Nkefor, 1997). Powdery mildew attacks and distortions of apical buds have been observed on seedlings in deep nursery shade in Limbe Botanic Garden (Fraser *et al.*, 1996; Sunderland & Nkefor, 1997).

2.3.6 Genetic variation

Efforts to appraise genetic variation in *Prunus africana* in West Africa have been restricted to the Cameroon populations and were not initiated until 1994 when Barker *et al.* (1994) sampled leaf materials for random amplified polymorphic DNA analysis (RAPD). The study demonstrated that each one of single populations of *Prunus africana* from Cameroon, Democratic Republic of Congo, Uganda and Madagascar was distinct. In-country variability was not captured. Significant variation among individuals within populations, and among populations within Cameroon (and Madagascar) emerged when four populations in Cameroon were sampled in a more recent investigation using RAPD techniques (Dawson & Powell, 1999). Dawson & Powell concluded that there are significant differences among populations within Cameroon. The genetic relationships among four populations of *Prunus africana* from Cameroon and elsewhere are illustrated in Figure 2.9.

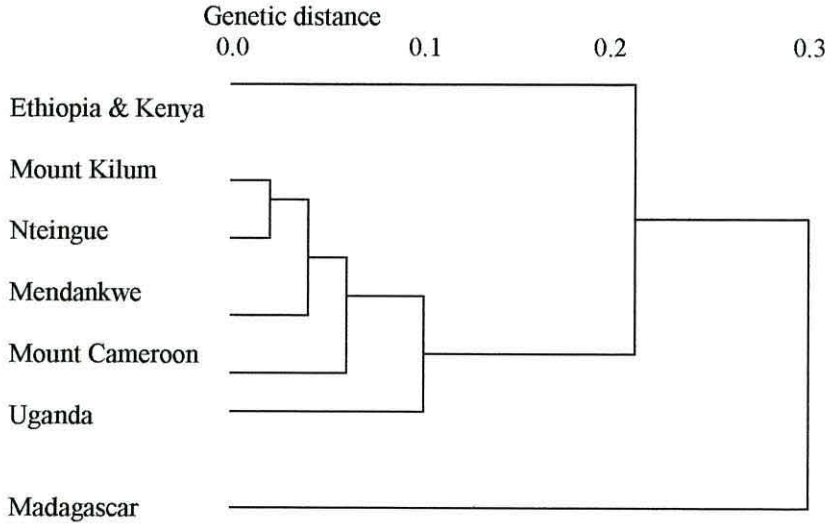

Figure 2.9: Genetic relationships among 4 populations of *Prunus africana* in Cameroon (relationships with populations in other countries indicated). Reproduced and modified from Dawson & Powell (1999)

The materials from Kilum forest and Nteingue enrichment planting reveal most similarity. There is however no documented evidence on the origin of seed used in Nteingue and Kilum forest may be treated as a possible source. The populations of Mendankwe and Mount Cameroon appear genetically more distinct. The population from Mendankwe plantation is genetically closer to the Kilum/Nteingue cluster than

to the population sampled on Mount Cameroon. Trees sampled in Mendankwe were established in farmland with unknown seed origin. Nevertheless, Mendankwe is geographically closer to Kilum than Mount Cameroon and the relative close similarity between Mendankwe and Kilum populations is not unexpected.

At the continental scale, *Prunus africana* from Cameroon are genetically closer to the Ugandan population than to the Ethiopian and Kenyan populations. The population from Madagascar is genetically distinct from the mainland Africa.

In addition to molecular analysis, there has also been an initiative to examine genetic variation in *Prunus africana* in Cameroon with a provenance trial. ICRAF, in collaboration with UNESCO, LBG, CDC and IRAD has established this in an open field at Tole, near Limbe, using seed collected off parent trees from Mendankwe (5°56' N - 10°12' E), Kilum (6°11' N – 10°35'E) and Mount Cameroon (4°05' N – 9°05' E) (Tchoundjeu *et al.*, undated). Preliminary results from this trial show that the survival rate of all provenances has varied from 60 to 100%. There are significant variations in early growth rate among the various accessions. Variation in mean height of 5 months old plants ranged from less than 40 cm to over 100 cm (Tchoundjeu *et al.*, undated; Bell *et al.*, 1998).

2.4 CONSERVATION MANAGEMENT STRATEGIES

This section reviews information related to *Prunus africana* conservation and management in Cameroon from 1972. Management and conservation actions are presented in two time phases: the solely extractive period prior to 1990 and the extraction and restocking era from 1990. The trend in bark production from Mount Cameroon from 1980, and information related to the resource character are considered as the final parts of the section.

2.4.1 Pre-1990: the extraction era

Little is published on management issues and conservation initiatives for *Prunus africana* in Cameroon prior to the period 1990. The legal framework to guide bark

harvesting and the state-sponsored plantations of medicinal plants in Santchou, Dschang, appear to be the only early efforts taken to ensure resource sustainability.

2.4.1.1 Legal framework

There is a six years interval between the granting of the first patent for the processing of *Prunus africana* bark to extract active ingredients (patent taken out by J. Debat in 1966) and the beginning of commercial exploitation in 1972 by SODEXMEDI, the predecessor to Plantecam. Until 1972, *Prunus africana* was thus known in Cameroon only for its traditional uses. Exploitation of the tree bark for commercial purposes started in West and North-West Provinces, but in less than five years, was extended to the Mount Cameroon region, South-West Province (Ngengwe, 1996; Ndibi & Kay, 1997). Apparently this large-scale exploitation was not initially regulated until April 1974, when Plantecam was first issued a formal official exploitation permit in accordance with the prescriptions of the 1973 forestry ordinance of the United Republic of Cameroon. There were then no technical debarking rules. When these were instituted twelve years later, in 1986, there were provisions allowing Plantecam to fell 10 000 and 12 000 trees through the five-year permits of 1986 and 1992 respectively (Asanga, 1993; Ndibi & Kay, 1997).

The ability of *Prunus africana* to survive severe bark removal and to exhibit bark regrowth has been widely documented. However, such regrowth is ensured when the technical debarking rules are followed. Ndibi & Kay (1997) offer a concise account of the rules in Cameroon. There are five key points. Firstly, only trees of diameter at breast height (dbh) greater than 30 cm can be exploited, and not at intervals less than four years and in such a way that the bark is removed in a strip from 1.30 m above ground level up to the first branch. Secondly, trees with dbh greater than 30 cm but less than 50 cm should be debarked as two strips on opposite sides of the bole, each strip being no wider than one quarter the girth of the tree. Thirdly, trees with dbh greater than or equal to 50 cm should be debarked in four strips regularly distributed around the bole, each no wider than one-eight of the girth. Fourthly, lateral roots with a minimum diameter of 20 cm on tree $\geq$ 50 cm dbh can also be debarked. The debarking should not exceed one quarter of the root's circumference. After debarking,

the roots should be re-covered with soil to avoid desiccation and to enable a rapid reconstitution of the bark. Finally, all trees with debarked roots and/or trunks should be marked with a number. Under this exploitation regime, a mean bark yield of 55 kg per tree with a range from 38-74 kg is expected (Macleod, 1987; Simons *et al.*, 1998). This has not been respected and higher quotas of bark have been harvested per tree.

Under the 1981 forestry legislation, special permit holders were required by law to pay a regeneration tax - 2% of the value of the raw material – to the Forestry Department as support for regeneration programmes. Whether regeneration activities under state sponsorship currently take place or not is an issue requiring further investigation. In addition to the 2% regeneration tax, special permit holders are required to plant 2 ha of exploited species per year. Although this requirement was stated in the early exploitation permits, no land was allocated for such planting until 1991/92 when the Ministry of Agriculture officially assigned the Bamboko Forest Reserve for partial conversion to plantations (Asanga, 1993). In the requirement, no reference is however made to tree spacing and permit holders have used this omission to their advantage. Thus, only 1000 seedlings were grown at the forestry nursery in Buea on behalf of Plantecam in 1992/93 (Cunningham & Mbenkum, 1993). Asanga (1993) indicates an enrichment planting of unspecified extent carried out by Plantecam on the slopes of Mount Cameroon in 1990, in addition to a 2 ha stand established behind the Parliamentarian Flats, Buea, at 5 m spacing. This plantation has been deemed a failure due to lack of care and inappropriate silviculture (Asanga, 1993).

2.4.1.2 *Prunus africana* plantations

Planting of *Prunus africana* as pure stands started as early as 1974/75 when the State Forestry Fund established a nursery at Nteingue near Santchou, Menoua division, Western Province (Cunningham & Mbenkum, 1993). At this time the Government of Cameroon was acting to address a perceived need for medicinal plants including *Prunus africana* for both conservation and diversification purposes. A financial allocation of 75 millions Fcfa (US$115 385) was made to cover inventory, harvesting and marketing, and a further 25 millions Fcfa (US$38 462) for experimentation and

regeneration as part of a five-year programme (1976-1981). In the same area, enrichment planting and pure plantations at lower altitude in 1982 continued this programme. Unfortunately, the majority of trees planted in 1974/75 and 1982 have been damaged through illegal exploitation. A recent report indicates poor quality in the remaining trees, as a result of the depredations of wood boring beetles (Cunningham *et al.*, 1998).

2.4.2 Post-1990: the extraction and restocking era

Besong *et al.* (1991) produced a report, which marked the beginning of the new era in the conservation and management of *Prunus africana* in Cameroon. The enactment of new forestry regulation and the implication of the local communities in resource management later reinforced these ideas.

2.4.2.1 Legal framework

The overall forestry policy of Cameroon has undergone significant changes since 1994 and there has been reorientation towards efficient long term and sustainable utilisation and conservation of all available resources and ecosystems (MINEF, 1995). Under the current legislation laid down by Presidential Decree No 94/01 of 20 January 1994, and the accompanying Decree of Implementation (Decree No 95/531/PM of 23 August 1995), *Prunus africana* like other economically important non timber forest products is listed as a special forest product. With this status its exploitation is subject to a special permit issued in accordance with the provisions of the legislation in force, which identifies the State as sole manager of such resource. The exploitation permit is granted upon the recommendation of a competent commission for a maximum non-renewable period of one year (Section 56:2 of the law No 94/01 of 20 January 1994).

An administrative shortcoming in the past has been the issuance of exploitation permits for *Prunus africana* without prior assessment of the resource base. Until very recently, quotas offered in exploitation permits had no scientific basis (Ewusi *et al.*, 1996; Acworth *et al.*, 1998). It has been argued forcefully that this has been

detrimental to the *Prunus africana* gene pool in Cameroon. However, early complaints about the resource mining that resulted were heeded and in 1991, an exploitation ban was applied following recommendations from senior members of the Forestry Department subsequent to a visit to the North-West, South-West and West Provinces (Besong *et al.*, 1991). The report warned of an escalating destruction of *Prunus africana* in the areas visited and made ten recommendations. These recommendations included the improvement of the legislation, the reinforcement of the terms of the exploitation permits, the initiation of afforestation programmes and the mobilisation and sensitisation of all stakeholders. Converting these ideas into realistic actions proved difficult. The partial exploitation ban that was applied resulted in an increase, by a factor of two, in the amount of bark sold to Plantecam (Cunningham & Mbenkum, 1993). The partial exploitation ban was lifted in 1992. At the same time, an inventory of *Prunus africana* on Mount Cameroon was commissioned by Plantecam and executed by the staff of the then Forest Conservation Services for the South-West Province (Ewusi *et al.*, 1992). None of the Ewusi *et al.* recommendations was apparently implemented, and the national picture of *Prunus africana* exploitation remained unclear until 1994, when the new forestry law was enacted. The Mount Cameroon Project, a biodiversity conservation project, instigated actions that led to another management inventory of *Prunus africana* on Mount Cameroon from 1996 (ONADEF, 1997). A national inventory of *Prunus africana* was initiated in 2000 under the leadership of the Ministry of the Environment and Forestry. Preliminary data on the stock from the Tchabal Mbabo and Tchabal Gang areas are available (Belinga, 2001), but details for further actions are not indicated.

2.4.2.2 *Prunus africana* resource and village livelihoods on Mt Cameroon

The current legal framework in Cameroon makes no provision for village communities to harvest *Prunus africana* bark or any other special forest product for commercial purposes without exploitation permits. No village community has applied for a permit to date, but there are indications of villagers' involvement in *Prunus africana* bark harvesting since 1994 (Eben Ebai *et al.*, 1994; Figure 2.11). However, through the Mount Cameroon Project, two villages – Mapanja and Bokwango - were able to embark on *Prunus africana* bark exploitation on Mount

Cameroon under the Plantecam license in 1997. This arrangement was made specially to involve local people in bark harvesting, protection and regeneration of the species as a way of ensuring long term sustainability. It was anticipated that such initiatives would put an end to illegal exploitation whilst simultaneously enabling local people to derive benefits directly from the resource, individually or collectively, creating employment, providing the finance for development projects and reducing out-migration (Eben Ebai *et al.*, 1994).

Under the terms of the village/Plantecam agreement, the villages' Prunus Harvesters Unions exploit bark in place of Plantecam-recruited workers and sell it directly to the pharmaceutical company. A gross price of US$0.32/kg (US$1 = 650 Fcfa), including tax, was paid to villagers from 1998, against US$0.15/kg offered by licensed middlemen before the agreement (Laird & Lisinge, 1999; Ndam *et al.*, 2000). A preliminary assessment (Ndam & Ewusi, 1999b; Ndam *et al.*, 2000) of the impact of the agreement reveals two positive results. Firstly, illegal exploitation has been kept under control and a joint monitoring team set up. This team is made up of MINEF/MCP personnel, Plantecam staff and harvesters' representatives. Secondly, village livelihoods have improved considerably as the result of the involvement in bark exploitation. The Mapanja Prunus Harvesters Union (MPHU) sold bark to Plantecam for the equivalent of US$38 461 over a period of nine months in 1998 (Ndam & Ewusi, 1999b; Ndam *et al.*, 2000). Of this amount, US$2431 went to the village development fund, against the meagre US$192.3 usually paid to village council by Plantecam for a period of two years prior to 1997 under an unclear agreement (Laird & Lisinge, 1999). A further US$1650 covered the running costs of the group. The remaining US$34 380 was shared among 60 harvesters according to the input each member made. All parties - including *Prunus africana* – benefit from this agreement, although its long term success depends on the wider national and international policy framework (Ndam *et al.*, 2000).

2.4.2.3 Agroforestry and pure stands tree planting initiatives

A call for action to introduce *Prunus africana* into rural household farming systems in montane areas of Cameroon was made only as late as 1991, when the destructive impacts of existing harvesting practices were recognised (Besong *et al.*, 1991). Recommendations to encourage domestication through formal programmes followed (Cunningham & Mbenkum, 1993; ICRAF, 1994; Anonymous, 1997; Cunningham *et al.*, 1997). The aims of the domestication programmes were to secure the long-term supply of bark to meet pharmaceutical demand and ease pressure on wild populations, while providing substantial revenue to rural households. An outcome is that *Prunus africana* has lately (since 1994) been planted both in association with other crops and as pure stands in several localities in the West, North-West and South-West Provinces (Figure 2.10).

Increased awareness of the economic importance and the potential disappearance of *Prunus africana* from the wild in recent years has prompted individual farmers and groups of farmers to plant the species in montane Cameroon. Cunningham *et al.*, (1998) identify two main motivations. First, *Prunus africana* planting is a cash-earning enterprise through bark and potential timber trades. This argument is particularly relevant in areas where the population has become increasingly dependent on exotic plantations. A calculation by Plantecam staff has suggested that a 10 000 trees plantations of *Prunus africana* would produce 800 t of bark after 20 years, representing at least 160 millions Fcfa (US$246 154) given the current factory gate buying net rate of approximately 200 Fcfa per kg (Djomkam, 1999). Second, *Prunus africana* is an important medicinal tree for local consumption. The use of *Prunus africana* either singly or in combination with other ingredients to treat a number of ailments locally, makes it a local favourite for agroforestry. Environmentally, by domesticating *Prunus africana*, farmers are enhancing the quality of their land through the establishment of trees in areas currently suffering from deforestation, erosion and loss of soil fertility (ICRAF, 1994).

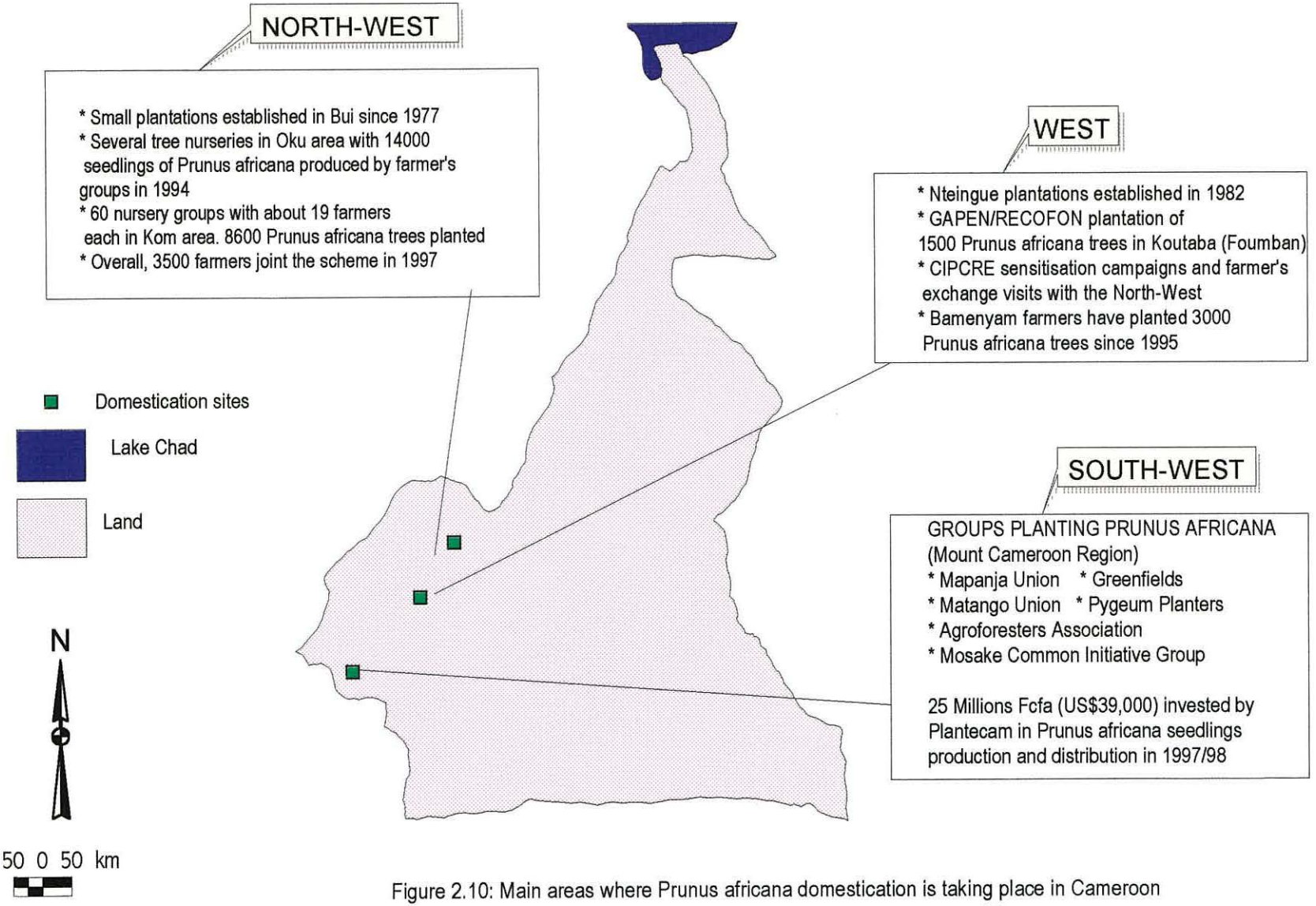

Figure 2.10: Main areas where Prunus africana domestication is taking place in Cameroon

Although the adoption rate of *Prunus africana* for rural farming systems varies markedly from one area to another in Afromontane Cameroon, this appears to be a fairly long-established practice in Bamenda highlands. *Prunus africana* was the most important species in farmers' tree nurseries in Oku in 1993, accounting for one-third of all the seedlings grown. A year later, in 1994, 23 of the 35 farmers' groups produced about 14 000 *Prunus africana* seedlings (Cunningham *et al.*, 1998). In the Kom area of Boyo Division, about 60 nursery groups composed of about 10 farmers each, produced and planted 8600 *Prunus africana* (Cunningham *et al.*, 1998). It is now believed that in the North-West Province alone, about 3500 farmers have joined *Prunus africana* tree planting schemes (Cunningham *et al.*, 1997).

Prunus africana tree planting has been a slow activity in the Mount Cameroon region of the South-West Province and attention here has focused on natural populations. Although few pioneer farmers were planting *Prunus africana* prior to 1994, planting by farmers increased sharply after the outbreak of illegal exploitation in the region (Eben Ebai *et al.*, 1994). There are registered farmers' groups at Mapanja (Mapanja Union), Bokwango(Matango Union), Ewongowe-Bova II (Pygeum Planters), Muyuka (Agroforesters Association), Buea (Greenfields) and Mosake Common Initiative Group (Nkuinkeu, 1999). Recent accounts of Plantecam regeneration efforts in the region mention an expenditure of 25 million Fcfa (US$38 642) in 1997/98 towards the cost of production of *Prunus africana* seedlings and their distribution (free of charge) to farmers, the cost of awareness raising campaigns and the cost of the fight against illegal bark harvesting (Djomkam, 1999).

Prunus africana tree planting is apparently a fairly recent practice in the Western Province although bark exploitation started in this region more than 30 years ago. Recently, the "Centre International Pour la Promotion de la Création - CIPCRE", a local Non Governmental Organisation (NGO), started a sensitisation campaign, mobilising villages for exchange visits with the nearby North-West Province (Mahop *et al.*, 1999). Villagers in Bameyam are the pioneers in the province and have planted 3000 *Prunus africana* trees since 1995 (Mahop *et al.*, 1999), involving the collection and successful germination and raising of plants from at least 2 kg of seeds (Albrecht, 1993). Towards the northern part of the Province in Foumban, activities have been

undertaken by "Programme de Régénération des Forêts du Noun - GAPEN/RECOFON", a local NGO. While waiting for its tree planting initiatives to be extended to rural farmers, this programme has planted 1500 *Prunus africana* trees in its 10 ha plot at Koutaba for demonstration purposes (Mahop *et al.*, 1999).

One problem faced in small *Prunus africana* tree planting schemes is seed availability. Seed in itself is already a lucrative business in many parts of Cameroon. In the Bamenda highlands of North-West Province, seed prices range from 250 Fcfa (US$0.4) to 4000 Fcfa (US$6.2) per kilogram and seedling prices vary from 25 Fcfa (US$0.04) for bare-root seedlings to 250 Fcfa (US$0.4) for potted seedlings (Cunningham *et al.*, 1998). Although a large *Prunus africana* tree can produce up to 20 kilograms of seeds per year, production fluctuates widely between years, with seed shortage likely to be exacerbated in future years as natural populations are reduced (Simons *et al.*, 1998).

2.4.2.4 Vegetative propagation

Research into the application of vegetative propagation techniques to *Prunus africana* is conducted under a joint ICRAF/IRAD project. The results of this work show that rooting is best in sawdust and in a mixture of sawdust and sand. Significant root development has also been observed with high leaf area index and a low concentration of applied rooting hormone (auxin) (Tchoundjeu *et al.*, undated). The "Centre International pour la Promotion de la Création" and the International Centre for Research in Agroforestry are using vegetative propagation with farmers in Bameyam, Bandjoun, Belo, and other areas (Mahop *et al.*, 1999).

2.4.3 Trend in bark exploitation

The quantities of *Prunus africana* bark exploited in Cameroon for export increased significantly from 200 tonnes in 1980 to 3100 tonnes in 1991 (Cunningham & Mbenkum, 1993). The domestic picture of the trend in exploitation is unavailable and the network is complex. Trade figures mentioned at least 9309 tonnes of bark processed from 1986 to 1991, with a further 2400 tonnes in 1992 (ICRAF, 1994;

Leakey, 1995). The trend of exploitation has been documented for Mount Cameroon (Figure 2.11). The Mount Cameroon region is the only site where there has been systematic documentation of exploitation levels. Data held in the archives of the Divisional Delegation of MINEF, Fako Division, South-West Province were used. The Mount Cameroon region is also considered to host the most important population of *Prunus africana* in West Africa (Acworth *et al.*, 1997).

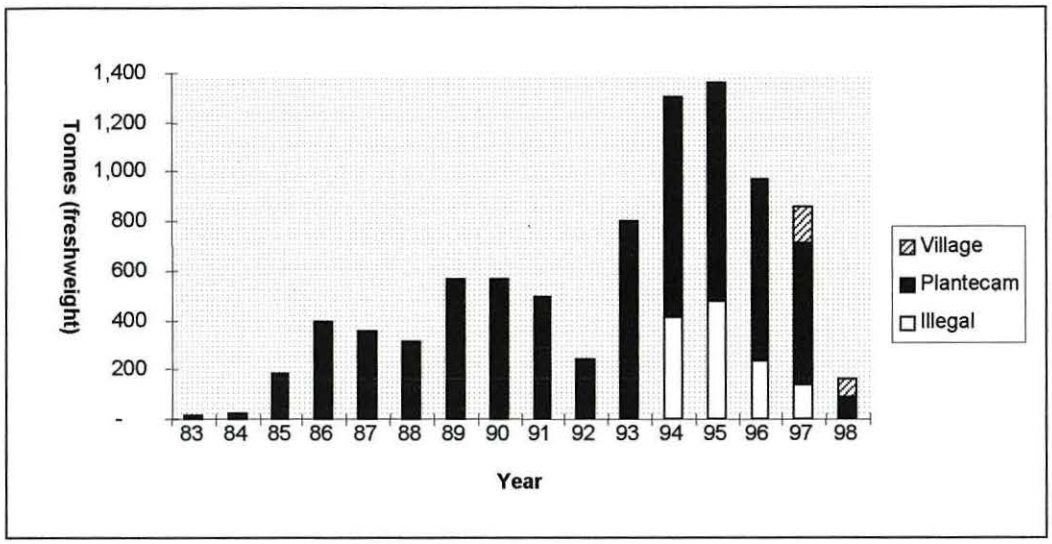

Figure 2.11: Trend in *Prunus africana* exploitation on Mount Cameroon (1983 - 1998)

Until 1993, neither villages nor illegal exploiters were involved with *Prunus africana* on Mount Cameroon and any tree harvested was supplied to Plantecam. The outbreak of illegal exploitation arose in 1994, following the issuance of export license to three other Cameroonian entrepreneurs and the involvement of many contractors and illegal buyers (Eben Ebai *et al.*, 1994). It also appears that exploitation permits were issued to two other Cameroonian entrepreneurs to operate on Mount Cameroon, in areas that overlap with Plantecam license (Ndibi & Kay, 1997).

Little information on exploitation in other parts of the country is available. Despite the withdrawal of Plantecam from Mount Oku in 1986, other licensed contractors took its place and exploited trees theoretically left for recovery (Parrot & Parrot, 1990). Pressure to harvest *Prunus africana* bark in this area peaked in the 1984-1985 harvesting season when the bark of 8000 trees was completely peeled (Asanga, 1993).

The deaths of almost 80% of the mature trees in the massif have been attributed to poor harvesting prior to 1993 (Asanga, 1993; Leakey, 1995).

2.4.4 Resource character

2.4.4.1 Timber and other local uses

The use of *Prunus africana* as timber *per se* is not documented in Cameroon and the tree appears nowhere on the list of exploitable timber species in the Forestry Department. Except in the Cameroon highlands, which are suffering from severe deforestation, other tree species are preferred for timber. Even in areas where the scarcity of timber is acute, because *Prunus africana* usually occurs at high elevations, people prefer exotic species, which can be grown quickly and in more accessible locations. In many localities on the Bamenda highlands and in the Western Province, exotic tree species are well established in the landscape.

Prunus africana is classified as a hard wood and this strength makes it a favoured wood for domestic purposes. Its red wood is hard and heavy, weighing 720 to 768 kg/m^3 when dried (Sunderland & Nkefor, 1997) and suitable where strong tough wood is required. The timber is fairly durable, planes well and is good for flooring, turning and moulding. It takes a high polish (ICRAF, 1994). However, Brown (1978) describes *Prunus africana* timber as refractory and liable to split, especially during nailing and bending.

Trees of small diameter are a source of axe and hoe handles in the Cameroon highlands and in the South-West Province (Nsom & Dick, 1992; Sunderland & Nkefor, 1997). Housewives favour *Prunus africana* wood for pestles (ICRAF, 1994) and trees of smaller size are suitable for this purpose. Poles are used for fencing around farmlands and compounds; meanwhile dead wood of larger trees is exploited either for firewood or for charcoal production (Sunderland & Nkefor, 1997). The durability of the wood has also made *Prunus africana* a preferred species for the salt troughs used by herders in the Tchabal Mbabo of the Adamaoua plateau, for their cattle (Pouakouyou, pers.obs.). Troughs of various sizes are placed in grazing areas

and filled regularly with salt at certain periods of the year for cattle. The life span of a trough is not known, but it is likely to be several years despite the frequent mist of the area.

2.4.4.2 Traditional medicinal uses

Prunus africana has been used for generations in traditional medicine to treat various ailments, but this virtue like many others in the traditional context was not documented until very recently. Reports indicate the implications of *Prunus africana* bark in the treatment of "old man's" diseases for centuries by the Bakweri peoples on the slopes of Mount Cameroon (Mbai, 1998). During a survey in the Mount Cameroon region, *Prunus africana* was ranked as the fourth most popular medicinal plant species, and collected by 14% of households (Jeanrenaud, 1991). The infusion of the bark is drunk to treat chest infections or as a tonic or tea from bark after which the patient's epiglottis is stimulated with the feather of a cock to induce vomiting (Sunderland & Nkefor, 1997). In association with the leaves and roots, the bark is used to treat malaria and stomach ache in Kom area of the Bamenda highlands (Nsom & Dick, 1992). Rheumatism and gonorrhoea are also treated using the bark of the tree in association with other, unspecified, herbal ingredients (Cunningham *et al.*, 1998).

2.4.4.3 Benign Prostatic Hyperplasia and *Prunus africana*-derived drugs

The therapeutic properties of *Prunus africana* bark came to attention in 1966 when J. Debat secured his patent for processing extracts from the bark. For over thirty years, the extract has been used in the treatment of benign prostatic hyperplasia. Together with the closely related prostate hypertrophy, benign prostatic hyperplasia affects 60% of older men in Europe and the United States of America (Cunningham & Mbenkum, 1993; Tchoundjeu *et al.*, undated; ICRAF, 1994; Leakey, 1995). It is now expected that one of out every two men in western countries will live longer than 80 years, with the result that 88% may develop histological evidence of benign prostatic hyperplasia (Cunningham & Mbenkum, 1993; Cunningham *et al.*, 1997). The situation is of significant concern in the USA where for example a 40 years old man has at least a 10% chance of needing surgery for benign prostatic hyperplasia. In a

survey in Scotland, 30.2% of a random sample of otherwise healthy men aged between 40 and 79 years had prostatic enlargement and symptoms of benign prostatic hyperplasia (Anonymous, 1992). This is the most common benign proliferative disorder of unknown etiology found in man (Boudon *et al.*, 1995; Weisser & Krieg, 1997) and associated with ageing. Symptoms include an increase in the frequency of urination, inability to empty the bladder, pain in passing urine and post urinary dribbling (ICRAF, 2000).

Despite its widespread occurrence in older men in the developed world, the mechanism of action of benign prostatic hyperplasia is not completely understood. Pauvertbraquet *et al.* (1994a) however, attribute the development of benign prostatic hyperplasia to basic fibroblast growth factor. Dysregulation of testosterone conversion to dihydrotestosterone by 5-alpha-reductase has also been described as a key step in its development (Boudon *et al.*, 1995). It is however widely accepted that benign prostatic hyperplasia is under the endocrine control of the testes and strongly associated with ageing (Weisser & Krieg, 1997). As the disease progresses, the bladder changes from a state of compensation to de-compensation with severe and irreversible alterations of its function (Levin *et al.*, 1996). The commercial epithet of *Prunus africana* bark extract-derived tablets, Tadenan, Pygenyl or Proscar (Finasteride), is known as a pharmaceutical agent used in the treatment of benign prostatic hyperplasia in lieu of classical surgery.

The mechanism of action of the bark extract has never been clearly resolved (Pauvertbraquet *et al.*, 1994b), but it is believed to promote anti-inflammatory activity and inhibition of bladder hyperactivity during the above conditions. The constituents of the bark extract have a safe toxicological profile, and some of them are reported to have anticarcinogenic and antimutagenic properties (Andro & Riffaud, 1995). A 5 mg tablet of Proscar once a day is reported to give a 20% size reduction of the prostate gland (ICRAF, 1994). Tadenan is known to have growth factor antagonism, offering an attractive therapeutic option as it confers significant improvement of urinary symptoms, maximum flow rate and residual volume, with no serious side-effects (Desgrandchamps, 1997).

Since 1969 when Tadenan was used in France for the first time to treat mild and moderate symptomatic benign prostatic hyperplasia (Andro & Riffaud, 1995), synthesis of the compounds active in the drug has not been achieved. Several natural ingredients in the bark extract are apparently present in the contents of Tadenan capsules.

Chemical and pharmacological studies have revealed that the efficacy of *Prunus africana* bark is a synergetic effect of a cocktail of a number of known and unknown compounds (Simons *et al.*, 1998; Martinelli *et al.*, 1986; ICRAF, 2001a). Among the known compounds, there are three categories. Firstly, there are phytosterols (*e.g.* B-sitosterol) which are reported to have anti-inflammatory effects, interfering with the accumulation of pro-inflammatory prostaglandin in the prostate. Secondly, there are pentacyclic triterpenes (including the derivatives of ursolic and oleanic acids, revealed in chloroformic extracts (Fourneau *et al.*, 1996), which have an anti-oedema or decongesting action. Lastly, there are ferulic esters (*n*-docosanol and tetracosanol) which reduce prolactin levels and block the accumulation of cholesterol in the prostate. It was initially believed that the activity of *Prunus africana* extracts could be attributed to the efficacy of *n*-docosanol. This component is found in trace amounts at the final stage of the processed bark (Mutzing *et al.*, 1979) and is apparently just one of the active components (Martinelli *et al.*, 1986).

CHAPTER THREE:
STUDY AREAS AND METHODOLOGY

This chapter describes the methodological approaches, materials used and data processing and analysis techniques of the study. The chapter is divided into four sections. Section 3.1 introduces the study areas, starting with the procedure used in selecting the research sites. Section 3.2 presents an ecosystem context for the investigation into the phenology and reproductive biology. Protocols for assessment and monitoring are the basis of Section 3.3 and Section 3.4 explains data summarisation approaches and analysis techniques. Sections are subdivided as appropriate.

3.1 Study Areas

3.1.1 Identification of locations

Preliminary information on the distribution of *Prunus africana* in Cameroon was gathered at Bangor in early 1999 in the framework of the *Prunus africana* monograph project. This information was augmented with data from voucher specimens at the National Herbarium, Yaounde, and discussions with Plantecam staff at Mutengene and government officials of the Ministry of the Environment and Forestry. Sixteen potential sites were identified at the end of this investigation (Table 3.1) and segregated into different groups on the basis of combinations of three biophysical factors: climate, accessibility to site, and exploitation pressure.

The following descriptions and explanations are provided for the biophysical factors used in the site allocation process.

Climatic regime

The distribution range of *Prunus africana* in Cameroon falls within two main climatic regime: the equatorial regime and the tropical regime (Neba, 1987). Both regimes were considered separately in the selection procedure.

Table 3.1. Distribution of potential research sites and characteristics

Potential sites	Geographical co-ordinates	Climate	Site accessibility	Exploitation pressure
Mt Bana	5°09'N – 10°18'E	Equatorial	Easy	Low
Mt Bafut-Nguemba	5°56'N – 10°10'N	Equatorial	Easy	Low
Mt Bamboutos	5°35'N – 10°11E	Equatorial	Easy	Low
Mt Cameroon	4°05'N – 9°05'E	Equatorial	Easy	High
Mt Golep	5°04'N – 11°17'E	Equatorial	Difficult	Low
Mt Kishong	6°20'N – 10°45'E	Equatorial	Difficult	Low
Mt Manengouba	5°00'N – 9°50'E	Equatorial	Easy	Low
Mbam massif	5°54'N – 10°44'E	Equatorial	Difficult	Low
Mt Oku	6°11'N – 10°35'E	Equatorial	Easy	Average
Oshie	6°10'N – 9°51 E	Equatorial	Difficult	Low
Mt Tabenken	6°33'N – 10°36'E	Equatorial	Difficult	Low
Tchabal Mbabo	7°16'N – 12°09'E	Tropical	Easy	Average
Tchabal Ouadde	7°02'N – 11°43'E	Tropical	Difficult	Low
Tiofou	5°30'N – 12°12'E	Equatorial	Difficult	Low
Wum	6°23'N – 10°05'E	Equatorial	Difficult	Low
Mt Yangba	5°10'N – 11°25'E	Equatorial	Difficult	Low

The equatorial regime covers the southern part of Cameroon, south of latitude 7° N and is represented by the Cameroonian or equatorial type of monsoon climate in the western part of the country and the Guinean type of climate elsewhere. The Cameroonian type is characterised by a unimodal rainfall distribution with wet months from March to November and the rainfall peak in July-August. Mean annual rainfall is in excess of 3500 mm although there are local variations such as on the wet aspects of Mount Cameroon: 9086 mm mean annual rainfall is indicated in Debundscha, for example, whilst only 2085 mm are received in Mpundu (Fraser *et al.*, 1998). Mean annual temperature is in the range of 20-22°C with only minor variations from one locality to another. The Guinean type of climate is characterised by a year round rainfall with two maxima: in September (main rainy season) and in March-April (smaller rainy season); the minima occur in December-January (main dry season) and in July-August (smaller dry season). The annual rainfall is in the range of 1500-2000 mm and the mean annual temperature is 25°C.

The tropical regime covers the region north of latitude 7° and is divided into a sudanian or humid tropical component (7-10° N) and a sudano-sahelian component

north of latitude 10°. Annual rainfall is within the range 900-1500 mm in the sudanian climate and spreads from March-April to November with a single peak in August. The mean annual temperature is 28°C. The sudano-sahelian component is much drier with an annual rainfall of only 400-900 mm and more than 7 months of dry season. The mean annual temperature is 28°C. *Prunus africana* is present in both the Cameroonian and Guinean component of the equatorial regime and only in the sudanian component of the tropical regime.

Exploitation pressure on *Prunus africana* populations

The exploitation pressure in the potential sites was ascertained using a subjective scale based on Plantecam records of bark received at Mutengene factory from 1995 to 1999 and staff knowledge through meetings with management and field staff members.

a. High: bark received more than 5 times in the last five years;
b. Average: bark received between 2-5 times in the last five years;
c. Low: bark received once only in the last five years or never received although the occurrence of *Prunus africana* in the area acknowledged.

Accessibility

Based on the information available on the national road map and a 1/200 000 topographic map, each prospective locality was located and rated as "easy" access or "difficult" access. Easy access indicates the existence of a road passing closer than 10 km to the location and generally negotiable with a 4WD vehicle throughout the year. Difficult access means there is no marked road within approximately 10 km of the site.

Localities with easy access were preliminarily selected. Field reconnaissance surveys were undertaken to check the existing situation before sampling sites were finalised. Seven localities were identified and data were gathered from these with reconnaissance surveys (Table 3.2).

Table 3.2. Biophysical characteristics of sites visited during the reconnaissance survey
Information on lithology and soils descriptions are based on FAO-UNESCO classification scheme - FAO (1977)

Localities	Lithology	Soils	Topography	Climate	Forest type and conditions
Mt Cameroon	Active volcano, basic effusive rocks: basalt and andesite. Presence of ancient and young lava.	Vitric andosols and leptosols	Montane region. Huge gullies and escarpments. Sharp slopes and deep gullies culminating at 4070 m	Equatorial regime. A single mode rainfall distribution with 8-9 months rainy season.	Mosaic of lowland forest, montane and submontane forest at different degrees of disturbance
Mt Bana	Basalt and andesite with patches of sedimentary rocks of various level of alteration	Orthic and rhodic ferralsols	Escarpments and gullies. Gentle slope with the summit around 1700 m altitude.	Equatorial regime. Single mode rainfall. Marked dry season lasting for 3-4 months.	Forest patches of montane forest completedly degraded.
Mt Oku	Basalt, andesite and pyroclastics	Humic andosols	Combination of sharp and gentle slopes. Presence of escarpments and a crater lake. Summit at 3011 m	Equatorial regime. Marked dry season lasting for 3-4 months.	Montane forest in good condition from 2200 m altitude. Subalpine vegetation from 2700 – 2800 m altitude.
Mt Bamboutos	Rhyolite, basalt and andesite	Acrisols, alisols and plinthosols	Series of hills with sharp and gentle slopes. Huge valleys and escarpment. Summit at around 2400 m	Equatorial regime. Marked dry season lasting for 3-4 months.	Completely degraded montane forest. High level of encroachment and intense farming pressure. Presence of patches of bamboo stands
Mt Manengouba	Basalt and andesite	Orthic and rhodinc ferralsols	Sharp slopes and huge escarpments. Accessibility restricted in places	Equatorial regime Marked dry season lasting for 3-4 months.	Patches of degraded montane forest on the southern flank
Mt Bafut-Nguemba	Basalt, andesite ad pyroclastics	Orthic ferralsols	Series of hills with flat top. Slopes moderate to sharp. Summit at around 2200m	Equatorial regime. Single Marked dry season lasting for 3-4 months.	Patches of degraded montane forest
Tchabal Mbabo	Basalt and andesite	Red ferrasols at mid elevation and thin, dry, rocky leptosols on the plateau	Succession of montane chains with gullies and escarpments.	Tropical regime. Marked and longer dry season lasting for 5-6 months	Patches of montane forest in good conditions. Gallery forests along the streams also present.

Three sites were finally selected for the study on the basis of easy access, high exploitation pressure and the distribution along the climatic gradient south-north (Table 3.3). The distribution of the sites is given in Figure 3.1.

Table 3.3. Site locations and aspects addressed: *Prunus africana* in Cameroon

Geographical areas	Location	Altitudinal range of Prunus (m)	Aspects addressed
Mount Cameroon	Bakingili (4°08' N 9°04' E)	1510 – 1700	Population status and stand characters Flowering and fruiting sequences Reproductive potential
	Bomana (4°17' N 9°10' E)	1700 – 2220	Population status and stand characters Flowering and fruiting sequences Reproductive potential Breeding systems
	Ekona Lelu (4°16 N 9°17' E)	1280 – 1860	Population status and stand characters Flowering and fruiting sequences Reproductive potential
	Mapanja (4°04' N 9°10' E)	860 – 2080	Population status and stand characters Reproductive structures and their development Flowering and fruiting sequences Reproductive potential Breeding systems
North-West province	Oku (6°13' N 10°31' E)	2240 – 2800	Population status and stand characters
Adamaoua province	Tchabal Mbabo (7°15' N 12°03' E)	1940 – 2200	Population status and stand characters

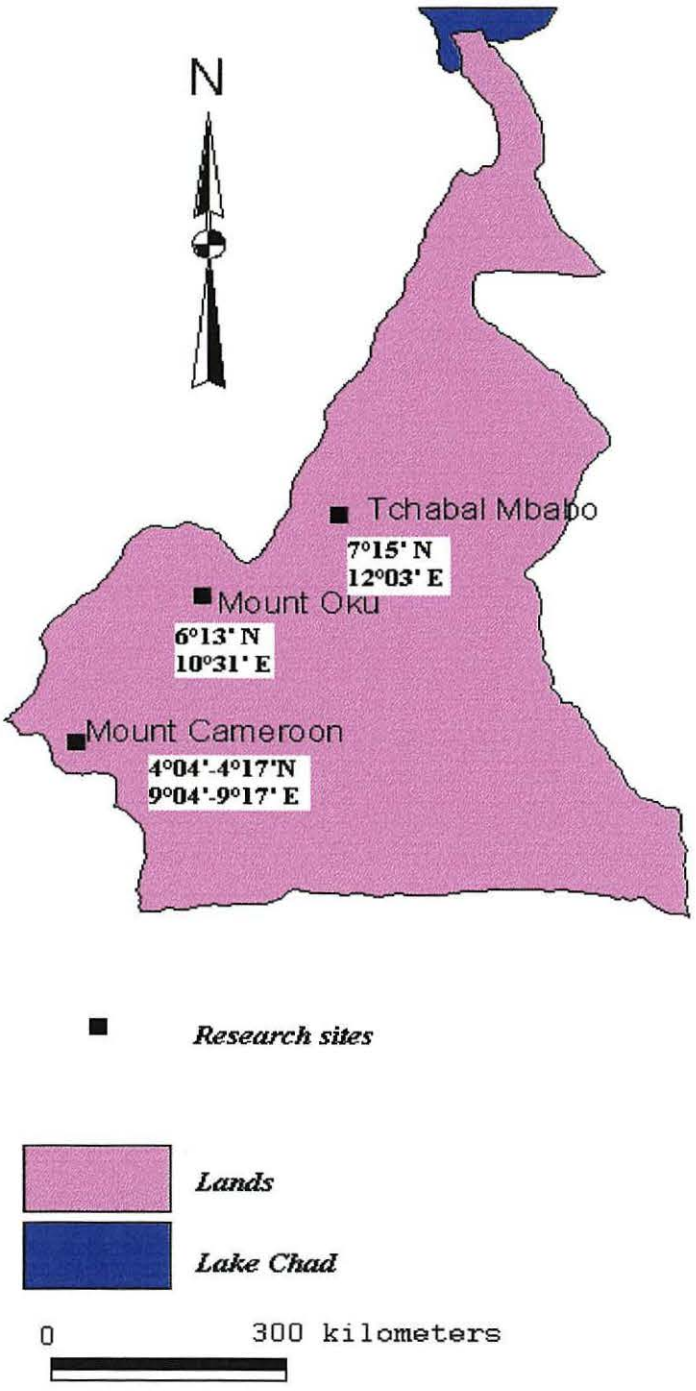

Figure 3.1: Geographical distribution of research sites in Cameroon

3.1.2 Courtesy and protocol

Meetings and consultations were held with government officials and local communities on Mount Cameroon, Mount Oku and Tchabal Mbabo, and with Plantecam staff.

Contacts were initiated with village communities on Mount Cameroon in Mapanja in October 5, 1999 following early discussions with MINEF provincial and divisional delegations of the South-West and Fako and the Mount Cameroon Project. Communities in Bakingili, Ekona Lelu, Bomana and Bonakanda were subsequently contacted. Members of the village council were approached in the first instance, followed by a large meeting involving wider community members. The objective of the research was explained, linking it as much as possible in terms of conservation and management purposes to the then ongoing *Prunus africana* inventory – reported by Underwood & Burn (2000) - and previous work on the species on the mountain by Ndam (1998). *Prunus africana* is a key forest resource on Mount Cameroon and gaining support for related activities was generally not problematic. The village requested a libation operation, as required by established practice in the Mount Cameroon region. This traditional ritual is performed with alcohol and is destined to secure the support of ancestors or so-called gods of the mountain for actions to be undertaken in the area. Community members directly involved with *Prunus africana* activities in the villages were contacted by the village councillors and linked with the researcher for further actions. This was however not possible in Bomana village where hostilities linked to previous Mount Cameroon Project activities in the village were voiced. One of the early objectives of the Limbe Botanic Garden and Rainforest Genetic Conservation Project, the predecessor to the Mount Cameroon Project, has been to establish protected areas on Mount Cameroon in areas of high conservation values. The forest above Bomana village was identified as one of such areas, hosting a diverse set of plant and animal species of conservation interest. As hunting and trapping for bushmeat is one of the main activities in this part of the mountain, villagers expressed unease over the implications for them of this conservation objective. Despite the reorientation of the project goal after the inception of the Mount Cameroon Project in 1994, suspicion remained and the project work with this village

has proved difficult. Bomana village was therefore discarded and a more co-operative Bonakanda village was involved to enable access to the forest above Bomana.

In Oku area, meetings were held with staff of the Kilum/Ijim Mountain Forest Project between 17-18 April 2000. The project has facilitated the creation of village-based forest management institutions in villages around the mountain in their attempt to offer a more responsible legal status to the remnant forest on Mount Oku. Contacts were established with these village-based institutions. EMFVEH-MII, a village management institution comprising Mbah, Keyo and Ngyuinkei II communities and covering the mountain areas with a sizeable population of *Prunus africana* was identified for further actions. Discussions were held with members of this group in relation to the distribution and management of *Prunus africana* on the mountain. A participatory map was produced to guide reconnaissance trips.

Unlike Mount Cameroon and Oku regions where the local populations are directly or indirectly involved in *Prunus africana* exploitation and management, nearly all the inhabitants of the Tchabal Mbabo areas are herders, living in dispersed small settlements with no major interest in the forest. Djaouro Bakari of Fungoi is the leader of the herders in this region and was contacted on April 3, 2000. The research ideas were explained to him. A recent visit of ONADEF staff in the area in the context of the *Prunus africana* national inventory added relevance to this initiative. No objection was voiced. For work in this area, guides were subsequently brought in from Banyo, some 150 km away, following early contacts and discussions with the staff of MINEF Divisional Delegation of Mayo Banyo.

3.2 Ecosystem context for phenology and reproductive biology

The site where the phenology and reproductive biology studies on *Prunus africana* were conducted was Mount Cameroon, South-West Province. Mount Cameroon is an active volcano, about 45 km long and 30 km wide, rising to 4070 m and located on the coast of the Gulf of Guinea (3°57' – 4°27 N, 8°58' – 9°24 E).

Mount Cameroon has a climate characterised by one wet and one dry season. Climatic variables change considerably however within relatively short distances. Exposure of the southern and western slopes to the Atlantic Ocean and the presence of either continental or maritime winds at different times of the year explain much of this variation (Figure 3.2).

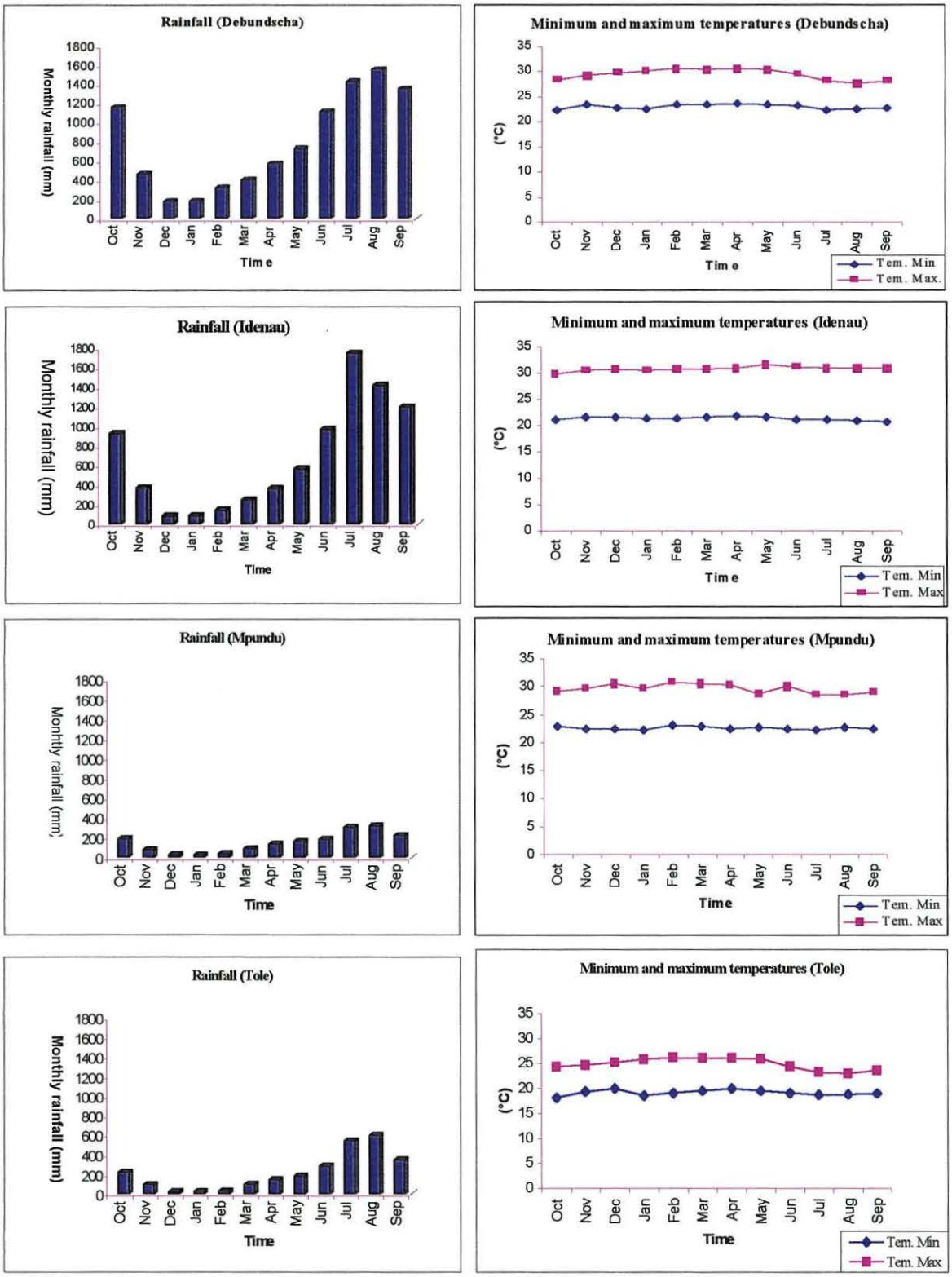

Figure 3.2. Rainfall patterns, minimum and maximum temperatures in four meteorological stations around Mount Cameroon

Mean annual rainfall on Mount Cameroon ranges from 2085 mm in Mpundu, some 44 km from the coast on the north-eastern slopes to 9086 mm at 20 m altitude at Cape Debundscha on the western slope. There is seldom any month without precipitation being recorded, but July and August are consistently the wettest months of the year. In each of these months, at least 100 mm rainfall is recorded even in years of low rainfall at the driest station (Mpundu). December to January is a dry period, although only in relative terms at the western foot where mean rainfall in the driest month (January) is 153 mm in Debundscha and 72 mm at Idenau (Fraser *et al.*, 1998). Mean monthly maximum temperatures are 27-31°C at lower altitudes (Idenau, Debundscha and Mpundu), but fall as low as 22.5°C at 700 m at Tole. Mean monthly minima are 20-24°C at Idenau, Debundscha and Mpundu, but lower (18-19°C) at Tole. Temperatures tend to be lower from July to October and higher from November to February, although there is often also a slight drop during the Harmattan period (December – January).

Air humidity is high during the day: 75-80% (Payton & Edwards, 1993), with persistent cloud covering the mountain for most of the year. The number of sunshine hours varies through the year; values are generally low between June and October. Mean annual numbers of sunshine hours range from 1188 at Idenau to 1625 at Mpundu (Fraser *et al.*, 1998). The FAO-UNESCO description indicates the presence of leptosols and vitric andosols on Mount Cameroon (FAO, 1977).

Habitat diversity is one of the main features of Mount Cameroon, where there is a forest vegetation continuum from sea level to the tree line. Mount Cameroon supports a rich and diverse set of plants including many endemic and near endemic species; in total over 2300 species of plants have been recorded from the area (Ndam *et al.*, 1999). Almost all the higher plant families endemic to tropical Africa: Hoplestigmataceae, Huaceae, Lepidobotryaceae, Medusandraceae, Olacaceae, Pandaceae, Scytopetalaceae are present on Mount Cameroon and the hills nearby (White, 1983; Cheek *et al.*, 1996). Mount Cameroon has therefore been recognised as a Centre of Plant Diversity (IUCN/WWF, 1994).

3.3 Protocols for assessment and health monitoring

3.3.1 Distribution and measurement of trees

A participatory map indicating areas with *Prunus africana* trees in each locality was produced with villagers in each locality during meeting sessions. The areas were positioned in relation to convenient reference points such as last farms, watercourses and hunting paths. This allowed the definition of the starting point and the identification of a path from the village, which would serve as a monitoring transect. From the first *Prunus africana* tree $\geq$ 10 cm dbh encountered at lower altitude, a sequence of *Prunus africana* trees $\geq$ 10 cm dbh were recruited during ascent through the forest belt. Those *Prunus africana* individuals satisfying the size criterion specified and visible from the path were measured and recorded. Figure 3.3 shows the ascent paths followed for this activity on Mount Cameroon (35 km in total). Figure 3.4 locates the path followed on Mount Oku (5 km), accessing the forest from Keyo village. This approach was however modified in two situations: for the *Prunus africana* population of the north-west of Mount Cameroon and for the Tchabal Mbabo assessment.

1. Mount Cameroon: north-west *Prunus africana* population

Bomana village denied access from lower altitude and the recruitment process of *Prunus africana* trees was initiated from the montane grassland downwards, following the eco-tourism track opened by the Buea component of the Mount Cameroon Project. Forest in this area was accessed from the east, entering through Bonakanda village, traversing to the so-called "Radio mast" and descending westwards into the Bomana forest.

2. Tchabal Mbabo

For the Tchabal Mbabo locality, the reconnaissance trip was organised from Sambo Labo village in the southern foothills of the mountain, progressing northwards to Mayo Kelele and thence to Fungoi village. Savanna woodland dominates the vegetation here with forest occurring in discrete patches, usually in gullies or river belts. There are large forests around Fungoi. Two belt transects, each approximately

200 m wide, were established across two forest patches following the main path used by exploiters and herders (Figure 3.5). The first transect was approximately 7 kilometres long and the second transect was 3 kilometres long, making a total of about 10 km (200 ha).

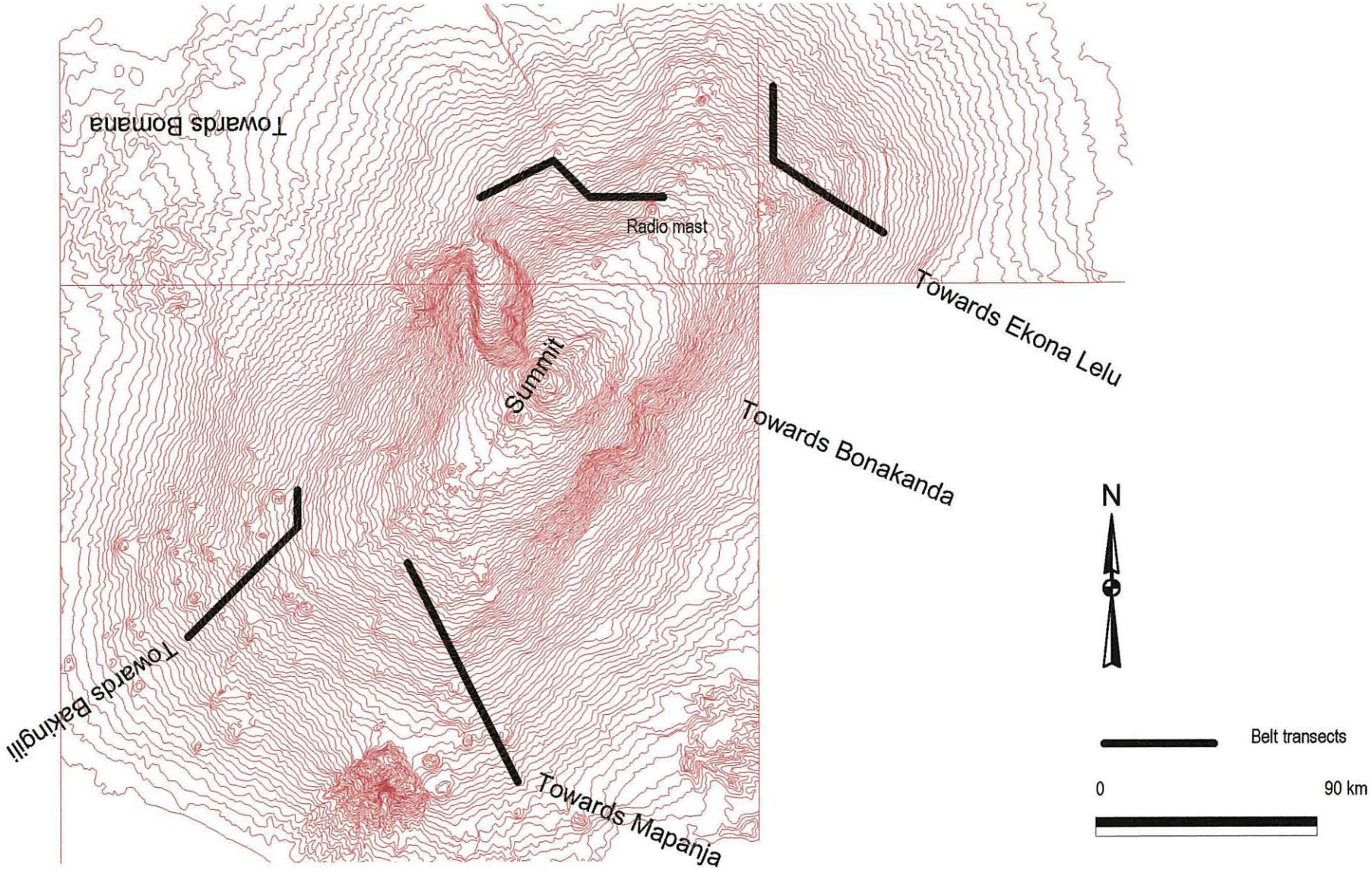

Figure 3.3: Approximated location of belt transects on Mount Cameroon

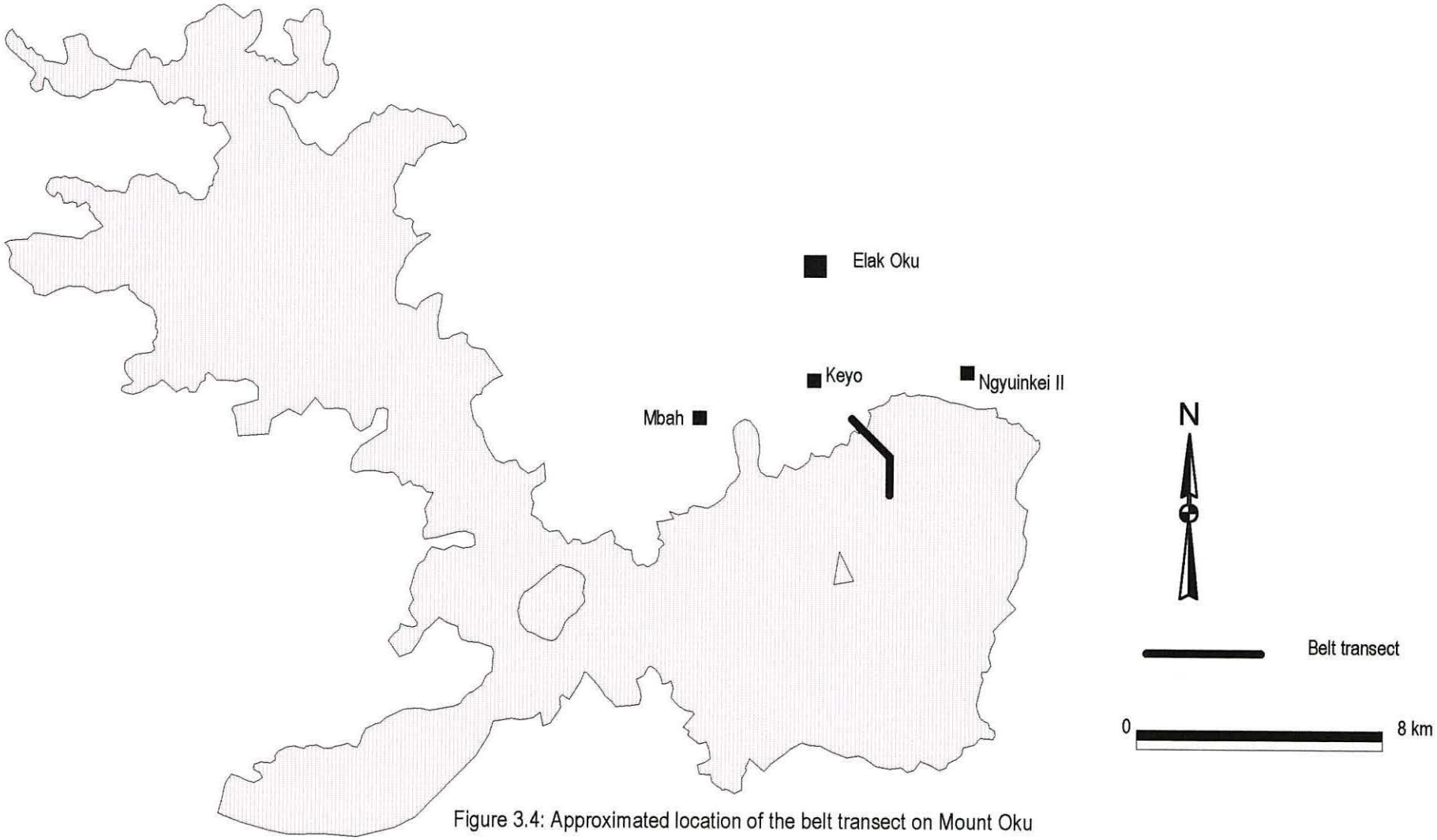

Figure 3.4: Approximated location of the belt transect on Mount Oku

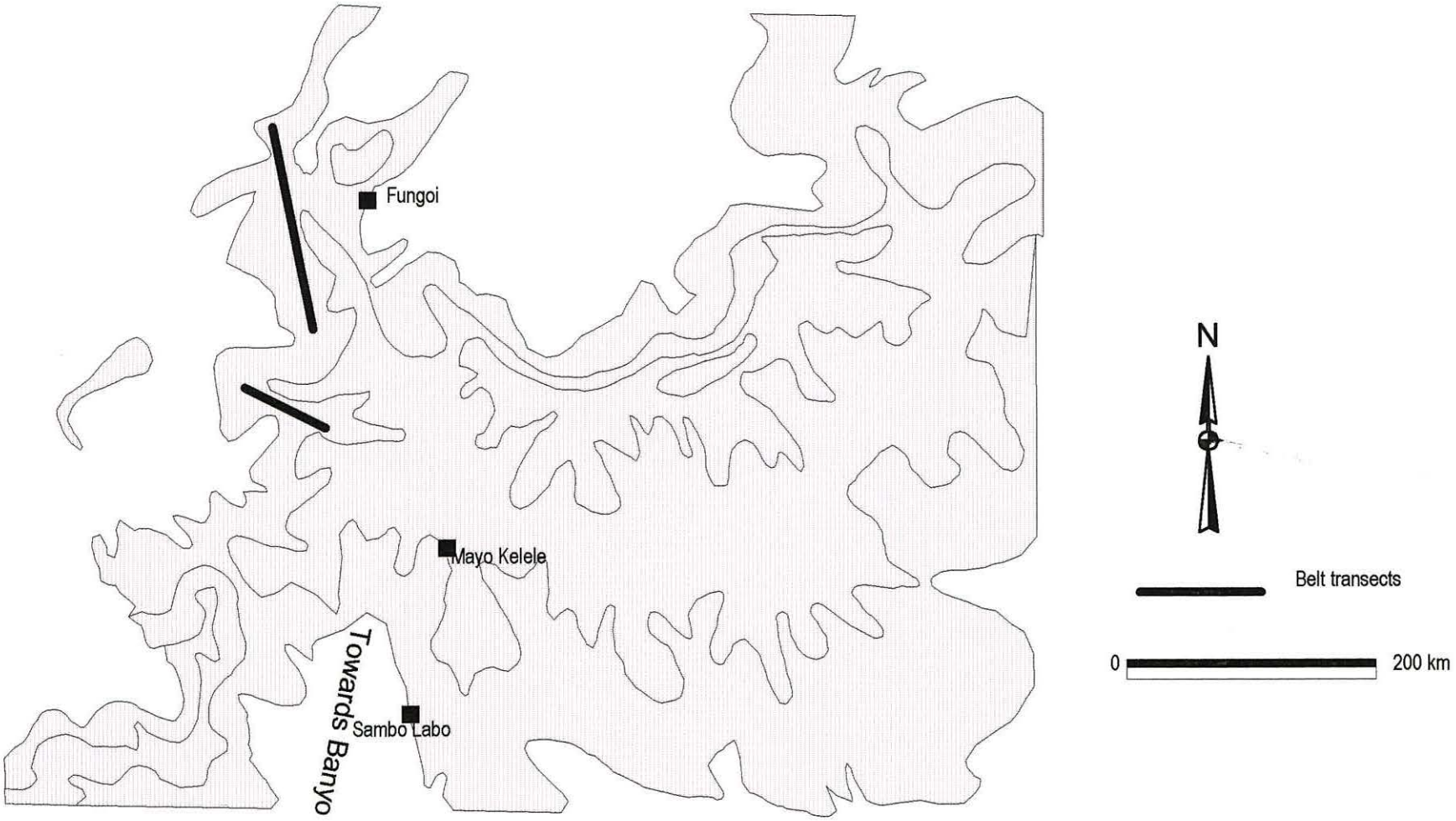

Figure 3.5: Approximated location of belt transects on the Tchabal Mbabo plateau

For each tree recorded, the following information was collected on Mount Cameroon (1 to 5), Mount Oku and Tchabal Mbabo (1,2,5):

1. Geographical position and elevation (using GPS instrumentation).
2. Diameter in cm at breast height (dbh)
3. The visibility of the crown (good; fairly good; poor)

The following definitions were applied:

- good visibility: 100% of the crown of the tree is entirely visible.
- fairly good visibility: more than 50% of the crown is visible.
- poor visibility: less than 50% of the crown is visible.

4. The suitability of the tree for inclusion in the study of reproductive potential (suitable/not suitable).

The following definitions were used:

- Suitable: forest mid-storey light; undergrowth (low interception of falling flowers and fruits).
- not suitable: forest mid-storey thick; undergrowth dense impeding the fall of flowers and fruits.

5. Health status: a combination of the health status of the trunk and of the crown was used to characterise health status (Table 3.4).

Table 3.4: Health assessment scale of *Prunus africana* trees

Health Class	Description
1	Undamaged tree with perfect trunk (100% intact) from 1.30 m dbh up to the first branch and all branches alive
2	Tree with evidence of debarking affecting less than 50% of the trunk and less than 50% of dead branches
3	Tree with evidence of debarking affecting less than 50% of the trunk and more than 50% of dead branches
4	Tree with evidence of debarking affecting more than 50% of the trunk and less than 50% of dead branches
5	Tree with evidence of debarking affecting more than 50% of the trunk and more than 50% dead branches

Viability was determined by direct observation. *Prunus africana* is an evergreen species and living branches bear a complement of leaves at different stages of maturity. This was used as an indication of the viability of the branches. Trees recruited in this process were permanently marked using a tag bearing a serial number. The serial number consisted of the first two initials of the locality - e.g. BA for Bakingili - followed by the corresponding numeric figure in sequence along the path – e.g. BA06 for the 6th tree incorporated in the set along the path in Bakingili.

3.3.2 Reproductive structures and their development

The objective of this exercise was to characterise inflorescence architecture and monitor the development of individual flowers. A wooden scaffold and a platform were constructed on the tree MA02 in Mapanja forest on the south-eastern slope of Mount Cameroon to allow access and close monitoring. This tree was purposely chosen and had large branches from 15 m height that could support a sizeable platform and hence easy and safe access to the flowers. Seventy-three inflorescences that were later involved in the pollination experiments were selected on the basis of accessibility from the platform. *Prunus africana* inflorescence is a simple raceme and parameters recorded on each raceme included the length along the axis, number of flower per raceme – and later the number of fruits per infructescence – and the sequence of flower opening along the axis starting from the most proximal flower. Individual racemes were labelled and given a serial number. Flowers were not labelled individually to avoid interference with pollinator attraction. Individual flowers were however virtually numbered from the bottom to the top of each raceme to allow data recording. Point of attachment of early-abscised flowers was inscribed on the axis using a permanent marker.

Development was observed in 202 flowers and fruits from 14 December 1999 to 31 March 2000. Using hydrogen peroxide, stigma receptivity was assayed on 20 flowers. The test for stigma receptivity was conducted when a tiny yellowish stigma protruded from the flower bud before the perianth opened. A small drop of 3% hydrogen

peroxide solution was applied to the stigma and any bubble developed in response was observed using a lens.

The development of each flower was recorded daily for the first 10 days and then at 7 days intervals up to 108 days. Classification of flowering stages was based on Dafni's (1992) scale:

A: small bud, petals not visible yet;
B: large bud, petals are visible, but not open;
C: flower opening;
D: full blooming (anthesis): D1: before pollen exposure; D2: at pollen exposure; D3: after pollen exposure;
E: flower wilting.

Major morphological changes in the flower were noted and information on the wilting order recorded according to Dafni's (1992) scale:
A - androecium;
B - gynoecium;
C - petals;
D - sepals.

A parallel subjective scale was developed and used to monitor fruiting stages.
(1) fruit initiation and elongation – androecium and petals completely dropped and the tiny fruit is fully differentiated and clearly visible;
(2) green fruit and seed set – a tiny seed can be felt when the fruit is squeezed;
(3) fruit maturation;
(4) mature fruit (purple colour).

3.3.3 Phenological sequences

Monitoring of flowering and fruiting was aimed at demonstrating and detailing patterns in the timing and duration, periodicity and frequency of individual trees. Variation among trees in reproductive activity over time was recorded and note taken

of the extent to which individual trees were reproductively active both in the 1999/2000 and 2000/2001 seasons.

Along the observation paths in the four geographical areas on Mount Cameroon, 127 individually tagged *Prunus africana* trees of various diameter classes were selected on the basis of the visibility of the crown and the health status. Only trees with at least 50% of the crown visible (section 3.3.1) were included in the sample and only if they had scored 1-3 on the health assessment scale (Table 3.4). The distribution of the trees sampled by locality on Mount Cameroon is given in Table 3.5.

Table 3.5. Geographical distribution of *Prunus africana* trees sampled for phenological observations on Mount Cameroon

Localities	Number of trees	1999 – 2000	2000 - 2001
Bakingili	23	29 Oct. – 7 Apr.	25 Nov. – 14 Apr.
Bomana	35	31 Oct. – 23 Apr.	27 Nov. – 30 Apr.
Ekona Lelu	34	27 Oct. – 26 Apr.	24 Nov. – 13 Apr.
Mapanja	35	25 Oct. – 26 Apr.	29 Nov. – 9 May

Observations were made from the ground using a CHINON SUPER FINE 8 x 42 R binocular. Data were recorded weekly from October 1999 to April 2000 and from November 2000 to May 2001 using the following subjective scale (Dafni,1992 - modified).

Flowering stages

1 Before flowering
2 Flowering commencement (up to 25% flowers are opened)
3 Peak of flowering (>50% of flowers or more are opened)
4 Termination of flowering (<10% of flowers are opened)

Fruiting stages

(1) Fruiting initiated
(2) More than 50% of fruits are set
(3) Up to 25% of fruits are ripe
(4) Between 25-50% of fruits are ripe
(5) More than 50% of fruits are ripe
(6) Up to 25% of ripe fruits have fallen
(7) Between 25-50% of ripe fruits have fallen
(8) More than 50% of ripe fruits have fallen
(9) No more fruits

The following working definitions were used throughout the observation periods:

(i) Fruit initiation: the development stage when petals and anthers start to drop from a successfully fertilised flower and the appearance of the tiny green fruit.

(ii) Fruit set: characterised by the visibility of a small, but fully differentiated tiny green fruit

(iii) Fruit ripe: the maturation stage, with the assessment based on fruit colour (purple colour indicates that a *Prunus africana* fruit is ripe).

3.3.4 Reproductive potential

3.3.4.1 Objective and basic design

The objective of this exercise was to quantify the production of flowers and fruits in *Prunus africana* on Mount Cameroon. Fifteen trees representing various diameter classes were selected on Mount Cameroon during the 1999-2000 and 2000-2001 reproductive seasons. Trees were selected on the basis of the openness of the mid-storey to reduce the effect of flowers/fruits interception and only those with opened or fairly opened mid-storey were selected. The vertical projection of the crown cover was estimated using the average diameter measured at right angles in the north-south and east-west directions. Table 3.6 gives the main characteristics of the trees sampled for this recording.

Table 3.6. Characteristics of trees sampled for the study of the reproductive potential of *Prunus africana* on Mount Cameroon- 1999/2000& 2000/2001 reproductive seasons combined

Locality	Tree No	Dbh	CL-NS	CL-EW	r	CS
Bakingili	BA20	82.0	16.5	15.4	8.0	199.9
Bomana	BO06	38.8	12.5	12	6.1	117.9
Bomana	BO51	82.3	20.5	15	8.9	247.6
Bomana	BO55	106	17	16	8.3	213.9
Bomana	BO62	38.5	12	10.5	5.6	99.4
Ekona Lelu	EL02	25	10	9	4.8	70.9
Ekona Lelu	EL06	30	7	11	4.5	63.6
Ekona Lelu	EL07	27	8	7	3.8	44.2
Ekona Lelu	EL08	68	13	12	6.3	122.8
Ekona Lelu	EL20	35	11	10.5	5.4	90.8
Ekona Lelu	EL45	47.2	14.7	14	7.2	161.8
Ekona Lelu	EL46	34.8	11.8	11.1	5.7	103.0
Mapanja	MA02	88.5	23.7	16	9.9	309.6
Mapanja	MA03	69.5	12.5	14	6.6	137.9
Mapanja	MA24	88	20	15	8.8	240.6

Dbh = tree diameter at breast height (in cm)
CL-NS = length of the vertical projection of the canopy cover area in the north-south direction (in m)
CL-EW = length of the vertical projection of the canopy cover area in the East-West direction (in m)
r = half the average (in m) of the east-west and north-south crown diameter measurements
CS = Canopy cover area (in m^2)

3.3.4.2 Procedure of flowers and fruits collection

Two sets of four 1 m x 1 m plots were established under the crown of each reproductive mature *Prunus africana* tree. The first set was established within 5-m radius from the tree in the N-S-E-W direction and the second set within 10-m radius in NW-SE-NE-SW direction, making a total of eight plots per tree. A diagrammatic representation of the plot layout under each tree is depicted in Figure 3.6. A plastic sheet was placed at the base of each plot and the borders raised using wooden materials to prevent displacement of fallen flowers or fruits. The plastic sheet was perforated to prevent collection of water that would encourage flower/fruit decay or render flower or fruit counts difficult.

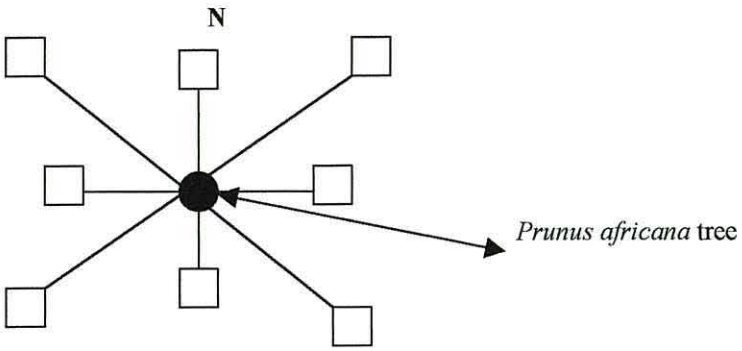

Figure 3.6: Plots layout under a tree

A systematic collection of fallen flowers and fruits was conducted weekly from November 1999 to April 2000 and from December 2000 to May 2001. Collected flowers and/or fruit were preserved in separate plastic bags bearing the tree and the plot numbers. The collected flowers and/or fruits were counted and their number recorded. This operation continued until the end of the reproductive season (April 2000; May 2001).

3.3.5 Pollination experiment

The objective of this experiment was to ascertain fruit set and seed set in *Prunus africana* and if there was any impact of each of five treatments on germination parameters. Three trees (Table 3.7) with easily accessible crowns were selected for the experiment: one tree in the forest above Mapanja (treated and observed from 14 December 1999 until 31 March 2000) and two in the forest above Bomana (treated and observed from 4 December 2000 until 23 April 2001). A wooden scaffold topped with a platform extended to the nearest branches was constructed under each tree to allow access and close manipulation of the flowers in the canopy. In the three trees, flowers located in the middle section (vertically) of the crown and easily accessible from the platform were manipulated.

Table 3.7: Locations, site conditions and characteristics of *Prunus africana* trees used in the pollination experiments on Mount Cameroon.

Tree Number	MA02 (88.5 cm dbh)	BO51 (82.3 cm dbh)	BO62 (38.5 cm dbh)
Location	Mapanja	Bomana	Bomana
Exposure	South-east	West	West
Slope	0%	< 10%	0%
Canopy profile	Open	Open	Open
Altitude (in m)	860	2020	2200
Position	04°04'45'' N	04°17'09'' N	04°17'08'' N
	09°10'06'' E	09°11'30'' E	09°12'13'' E
Vertical projection of crown cover area (m^2)	309.6	247.6	99.4
Estimated crown Height (m)	15	14	10
Vegetation type	Heavily disturbed sub-montane forest	Undisturbed montane forest	Undisturbed montane forest

3.3.5.1 Treatments and replication

Five treatments were applied to flowers selected within 3-5 m from the platform and the development stage. Racemes with unopened flower buds were initially isolated using PBS-10-3 pollination bags to prevent any contamination with uncontrolled pollen. Treated racemes were labelled at the base with a water-resistant tag bearing the treatment code and the raceme number written with an all-weather pen. The five treatments applied were:

- Control treatment

  Natural pollination – 202 individual flowers on 10 tagged racemes (1999 – 2000) and 2350 flowers on 132 tagged racemes (2000-2001) were marked at the base with a blue permanent marker but left uncovered.

- Other treatments

(i) Autogamy - 156 individual flowers on 10 tagged racemes (1999-2000) and 2625 flowers on 200 tagged racemes (2000-2001) were marked and bagged to prevent the access of external pollen.

(ii) Geitonogamy – pollen collected from other flowers on the same tree was applied the same morning to 203 individual flowers on 21 racemes (1999-2000) and 4675 flowers on 432 tagged racemes (2000-2001).

(iii) Xenogamy – 193 flowers on 18 tagged racemes (1999-2000) and 1500 flowers on 144 tagged racemes (2000-2001) were dusted with pollen from conspecific tree 1.5 km away (Mapanja) and 3-4 km away (Bomana) the same morning.

(iv) Agamospermy – the emergence of a receptive stigma from the perianth before flower opening complicated emasculation. In the *Prunus africana* flowers, anthers are arranged in two or three ill-defined whorls within the enclosed petals (Hall *et al.*, in press). Removal of the inner anthers requires great care to avoid inflicting additional damage to the flower. Thirteen flowers on 4 racemes in Mapanja (1999-2000) and 105 flowers on 31 tagged racemes in Bomana (2000-2001) were emasculated. Manipulated flowers were immediately bagged.

External pollen was dusted on selected flowers by gently rubbing crushed anthers against the stigma. Stigma receptivity was tested using hydrogen peroxide when the stigma visibly protruded from the perianth on a sample of 20 flowers on each tree to confirm the early receptivity stage. Racemes bearing contaminated flowers were immediately sealed in PBS-10-3 pollination bags using clips to exclude pollen entry. Small branches and leaves wrapped together with the raceme prevented contact of the raceme with the bag surface. PBS-10-3 bags are pollen-proof and impermeable, but allow air exchange between the enclosed medium and the external environment. Since in this species the stigma protrudes from the perianth of the flower before the emergence of the anthers, there is a time-window during which external pollen can be brought to a previously pollen-free stigma. In the geitonogamy and xenogamy treatments, pollen was applied during this time-window. Isolation of individual

raceme in pollination bags prior to any flower opening ensured that no external pollen had reached the stigma before the treatment. Fully opened and unopened flowers with enclosed stigma were systematically removed and the treated ones bagged.

3.3.5.2 Assessment

Fruit set and seed set were the two variables ascertained and were taken as surrogate indications of reproductive success. Manipulated flowers were inspected at two-day intervals in all treatments for the 10 days after treatment application to ascertain fruit set and also to ensure that any dampness was controlled. A transparent window on the pollination bags allowed inspection without opening the bag. Fruit set was recorded on Day 10 and Day 11 after treatment, by which time any developing fruit could be easily observed. Pollination bags were removed at this stage to allow free further development of the fruit. Labels were however left on the raceme to allow simplified continuation of monitoring. Seed set was ascertained later, on Days 51 and 52 after treatment application, by which time a tiny seed could be felt when squeezing a fruit. Mature purple fruits resulting from each treatment were collected on two trees in Bomana for the germination trial on 19 March 2001 and on 23 April 2001 (105 days and 96 days after treatment respectively).

3.3.5.3 Supplemental greenhouse test

The bulk of seeds resulting from the pollination experiment were separated from the fruit flesh by depulping. Seeds were thoroughly washed with tap water within five hours of collection to reduce the impact of any possible presence of germination inhibitors in the pericarp (Albrecht, 1993; ICRAF, 2001b). Seeds were exposed at room temperature (*ca* 18°C) for two days in Bokwango village and lots were bagged separately and stored in a freezer at about 4°C for approximately 15 weeks prior to the germination test.

The objective of the germination test was to ascertain the impact of each of four pollination treatments on germination parameters. The germination test was conducted in growing cabinets at the Pen-y-Ffridd field station in Bangor from 20

July to 17 September 2001. Seeds were preliminarily soaked overnight in tap water and samples of 80 seeds from each origin (treatment) were sown 5 cm deep in separated trays. The growing medium consisted of Humax John Innes compost. This is a traditional loam-based mixture of sterilised soil, peat and sand, made to a precise formulation containing all the essential plant nutrients needed for healthy growth. Seeds were kept in the dark at 18°C until the beginning of germination and thereafter subjected to alternating periods of 12 hours light and 12 hours darkness. The growing medium was checked and watered twice a week to ensure a continually available but not excessive supply of water. The number of germinated seeds was recorded daily until 17 September 2001. Seed was considered to have germinated after the emergence and development from the seed embryo of those essential structures, which are indicative of the seed's capacity to produce a normal seedling under favourable conditions (Willan, 1985).

3.3.5.4 Collection of flower visitors

Observation and collections of flower visitors were conducted in the forest above Mapanja in 1999-2000 and in the Bomana forest in 2000-2001. Flower visitors were caught in the immediate neighbourhood of flowers on the three trees with scaffold access and preserved for identification. Insect collection was conducted in two complementary ways. First, during the presence of the research team in the tree canopy, insects approaching or landing on flowering racemes were caught using a net. The net had a basket-like shape with a circular iron border and was made up of fine mesh. Insects caught were preserved in small jars containing small cotton wads soaked in 95° alcohol. Second, because it was suspected that the presence of the pollination team on the tree canopy could interfere with the number of flower visitors, four permanent traps were set as close as possible to flowering branches. These traps were cylindrical, about 40 cm high and 20 cm in diameter and the wall was of mosquito net. The top of trap was a disk of plywood, which maintained the cylindrical shape. A similar disk of plywood with three or four perforations (*ca.* 1 cm diameter each) formed the base of the trap and allowed insect entry. Strings were put around the trap to suspend from the tree branch and also facilitate its displacement towards

and from the platform. Insects were collected on a daily basis in Mapanja from 14 December to 25 December 1999 and from 4 December to 15 December 2000, and from 23 January 2001 to 3 February 2001 in Bomana.

3.4 Data summarisation and analysis

3.4.1 Data summarisation

3.4.1.1 *Prunus africana* diameter class frequencies

Individual trees of *Prunus africana* were assigned to 10 cm diameter classes, the smallest being 10-19. Population size class frequencies were produced for each site and location maps generated using Arcview for GIS software.

3.4.1.2 Reproductive structures and their development

Data on the reproductive structures and their development were summarised in two steps. In the first step, measurements on raceme length, number of flowers per raceme and the number of fruits per infructescence were tabulated in an Excel 4.0 spreadsheet with measurements and counts in the columns and raceme number in the rows. The mean inflorescence length and the mean number of flowers per raceme (and later the mean number of fruit per infructescence) were then calculated, together with their respective standard deviations.

In the second step, data on the number of flowers at each development stage (A – E) were summarised in a further Excel 4.0 spreadsheet. Each column represented a development stage and each row was a time period, expressed as a point in a sequence of days. The number of flowers at a given development stage made up the cell entries. A line plot, showing the intensity and duration of each development stage was plotted with the duration (in days) on X-axis and the flowering intensity on the Y-axis. A similar summary approach was used with fruit development, except that fruiting intensity was expressed on a weekly basis.

3.4.1.3 Phenological sequences

Data from the two successive reproductive seasons were summarised in four ways.

Flowering intensity and relationships with meteorological information

Flowering and fruiting intensity were calculated at the level of individual areas and at the level of the entire mountain to expose any geographic variation. Combined charts (bar chart and line plot) displaying the intensity and duration of each phenophase in relation to the three available meteorological data sets were constructed for each site and a summary for the whole mountain produced. Meteorological data were the mean monthly rainfall (in mm), and the mean monthly minimum and mean monthly maximum temperatures (in °C) for the four nearest meteorological stations (Table 3.8).

Table 3.8: Distribution and magnitude of meteorological data

Research site	Nearest meteo. Station	Meteorological information	Years of data
		Mean monthly min. Temp.	1972-'75 & '84-'99
		Mean monthly max. Temp.	1971-'73 & '84-'99
Bomana	Idenau	Mean monthly rainfall	1970-1999
		Mean monthly min. Temp.	1971-'75 & '85-'99
		Mean monthly max. Temp.	1971-'75 & '85-'99
Ekona Lelu	Mpundu	Mean monthly rainfall	1965-'72 & '74-'99
		Mean monthly min. Temp.	1974-'75 & '84-'99
		Mean monthly max. Temp.	1974-'75 & '84-'99
Mapanja	Tole	Mean monthly rainfall	1970-1999
		Mean monthly min. Temp.	1971-'75 & '84-'99
		Mean monthly max. Temp.	'71-'75 & '84-'85&'87-'99
Mount Cameroon		Mean monthly rainfall	1970 -'72 & '74 - '99
		Mean monthly min. Temp.	1974-'75 & '85 – '99
		Mean monthly max. Temp.	1985 & '87 – '99

Data were extracted from Fraser *et al.* (1998) and supplemented with information gathered at the CDC meteorological station located at the foothill of Mount Cameroon in Tiko. Meteorological data used in the analysis at the scale of the entire mountain were the average of the four meteorological stations for the matching years – mean monthly rainfall (1970-1972 and 1974-1999), mean monthly minimum temperatures (1974-1975 and 1985-1999), mean monthly maximum temperatures (1985 and 1987-1999).

Flowering and fruiting frequency

There are relatively few procedures in describing patterns displayed by tropical forest trees in their flowering and fruiting seasonality. The problem is exacerbated by the tendency of individual trees within a population to exhibit fluctuating states within a reproductive cycle. Drawing from a time series approach based on information theory, Colwell's (1974) technique combines the state of individual trees and their fluctuation within a time period to generate values of predictability, constancy and contingency. This technique was adopted in this study to examine flowering and fruiting seasonality in *Prunus africana* on Mount Cameroon.

Phenological data were organised for each tree based on its reproductive state. A frequency matrix of 3 rows and 7 columns was constructed for each tree. Relevant definitions and explanations are:

(i) State of a tree: refers to the reproductive situation. Three states were defined: flowering only; flowering and fruiting; neither flowering nor fruiting.

(ii) Cycle: a cycle is a reproductive season. In this study, the state of a tree was recorded for two successive reproductive seasons (2 cycles).

(iii) Time within the cycle: the temporal points of measurement of the trees' states. Data were recorded on a weekly basis and in re-organising the monthly contingency table, the predominant state of a tree was reported at the end of each month from November to May each year (7 months). The period from June to October was not included in the table because it was assumed there would be no reproductive activity.

(iv) Source of data in a table of seasonal frequencies of phenological states: the tree's prevailing reproductive state in a given month scored "1" and other states scored "0". With two cycles, the sum in each column thus makes 2. An example of the tabulated frequencies is given as Table 3.9.

Table 3.9: Contingency table of tree No BA06 (Tree 6, Bakingili population)

	Time within the cycle (Nov.99-May00&Nov.00–May01)						
State of a tree	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May
Flowering only (Fl)	0	1	0	0	0	0	0
Flowering and fruiting (Flr)	0	0	1	1	1	1	0
No flowering or fruiting (Nf)	2	1	1	1	1	1	2

Flowering synchrony

Those trees reproductively active in each observation cycle were grouped together per geographical area. Diagrams of the timing and duration of flowering episodes were prepared. The diagrams consisted of columns that represented the timing (in weeks) of flowering and the rows corresponding to the state of a tree. Any sign of flowers in the tree canopy was considered as flowering episode. The duration of flowering in each tree was indicated. This allowed the identification of times of overlaps in flowering among individuals and the calculation of the flowering synchronicity indices. An example of the timing of flowering diagram is presented (Table 3.10).

Table 3.10: Diagram of the timing of flowering of individual trees in Bomana forest (1999-2000 reproductive season)

Tree No/Time	19/12	26/12	2/1	9/1	16/1	23/1	30/1	6/2	13/2
BO51	*	*	*	*					
BO54	*	*	*	*					
BO55				*	*	*	*		
BO56	*	*	*	*					
BO59						*	*	*	*
BO60						*	*	*	*

Flowering and fruiting intensity in relation to elevation, tree size and health status

Data from the two observation periods were organised in three different ways. Firstly, a three-column table: dbh, elevation and reproductive status – flowering tree (label = 1) and non flowering tree (no label) - was constructed. From this, a scatter plot of the distribution of trees by diameter class in relation to elevation was generated for Mount Cameroon and for each geographical location. Each reproductive season was treated separately.

Secondly, the three-column table was re-organised by replacing the reproductive status column by the health status of the trees. Only trees that flowered score their respective health index (non flowering trees were not indexed against their health status for clarity purposes). Treating each reproductive season separately, a scatter plot of the distribution of trees by diameter class in relation to the tree health was generated for Mount Cameroon and for each geographical location.

Thirdly, a table with two columns corresponding to the reproductive status – flowering and non flowering – and three rows corresponding to the three health classes was constructed. The numbers of flowering and non flowering trees in each health class were entered, combining the reproductive situation for the two reproductive seasons combined and for Mount Cameroon.

3.4.1.4 Reproductive potential

Data were recorded for each tree of:

(i) Total flower litter fall (L) defined as the number of flowers collected by sampling under a tree.

(ii) Floral productivity (Fl) defined as the estimated total number of flowers produced per tree.

(iii) Fruit productivity (Fr) defined as the total number of fruits produced per tree.

In estimating the total flower litter fall, the mean number of flowers (F) collected and counted per plot under the crown of each of the 15 trees was calculated for the eight 1 m x 1 m plots. The total flower litter fall was estimated as the product of the mean number of flower per plot and the vertical projection down to the soil surface of the canopy cover area (CS). The vertical projection of the canopy cover area was calculated as $CS = \pi r^2$ (in m^2) where r is taken as half the average (in m) of the east-west and north-south crown diameter measurements. The total flower litter fall L was estimated as $L = F.CS = \pi r^2 F$. The floral productivity Fl therefore was calculated as the sum of the total flower litter fall and the estimated number of fruits.

Similarly, the mean number of fruit (S) per 1 m x 1 m plot was calculated. This included both juvenile and mature fruits. Fruiting productivity was estimated from the formula: $Fr = S.CS = \pi r^2 S$.

3.4.1.5 Pollination success

Percentage fruit set following each treatment was calculated for each tree as the ratio of the number of developing fruits recorded 10-11 days after treatment to the number of flowers treated. The percentage seed set per treatment was calculated in the same way using the situation 51-52 days after treatment when mature reddish single-seeded fruits could be observed. The ratio of the number of mature fruits to the initial number of flowers subjected to each treatment was therefore taken as the percentage seed set.

3.4.1.6 Seed germination

The final percentage germination of seeds from different treatments was calculated and the effects of the different treatments were compared in the form of a bar chart. Germination curves for the batch of seeds from each treatment were plotted, following the situation day by day. The performance of each seed batch was characterised in terms of imbibition period, total germination period, cumulative germination percentage, mean daily germination percentage, final daily speed of

germination, germination energy, energy period and germination value (definitions: Appendix 3.1).

3.4.1.7 Associated insects

All the insects collected by the end of each flowering season were sorted into morpho-orders of obvious physical resemblance, such as coleoptera, diptera and hemiptera. The insects concerned were mounted individually among scattered pieces of mothballs (camphor) on a board covered in cotton. Sample individuals were taken to the Entomology Department, Institute of Agronomic Research for Development, Yaounde, for identification. Reference specimens have been retained there. Identified insects were grouped by order, family and genus. The percentage of morpho-taxa was calculated.

3.4.2 Data analysis

3.4.2.1 Phenological sequences

Flowering intensity and relationships with meteorological information

Pearson correlation coefficients were calculated between phenological data and meteorological information. Phenological data were flowering and fruiting intensity expressed as the number of flowering individuals in each locality and for the entire mountain. Meteorological data involved in the calculation of the correlation coefficient were mean monthly rainfall (mm) and mean monthly minimum and maximum temperatures (in °C). These data were extended to a month before and after each phenological episode. The strength of the relationship was displayed on a bar chart.

Flowering and fruiting frequency

Temporal coincidences in flowering and fruiting phenology were analysed using the approach based on the information statistic developed by Colwell (1974). Seasonal

predictability (P), constancy (C) and contingency (M) of flowering and fruiting in 127 individuals distributed among the four sample populations on the mountain for two successive seasons were estimated. According to Colwell (1974), predictability, constancy and contingency are sufficient to describe patterns of periodic phenomena of general biological interest. Constancy measures the degree of variability in the states of the subjects (*Prunus africana* individuals in the present case) over time. Contingency is a function of tendency for the states to be re-established in the corresponding time period of different cycles. Predictability is the sum of constancy and contingency and ranges from 0 to 1. Colwell (1974) offers the following summarised mathematical formula to express predictability, constancy and contingency.

Let t be the time column within a cycle and s rows the states of a phenomenon. Let N_{ij} be the number of cycles for which the phenomenon was in state i at time j and let X_j be the column totals, Y_i the row totals and Z the grand total. The uncertainty with respect to time $H(X) = -\Sigma[(X_j/Z)\log(X_j/Z)]$ (from $j = 1$ to $j = t$). The uncertainty with respect to state $H(Y) = -\Sigma[(Y_i/Z)\log(Y_i/Z)]$ (from $i = 1$ to $i = s$). The uncertainty with respect to the interaction of time and state $H(XY) = -\Sigma\Sigma[(N_{ij}/Z)\log(N_{ij}/Z)$. Predictability, constancy and contingency with range (0,1) are given by the following formula:

Predictability: $\mathbf{P} = 1 - [H(XY) - H(X)/\log s]$

Constancy: $\mathbf{C} = 1 - [H(Y)/\log s]$

Contingency: $\mathbf{M} = [H(X) + H(Y) - H(XY)]/\log s$

The contingency table (Table 3.11) for tree No BA06 illustrates the application of the calculation procedure.

Table 3.11. Contingency table of tree No BA06 phenological data (Xj and Yi represent the column and row totals)

	Time within the cycle (Nov.99 – May 00 & Nov.00 – May 01)							
States	Jan.	Feb.	Mar.	Apr.	May	Nov.	Dec.	Yi
Fl	0	0	0	0	0	0	1	1
Flr	1	1	1	1	0	0	0	4
Nf	1	1	1	1	2	2	1	9
Xj	2	2	2	2	2	2	2	14

$H(X) = - [7x(2/14)\ln(2/14)] = - \ln7 = 1.9459$

$H(Y) = - [(1/14)\ln(1/14) + (4/14)\ln(4/14) + (9/14)\ln(9/14)] = 0.8304$

$H(XY) = - [(10x1/14\ln(1/14) + 2x2/14\ln(2/14)] = 2.4409$

$C = [1 - H(Y)/\ln7)] = 0.57$

$M = [H(X) + H(Y) - H(XY)]/\ln7 = 0.34$

$P = C + M = 0.91$

The significance of the estimates was gauged with the G-statistic, the probabilities being indicated in the conventional chi-square table. A scatter plot of the constancy and contingency values of each of the 28 trees that flowered and/or fruited at least once during the two reproductive seasons was constructed to detect patterns of similarity. Non flowering trees were not considered in this approach. Due to the limited number of trees that flowered in the course of the two reproductive seasons, it was not possible to scale down such analysis to the geographical area level.

Putz (1979) and Williams-Linera (1997) have applied this analytical technique in Malaysia and in a Mexican tropical lower montane forest respectively. Both authors operated the technique at the species level within species-rich communities however, analysing phenological data collected on 63 species over a four year period (Putz, 1979) and on 24 species over a five year period (Williams-Linera, 1997)

Flowering synchrony

Flowering synchrony was calculated in each of the geographical areas on the mountain. Two indices of synchrony were calculated (Augspurger, 1983; Boshier & Lamb, 1997). The first was the index of individual tree synchrony. This was defined as the composite of the amount of overlap of a given individual's flowering days with those of one or more other individuals in the sample. The day of onset of flowering was defined as the occasion when flowers were first spotted in the tree canopy. The second was the index of sample synchrony defined as the composite measure of the amount of overlap of all flowering days of every individual with every other individual in the sample. The following formula (Augspuger, 1983) was used in the case of individual tree synchrony:

$$X_i = (n-1)^{-1}(f_i)^{-1}\sum_{1}^{n} e_{j \neq i}$$

Where X_i = index of synchrony of a given individual i with its conspecifics;

$e_{j \neq i}$ = number of days both individuals i and j are flowering synchronously;

f_i = number of days individual i is flowering;

n = number of individuals in the sample.

When X = 1 synchrony is perfect and when X = 0, there is no synchrony.

The index of sample synchrony is defined as:

$$Z = (1/n)\sum_{i=1}^{n} X_i$$

Where X_i = index of synchrony of a given individual i with its conspecifics;

n = number of individuals in the sample; Z ranges from 0 to 1.

The difference in mean flowering synchrony in each area between the two years was tested by means of 2-sample t-test at 5% confidence limit using the MINITAB statistical package. Individual tree synchrony indices for each locality were entered in

two separate columns corresponding to the first and the second reproductive season respectively.

Flowering intensity in relation to tree health

The significance of differences in the numbers of flowering trees in the different health categories was examined using G-test. The value of the G statistic calculated was adjusted using William's correction factor (Sokal & Rohlf, 1995).

3.4.2.2 Reproductive potential

Linear regressions of flower and fruit production against tree size were carried out to identify any relationship between them. Flower and fruit production data were log-transformed to increase the prospects for a normal distribution of the points around the regression line (Appendices 3.2 and 3.3). Fruit:flower ratio was estimated for monitored trees that produced mature fruits within the observation period. Regression analysis was conducted between the tree size and the fruit:flower ratio.

3.4.2.3 Pollination success

Differences in fruit set following the different treatments were examined through G-tests using the summarised data for all the three trees. Self-incompatibility was calculated as an index (Bawa, 1974) using the data from the selfing and assisted crosses. The self-incompatibility index is the ratio of fruit set from the self to the cross-pollination treatments (Bawa, 1974). In this study, the index is the ratio of fruit set following the autogamy treatment to the fruit set following the xenogamy treatment. Flowers subjected to the agamospermy treatment were excluded from this analysis.

3.4.2.4 Seed germination

The significance of differences in germination parameters in all treatments was tested by means of G-statistics.

CHAPTER FOUR:
RESULTS

This chapter presents the research findings in five sections. Section 4.1 presents the characteristics of *Prunus africana* populations for the areas included in the study, the Mount Cameroon population being subdivided according to aspects of the mountain where sampling was carried out. Section 4.2 is concerned with flower and fruit development, while the information collected on flowering and fruiting sequences within the Mount Cameroon region are presented in Section 4.3. Section 4.4 deals with flower and fruit production. In Section 4.5, the final section, the results in terms of fruit and seed set, following the pollination experiments are presented. This section (4.5) closes with findings on the germination test undertaken in Bangor, and the diversity of flower visitors/potential pollinators.

4.1 Population structure

The population structure as indicated by the stem distribution by diameter class showed considerable variation from one locality to another. Variability was also observed around Mount Cameroon with the status changing with aspect. The population size class frequencies of *Prunus africana* in the different localities are summarised in Table 4.1. Sampling maps for each locality and the population structures are given in Figure 4.1 (a-d).

Table 4.1: Population size class frequencies of *Prunus africana* on Mount Cameroon, Mount Oku and Tchabal Mbabo

Localities	Diameter classes (cm)															
	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-99	100-109	110-119	120-129	130-139	140-149	150-159	Total (≥ 10 cm)
Bakingili	0	0	1	2	1	5	3	4	2	1	2	2	1	1	0	25
Bomana	0	2	8	4	5	9	8	6	2	8	7	1	0	2	1	63
Ekona Lelu	6	16	7	6	1	4	0	1	0	2	2	1	0	0	0	46
Mapanja	0	4	5	9	10	6	6	4	1	1	1	0	0	0	1	48
Combined values – Mt Cameroon	**6**	**22**	**21**	**21**	**17**	**24**	**17**	**15**	**5**	**12**	**12**	**4**	**1**	**3**	**2**	**182**
Oku	6	11	21	35	15	11	3	1	3	1	0	0	0	0	0	107
Tchabal Mbabo	0	3	5	8	5	7	1	2	2	0	0	0	0	0	0	33

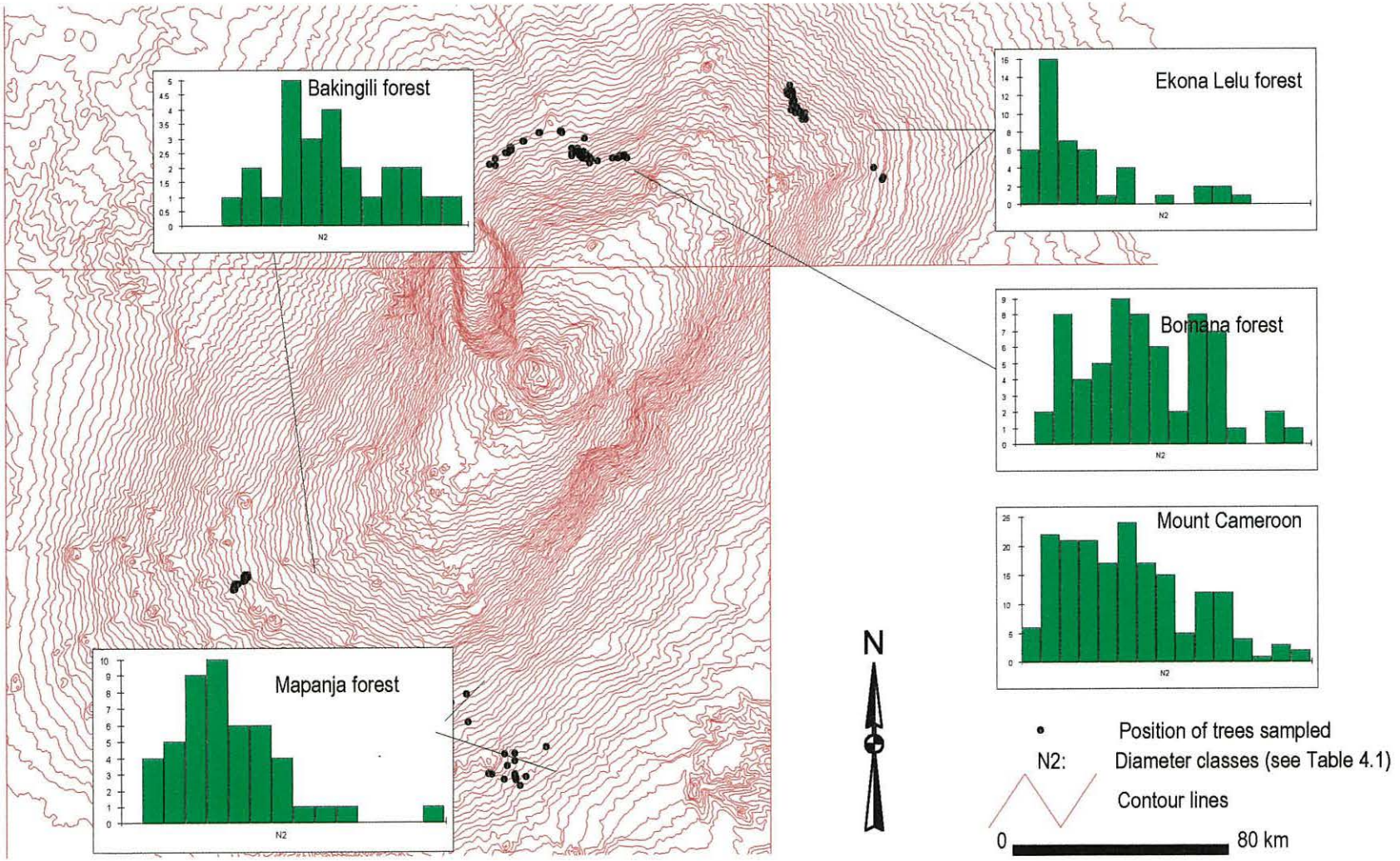

Figure 4.1a: Location map and structure of Prunus africana on Mount Cameroon
(The population structure diagrams are equally scaled in Figure 4.1d)

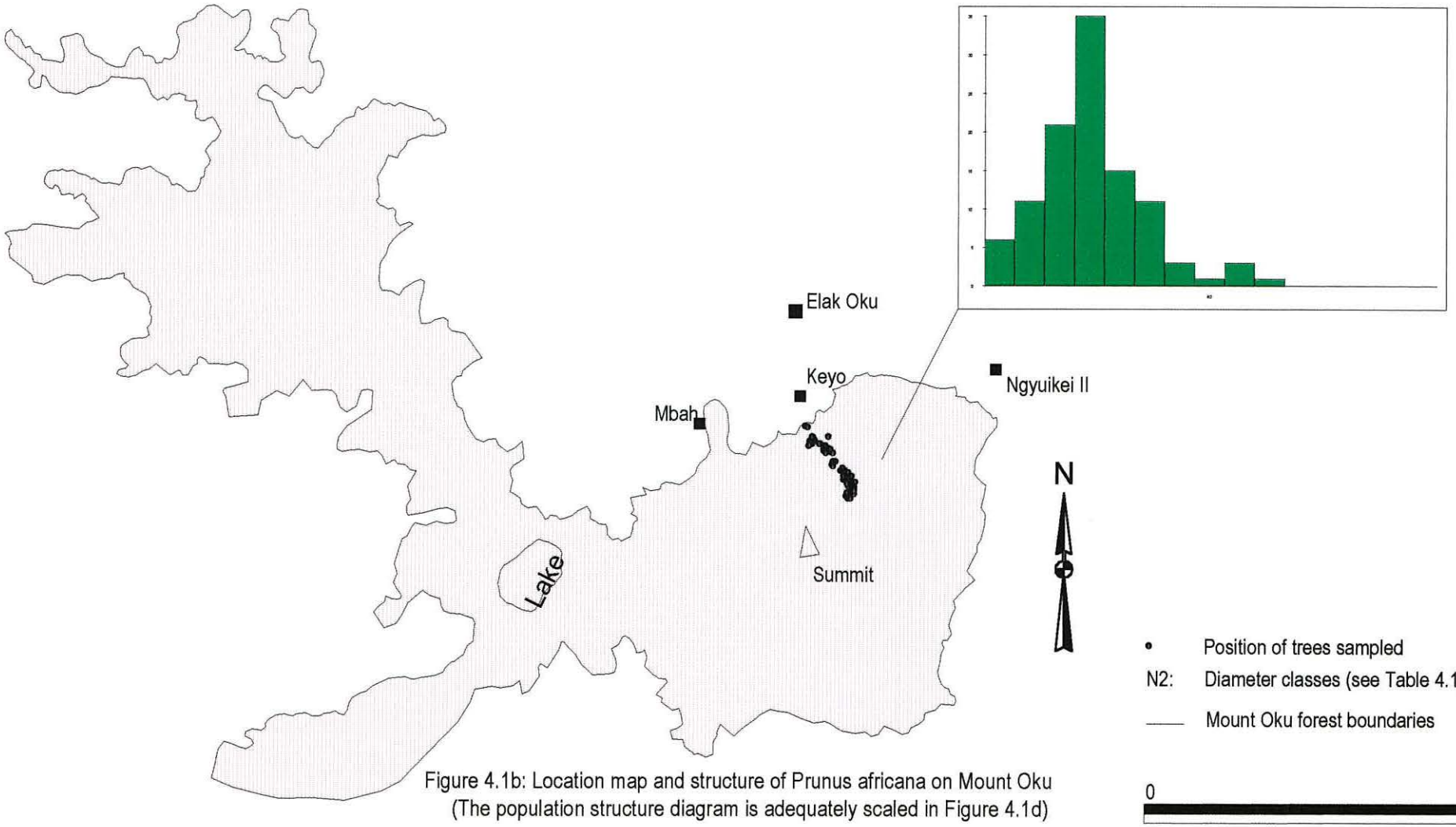

Figure 4.1b: Location map and structure of Prunus africana on Mount Oku
(The population structure diagram is adequately scaled in Figure 4.1d)

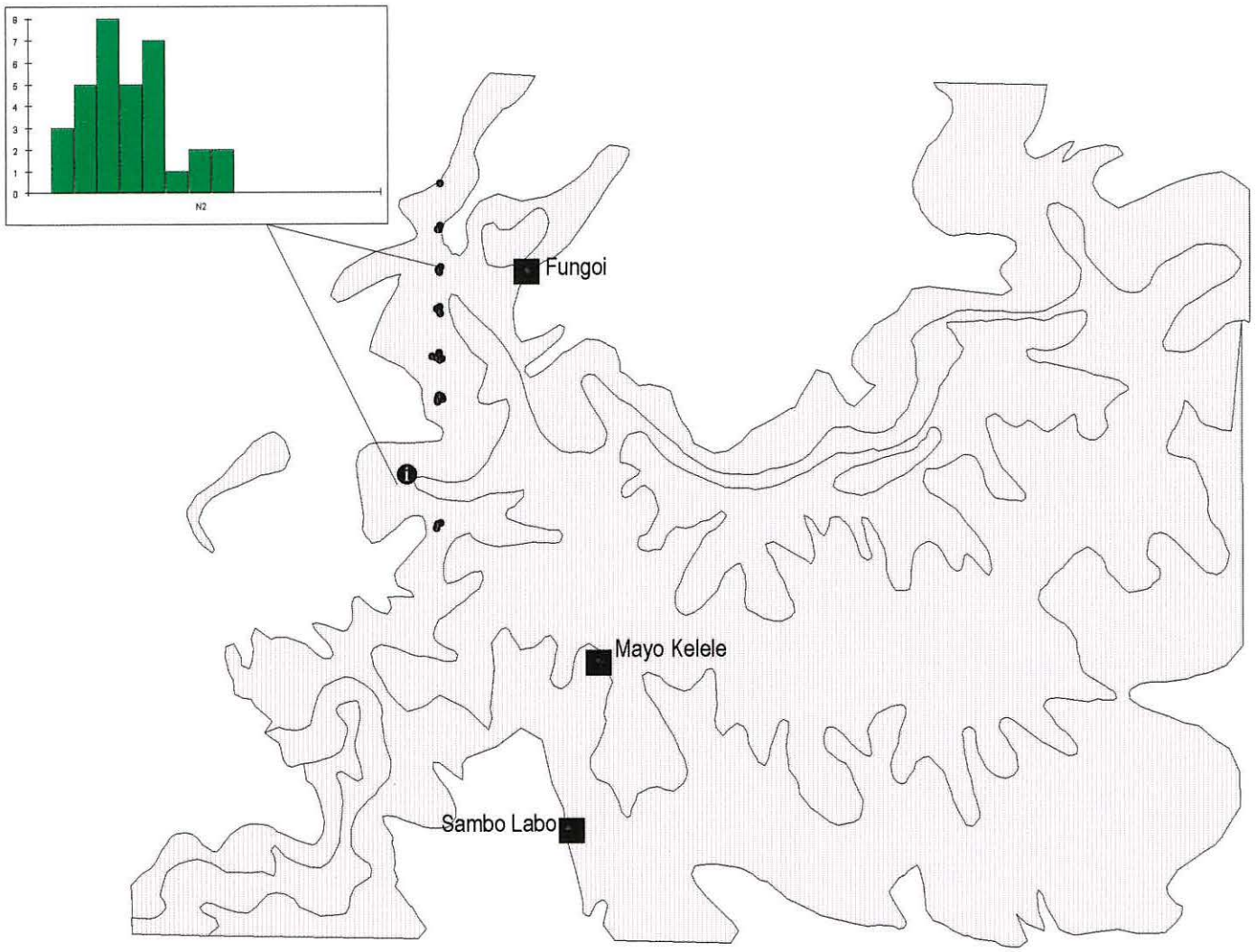

Figure 4.1c: Sampling map of Prunus africana on Tchabal Mbabo
(The population structure diagram is adequately scaled in Figure 4.1d)

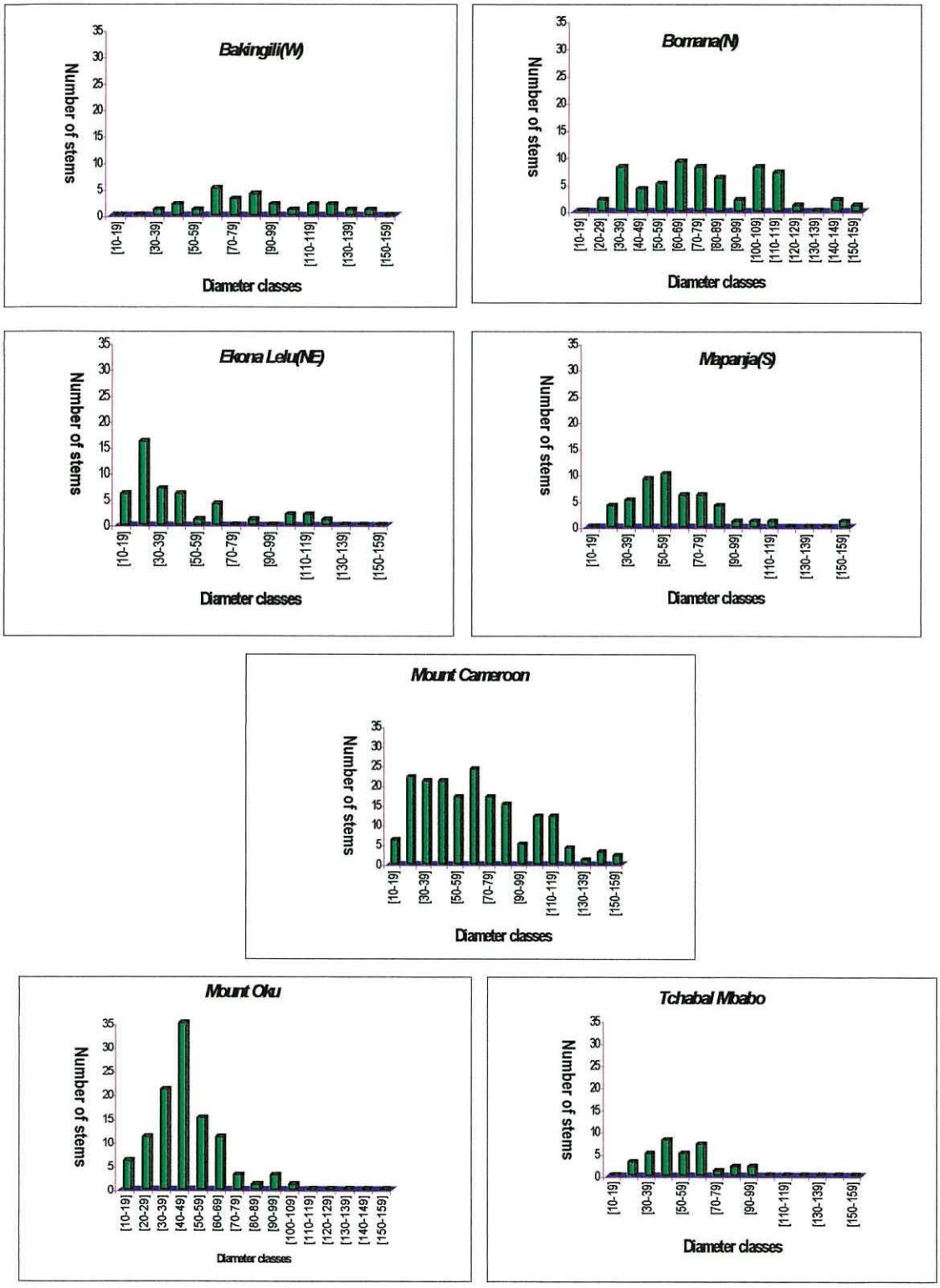

Figure 4.1d: Size class (diameter) distribution in *Prunus africana* populations on Mount Cameroon (Bakingili, Bomana, Ekona Lelu, Mapanja), Mount Oku and Tchabal Mbabo.

4.1.1 Population status on Mount Cameroon

Prunus africana trees tallied were unevenly distributed among the different diameter classes for the population sampled on Mount Cameroon (Figure 4.1d). There were few trees in the diameter categories below 20 cm or over 120 cm dbh. Over 90% of all the trees tallied were within the range 20-110 cm. There were however considerable variations with aspect on the mountain.

The population structure showed an anti-clockwise age sequence from Ekona Lelu to Bakingili and Bomana. The younger population was recorded for the population above Ekona Lelu. The largest number of trees tallied in this area was under 50 cm dbh (35 trees). Few larger trees were tallied up to the diameter class 120-129 cm (10 trees), but there were no trees in the diameter class 70-79 cm and 90-99 cm. The second youngest population was in Mapanja, although no tree was tallied in the diameter class 10-19 cm. More than 90% of the trees tallied in this forest were within the diameter range 20-89 cm (44 trees). Only four trees tallied were over the diameter class 80-89 cm. The populations sampled from Bomana and Bakingili are probably of the same age and the difference expressed in the size class distribution resulted from sampling. There was no tree in Bomana in the diameter class 10-19 cm. Trees were, however, tallied in all the diameter classes up to 150-159 cm, except the diameter class 130-139 cm. In the population from Bakingili, there was no tree below 30 cm dbh. Most of the trees were tallied in larger diameter classes up to 140-149 cm.

4.1.2 Population status on Mount Oku

The *Prunus africana* population sampled in the forest above Elak Oku appeared young (Figure 4.1d), with more than 50% of the trees tallied being less than 50 cm dbh. Nevertheless, the diameter class 10-19 cm was less well represented than larger size classes up to 69 cm dbh. The best represented size class (35 of 107 individuals tallied) was 40-49 cm dbh. No tree above 110 cm dbh was tallied and there were few trees over 70 cm dbh.

4.1.3 Population status on Tchabal Mbabo plateau

Unlike on Mount Cameroon and Mount Oku, where a number of *Prunus africana* trees were tallied in the diameter class 10-19 cm, no tree was tallied in this diameter classes in the forest patches on the Tchabal Mbabo plateau (Figure 4.1d). The younger trees were tallied from the diameter class over 20 cm. More than 70% of the trees tallied were under 70 cm dbh, the highest class being 40-49 cm. This tendency was also recorded on Mount Oku. There were very few trees over 70 cm dbh and no tree larger than 99 cm.

The population from the Tchabal Mbabo plateau is, however, an outlier of the main distribution range and possibly provides sub-optimal conditions. The population is of rather small-sized trees, but they may not be as young as trees on Mount Cameroon that reach the same size. However, it is a small sample and should be interpreted cautiously.

4.2 Reproductive structures and their development

4.2.1 Racemes, flowers and fruits characteristics

Mean raceme length was 50.0±11.3 mm (n = 73). The mean number of flowers per raceme was 17.8 ± 4.6 (n = 73), ranging from 8 to 25, but the mean number of fruits per infructescence estimated on open pollinated racemes with fully differentiated and clearly visible fruit was much lower 3.1 ± 1.4 ($n = 9$), ranging from 1 to 6.

Inflorescences emerged almost at an angle of 45° in relation to the plant axis, a position that shifted to become almost horizontal with the fruit's weight. Flowering was generally acropetal, starting at the bottom or the middle of the racemes and recruiting adjacent flowers upwards.

4.2.2 Temporal variation in stigma receptivity and anthesis

A test for stigma receptivity using 3% H_2O_2 indicated that the *Prunus africana* stigma was receptive for almost a day before the flower opening and remained receptive for the next 2 or 3 days. Flowers opened at various times of day, but most did so in the

morning. Flowers did not develop at equal rates and flower buds emerging at the same time appeared to pass differently from one development stage to another. Flowering was completed in every one of the 202 flowers sampled within the 10 days period from 14 December 1999 to 23 December 1999.

Two overlapping phases could be identified in the course of development of a flower (Figure 4.2).

The female phase that corresponded to the period during which the stigma was receptive lasted for 3 to 5 days. Petals were visible on the first day, but were not open. At this stage, the stigma emerged beyond the perianth and tested positive to hydrogen peroxide. On the following day when the petals were opening, the stigma remained receptive and the peripheral ring of anthers started to emerge, but were undehisced. Pollen exposure occurred a day after, when the filaments carried the anthers clear of the perianth. The stigma remained receptive at this stage. A test on a sample of 20 individual flowers showed that only 30% of stigmatic surfaces remained receptive on the fourth day, suggesting that the majority of the stigmas were receptive for only the first three days. Data on a sample of 202 flowers showed that the female phase in no instance lasted more than 5 days. One hundred and forty nine flowers developed beyond this phase.

The male phase was initiated at full blooming with the exposure of all anthers and lasted for no more than 6 days. The anthers of the peripheral ring emerged first, the loculi opening to release the pollen after a day. Pollen exposure was phased, starting with the anthers of the peripheral ring and ending with those of the inner whorl. The pollen remained exposed for 3 to 4 days after which the filament started to weaken, the anthers descending to the side. Flower wilting occurred in sequence, starting with the petals and followed by the androecium after successful pollination. The sepals were persistent on the fertilised fruit for about a week before abscission.

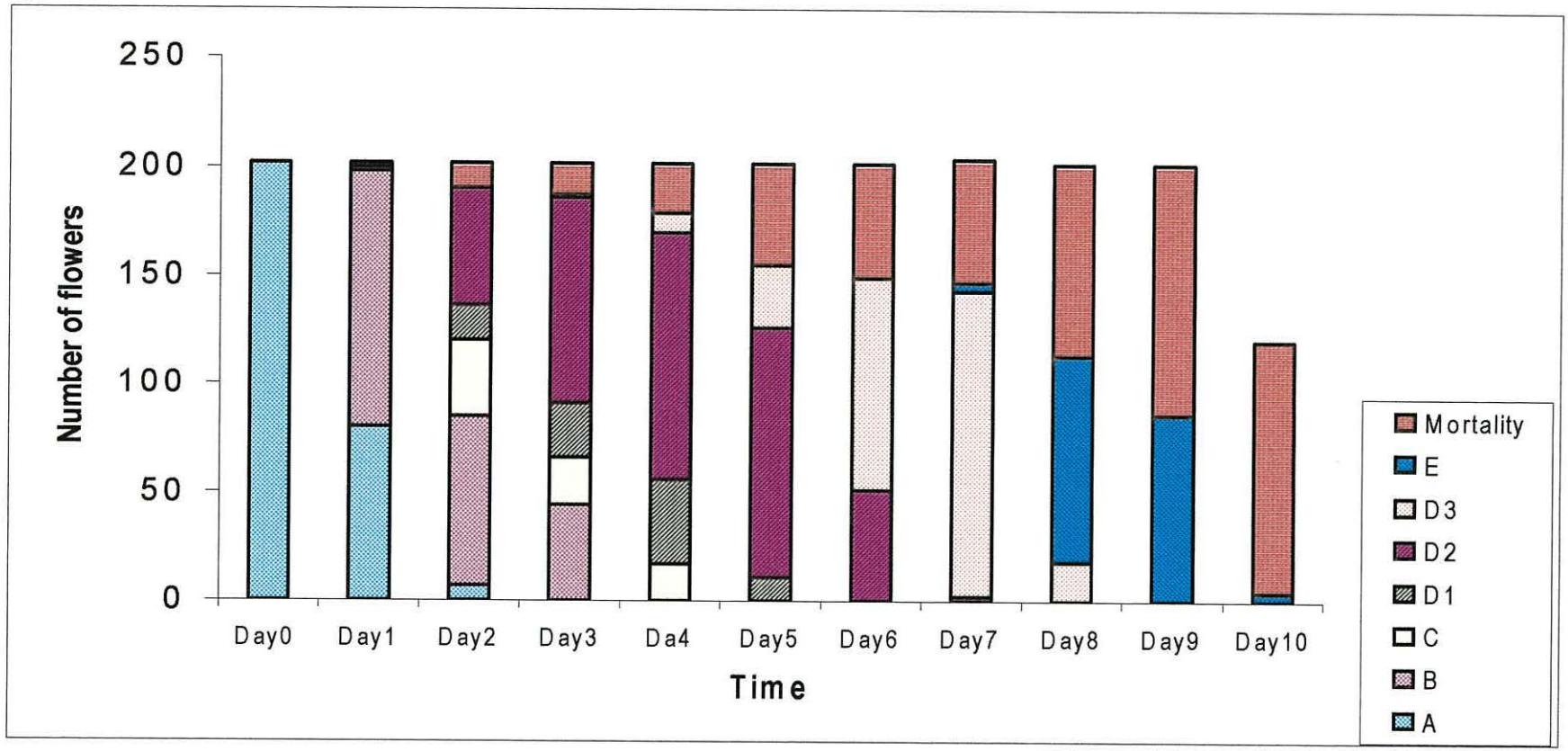

Figure 4.2: Development of *Prunus africana* flowers on Mount Cameroon
Flowering stages are classified according to Dafni's (1992) scale: A: small bud, but petals not visible yet; B: large bud, petals are visible, but not open; C: flower opening; D1: full blooming (anthesis), before pollen exposure; D2: full blooming (anthesis), at pollen exposure; D3: after pollen exposure; E: flower wilting.

4.2.3 Fruit development

Figure 4.3 depicts the fate of *Prunus africana* fruits on Mount Cameroon following successful pollination. Fruit development involved three phases of unequal duration and intensity. The first phase was fruit initiation and elongation. This phase was brief, lasting no more than two weeks and ending with the appearance of clearly differentiated juvenile fruits. The speed of passage through this phase was high and almost all the fruits underwent this process within this time frame. The second phase was seed set, which was initiated after fruit elongation. This phase lasted up to 4 weeks, ending with the sizeable greenish fruits developed. There was a sharp increment in fruit abortion in the meantime that reached its first peak in week 3. Nearly 65% of the juvenile fruits were lost during this phase.

The last phase was seed set and fruit maturation that preceded a second, but less intense, phase of fruit abortion. Less than 12% of the juvenile fruits recorded at fruit set developed to this phase. The fruits that escaped the two phases of fruit abortion developed successfully into mature fruits.

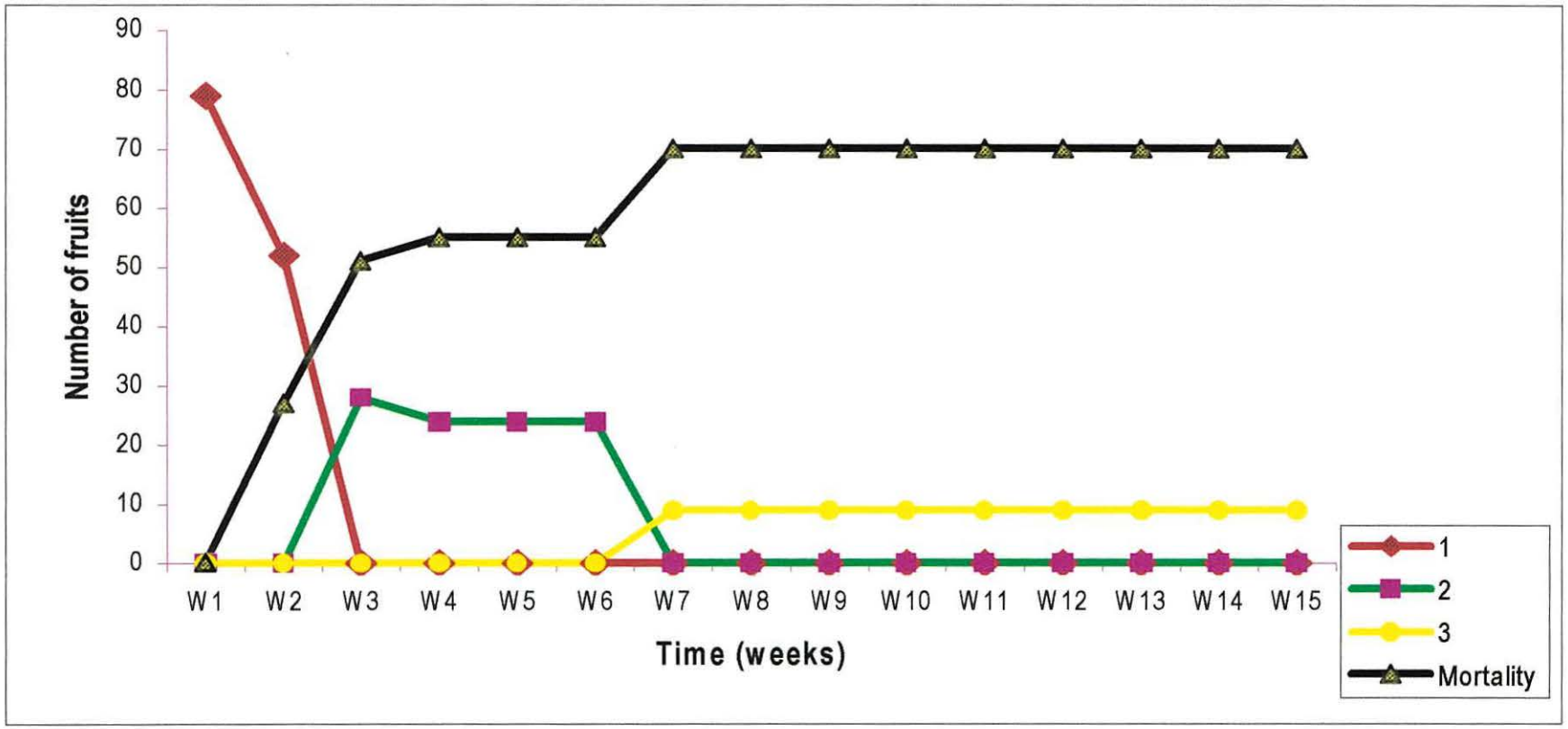

Figure 4.3: Fruit development in *Prunus africana* on Mount Cameroon
The development stages are classified as: 1: fruit initiation and elongation – androecium and petals are completely dropped and the tiny fruit is fully differentiated and clearly visible; 2: green fruit and seed set – a tiny seed can be felt when the fruit is squeezed; 3: fruit maturation which progresses up to the appearance of purple fruits.

4.3 Flowering and fruiting phenological sequences

The numbers by size class, of the *Prunus africana* trees monitored for flowering and fruiting events are given in Table 4.2.

Table 4.2: Distribution and size characteristics of *Prunus africana* trees monitored for flowering and fruiting phenology on Mount Cameroon (1999-200&2000-2001 reproductive seasons) – all the flowering trees were above 20 cm dbh.

Localities	Diameter classes (cm)														
	10-19	20-29	30-39	40-49	50-59	60-69	70-79	80-89	90-99	100-109	110-119	120-129	130-139	140-149	150-159	Total (≥ 10 cm)
Bakingili	0	0	1	1	1	5	3	3	2	1	2	2	1	1	0	23
Bomana	0	2	5	4	1	4	3	2	1	5	5	1	0	2	0	35
Ekona Lelu	6	10	7	4	1	3	0	0	0	2	0	1	0	0	0	34
Mapanja	0	3	3	9	5	6	4	3	0	1	0	0	0	0	1	35
Total	6	15	16	18	8	18	10	8	3	9	7	4	1	3	1	127

4.3.1 Intensity, periodicity and duration of flowering and fruiting

4.3.1.1 Flowering phenology

Flowering in *Prunus africana* on Mount Cameroon was periodic, occurring once every 12 months between November and February (Figure 4.4a-c). Average monthly rainfall was at its lowest levels at this period of the year (Figure 4.4a), suggesting that flowering is mainly a dry season event. This period coincided also with a steady increase in minimum and maximum temperatures (Figure 4.4b & 4.4c) after the heavy rainfall during which both temperatures dropped to their lowest monthly values. Around January however, while the maximum temperature experienced only a slight decline, minimum temperatures dropped considerably. At this time of the year, the maximum number of individuals came into flower in both years. The duration of

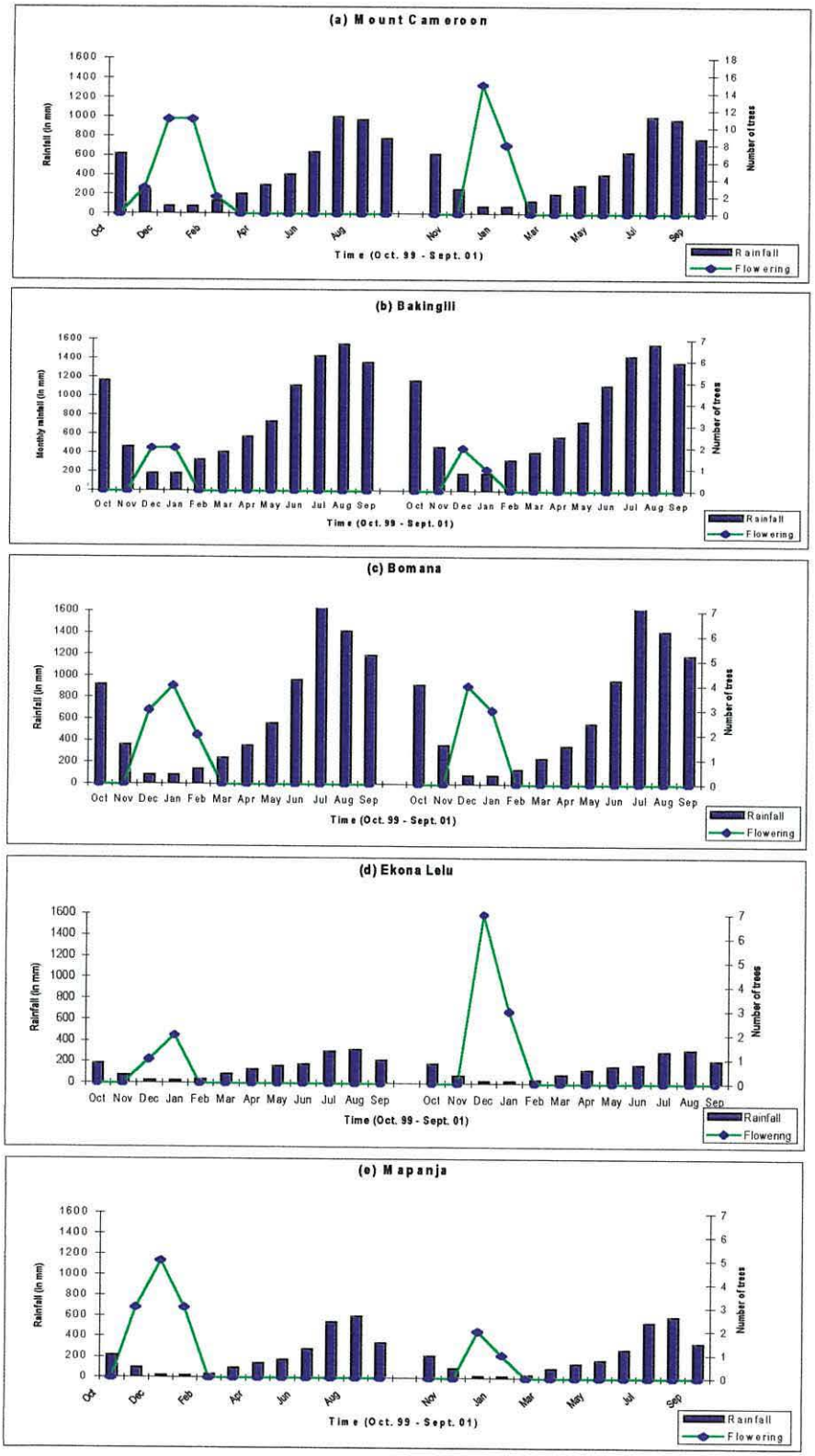

Figure 4.4a: Flowering intensity in *Prunus africana* on Mount Cameroon (overall) and from four geographical locations in relation to mean monthly rainfall.

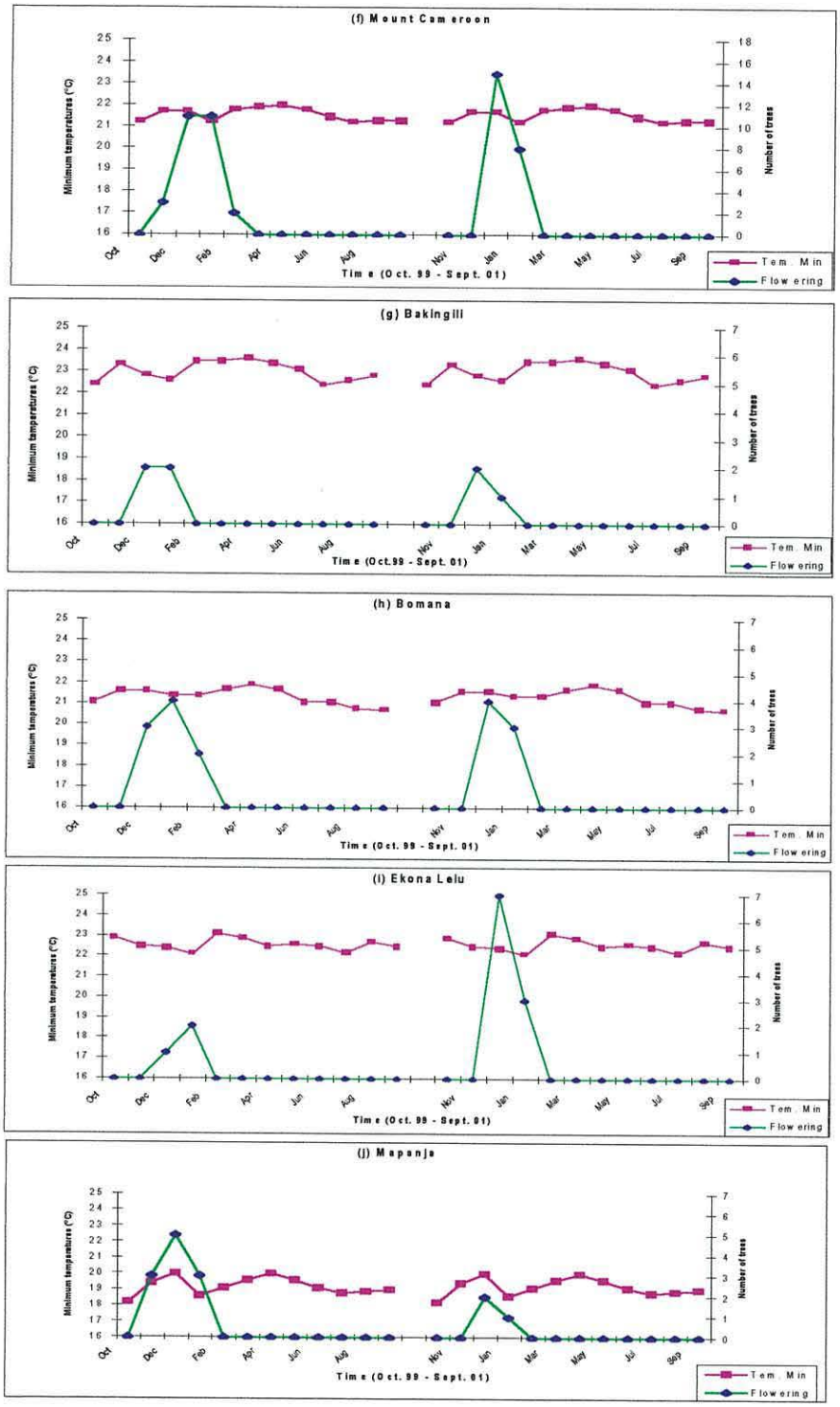

Figure 4.4b: Flowering intensity in *Prunus africana* on Mount Cameroon (overall) and from four geographical locations in relation to mean monthly minimum temperatures.

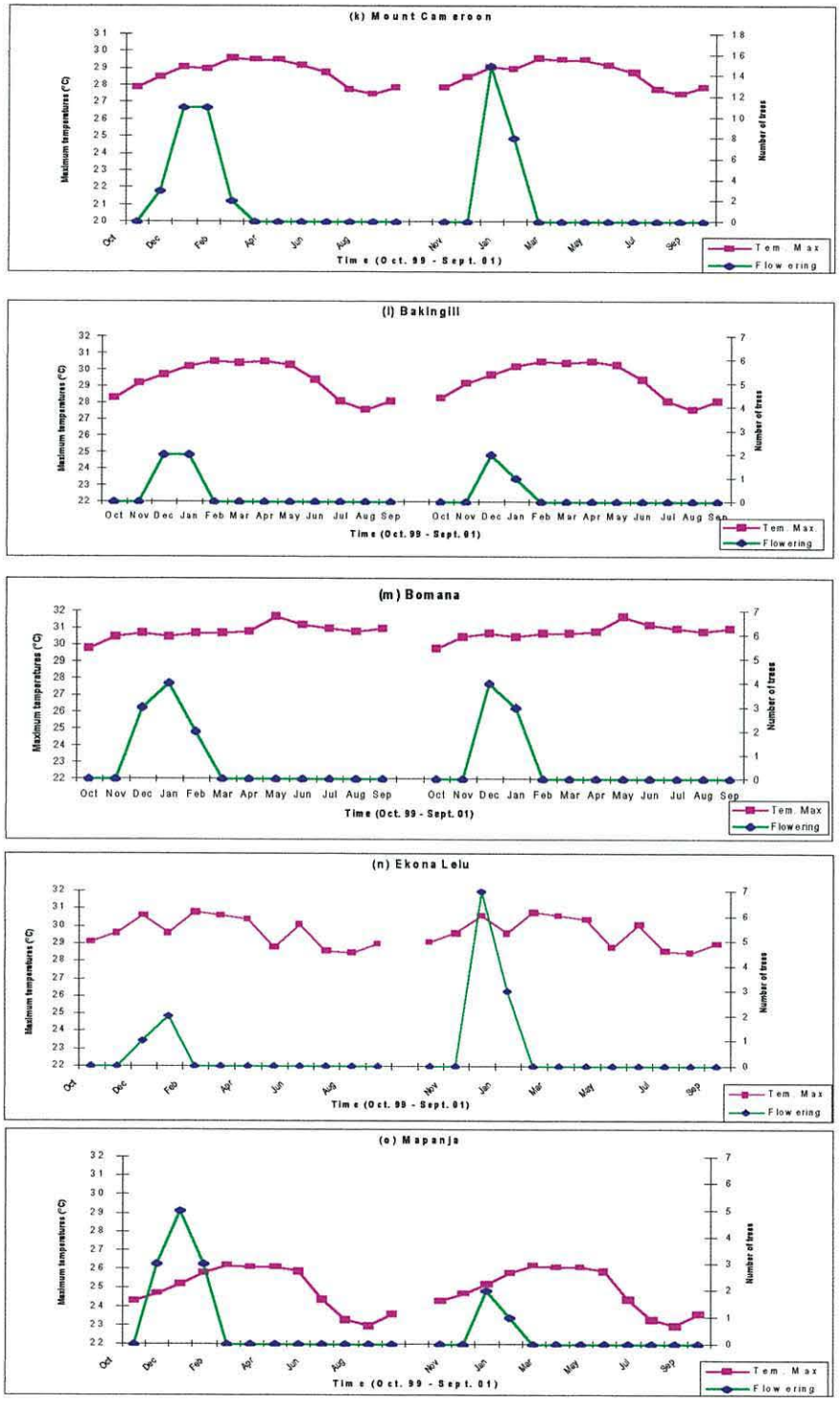

Figure 4.4c: Flowering intensity in *Prunus africana* on Mount Cameroon (overall) and from four geographical locations in relation to mean monthly maximum temperatures.

flowering was longer during the 1999-2000 reproductive season, starting in November and lasting to February with its peak in December – January. In the following year, the duration was shorter, with no single flower on a tree before the first week of December 2000. The onset of flowering in the individuals that flowered in that season was highly synchronised, starting in early December and peaking within a month at 15 individuals, before dropping to 8 individuals in flower by the end of January. No *Prunus africana* flower was observed anywhere on the mountain after this date. Flowering intensity was low: only 14.1% and 13.4% of the trees came into flower in the first and second year of observation respectively. Variability was however observed from one aspect of the mountain to another and also from one year to another (Table 4.3).

Table 4.3: Duration and flowering intensity in *Prunus africana* from four localities around Mount Cameroon

Localities	1999 – 2000			2000 – 2001		
	Duration	Flowering trees	% intensity	Duration	Flowering trees	% intensity
Bakingili	Dec.–Jan.	2	8.7	Dec.–Jan.	2	8.7
Bomana	Dec.-Feb.	6	17.1	Dec.–Jan.	4	11.4
Ekona Lelu	Dec.–Jan.	4	11.8	Dec.–Jan.	8	23.5
Mapanja	Nov.-Jan.	6	17.1	Dec.–Jan.	3	8.6
Mt Cameroon	Nov.-Jan.	18	14.2	Dec.–Jan.	17	13.4

4.3.1.2 Flowering intensity and relationships with meteorological variables

Results of the analysis of the relationships between flowering intensity, monthly rainfall, minimum and maximum temperatures by means of Pearson correlation coefficients are shown in Table 4.4. Phenological and meteorological data are appended (Appendix 4.1).

Table 4.4. Strength of relationship (r values) between flowering intensity, rainfall, minimum and maximum temperatures for *Prunus africana* on Mount Cameroon – BA1 = Bakingili 1999-2000; BA2 = Bakingili 2000-2001; BO1 = Bomana 1999-2000; BO2 = Bomana 2000-2001; EL1 = Ekona Lelu 1999-2000; EL2 = Ekona Lelu 2000-2001; MA1 = Mapanja 1999-2000; MA2 = Mapanja 2000-2001; MC1 = Mount Cameroon 1999-2000; MC2 = Mount Cameroon 2000-2001; * = significant ($p < 0.05$)

Localities	Rainfall	Minimum Temperatures	Maximum Temperatures.
BA1	- 0.9	- 0.96*	- 0.10
BA2	- 0.82	- 0.79	- 0.06
BO1	- 0.9*	- 0.69	- 0.10
BO2	0.71	0.14	0.14
EL1	- 0.67	- 0.81	- 0.35
EL2	- 0.63	- 0.51	0.23
MA1	- 0.54	0.72	- 0.02
MA2	- 0.62	0.46	- 0.12
MC1	- 0.64	- 0.02	0.26
MC2	- 0.71	- 0.01	- 0.13

Flowering in *Prunus africana* on Mount Cameroon was a dry season event and occurred when the least rainfall was recorded in the four localities. The relationships between the flowering intensity and the meteorological data were non-significant in most cases. The correlation coefficient was negatively significant ($p < 0.05$) in only two situations: between the rainfall and flowering intensity for Bomana in 1999-2000 ($df = 3$) and between flowering intensity and minimum temperatures for Bakingili in 1999-2000 ($df = 2$).

4.3.1.3 Fruiting phenology

The flowering cycle was completed in most individuals in a matter of weeks and then followed immediately by the fruiting process that lasted longer. There was no clear separation of flowering and fruiting episodes, but fruiting in *Prunus africana* on Mount Cameroon started in December and lasted for 5-6 months, until April or May when mature fruits were available (Figure 4.5a-c). The peak of fruiting appeared to occur between February and March in both years. The duration of fruiting was short in 1999-2000, starting in December and reaching its peak by March, with the cycle being completed by the end of April. In 2000-2001, fruiting continued until the first week of May with mature purple fruits visible on a few trees. Fruit initiation and elongation occurred between December and February during the dry period, but fruit maturation corresponded with a steady increment in the mean monthly rainfall (Figure 4.5a). A fall in mean monthly minimum temperatures coincided with the onset of fruit initiation, but there was an increase from February (Figure 4.5b). Mean maximum temperatures increased steadily through the same period and rarely dropped below 25°C (Figure 4.5c). Fruiting intensity was low in both years and few individuals produced mature fruits: 18 of 127 trees (14.2%) in 1999-2000 and 14 of 127 trees (11%) during the 2000-2001 reproductive season. There was however variations with locality around the mountain (Table 4.5).

Table 4.5: Duration and fruiting intensity in *Prunus africana* from four localities around Mount Cameroon

Localities	1999 – 2000			2000 – 2001		
	Duration	Fruiting trees	% intensity	Duration	Fruiting trees	% intensity
Bakingili	Feb.-Apr.	2	8.7	Jan.-Apr.	1	4.3
Bomana	Jan.-May	6	17.1	Jan.-May	4	11.4
Ekona Lelu	Jan.-Apr.	4	11.8	Dec.-May	7	20.6
Mapanja	Jan.-May	6	17.1	Jan.-Apr.	2	5.7
Mt Cameroon	Jan.-May	18	14.2	Dec.-May	14	11.0

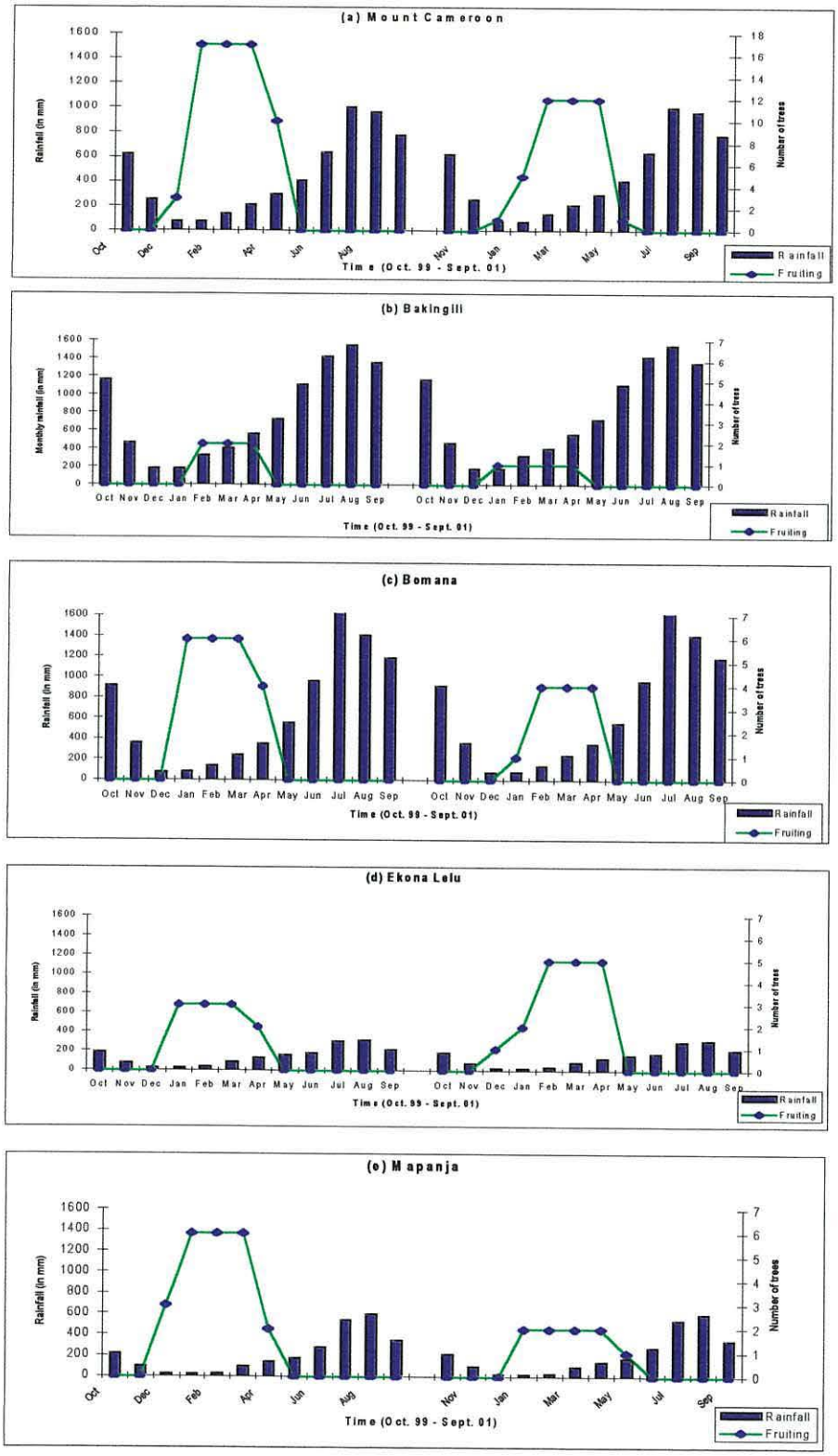

Figure 4.5a: Fruiting intensity in *Prunus africana* on Mount Cameroon (overall) and from four geographical locations in relation to mean monthly rainfall.

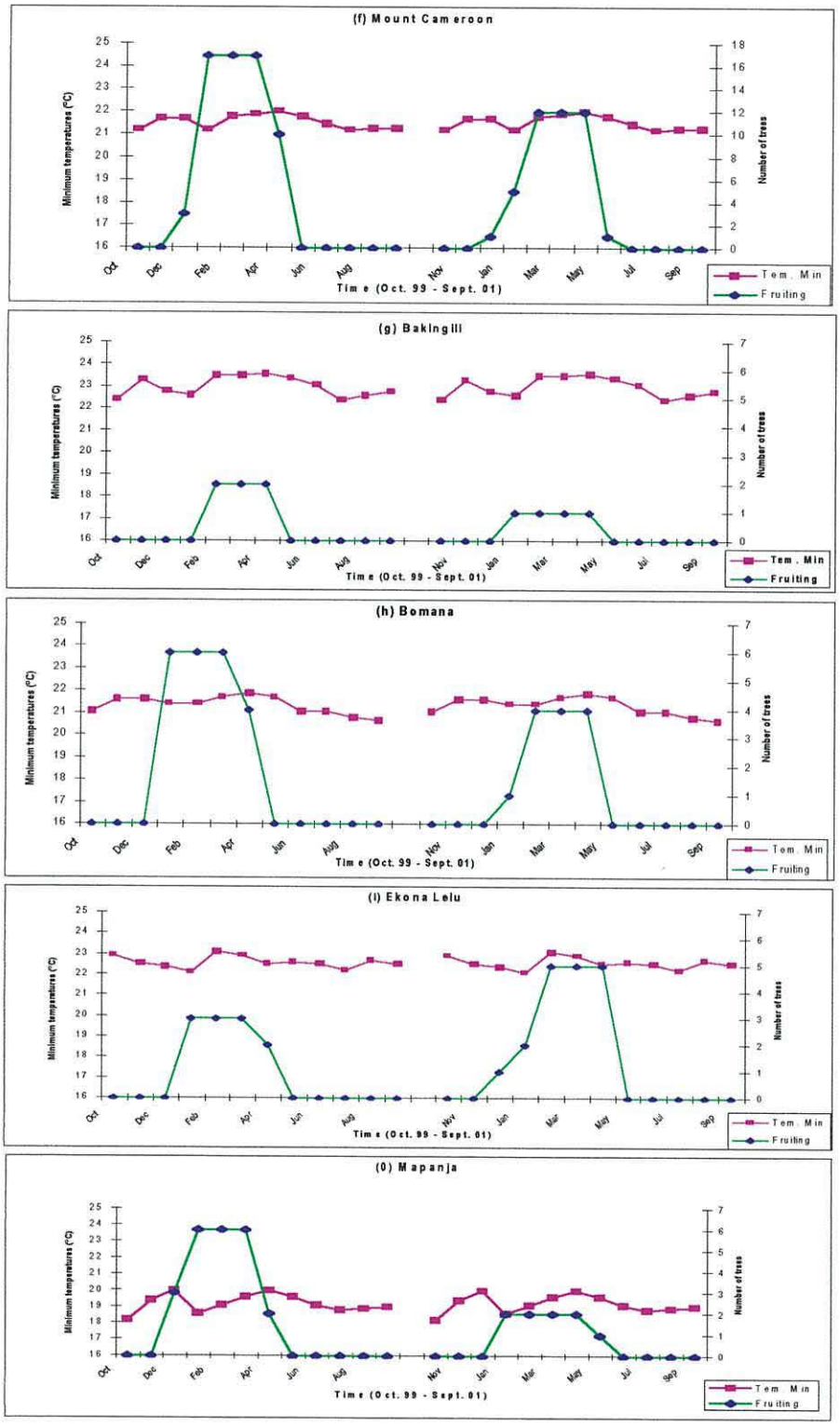

Figure 4.5b: Fruiting intensity in *Prunus africana* on Mount Cameroon (overall) and from four geographical locations in relation to mean monthly minimum temperatures.

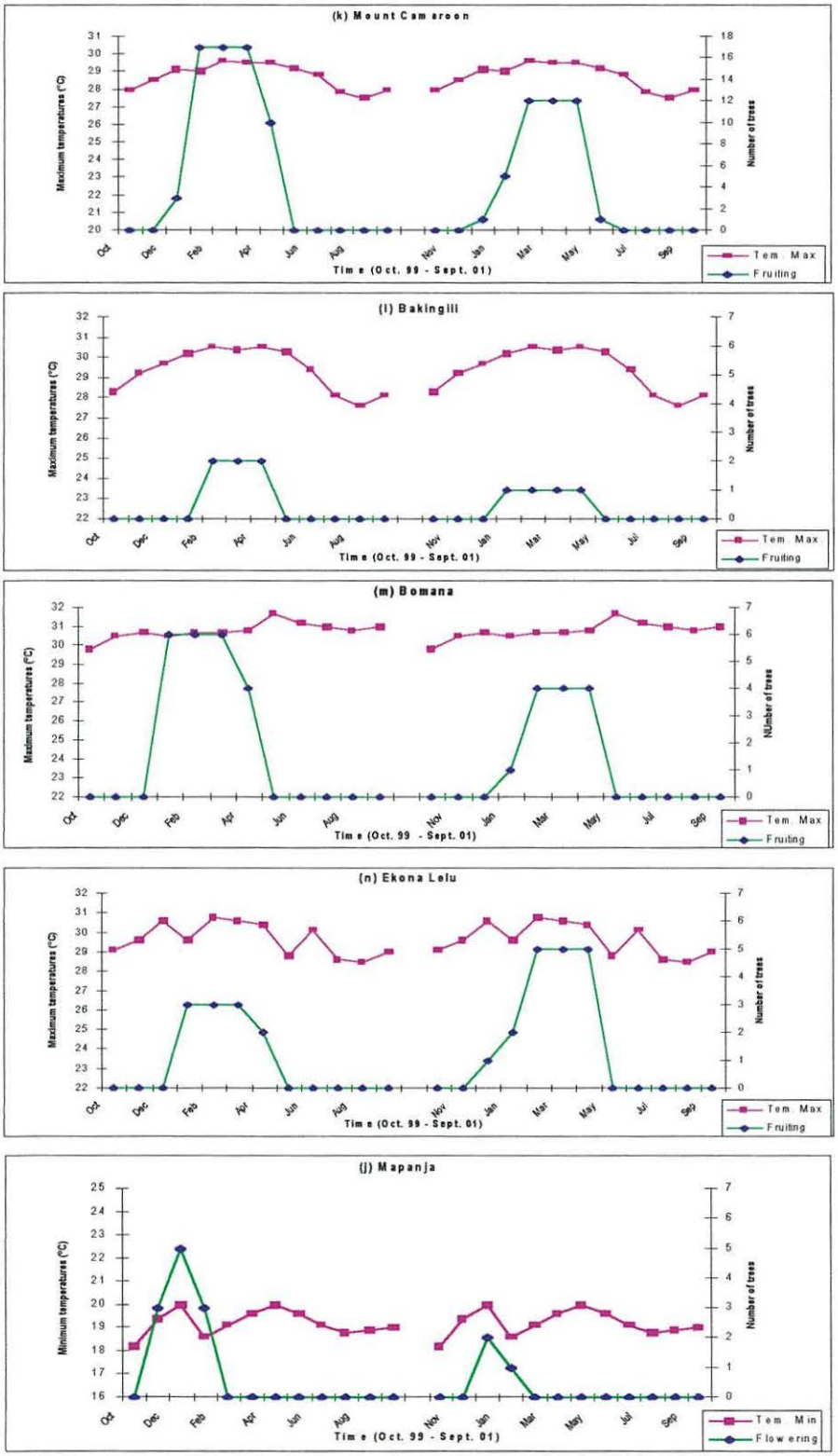

Figure 4.5c: Fruiting intensity in *Prunus africana* on Mount Cameroon (overall) and from four geographical locations in relation to mean monthly maximum temperatures.

4.3.1.4 Fruiting intensity and relationships with meteorological variables

The results of an analysis of relationships between fruiting intensity, monthly rainfall, minimum and maximum temperatures by means of Pearson correlation coefficients are displayed in Table 4.6.

Table 4.6. Strength of relationship (r values) between fruiting intensity, rainfall, minimum and maximum temperatures for *Prunus africana* on Mount Cameroon – BA1 = Bakingili 1999-2000; BA2 = Bakingili 2000-2001; BO1 = Bomana 1999-2000; BO2 = Bomana 2000-2001; EL1 = Ekona Lelu 1999-2000; EL2 = Ekona Lelu 2000-2001; MA1 = Mapanja 1999-2000; MA2 = Mapanja 2000-2001; MC1 = Mount Cameroon 1999-2000; MC2 = Mount Cameroon 2000-2001; * = significant ($p < 0.05$)

	Rainfall	Minimum Temperatures	Maximum Temperatures
BA1	-0.05	0.71	0.91
BA2	-0.2	0.24	0.68
BO1	-0.42	-0.34	-0.65
BO2	-0.07	0.19	-0.4
EL1	-0.33	0.26	0.41
EL2	-0.05	0.5	0.74
MA1	-0.97*	-0.44	-0.14
MA2	-0.42	-0.22	0.87*
MC1	-0.51	-0.4	0.47
MC2	-0.41	0.16	0.71*

Fruiting episodes at the scale of Mount Cameroon started in December in the dry season and continued into the rainy season when fruits matured. This period coincided with a steady increase in the amount of rainfall that started in February and reached a peak in July – August. Minimum and maximum temperatures experienced a steady, but less considerable increase during this period and came to their peaks in March-April, a period that coincided with fruit maturation in both years. There was a significant correlation ($p < 0.05$) between fruiting intensity and maximum temperatures in 2000-2001 for the combined data for the mountain ($df = 6$). At the locality level, there was a significant correlation ($p < 0.05$) between fruiting intensity and rainfall for Mapanja in 1999-2000 ($df = 5$) and between fruiting intensity and maximum temperature in the same locality in 2000-2001 ($df = 5$).

4.3.2 Frequency of flowering and fruiting on Mount Cameroon

The overall pattern of flowering and fruiting frequency in *Prunus africana* on Mount Cameroon is summarised in Table 4.7, together with the significance level of the G-test of goodness-of-fit. Frequency matrix data are appended (Appendix 4.2).

Table 4.7: Constancy (C), Contingency (M) and Predictability (P) of flowering and fruiting (1999/2000 and 2000/2001 seasons) for 28 *Prunus africana* trees on Mount Cameroon. Significance of the estimate in each case was tested by means of G-statistics and compared with a chi-square distribution (Colwell, 1974). The codes in the tree number column indicate the serial number of the tree preceded by the first two letters for the corresponding locality as follow: BA, Bakingili; BO, Bomana, EL, Ekona Lelu; MA, Mapanja. Significance level: *p<0.01; **p<0.001.

Tree No	C	M	P	Fig.4.8	Tree No	C	M	P	Fig. 4.8
BA06	0.57	0.34*	0.91	2	EL07	0.57	0.34*	0.91	2
BA15	0.87	0.08*	0.95	3	EL08	0.57	0.34*	0.91	2
BA20	0.57	0.34*	0.91	2	EL14	0.61	0.19*	0.80	2
BA25	0.57	0.34*	0.91	2	EL20	0.66	0.08*	0.74	2
BO06	0.57	0.34*	0.91	2	EL23	0.61	0.19*	0.80	2
BO51	0.50	0.49*	0.99	1	EL45	0.87	0.08*	0.95	3
BO54	0.57	0.34*	0.91	2	EL46	0.65	0.20*	0.85	2
BO55	0.50	0.24**	0.74	1	MA02	0.49	0.20*	0.69	2
BO56	0.57	0.34*	0.91	2	MA03	0.57	0.34*	0.91	2
BO59	0.61	0.19*	0.80	2	MA05	0.66	0.08*	0.74	2
BO60	0.49	0.40*	0.89	1	MA06	0.57	0.34*	0.91	2
EL02	0.66	0.08*	0.74	2	MA07	0.54	0.14*	0.68	2
EL03	0.65	0.15*	0.80	1	MA08	0.57	0.34*	0.91	2
EL06	0.57	0.34*	0.91	2	MA24	0.54	0.14*	0.68	2

Each of the 99 remaining trees in the sample that did not flower in two years scored a constancy value of 1 and a contingency value of 0 (Predictability = 1)

The predictability for trees that flowered at least once in the two reproductive seasons ranged from 0.68 to 0.95. The G-test of significance suggested however, that this value was not fundamentally different from zero, suggesting that the reproductive activity in *Prunus africana* on Mount Cameroon is not in accordance with a definite pattern. The predictability value recorded for each individual was largely driven by its constancy component, suggesting variation from year to year in the reproductive state of the trees. Equally, the constancy value in all individual trees was not significant,

indicating that flowering and fruiting may occur at any time within the period of the year when observations were made (November to May) and varied between years for individual trees. The contingency values were highly significant for all the flowering trees, suggesting that the reproductive activity in *Prunus africana* is seasonal on Mount Cameroon and occurs between November and May.

The examination of the variation in the state of the trees and in the timing and duration of the reproductive episodes (Figure 4.6) indicates a gradient in the frequency of flowering and fruiting in *Prunus africana* on Mount Cameroon.

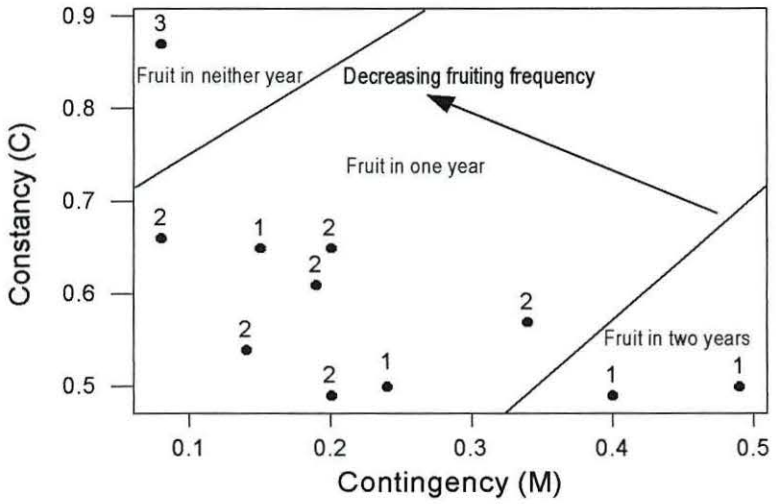

Figure 4.6: Typology of flowering and fruiting frequency (1999/2000 and 2000/2001) for 28 *Prunus africana* trees on Mount Cameroon. The labels are specified as follow: 1, flowering and fruiting in both years; 2, flowering and fruiting once in two years; 3, flowering and fruiting in neither year.

Three possible categories of trees were identified in relation to the frequency of fruiting. The first category comprised four individuals of which there were two with constancy and contingency values of similar magnitude (Label 1). The third and fourth tree in the category had fruit in both years, but in only a single month (December for EL03 and January for BO55) compared with the 3-months (BO60) and

4-months (BO51) period of others. In the second category (Label 2), fruits were recorded in one of the two years only as far as the individual trees were concerned. The dominant pattern, shown by twelve out of 28 individuals falls in this category. Ten other trees reproductively active for different duration and over periods beginning in different months make up the rest of the category. Within this group of ten trees, three individuals (EL46, MA02, and MA03) flowered in both years, but produced no single fruit in one of the two seasons. The last category (Label 3) contained two trees (BA15 and EL45) that flowered once in two years both in December, but produced no fruit.

4.3.3 Flowering synchrony

The timing and duration of the flowering period for individual trees are diagrammatically represented in Figure 4.7. The synchrony indices for individual trees are summarised in Table 4.8 and the sample synchrony are offered in Table 4.9.

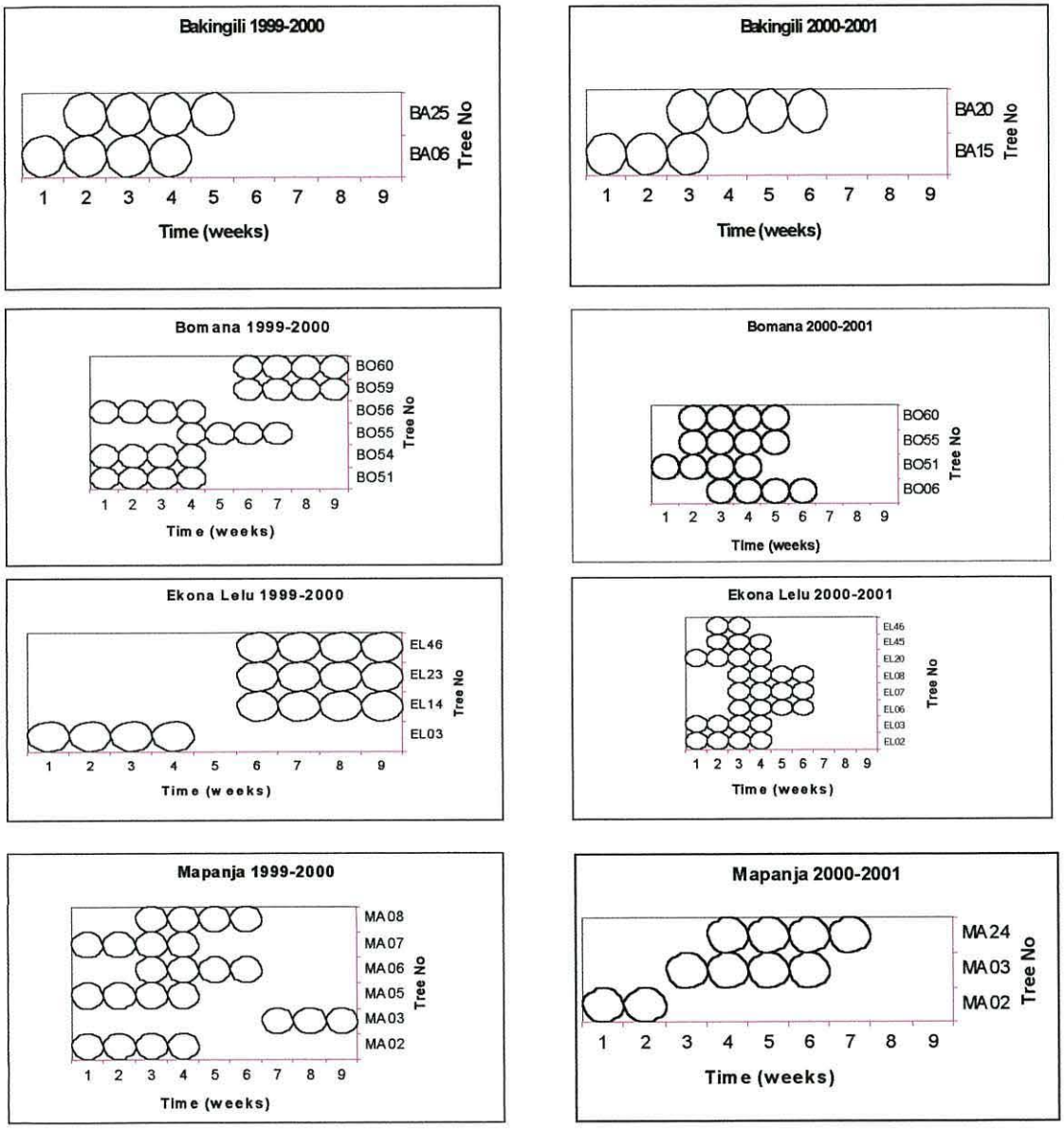

Figure 4.7: Diagram of the timing and duration of flowering episodes in *Prunus africana* on Mount Cameroon (Each circle represents a flowering period of 7 days – Superposition of circles within a similar time scale denotes period of overlap in flowering) – Flowering occurred in seven individuals (BO51, BO55, BO60, EL03, EL46, MA02 and MA03) every year, but fruit maturation occurred only in two trees (BO51 and BO60) – Refer also to figure 4.8 and accompanying text.

Table 4.8: Flowering synchrony indices for individual *Prunus africana* trees from four localities on Mount Cameroon for 2 reproductive seasons (1999-2000 & 2000-2001). The tree codes are defined in relation to the four localities: BA = Bakingili; BO = Bomana; EL = Ekona Lelu; MA = Mapanja – X_i = Index of synchrony of individual $_i$.

Reproductive seasons			
1999 – 2000		2000 – 2001	
Tree No	Individual synchrony (X_i)	Tree No	Individual synchrony (X_i)
BA06	0.75	BA15	0.33
BA25	0.76	BA20	0.25
BO51	0.45	BO06	0.67
BO54	0.45	BO51	0.67
BO55	0.35	BO55	0.83
BO56	0.45	BO60	0.83
BO59	0.30	EL02	0.68
BO60	0.30	EL03	0.68
EL03	0.00	EL06	0.60
EL14	0.67	EL07	0.60
EL23	0.67	EL08	0.60
EL46	0.67	EL20	0.68
MA02	0.60	EL45	0.81
MA03	0.00	EL46	0.79
MA05	0.60	MA02	0.00
MA06	0.40	MA03	0.75
MA07	0.60	MA24	0.75
MA08	0.50	-	-

Table 4.9: Flowering synchrony indices for four populations of *Prunus africana* on Mount Cameroon

Geographical location	Sample synchrony (Z)	
	1999-2000	2000-2001
Bakingili	0.75 ± 0.00	0.29 ± 0.05
Bomana	0.38 ± 0.07	0.75 ± 0.09
Ekona Lelu	0.43 ± 0.28	0.68 ± 0.08
Mapanja	0.45 ± 0.23	0.50 ± 0.43

The result of the examination of the variation in the mean synchrony for each locality from 1999-2000 to 2000-2001 reproductive seasons is presented in Table 4.10. Individual synchrony indices for each locality (Table 4.8) were entered in two separate columns corresponding to the first and second reproductive seasons respectively.

Table 4.10: Results of t-test of difference in mean synchrony for 1999-2000 and 2000-2001 (2-sample t test).

Localities	Df	t-value	P-value
Bakingili	1	11.5	0.056
Bomana	5	6.6**	0.001
Ekona Lelu	3	1.0	0.37
Mapanja	2	0.2	0.87

** Highly significant ($p<0.01$)

Flowering synchrony for individual trees was high in Bakingili the first year (0.75) and the two trees that came to flower differed just in a matter of a single week in the timing of their flowering pattern. The mean synchrony was concomitantly high (0.75 ± 0.00). This trend was reversed the following year and the synchrony indices of individual trees felled to 0.33 and 0.25. The mean synchrony was therefore reduced to 0.29 ± 0.05. In the trees from Bomana, the synchrony indices for individual trees were low the first year and ranged from only 0.30 to 0.45 for a synchrony mean of 0.38 ± 0.07. The second year experienced a different scenario. All the trees displayed considerable overlaps in the timing and duration of flowering, as expressed in the synchrony indices (from 0.67 to 0.83 for a mean of 0.75 ± 0.09). The situation in Ekona Lelu was peculiar the first year. While one individual flowered completely in solo (index = 0), 3 others trees flowered almost synchronously (index = 0.67). The mean synchrony index was slightly misleading and amounted to 0.43 ± 0.28. The following year showed an apparently conversed situation with medium to high individual flowering indices that ranged from 0.60 to 0.81 (mean synchrony = 0.68 ± 0.08). In Mapanja forest, individual flowering synchrony indices ranged from 0.40 to 0.60, for a mean of 0.45 ± 0.23 during the 1999-2000 season. One tree also flowered

in solo during this period. During the second year, two trees flowered almost synchronously, at least for three weeks, while a third one flowered alone. Individual synchrony indices ranged from 0 to 0.75 for a mean of 0.50 ± 0.43.

The t-test of difference in the mean synchrony indices from the first reproductive season to the second (Table 4.10) was only significant for the trees from Bomana forest ($t = 6.6$; $P = 0.001$).

4.3.4 Flowering and fruiting in relation to elevation

There was no obvious relationship between elevation and the flowering/fruiting pattern (Figure 4.8), although flowering trees were dispersed over a wide range of altitude. During the 1999-2000 reproductive season, seven of the eighteen trees at elevations below 1500 m flowered and produced fruits, but only four trees within this elevation range flowered and/or produced fruits during the 2000-2001 reproductive season. Analysis at the level of separate geographical locations indicated no obvious pattern (Figure 4.9). However, during the 1999-2000 reproductive season, all the flowering trees at Mapanja were located at elevation below 1200 m and all flowering trees at Bomana were located over 2000 m.

The flowering pattern in relation to the size of the tree indicated that no tree under 20 cm or over 109 cm dbh produced flowers and/or fruits in the course of the two reproductive seasons (Figure 4.8). The majority of the trees that flowered were over 50 cm dbh. This trend was more pronounced in Bomana and Mapanja during the two reproductive seasons.

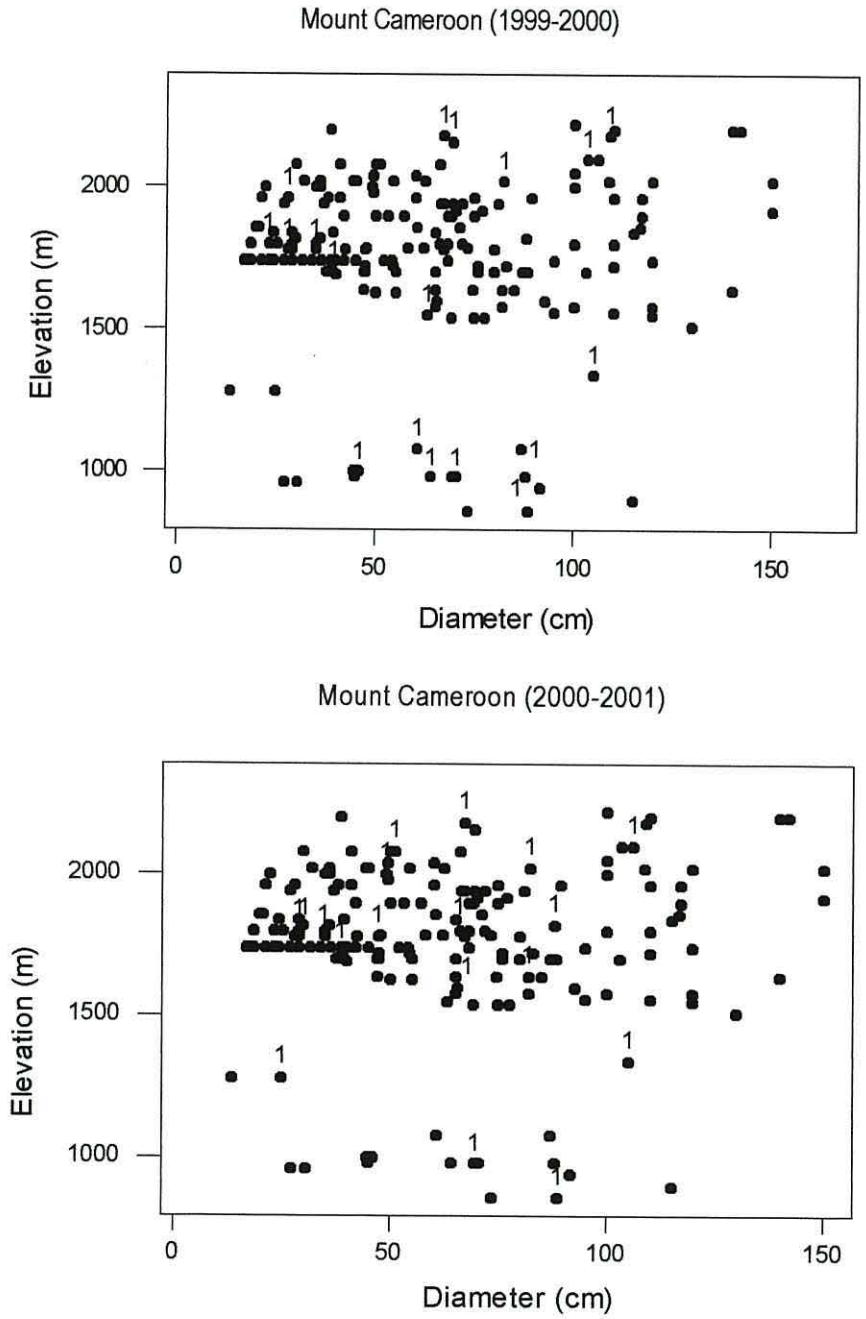

Figure 4.8: Flowering pattern in *Prunus africana* on Mount Cameroon in relation to elevation and tree size (1999-2000 & 2000-2001) – Flowering trees are labelled "1" on a location dot and non-flowering trees are unlabelled.

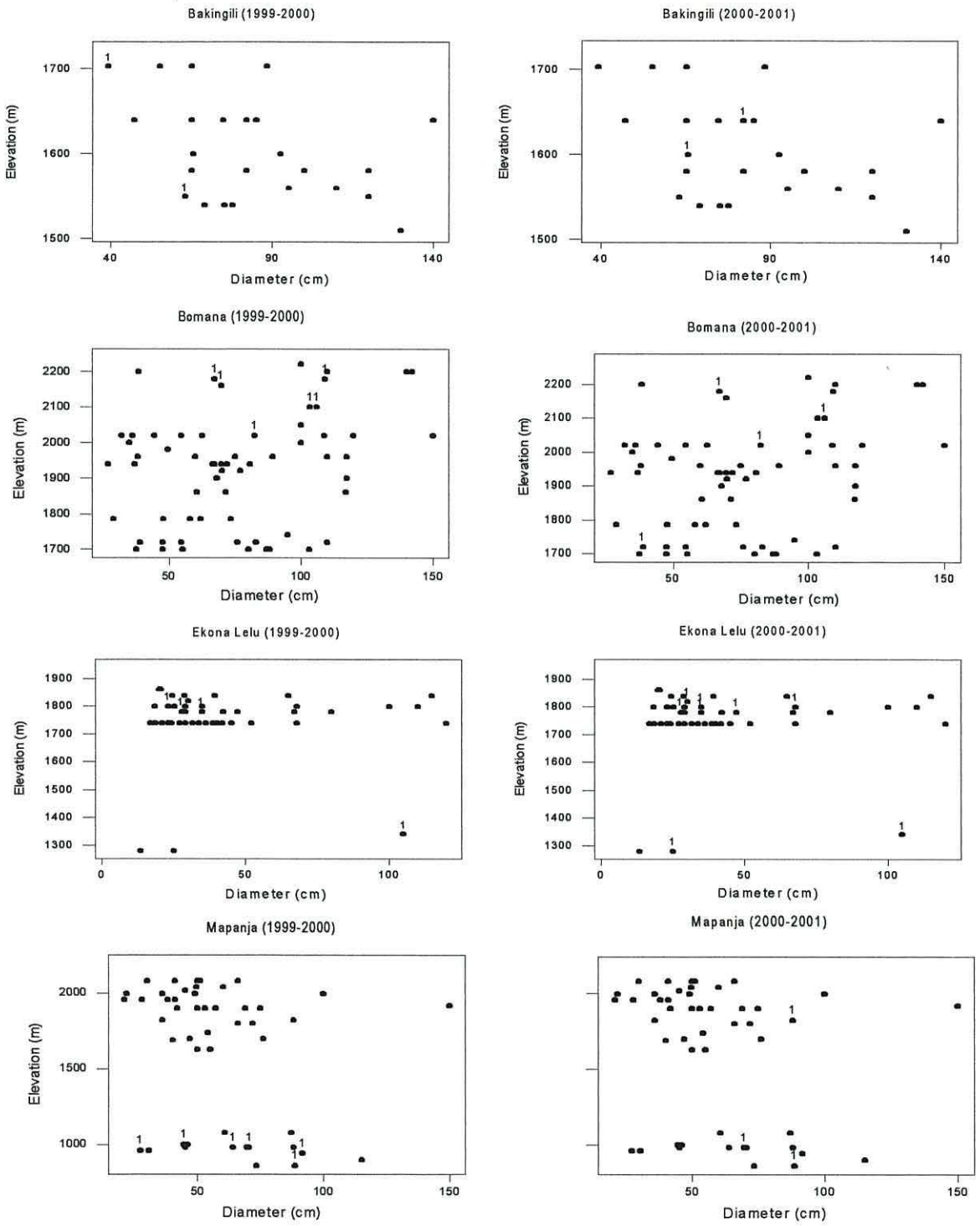

Figure 4.9: Flowering pattern in *Prunus africana* in four localities on Mount Cameroon in relation to elevation and tree size (1999-2000 and 2000-2001) – Flowering trees are labelled "1" on a location dot and non-flowering trees are unlabelled.

4.3.5 Flowering and fruiting in relation to tree health

The analysis of the significance of difference in flowering intensity - taken as the number of flowering trees -, in relation to the tree health class by mean of a G-test of independence (Table 4.11) was conducted for the total number of trees that flowered during the two reproductive seasons. This analysis indicated no significant difference ($G^* = 5.46 < \chi^2$ with 2 degree of freedom = 5.99 at 5%), suggesting that tree debarking was not associated with the flowering of individuals during the observation periods.

Table 4.11: G-test - flowering and fruiting intensity in relation to tree health.
Figures in brackets represent the expected values - * = G adjusted – Figures in the health classes column refer to the health indices as follow: 1 = Undamaged tree with perfect trunk (100% intact) from 1.30 m dbh up to the first branch and all branches alive - 2 = Tree with evidence of debarking affecting less than 50% of the trunk and less than 50% of dead branches - 3 = Tree with evidence of debarking affecting less than 50% of the trunk and more than 50% of dead branches.

Health classes	Reproductive behaviour		Total
	Flowering	Non flowering	
1	8 (7.06)	24 (24.94)	32
2	11 (15.87)	61 (56.13)	72
3	9 (5.07)	14 (17.93)	23
Total	28	99	127
G-value	5.64		
G*	5.46		

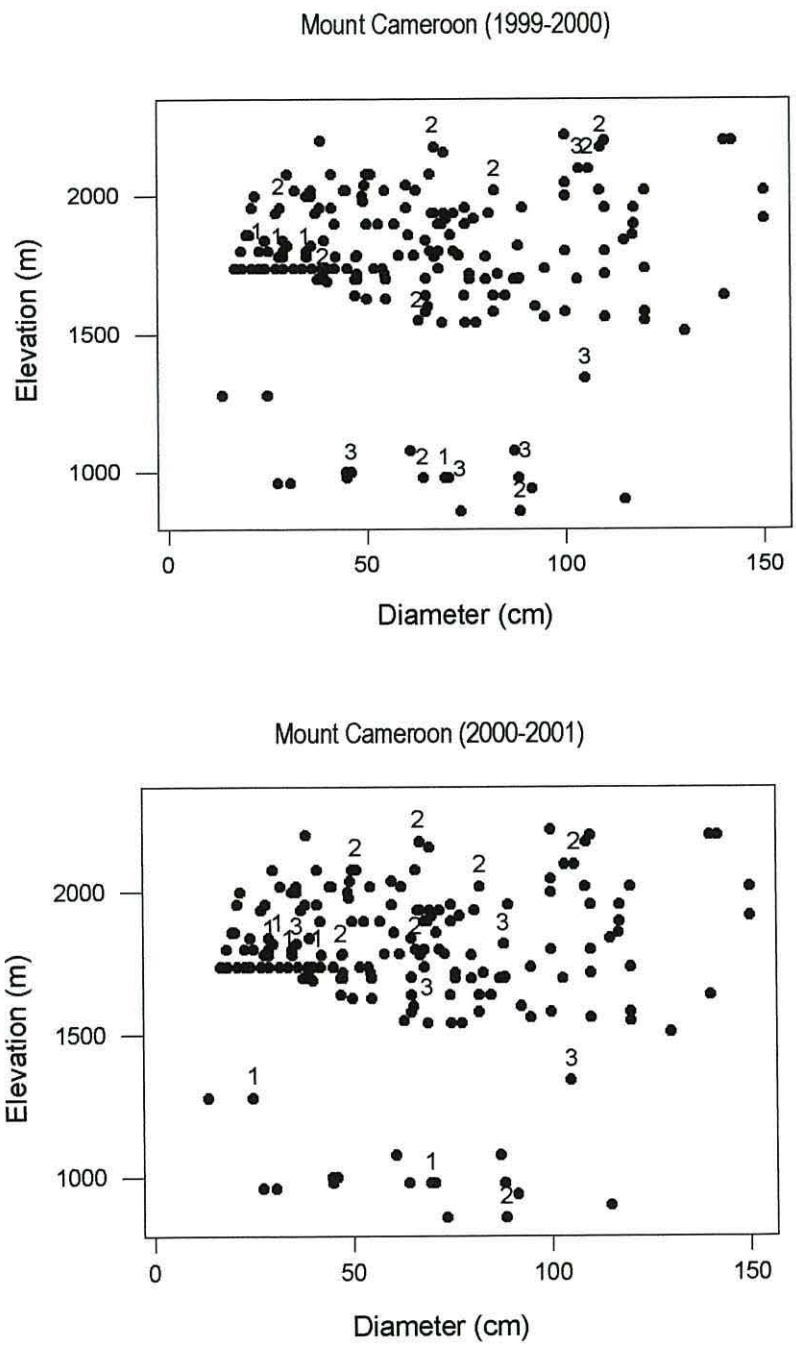

Figure 4.10: Flowering pattern in *Prunus africana* on Mount Cameroon in relation to the tree health and the tree size (1999-2000 & 2000-2001). - The labels on location dot of flowering trees denote the health classes as follow: 1 = Undamaged tree with perfect trunk (100% intact) from 1.30 m dbh up to the first branch and all branches alive - 2 = Tree with evidence of debarking affecting less than 50% of the trunk and less than 50% of dead branches - 3 = Tree with evidence of debarking affecting less than 50% of the trunk and more than 50% of dead branches. Non-flowering trees are not labelled.

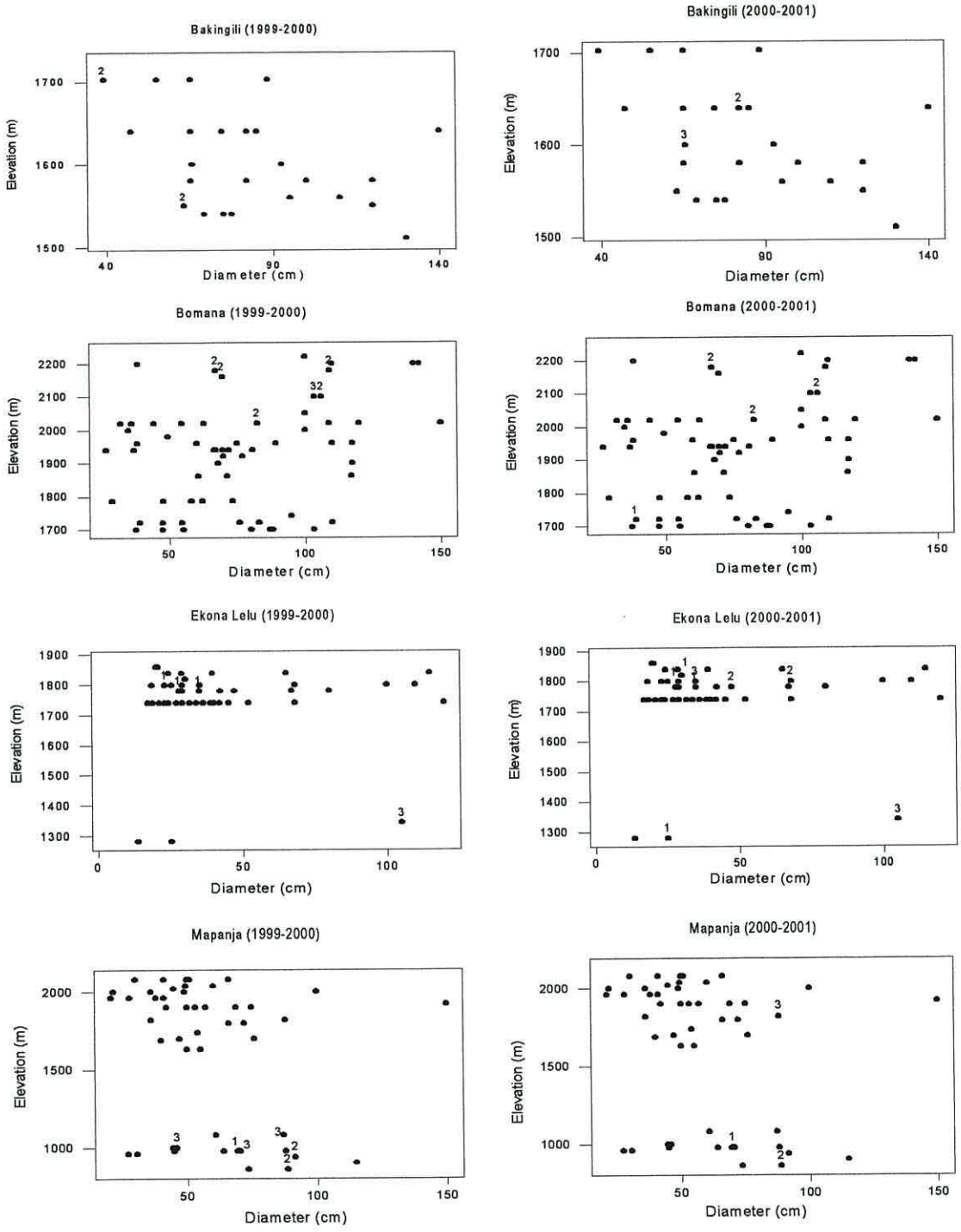

Figure 4.11: Flowering pattern in *Prunus africana* in four localities on Mount Cameroon in relation to the tree health and the tree size (1999-2000 and 2000-2001). The labels on the location dot of flowering trees denote the health classes as follow: 1, undamaged tree with perfect trunk (100% intact) from 1.30 m dbh up to the first branch and all branches alive; 2, trees with evidence of debarking affecting less than 50% of the trunk and less than 50% of dead branches; 3, tree with evidence of debarking affecting less than 50% of the trunk and more than 50% of dead branches. Non-flowering trees are not labelled.

4.4 Flower and fruit production

Estimates of flower productivity in *Prunus africana* on Mount Cameroon are summarised in Table 4.12.

Table 4.12 indicates that the canopy cover area ranges from 44 m^2 for the tree 27 cm dbh (EL07) to 310 m^2 for the tree 89 cm dbh (MA02). The mean number of flowers counted per 1 m x 1 m plot during the flowering period (November-February) yielded an average of 100 ±114 flowers to 2952 ± 646 flowers per m^2. The sample standard deviations for individual trees were high, suggesting that flower production on a tree was not uniform and there were sections of the crown that produced significantly more flowers than others. The estimated total flower litter fall L, was 4402 flowers for the tree 27 cm dbh and 730765 flowers for the tree 82 cm dbh. Taking account of the number of fruits produced resulted in adjusted estimates of 4424 and 731001 flowers.

Fruit production was low compared with flower production. The mean number of fruits counted m^{-2} ranged from 14 (tree No EL06) to 261 fruits (tree No MA24). The estimated number of fruits produced per tree ranged from 891 (tree No EL06) to 80493 fruits (tree No MA02). Estimated fruit:flower ratio ranged from 0.06 to 0.18.

Table 4.12: Flower and fruit production in *Prunus africana* on Mount Cameroon

Abbreviations in the Tree No column refer to the geographical location of a tree, followed by its serial number - BA = Bakingili; BO = Bomana; EL = Ekona Lelu; MA = Mapanja. Dbh = Diameter at breast height (in cm) - CL-NS = length of the vertical projection of the canopy cover area in the north-south direction (in m); CL-EW = length of the vertical projection of the canopy cover area in the East-West direction (in m); r = half the average (in m) of the east-west and north-south crown diameter measurements; CS = Canopy cover area (in m^2); F = Mean Number of flower/m^2; L = Total flower litter fall; S = Mean number of fruit/m^2; Fl = Estimated total number of flowers/tree (L + Fr); Fr = Estimated total number of fruits/tree; Fr:Fl = Fruit:flower ratio.

Tree No	Dbh	CL-NS	CL-EW	r	CS	F	L	S	Fl	Fr	Fr:Fl
BA20	82	17	15	8	200	2369±754	473534	251±60	523706	50172	0.10
BO06	39	13	12	6	118	188±138	22202	19±12	24442	2240	0.09
BO51	82	21	15	9	248	2952±646	730765	236±63	789187	58422	0.07
BO55	106	17	16	8	214	2549±813	545258	243±81	597239	51980	0.09
BO62	39	12	11	6	99	249±44	24721	27±8	27406	2685	0.10
EL02	25	10	9	5	71	145±128	10268	17±15	11473	1205	0.11
EL06	30	7	11	5	64	126±153	8019	14±16	8910	891	0.10
EL07	27	8	7	4	44	100±114	4402	22±31	5374	972	0.18
EL08	68	13	12	6	123	171±128	21042	16±11	23007	1964	0.09
EL20	35	11	11	5	91	158±140	14346	16±14	15799	1453	0.09
EL45	47	15	14	7	162	128±95	20629	0	20629	0.0	0.00
EL46	35	12	11	6	103	210±135	21622	19±12	23579	1957	0.08
MA02	89	24	16	10	310	2172±573	672428	260±102	752921	80493	0.11
MA03	70	13	14	7	138	296±283	40831	20±10	43590	2759	0.06
MA24	88	20	15	9	241	2085±649	501703	261±76	564506	62803	0.11

4.5 Tree size, flower and fruit production

Figure 4.14, 4.15 and 4.16 display the line fit plots established between the size of *Prunus africana* trees, the flower and fruit production, and the fruit set. The results of the significance of the relationships are summarised in Table 4.13

Table 4.13: Flower and fruit production in *Prunus africana*: relationship with tree size

Total number of flowers and fruits were log-transformed and the fruit:flower ratio square-root transformed prior to the regression.

Independent variable (X)	Dependant variable (Y)	F (Regression coefficient)	Linear regression relationships
Dbh	Total number of flowers produced per tree	69.7**	$\ln Y = 3.22551+0.0267876X$ ($r^2 = 83.1\%$)
Dbh	Total number of fruits produced per tree	51.6**	$\ln Y = 2.298 + 0.0253920X$ ($r^2 = 79.6\%$)
Dbh	Fruit:flower ratio or fruit set	1.2	$Y^{1/2} = 0.3371 - 0.0004412X$ ($r^2 = 1.4\%$)

Dbh = Diameter at breast height; ** = highly significant ($p < 0.01$)

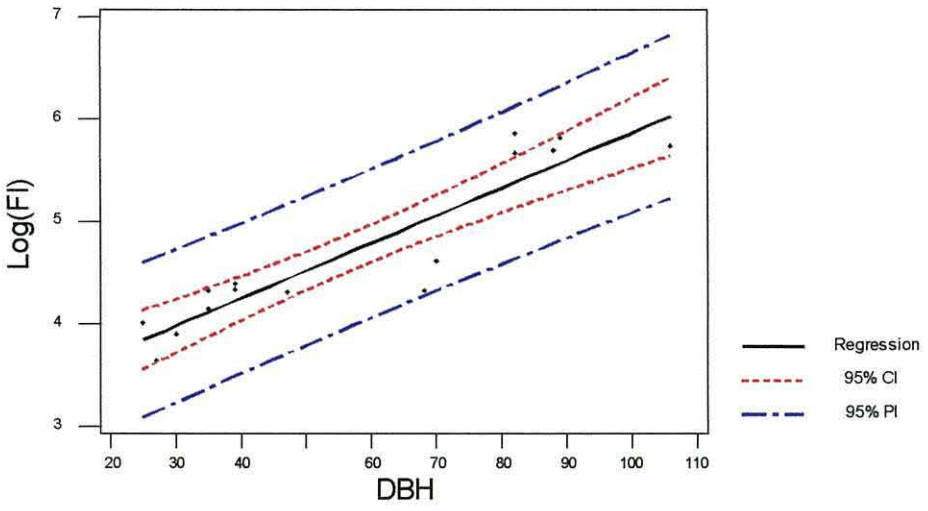

Figure 4.12: Linear regression – Tree size and flower production in *Prunus africana* on Mount Cameroon (CI = Confidence intervals; PI = Prediction intervals)

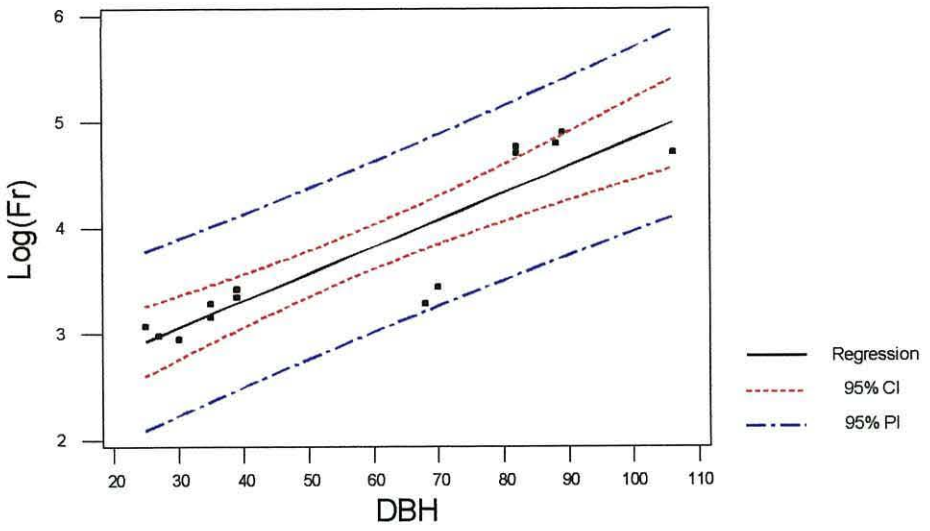

Figure 4.13: Linear regression – Tree size and fruit production in *Prunus africana* on Mount Cameroon (CI = Confidence intervals; PI = Prediction intervals)

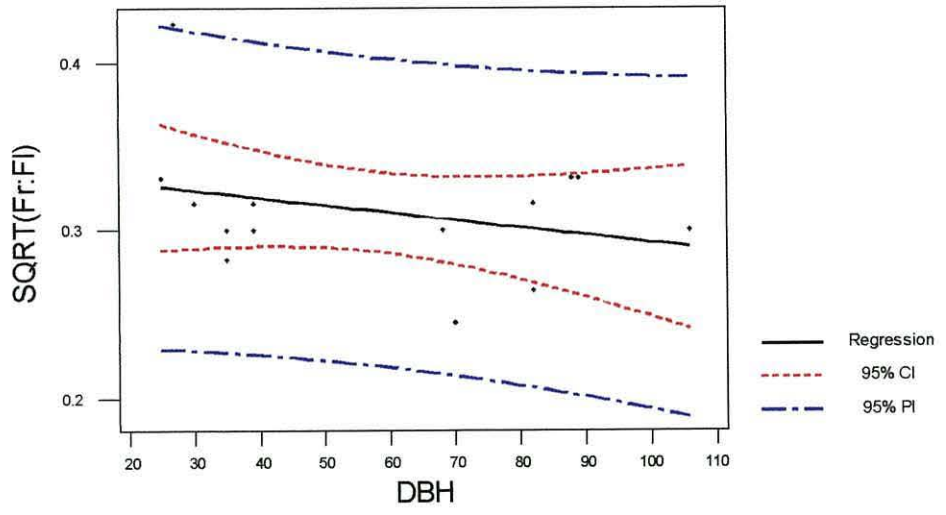

Figure 4.14: Linear regression – Tree size and fruit:flower ratio in *Prunus africana* on Mount Cameroon (CI = Confidence intervals; PI = Prediction intervals)

The regression analyses (Table 4.13) indicate a highly significant relationship between the tree diameter and the total flower production. The relationship is equally highly significant between the tree diameter and the total number of fruit. Both relationships reflect increasing production of flowers and fruits with the tree size. The relationship between the tree size and the fruit:flower ratio was non-significant.

4.6 Breeding mechanisms

4.6.1 Fruit set and seed set in *Prunus africana*

Fruit and seed set following natural and assisted pollinations of *Prunus africana* flowers on Mount Cameroon are summarised in Table 4.14.

Table 4.14: Fruit and seed set in *Prunus africana* considering both pollination intensity and pollen source.
I, Flowers tagged and left unbagged (open-pollination - control); II, Flowers unmanipulated, but bagged (Autogamy); III, Flowers unmanipulated, but stigma contaminated with pollen from another flower on the same tree (Geitonogamy); IV, Flowers emasculated and bagged without pollination (Agamospermy);V, Flowers unmanipulated, but stigma contaminated with pollen from another flowers on a different tree (Xenogamy). 1, Tree No MA02 (1999-2000); 2, Tree No BO51 (2000-2001); 3, Tree No BO62 (2000-2001); fruit set is the ratio of the number of juvenile fruits to the number of flowers; seed set is the ratio of the number of mature fruits to the number of flowers.

Inflorescences traits	Treatments														
Treatment codes	I			II			III			IV			V		
Pollen source	Unrestricted			Same inflorescence			Same tree			None			Distant individual		
Tree No	1	2	3	1	2	3	1	2	3	1	2	3	1	2	3
No of flowers treated	202	863	1487	156	1043	1582	203	1756	2919	13	47	58	193	667	883
No of inflorescences used	10	50	82	10	89	111	21	156	276	4	11	20	18	61	83
No of fruits obtained	28	132	221	17	95	142	18	142	232	0	0	0	38	140	175
No of seeds obtained	9	44	74	6	41	64	2	50	62	0	0	0	15	53	67
Fruit set (%)	13.8	15.3	14.9	10.9	9.1	9.0	8.9	8.0	7.9	0	0	0	19.7	20.9	19.8
Seed set (%)	4.4	5.0	5.0	3.8	3.9	4.0	0.9	2.8	2.1	0	0	0	7.8	7.9	7.6

No fruit was recorded in flowers subjected to anther removal and bagging prior to anthesis, suggesting that agamospermy did not occur in *Prunus africana* on Mount Cameroon. Differences were observed in fruit and seed set depending on the pollen source (Figure 4.15).

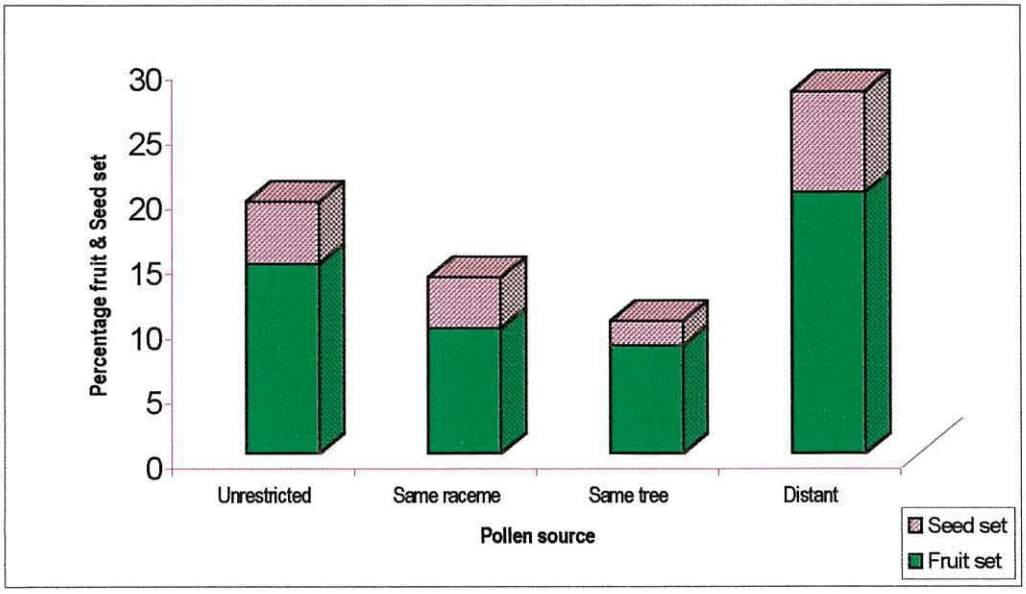

Figure 4.15: Variation in fruit set and seed set in *Prunus africana* following the pollen source

The results of G-tests of significance of differences in fruit set following the four treatments are summarised in Table 4.15. Flowers subjected to anther removal and bagging without pollen transfer (agamospermous treatment), produced no fruits and were excluded from the analysis.

Table 4.15: G-test of independence for fruit set in *Prunus africana* on Mount Cameroon in relation to treatment. Figures in brackets are expected values (* = G adjusted) – ISI = Index of self-incompatibility (Bawa, 1974).

Treatments	Reaction to treatments		
	# fruits set	# dead flowers	Total
Autogamy	254 (321.0)	2527 (2459.9)	2781
Geitonogamy	392 (563.1)	4486 (4314.8)	4878
Natural – control	381 (294.6)	2171 (2257.4)	2552
Xenogamy	353 (201.2)	1390 (1541.8)	1743
Total	1380	10574	11954
G-value	217.1		
G*	216.8		
ISI	0.45		

G* indicates that fruit set varies with treatment. To isolate the effects, the G value was partitioned into three components corresponding to the pollen sources (Table 4.16).

Table 4.16: G-test of independence for fruit in *Prunus africana* on Mount Cameroon in relation to pollen source - Unrestricted pollen source refers to the control treatment or natural pollination. Restricted pollen source indicates the combination of flowers subjected to xenogamy, autogamy and geitonogamy. Close pollen source refers to autogamy and geitonogamy; distant pollen source refers to xenogamy. (* = G adjusted; P is the significance level)

Constraints	df	G	G*	P
Unrestricted vs. restricted pollinations	1	34.47	34.45	< 0.01
Close vs. distant pollen sources	1	179.90	179.70	< 0.01
Autogamy vs. geitonogamy	1	2.80	2.70	n.s
Total	3	217.17	216.85	-

n.s = not significant

Fruit set was significantly different between restricted and unrestricted pollen sources ($G^* > 3.8 = \chi^2$, df = 1, p = 0.05). Within the restricted pollen source, there was also a significant difference between xenogamy and combined autogamy and geitonogamy. However, no difference in fruit set was revealed between the autogamy and geitonogamy treatments.

4.6.2 Germination performance

Germination parameters determined for seeds generated after different treatments are summarised in Table 4.17. The final germination percentages for the four treatments are displayed in Figure 4.16 and the germination trends in Figure 4.17.

Table 4.17: Variation in germination parameters in seed lots from four treatments in *Prunus africana* on Mount Cameroon (80 seeds from each treatment were germinated, making a total of 320 seeds for the experiment).

Germination parameters	Source of seeds (treatments)			
	Autogamy	Geitonogamy	Natural	Xenogamy
Imbibition period (days)	25	27	25	25
Total germination period (days)	57	58	55	59
Cumulative germination (%)	75.0	71.2	51.2	76.2
Final daily speed of germination (%)	1.3	1.2	0.9	1.3
Germination energy(%)	1.5	1.4	0.9	1.5
Energy period (days)	48	44	49	43
Germination value	1.9	1.7	0.8	1.9

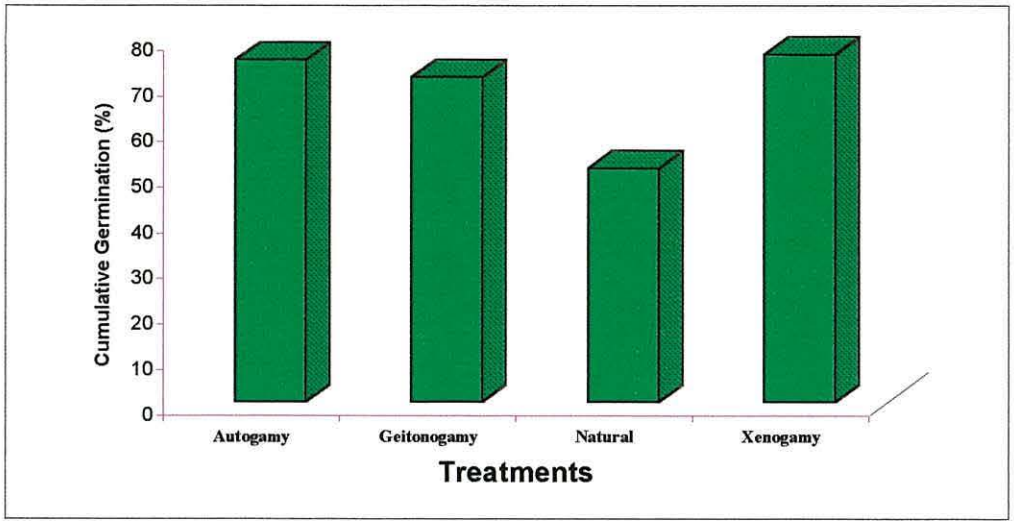

Figure 4.16: Final Percentage germination of seeds from four treatments in *Prunus africana* from Mount Cameroon.

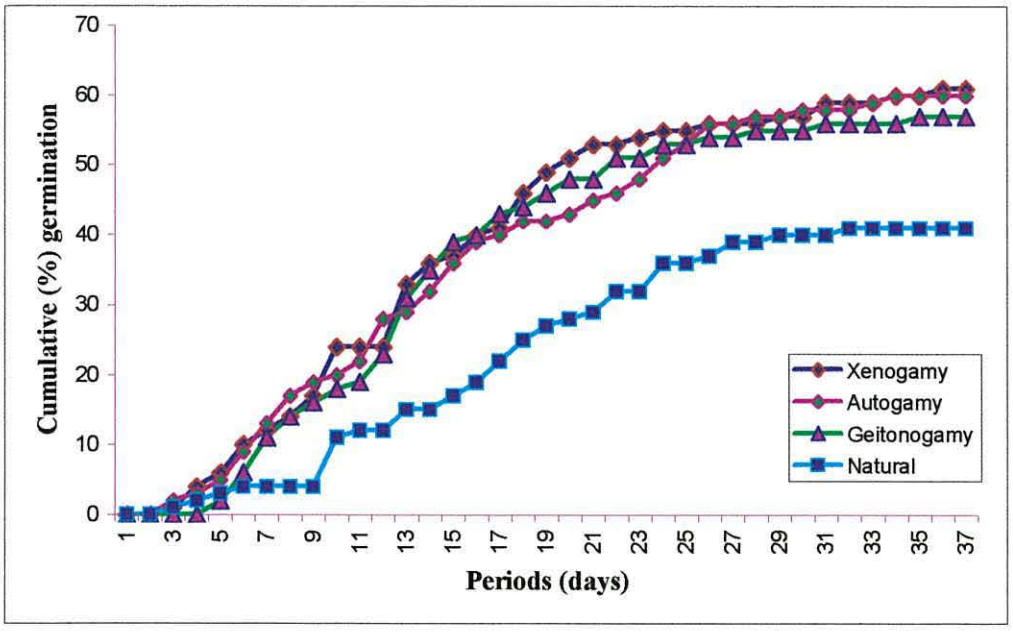

Figure 4.17: Germination trends of *Prunus africana* seeds from four treatments on Mount Cameroon - a sample of 80 seeds were sown for each treatment.

The significance of difference in the germination parameters among four treatments was tested by means of G-tests of goodness-of-fit (Table 4.18).

Table 4.18: Summary of G-tests of goodness-of-fit in germination parameters among treatments in *Prunus africana* from Mount Cameroon. – The expected values for each germination parameter were calculated as the average value for the four treatments. n.s. = non significant; * = G adjusted.

Germination parameters	df	G	G*	P
Imbibition period	3	0.06	0.06	n.s.
Total germination period	3	0.14	0.14	n.s.
Cumulative germination percentage	3	6.30	6.28	n.s.
Final daily speed of germination	3	0.10	0.10	n.s.
Germination energy	3	0.20	0.19	n.s.
Energy period	3	0.55	0.55	n.s.
Germination value	3	0.60	0.60	n.s.

There were no significant differences among treatments with respect to any germination parameter.

4.6.3 Potential pollinators in *Prunus africana* on Mount Cameroon

Nine insect species were caught in the tree canopy during the pollination exercises (Table 4.19). The most of the visitors caught were observed moving from one flower to another within the same inflorescence or between flowers on the same tree. Honeybees (*Apis mellifera)* were the most frequent visitors to *Prunus africana* racemes at anthesis. This frequency was higher in the forest above Bomana where this group of visitors accounted for more than 50% of all the visitors to all the trees. The visitation rate was higher in the late hours of the morning (10.00 - 12.00 h local time), when it was warm enough, and the peak was reached when the maximum number of flowers came to bloom on a tree.

The little greenbul was also observed on the flowering tree above Mapanja, but had no apparent contact with the flowers. Two species of butterflies were also caught flying within the canopy of the flowering tree. These were *Mylothris hilara* Karsch (Pieridae) and *Acrea* sp. (Acraeidae). Both species were caught in the forest above Mapanja and no butterflies were observed in the tree's canopy in Bomana. Because of inadequate identification of some species, only generic names are given in Table 4.19.

Table 4.19: Insects visiting flowers of *Prunus africana* on Mount Cameroon (Common names in parentheses under family names)

Order and family	Species	Insect-plant interactions	References
Coleoptera			
Staphylinidae (Rove beetles)	*Paederus sabaeus* Enchson	*Paederus* are sequester of cyanogenic compounds on plants and not mentioned as anthophilous	Gullan & Cranston, 1994
Cerambicydae (Longhorn beetles)	*Mecosaspis* sp.	Cerambicydae are primarily wood borers, but also anthophilous	Slansky & Rodriguez, 1987; Gullan & Cranston, 2000
Lycidae (Net-winged beetles)	*Cladophorus* ? sp. Nov.	Lycidae are mentioned as anthophilous, visiting flowers for pollen and possibly nectar	Gullan & Cranston, 2000
Diptera			
Dolichopodidae (Long legged flies)	*Argyra* sp.	Several species visit flowers and probably feed upon nectar	Richards & Davies, 1977
Sciomyzidae (Blow flies)	*Limnia* sp.	Sciomyzidae have reported as pests on animals	Gullan & Cranston, 2000
Hemiptera, Heteroptera			
Pyrrhocoridae (Red or fire bugs)	*Dysdercus megalopygus* Breddin	Associated with damages on plants (mentioned as cotton stainers)	Richards & Davies, 1977
Hymenoptera			
Apidae (Hive bees)	*Apis mellifera* Linnaeus	Pollen and nectar collectors	Coulson & Witter, 1984
Formicidae (Ants)	*Polyrhachis militaris* Fabricus	Predators, unlikely to effect pollination	Gullan & Cranston, 2000
Megachilidae (Leaf-cutting bees)	*Megachile latimanus* Say	Pollen collector and leaf-cutter	Huffaker & Rabb, 1984; Richards & Davies, 1977

CHAPTER FIVE:

DISCUSSION

The growing apprehension that current exploitation of the bark of *Prunus africana* for commercial purposes may have adverse impacts on the natural genepool of the species range-wide has prompted investigations since the beginning of the last decade. Available information on the species reveals, however, insufficient knowledge of the reproductive process of the species to guide conservation and management strategies. This thesis reports an attempt to provide relevant information for the population of *Prunus africana* on Mount Cameroon. In this chapter, the findings in relation to the flowering phenology and the pollination biology are re-examined in the light of the pre-existing knowledge base for *Prunus africana* and investigations conducted on other tropical species or other morphologically and ecologically comparable taxa. Major current management problems are specified and considered in relation to the species reproductive process and improved *in situ* conservation approaches are highlighted.

The bisexual flowers of *Prunus africana* are incompletely dichogamous, displaying overlapping sequential female and male phases during anthesis. Flowers in different functional stages coexist in the same inflorescence, the reproduction scenario Medan & D'Ambrogio (1998) term asynchronous dichogamy. The longevity of flowers is however long in comparison to most tropical forest species, where flowers generally hardly function for more than six days (Appendix 5.1). The longevity of the *Prunus africana* flower is about 6-8 days, a value within the 4-8 days predictive range offered by Stratton (1989) for tropical montane species. Feil (1992) found much longer duration – up to one month - in species of *Siparuna* (Monimiaceae) at higher altitude in Ecuador and attributed this to weather conditions in montane environment where consecutive days of cold and continuous rain are frequent.

Several factors that influence flower longevity are mentioned in the literature and Primack (1985) sorts these into three categories. The first category is genetic,

concerning the level of outcrossing. Primack's predictive model assumes that the outcrossing rate is inversely proportional to the product of flower longevity and the number of flowers produced per day. This implies that the level of outcrossing will decrease as flower longevity and the daily production of flowers increase. In this case, longer floral longevity will increase the number of open flowers on any given day, increasing the probability of geitonogamous inbreeding in self-compatible species. *Prunus africana* fits into this pattern. Furthermore, the persistence of the female phase over 3-4 days offers a flower an enhanced possibility of fertilisation, either by its own or outside pollen. The second category is physiological and recognises the need for a flower to reduce transpirational water loss and metabolic cost. In the Mount Cameroon region where a large population of *Prunus africana* occurs within cloud forest, water lost via transpiration is probably negligible and no obstacle to an extended flowering period. The third category is of strategic factors – essentially the operation of pollen vectors. In a situation of zoophilous pollination, pollinator scarcity or unpredictability may be associated with increased floral longevity, to maximise the chance of cross-pollination (Stratton, 1989).

Flowering occurs acropetally within a raceme of *Prunus africana* and there have been indications that the direction of flowering within an inflorescence has some implications for the level of fruit set and maturation. The fruits from the first pollinated flowers are more likely to mature than those pollinated later (Stephenson, 1980; Wyatt, 1982). It is also believed that fruits from the basal flowers have the advantage that assimilates reach the lower fruits in higher concentration, en route to the more distal parts of the inflorescence (Stephenson, 1981). Arguing on the basis of a situation of limited resources, Wyatt (1982) posits that the reproductive structures located furthest from the source of assimilates are shed first. However, these spatial and temporal advantages are not always absolute and sometimes the first pollinated flowers fail to mature while the later produce mature fruits (Stephenson, 1980; Wyatt, 1982). Neither Stephenson nor Wyatt offers, however, a justification for this unexpected failure.

Referring to fruit development, Stephenson (1981) plotted measurements of growth parameters - dry weight, volume or fresh weight - against time from anthesis and concluded that there are two categories of plants with respect to fruit growth. The first category is of species in which fruit growth comprises three successive phases: an initial slow growth phase, a period of accelerated growth and a period of decreasing growth. In the second category are species where the initial phase of fruit growth is slow and coincides with a period of early and heavy fruit abortion prior to a rapid growth phase. When this phase of rapid growth ends, there is stagnation, during which a second episode of fruit abortion occurs. The final phase is one of exponential growth to the maturation of the fruit. The development of *Prunus africana* fruits on Mount Cameroon seems to match the growth trend of the second category (Figure 4.3 – mortality curve). A similar conclusion has been reached for other "stone" fruits - *Prunus* spp. -; Moraceae: *Ficus carica* L.; Saxifragaceae: *Ribes nigum* Richards.; Rosaceae: *Rubus* spp.; Ericaceae: *Vaccinium* spp.; Vitaceae: *Vitis* spp.; and Oleaceae: *Olea europaea* L. (Stephenson, 1981).

Investigating the reasons for massive fruit abortion in *Prunus africana* and characterising the physiological process that sustain each phase of fruit development more generally have not been aims of this study. However, in studies of other plant species, explanations for massive fruit abortion such as was observed for *Prunus africana* have sometimes been offered. Stephenson (1981) distinguishes the abortion of damaged fruits from the abortion of undamaged fruits and argues that a plant selectively aborts fruits that have been subject to predation, to terminate unrewarding resource investment in these. Where the abortion of undamaged fruits is concerned, it is believed that most abortions occur as a response to resource shortage. In a situation of limited resources – nutrients, light, water, heat -, the proportion of mature fruits is negatively related to the number of fruits initiated (Willson & Price, 1977; Stephenson, 1980; Udovic, 1981). Janzen (1971) offers the additional argument that overproduction of juvenile fruits that abscise afterwards functions to satiate predispersal fruit and seed predators. If predation occurs early in the maturation process, and if the number of damaged fruits is independent of the number of fruits initiated, then natural selection could favour initiation of more fruits than can be

supported with the available resources. Without such abortion, the limited resources would be partitioned among so many fruits and seeds that their individual weights would be reduced. This situation could have profound effects on dispersal, germination or seedling establishment (Stephenson, 1981). Fruit abortion also occurs as a result of genetic or developmental abnormalities (Bradbury, 1929). In this case, according to Janzen (1977), the process of natural selection would tend to favour the development and maturation of fruits of "highest quality", resulting from outcrossing.

The pollination experiment in this study indicates that both outbreeding and inbreeding are potential reproductive modes in *Prunus africana* on Mount Cameroon, but that agamospermy – apomitic reproduction - does not occur. This result is in conformity with Munjuga *et al.* (2001). However, although failure of emasculated and bagged flowers to produce a single fruit may be an indication of the complete lack of agamospermy in *Prunus africana*, it is worth mentioning that the damage following the manipulation of the flowers may also contribute to this result. In reality, after anther removals from the two or three staminal rings in this relatively small flower, the tiny isolated stigma looks so weak that the chance of survival is very thin. There have been however, reports of agamospermy in the Rosaceae - species of *Rubus* and *Sorbus* are often cited as examples for the northern temperate flora (Briggs & Waters, 1984).

The fruit set estimated in this study following cross-pollination (20%) is small in comparison to the estimate of 28% of Munjuga *et al.* (2001) for *Prunus africana* trees on farmlands or on farm boundaries at Kiambu, Kenya. It is equally at the lower limit of the 20-30% range indicated for the legume *Dalbergia miscolobium* Benth. (Leguminosae-Papilionoideae) from an area of "cerrado" vegetation in South-East Brazil (Gibbs & Sassaki, 1998) and well below the 40-47% estimated for the protogynous, self-incompatible *Xylopia brasiliensis* Sprengel (Annonaceae), a tall evergreen Atlantic coastal rain forest and hinterland semi-deciduous forest tree species in a nursery study in South-Eastern Brazil (Andrade *et al.*, 1996). It is however high in comparison to the 13% estimated in a natural *Prunus mahaleb* L. stand in Mediterranean woodland dominated by *Quercus rotundifolia* Lam. at El

Bierzo, in the Iberian peninsula following supplementary pollination (Guitian, 1993). Bawa *et al.* (1985) noted the lack of, or low fruit set that followed cross-pollination in the hermaphroditic forest tree species *Anaxagorea crassipetala* Hemsl. (Annonaceae), *Pentaclethra macroloba* (Willd.) O.Ktze. (Leguminosae-Mimosoideae), *Ardisia nigropunctata* Oerst. (Myrsinaceae) and *Vitex cooperi* Standl. (Verbenaceae) in the tropical wet forest zone at La Selva Field Station, Costa Rica. Bawa *et al.* (1985) suggest that three complementary factors may reduce cross-pollination success. Firstly, the result could be an artefact of hand-pollination techniques. In the case of *Prunus africana*, the difficulties associated with the size of the flowers in dense racemes imply that the flowers can adversely suffer from damage during manipulation. Secondly, in most species, a large number of flowers abort a day or two after anthesis; it is conceivable that some pollinations involved flowers destined to abort anyway, as abortion is not necessarily due to lack of compatible pollen (Bawa & Webb, 1984). The high level of flower abortion reported for *Prunus africana* in this study following cross-pollination would support this as a relevant factor. Thirdly, if cross-pollination involves close relatives, low or lack of fruit set could reflect inbreeding depression. As the processes of pollen flow and seed dispersal remain unclear for *Prunus africana*, spatial relationships and kinship among the trees involved in cross-pollinations is also unclear.

The high percentage of fruit set in cross-pollination compared with that from self-pollination implies that *Prunus africana* is predominantly outcrossed and confirms the results of Dawson and Powell's (1999) molecular scrutiny, and the pollination experiments at Kiambu, Kenya (Munjuga *et al.*, 2001). The effectiveness of outbreeding in maintaining genetic variability is probably limited in natural conditions, however, by a number of factors, including the low population density, which affect gene exchange (Ha *et al.*, 1988). On Mount Cameroon where mature *Prunus africana* trees are unevenly distributed, usually as aggregated clusters of wide-spread individuals with a density of no more than 4.27 trees $\geq$ 10 cm dbh per hectare (Underwood & Burn, 2000), in years of low flowering intensity, the effective distance between synchronously flowering individuals will be increased and the likelihood of a poor fruit crop will be greater.

Similarly, the higher fruit set level in cross-pollination in comparison to the natural pollination is not unusual. It is commonly admitted that when samples of flowers are hand-pollinated, the hand-pollinated flowers have a higher probability of initiating and developing a fruit than other flowers (Wyatt, 1976; Schemske, 1980). Pollinator limitation is often presented as the main raison (Schemske, 1980; Bierzychudek, 1981). Nevertheless, Bawa & Webb (1984) challenge this view and posit that such an argument suffers shortcomings arising from flawed experimental design or invalid research assumptions. The first shortcoming is that the elevated fruit set in hand-pollinated flowers merely suggests, and does not unequivocally prove pollinator limitation, unless whole plants or large flowering branches are the units of the experimental pollinations. The second shortcoming is that increased seed and fruit set following hand-pollinations could also result from reallocation of resources from other parts of the plant. This reduces the number of flowers borne by an inflorescence, thereby decreasing the dispersal of pollen, and thus a male component of fitness. Lee & Bazzaz (1982) support Bawa and Webb in this and have demonstrated in a study of the regulation of fruit maturation patterns in *Cassia fasciculata* Michx. (Leguminosae-Caesalpinioideae) that more intensively pollinated flowers selectively mature, raising the possibility that flowers at the immediate neighbourhood of hand-pollinated treatments may show lower fruit set than those close to open-pollinated flowers. The third shortcoming is that in experiments designed to support the pollinator limitation on fruit set argument, data for hand-pollinated treatments are generally derived from the pollination of a few flowers per inflorescence, but open-pollinated data are based on all flowers in an inflorescence. Such bias in the selection of the two types of flowers makes greater fruit set in hand-pollinated flowers almost inevitable.

Seed set in all treatments (0.9 - 7.9%) is far lower than documented evidence referring to other *Prunus* species (Stephenson, 1981; Sutherland & Delph, 1984). Stephenson's (1981) in a review of possible causes of flower and fruit abortion in several species indicates that natural seed set success is 23-50% in *Prunus cerasus* Scop., 16-32% in *Prunus persica* (L.) Batsch and 0-25% in *Prunus domestica* Linn. It is estimated at 30% in *Prunus amygdalus* Stokes (Sutherland & Delph, 1984). These reports,

however, must be compared with great caution as they are not accompanied by explicit descriptions of the experimental conditions where the results were obtained (it is probable that most of the studies were conducted in orchards in temperate regions). This percentage seed set is, however, similar in magnitude to findings for 5 of 7 species studied (Bawa & Webb, 1984), with regard to aspects of flower, fruit and seed abortion in the tropical dry forest at Hacienda La Pacifica, Costa Rica (Table 5.1). Unlike *Prunus africana*, all the seven species are self-incompatible and all except *Bauhinia ungulata* L., pollinated by bats, are pollinated by medium to large-size bees (Bawa & Webb, 1984). In the present study, species of bees captured included members of the Apidae and the Megachilidae, but no attempt was made to quantify their effectiveness in pollen transfer within and among *Prunus africana* trees.

Table 5.1. Percentage seed set for 7 tree species in a deciduous or semi-deciduous forest at Hacienda La Pacifica, Costa Rica (Bawa & Webb, 1984) – Apart from *Bauhinia ungulata* L. (shrub or a small tree), other species are either a small or a large tree.

Species	Flower arrangement	Seed set (%)
Bauhinia ungulata L. (Leguminosae – Caesalpinioideae)	Terminal or pseudo-lateral racemes	10.15
Caesalpinia eriostachys Benth. (Leguminosae – Caesalpinioideae)	Terminal or subterminal raceme	0.98
Cochlospermum vitifolium (Willd.) Spreng. (Cochlospermaceae)	Terminal panicles	26.00
Dalbergia retusa Hemsl. (Leguminosae-Papilionoideae)	Racemes clustered as terminal or axillary panicles	8
Myrospermum frutescens Jacq. (Leguminosae-Papilionoideae)	Racemes clustered as terminal or axillary panicles	3.40
Pterocarpus rohrii Vahl (Leguminosae-Papilionoideae)	Racemes clustered as terminal or axillary panicles	7
Tabebuia rosea (Bertol.) DC. (Bignoniaceae)	Terminal panicles	1

Regarding the flowering phenology at the level of individual trees, information in the literature indicates that species differ with respect to timing, duration and frequency of flowering and fruiting, but among tropical trees, the flowering phenology of individual plants varies continuously between two extremes (Gentry, 1974; Augspurger, 1983). At one extreme are species with "mass-flowering" individuals

that produce large numbers of new flowers each day over a short period - week or less. At the opposite extreme are species with "steady-state" individuals producing small numbers of new flowers almost daily for many weeks. The quality and quantity of a fruit crop depend on the intensity of flowering and the success of pollination and subsequent development of fruits (Bawa *et al.*, 1990; Kigomo *et al.*, 1994). Adequate seed sampling for *ex situ* collections is thus only a good prospect if the collections are made in years when the maximum number of individuals participate in the reproductive episodes (Bawa & Ng, 1990). Flowering strategies and the range of possible interactions involving these are potentially diverse, but may be limited by the physical and biotic environment (Bawa & Ng, 1990; Kularatne *et al.*, 1996). Variability among individuals in response to flowering cues determines the synchrony of the initiation day and, consequently, affects the population synchrony and flower abundance through the population's flowering period (Auspurger, 1983).

As elsewhere, flowering in *Prunus africana* occurs periodically on Mount Cameroon. This study suggests that the onset is in November-December, which is in conformity with collectors' notes and information from the Flora of West Tropical Africa (Hutchinson & Daziel, 1954-1958). The early onset of flowering mentioned by plant collectors such as R. Letouzey flowering specimen No 9589, collected in September and opportunistic observations (October – B. Ewusi, Kenya wkps) appear in this regard as isolated situations, or an improbable second phase of flowering within a year that was completely missed in the course of this study. Variation, in terms of the beginning of flowering, from one aspect of the mountain to another amounts to a few weeks and this was consistent through the observation period (Oct. 1999 - May 2001). Collector's notes mention fruits in *Prunus africana* on Mount Cameroon between March and July (Thomas 4459; Dawson & Fondoun, 1996). This study times fruit initiation in December, with a fruiting peak that occurs between February and March each year. The duration of fruiting events is longer than the duration of flowering events, lasting for 5-6 months (until April or May), when mature purple fruits are available on trees and/or on the forest floor.

The short duration of flowering suggests competition for pollinators as a result of the abundant flowers that attract many types of opportunistic pollinators with density-dependant foraging behaviour (Augspurger, 1983). The short period of flowering will, on the other hand, impose some risk if it occurs during weather conditions unfavourable for pollination or for subsequent reproductive stages. At the individual tree level, flowering is completed in a matter of four weeks, but the duration at population level extends to nine weeks. Continuation of flowering within the population over nine weeks suggests that although there are overlaps in the flowering episodes between trees (individual synchrony index > 0 in most cases), flowering synchrony at the population level is lower than most individual tree's synchrony. For a species like *Prunus africana*, which occurs at low density, a low population flowering synchrony coupled with spatial isolation from conspecifics could result in limited pollen flow. This situation creates favourable conditions for the process of speciation in which the role of genetic drift prevails over that of natural selection according to Fedorov (1966). Asynchronicity in mass-flowering individuals reduces the effective population size, as it reduces the number of nearby conspecifics with which mating is possible (Augspurger, 1983). Conversely, selection for high degree of synchrony ($Z > 0.60$), occasionally observed in Bakingili, Bomana and Ekona Lelu, increases the potential for cross-pollination. It is believed that a high population synchrony increases not only the efficiency of pollinators (Beattie *et al.*, 1973; Gentry, 1974; Bawa, 1983), but also spares flowers, and later seeds, from predators (Beattie *et al.*, 1973). Apart from maximising opportunities for outcrossing, synchronous flowering also increases the size of the pool for potential gene exchange (Chan & Appanah, 1980).

Flowering and fruiting in *Prunus africana* is irregular (Geldenhuys, 1981), with full fruit-crops developing only at 2-3 years intervals (Hall *et al.*, in press). The results of this study are in accordance with this broad view at individual tree level, although the brevity of this study warns against accepting its findings in this regard as confirmation of a general tendency. However, the complex and variable constancy and contingency values – C: 0.49-0.87 and M: 0.08-0.49 - in the individual trees that produced flowers and/or fruits suggest that flowering and fruiting frequency in *Prunus africana* is more

complex than initially thought. These data indicate three other scenarios in addition to individual trees that flower and/or set fruit once every two years and which accounted for nearly 86% of the total number of trees that came to bloom in the course of two reproductive seasons. Individual trees that flowered and set fruit successfully every year represent the first scenario. The second scenario is made up of individuals that flowered once in the two years of observation, but set no fruit. Lack of fruit set following a flowering episode is not particularly unusual. Thus, Yap & Chan (1990) attribute such behaviour in *Shorea* spp. in Peninsular Malaysia to low pollination success, either as the result of insufficient pollinators or resource depletion from a previous mass fruiting episode or the combination of both. Trees in which no flowering activity was noted during the two successive reproductive seasons demonstrate the final scenario. The consolidation of this categorisation requires further observations – perhaps to emulate a recent work in the transition between lowland rain forest and montane forest at Kibale National Park, Uganda (Chapman *et al.*, 1999). Chapman *et al.*, (1999) summarise the flowering and fruiting patterns of 104 species, over six years including *Prunus africana*. They found that trends emerging from one year of data were not maintained when additional years were considered.

The production of flowers by canopy forest trees in tropical rain forest has been poorly quantified (Zagt, 1997). Comparison of flower and fruit production between *Prunus africana* and other tropical species is hampered by poor documentation. However, information for three tropical dioecious canopy forest trees species in northern Queensland, Australia (House, 1992), for a dominant neotropical forest tree species in Guyana (Zagt, 1997) and Central Amazon, Brazil (Gribel *et al.*, 1999) are available (Table 5.2).

The mean number of flowers per m^2 of crown shadow collected during the reproductive period in this study ranges from 100±144 (individual, dbh = 27 cm) to 2952±646 (individual, dbh = 82 cm). This production is of similar magnitude to the production reported for *Dicymbe altsonii* and *Ceiba pentandra*.

Table 5.2: Tree descriptions, flower/fruits characteristics and flower production in six tropical trees
FP, mean number of flowers per m^2 of crown shadow; SA, Spatial arrangement of male and female organs: M, Monoecious; D, dioecious; H, Hermaphrodite – Data on *Neolitsea dealbata, Litsea leefeana* and *Diospyros pentamera* refer to male flowers only; All the species are large trees studied in rain forest environment, except for *Ceiba pentandra* in which some individuals were located on a campus and others in a seasonally flooded lowland habitat – *Prunus africana* was studied in Afromontane forest on Mount Cameroon.

Species	Observation period	Description of flowers and fruits	SA	FP	References
Neolitsea dealbata (R. Br.) Merr. (Lauraceae)	1982-1983	Small and unspecialised flowers. The fruit is a small single-seeded drupe	D	104118	House (1992)
Litsea leefeana (F. Muell.) Merr. (Lauraceae)	1982	Small and unspecialised. The fruit is a small single-seeded drupe	D	3715	House (1992)
Diospyros pentamera (Wools & F. Muell.) Wools & F. Muell. Ex Hiern (Ebenaceae)	1982-1983	Fruit is a capsule containing 5 seeds	D	12462	House (1992)
Dicymbe altsonii Clump Wallaba (Leguminosae – Caesalpinioideae)	1993	Flowers: *c.*5 cm in diameter and assembled in racemes. Fruits are dehiscent pods, 20 x 6 cm	H	137±53	Zagt (1997)
Ceiba pentandra (L.) Gaertn. (Bombacaceae)	1992-1997	Terminal panicles. Fruits are elliptic capsules, 4-6 mm in diameter	H	845±203 to 2085±444	Gribel *et al.* (1999)
Prunus africana (Hook. f.) Kalkman (Rosaceae)	1999-2001	Axillary racemes, 10 cm long or shorter and bearing 10 to 20 bisexual flowers. Mature fruit is a drupe, 5-8X10-12 mm long.	H	100±144 2952±646	This study

House (1992) found a significant positive relationship between the diameter at breast height and the number of flowers collected in litter traps for males of *Neolitsea* and *Litsea* male trees, but not for *Diospyros* males or female trees of any species. For *Diospyros*, a significant negative relationship was found between the mean number of fruits per shoot and the diameter at breast height.

The first study on natural regeneration of *Prunus africana* on Mount Cameroon suggested a density of 5 saplings/m^2, with patches of up to 50 saplings/m^2 in areas with sparse undergrowth (Ewusi *et al.*, 1992). A later investigation in forest above Mapanja village indicated a much lower density of 0.17 to 1.45 seedlings/m^2 (Ndam, 1998). Neither Ewusi and colleagues, nor Ndam offers a concise definition of saplings or seedlings, but it is likely that both terms refer to young tender plants from germinating seeds and which usually do not exceed 1 m in height. In both cases, the density appears very low in comparison to the mean number of fruit per m^2 reported in this study – 16±11 to 261±76 fruits per m^2. Several explanations are possible. Firstly, most fruits collected in the litter traps were physiologically immature and unable to germinate. Secondly, there are indications in the literature that frugivorous birds and mammals on Mount Cameroon favour the *Prunus africana* drupe (Sunderland & Nkefor, 1997) and which suggest a certain level of damages. Thirdly, the presence of unidentified larvae in certain fruits observed in this study also indicates losses from insect predation. The fourth reason is the recalcitrancy of *Prunus africana* seeds. Seeds resulting from mature fruits that have escaped predation do not experience a 100% germination rate and this problem is further worsened in difficult forest environment. Finally, for a species like *Prunus africana* that experiences temporal variation in flowering intensity, the quality and quantities of seeds produced change from one year to another. Bawa & Krugman (1991) suggest two antagonistic hypotheses for a species that exhibits such behaviour. The first hypothesis is that, in years of poor seeding, it is possible that fewer trees contribute to a small crop of flowers at the population level, thereby increasing the likelihood of inbreeding. The second hypothesis stipulates that, fewer resources may increase competition among pollinators, and hence induce them to increase their foraging ranges and inter-tree visits, a scenario that would promote outcrossing.

The production of vastly more flowers than fruits, as recorded here for *Prunus africana*, is common in hermaphroditic plants (Stephenson, 1980-1981; Udovic, 1981; Sutherland & Delph, 1984; Sutherland, 1986a –1987; Ehrlén, 1991; Burd, 1998). Fruit:flower ratio in *Prunus africana* is low, and 10 flowers produce only one juvenile fruit with an uncertain fate on average. This ratio is low in comparison to 42.1% that constitutes the average fruit set established for hermaphrodite plants from 316 species including nine species of Rosaceae (Sutherland & Delph, 1984). It is also low compared with a tentative average for tropical plants (26.9% – Sutherland, 1986b). For example, flower:fruit ratio is 5:1 in *Dalbergia miscolobium*, a neotropical papilionoid tree with hermaphroditic flowers (Gibbs & Sassaki, 1998).

There are five hypotheses regarding the possible causes of massive flower production and low fruit set. Although this study did not attempt to test any of these, some relevant comments can be made. The first hypothesis concerns pollen limitation and postulates that if fruit production is limited by the availability of pollen to fertilise ovules, then low fruit-set indicates low pollination success (Sutherland & Delph, 1984; Sutherland, 1987). In the case of *Prunus africana*, the male phase is longer than the female phase and this indicates that pollen is available for most of the flowering period within a tree. Thus, low fruit set as a result of lack of pollination can only be envisaged in relation to pollinator availability, assuming that incompatibility is unlikely to be involved. It is reasonably well-established that fruit set in tropical trees is not usually limited by pollination (Zapata & Arroyo, 1978). The second hypothesis is pollinator attraction. Under this hypothesis, pollinators preferentially visit large inflorescences because these provide a larger signal to attract them and/or offer greater rewards (Willson & Price, 1977; Stephenson, 1979; Augspurger, 1980; Udovic, 1981). The third hypothesis is the "bet-hedging" concept. The production of excess flowers allows the plant to compensate for either variation in resources available for fruit maturation or variations in pollination success because of variations in pollinators densities or pollinator visitation rates (Stephenson, 1980; Bawa & Webb, 1984).

The concept of bet-hedging integrates the hypothesis of an ecological window and the reserve-ovary hypothesis. Ehrlén (1991) outlines the ecological window hypothesis as the idea that the optimal number of offspring changes unpredictably from breeding attempt to breeding attempt. This implies varying average mortality or resource availability at the population or sub-population level. Continuous production of surplus flowers enables plants to exploit conditions that are more favourable in terms of resources, pollinator availability, or relaxed predation pressure even if these occur in an unpredictable way in time and space (Stephenson, 1980-81; Udovic, 1981). Uncertainties in resource availability during a reproductive episode could favour surplus flower and fruit production. In this case, a surplus of flowers enables plant to take advantage of the occasional "good years" when resources are plentiful (Willson & Price, 1977; Udovic, 1981; Burd, 1998). The reserve-ovary hypothesis, on the other hand, assumes neither variation in optimal number of offspring nor variation in mortality at levels above the "integrated physiological unit" (Ehrlén, 1991). Watson & Casper (1984) define the integrated physiological units as an assemblage of discrete morphological structures, that together function as relatively autonomous entities with respect to the assimilation, distribution and utilisation of carbon. Stephenson (1979, 1981) suggests that surplus flower production may serve as a buffer in adverse weather conditions or when competition from other flowering species reduces pollen flow. Surplus flower production could also buffer the individual against loss due to early damage to flowers or young fruits from herbivores.

The fourth hypothesis is selective abortion. This hypothesis postulates that high pollination success results in the initiation of more juvenile fruits and discriminated abortion of some of these. In this case, the maturing fruits are only those which are of high quality in terms of the number of ovules fertilised or the genetic constitution of the seeds (Stephenson, 1981; Bawa & Webb, 1984). The final hypothesis is male function or pollen donation. Sutherland & Delph (1984) and Sutherland (1987) argue that hermaphroditic plants achieve fitness through fruit maturation - female function - and through pollen donation - male function. If the optimal number of androecia is higher than the optimal number of gynoecia in a plant with hermaphroditic flowers, then some perfect flowers are produced that function only as pollen donors (Bawa &

Webb, 1984; Sutherland & Delph, 1984; Sutherland, 1986a). In this argument, excess flower production elevates male fitness by dispersing additional pollen and siring more seeds on other plants before abortion occurs (Burd, 1998). Conversely, if all perfect flowers are functionally cosexual – potential pollen donors and potential fruit producers – then it can be demonstrated theoretically that there is an equilibrium allocation strategy to male and female function, which maximises plant fitness (Sutherland & Delph, 1984). Data gathered in this study do not allow, however, to test for the last four of these hypotheses.

The implications for the pollination of *Prunus africana* on Mount Cameroon of uncontrolled killing of mature trees is widening spacing of conspecific trees and reduced prospects for gene flow. This would be compounded by the lack of perfect flowering synchrony among trees and the irregularity in flowering as revealed in this study. The appraisal of *Prunus africana* population structure undertaken in this investigation suggests that the population is maintained through sporadic or irregular seedling establishment (Peters, 1994), rather than continuous, even recruitment. The population structure from Mount Cameroon does not display a classical reverse J curve that usually represents the ideal of a stable, self-maintaining population, but the shape of a population that experiences sporadic or irregular seedling establishment (Peters, 1994). Peters describes this kind of structure as that characterising a population of late secondary succession that depends on canopy gaps for regeneration. In such situation, the level of regeneration may be sufficient to maintain the population, but its infrequency of occurrence causes notable "peaks" and "valleys" in the size class distribution as the new seedlings grow into larger diameter classes. Felling of trees prior to debarking (Eben Ebai *et al.*, 1994) and bark exploitation in the area from 1977 (Ngengwe, 1996), have certainly exacerbated this trend, following removal of mature trees and subsequent seed shortage for natural regeneration. Further analysis of this structure in relation to the history of bark exploitation at the level of mountain aspect on the other hand, indicates that natural regeneration has been severely limited in the forest at Bakingili (exempted from bark exploitation until 1998). This suggests that the production of seeds of high quality does not necessarily guarantee a successful regeneration in the wild.

The implication of the relationship between the production of flowers/fruits and the tree size in *Prunus africana* is that natural regeneration is poor under the crown of smaller trees, as the result of the reduced number of seeds. Light requirement for seedling establishment and seed predation could only compound this problem. It appears that natural regeneration of *Prunus africana* is suppressed in the forest at Ekona Lelu where trees are smaller in size, though reproductively mature. Speculative management intervention (J. Acworth, pers. communication), suggesting the felling of large trees before debarking would only increase seed shortage for natural regeneration and on-farm or any domestication programme in this species. Such management intervention would only be less disastrous if felling of large trees before debarking were restricted to individuals that display crown die-back, implying limitation of reproductive potential. This would, of course, require the development and implementation of assessment criteria understood, accepted and respected by all stakeholders.

An improved *in situ* conservation strategy of *Prunus africana* would require not a complete protection of natural stands, but a scenario combining sustainable bark production with external management interventions. Such intervention might include the manipulation of the forest undergrowth beneath mature *Prunus africana* trees to encourage and sustain natural regeneration. This would improve not only the population size, but also alleviate the risk of seed shortage in years of poor seeding. In localities that are suffering from severe depletion of the natural population, re-stocking through enrichment planting may be contemplated. In situations where nursery-raised seedlings are not readily available, wildings collected preferably from clustered trees could be considered. Management interventions to promote regeneration establishment and survival would require, however, labour and capital. The establishment of a direct and effective link between revenue from bark production and management interventions could provide this.

The population level and representation of *Prunus africana* has received more attention than any other useful forest species through repeated inventories, particularly for the population on Mount Cameroon. Reconciliation of the contrasting

findings is necessary for developing a realistic management strategy that takes into account, not only the increasing bark demand for the international pharmaceutical industries, but also the ecological requirements of *Prunus africana* to survive and evolve as viable populations throughout Afromontane Cameroon. This study and other inventory results confirm that from the Mount Cameroon region to the Tchabal Mbabo plateau, *Prunus africana* is unevenly distributed at local level in the Afromontane forests where it occurs. This occurrence pattern implies that the development of realistic sustainable quotas would require the stratification of each area into several management units in which the distribution of the trees is fully known. In a situation where the spatial distribution of trees within clusters is known, enrichment planting could attempt to create new clusters in places where the growing conditions seem appropriate.

Effective *in situ* conservation of natural stands of *Prunus africana* in Cameroon requires the modification of the existing structure and legislation where state institutions alone play a pivotal role. The involvement of local communities in bark harvesting – as pioneered in the Mount Cameroon region – has proved helpful, not only in reducing unscrupulous bark harvesting practices, but also in improving village livelihoods. Bark harvesting activities and other regeneration-related initiatives, operated within the framework of "homogeneous" management units, should be conducted by community members organised in the form of voluntary associations that symbolise trust, voluntarism and other aspects of social capital and supervised by a management committee. The management committee made up of all major stakeholders sets rules and regulations governing the body and develops a participatory monitoring and evaluation system in accordance with the regulation in force and the provisions of the "cahier de charge". An immediate amendment to the exploitation license would be the incorporation in the "cahier de charge", of provisions defining the role of neighbouring communities in bark exploitation and re-stocking activities. This specific amendment defines the workforce implicated in the activities and reduces government intervention to a more educational role in creating and strengthening community-based resource management institutions.

CHAPTER SIX:
CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

The following conclusions are drawn from this investigation:

1. *Prunus africana* flowers are protogynous and incompletely dichogamous. The longevity of a flower is 6-8 days, the male phase lasting longer than the female phase.

2. *Prunus africana* is predominantly outcrossed, but flowers are self-compatible. Flowers are visited by a number of anthophilous insects, but only members of Cerambicydae, Lycidae, Apidae and Megachilidae potentially effect pollination. The source of the pollen has no significant impact on the germination parameters of the resulting seed.

3. Flowering and fruiting in *Prunus africana* on Mount Cameroon is periodical and occurs generally between December and May. In terms of frequency, flowering/fruiting is irregular and an individual tree flowers and fruits generally no more than once every two years. Occasional departures from this general trend are, however, possible.

4. The flowering synchrony of an individual tree in successive years is high (up to 0.83), while the synchrony within a population is in the range 0.25-0.75. The flowering synchrony trend within a population does not appear to change significantly from one reproductive season to another.

5. The estimated floral productivity ranges from around 4500 (dbh = 27 cm) to around 730000 (dbh = 82 cm) flowers per tree and the fruit productivity ranges

from around 900 to around 80000 fruits per tree. There is a strong and positive relationship between the tree size and flower/fruit productivity.

6.2 Recommendations

The information assembled and generated in the course of this study has prompted the following recommendations, grouped into management and research components.

6.2.1 Management recommendations

1. Total protection of natural stands in localities with dense undergrowth contributes little to the process of natural regeneration. The management practices should allow bark exploitation within the limits of the prescribed technical debarking rules to create disturbance that could encourage natural regeneration and seedling establishment.

2. Enrichment planting should be encouraged to rehabilitate degraded areas and where viable population exists, such initiative should favour the creation of new clusters around isolated trees.

3. The local communities - organised in the form of management committee - should be increasingly involved in the exploitation of the bark to reduce the destructive illegal harvesting, hence reducing the level of mortality of wild trees.

4. The intention of allocating an exploitation licence in an area should be publicly advertised – as with timber species - allowing time for any opposition to be voiced. This would reduce the risk of overlaps in the exploitation areas allocated to different exploiters and the subsequent illegal exploitation practices.

5. The occurrence of *Prunus africana* is localised in Afromontane regions of Cameroon. The number of exploitation licences should therefore be limited to allow a realistic monitoring of the activities of licence holders and the effective implementation of other prescriptions stipulated in the improved "cahier de charge".

6.2.2 Recommendations for further research

1. The estimation of the size of the genetic neighbourhood could be made using information on the distance travelled by genes via pollen and seeds. This would inform on the degree of inbreeding, the level of heterozygosity, and the importance of a possible genetic drift caused by mortality from inappropriate bark harvesting practices.

2. The investigation of the underlying causes of massive flower and juvenile fruit abortion would allow the identification of specific causes that could be possibly manipulated to improve fruit:flower ratio particularly in situation of *in situ* enriched stands or seed orchards.

3. Flowering and fruiting phenology need monitoring over longer periods (10 years or more) to confirm the consistency of patterns in the flowering and fruiting intensity, duration, periodicity and frequency.

4. Comparison between fruit set in "isolated" and "clustered" trees should allow the assessment of the impact of the nearest conspecific on the pollination success in natural environment.

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Appendix 2.1: Altitudes of occurrence of *Prunus africana* in the West African Mountain System

Localities omitted include: Mba Kokeka, Cameroon, 5°57'N-10°12'E (Lightbody, 1952); Lago Baio, Bioko, 3°20'N-8°42'E (Sunderland & Tako, 1999); Moca, Bioko, 3°16'N-8°37'E (Sunderland & Tako, 1999); S of Pico de Basile, Bioko, 3°30'N-8°44'E (Sunderland & Tako, 1999); Cabbal Wade, Nigeria, 7°02'N-11°41'E (Chapman 3566, K); Pico Pequeno, Sao Tome, 0°15'N-6°35'E (Monod 11977, BM, COI). References in italics and published records appended in the bibliography and other references are voucher specimen information (wherever possible) in the sequence collector's name, specimen number, year of collection and herbarium where the specimen is kept. K = Kew Herbarium; P = Laboratoire de Phanérogamie, Paris; MO = Missouri Botanical Garden, St. Louis; BM = Natural History Museum, London; SFR = Section de recherches forestieres du Cameroon (now Cameroon National Herbarium).

Country	**Altitudinal range (m)**	**Location**	**Geographical coordinates**	**References**
Cameroon	1000 – 1960	Tchabal Gang Daba	7°39'N- 12°45'E	*Belinga, 2001*
	2100	Tchabal Mbabo	7°16'N – 12°09'E	Fotius 3123 (?HN41290), 1978; Jacques-Felix 8987, 1967, K; *Letouzey, 1978, 1985; Achoundong, 1995; Thomas & Thomas, 1996; Belinga, 2001*
	1800 – 2400	Tchabal Ouadde	7°02'N – 11°43'E	*Letouzey, 1978, 1985; Achoundong, 1995*
	1525	Binka	6°34'N – 10°45'E	Brunt 978, 1963, K
	2000 – 2200	Mt Tabenken	6°33'N – 10°36'E	*Letouzey, 1978, 1985; Achoundong, 1995*
	1000	Wum	6°23'N – 10°05'E	*Letouzey, 1985; Achoundong, 1995; Belinga, 2001*
	2200	Mt de Kishong	6°20'N – 10°45'E	*Letouzey, 1985; Achoundong, 1995*
	1700 – 3000	Mt Oku	6°11'N – 10°35'E	*Letouzey, 1978, 1985; Achoundong, 1995;* Thomas 4383,1985, K, MO; Thomas & Mcleod 6003, 1986, MO; *Dawson & Fondoun, 1996; Belinga, 2001*
	1800	Oshie	6°10'N - 9°51 E	*Letouzey, 1985; Achoundong, 1995*
	2100	Bambalue, Bamenda	6°06'N – 10°20'E	Johnstone 12, 1931, K; Keay & Lightbody FHI 28377, 1951, K
	1525	Bamenda	5°57'N – 10°09'E	Johnstone 255, 1931, K
	1700 – 2100	Bafut-Ngemba	5°56'N – 10°10'N	*Letouzey, 1978, 1985; Achoundong, 1995*; White 8544, 1963, K; Tiku FHI22232, 1951, K
	1500 – 1550	Mendankwe	5°56'N – 10°12'E	*Dawson & Fondoun, 1996*
	1900 – 2200	Massif du Mbam	5°54'N – 10°44'E	*Letouzey, 1978, 1985; Achoundong, 1995*; Letouzey 140,1946, K; Letouzey 126, 1946, K; Satabie 41, 1974, K
	1000	Baboua	5°50'N – 14°40'E	Mildbraed 9283, 1914, K

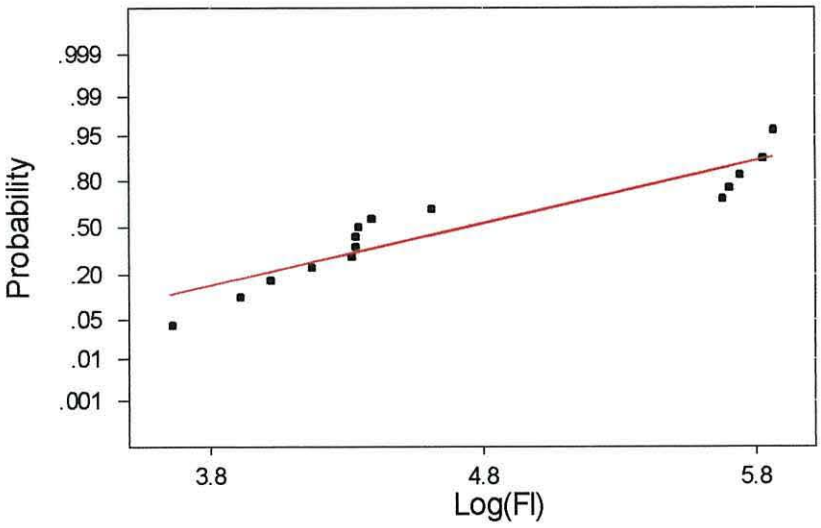
Appendix 2.1. (Continued)

Cameroon	1500 – 2400	Mt Bamboutos	5°35'N – 10°11E	*Letouzey, 1978, 1985; Achoundong, 1995; Belinga, 2001*; Jacques-Felix 2856, 1938, K; Jacques-Felix 5282,1939, K; Aubreville 932, 1945, K, P?; Aubreville, 933, 1945, K, P?; Ledermann 5918; Ledermann 5993, 1909; Letouzey 3, 1946, K; SRF Cam 1583, 1952; Letouzey 1583;
	1000	Falaise de Tiofou	5°30'N – 12°12'E	*Letouzey, 1978, 1985; Achoundong, 1995*
	700	Nteingue	5°21'N – 10°02'E	*Dawson & Fondoun, 1996*
	1650	Balembo	5°10'N – 10°21E	Satabie 115, 1974, K
	1200	Mt Yangba	5°10'N – 11°25'E	Letouzey 7854, 1946, K
	1500 – 1650	Mt de Bana	5°09'N – 10°18'E	*Letouzey, 1978, 1985; Achoundong, 1995*
	1250 – 1650	Mt de Ngoro (Golep)	5°04'N – 11°17'E	*Letouzey, 1985; Achoundong, 1995*
	1200 – 2100	Mt Manengouba	5°00'N - 9°50'E	*Letouzey, 1978, 1985; Achoundong, 1995; Belinga, 2001*; De Wit 5589, WAG; Letouzey, 162, 1947, K
	750 – 2500	Mt Cameroon	4°05'N - 9°05'E	*Letouzey, 1978, 1985; Achoundong, 1995; Dawson & Fondoun, 1996; Belinga, 2001*; Thomas 4459, 1985; Mission Camerounaise 174, 1962, K; Mann 1207, 1862, K; Mann 2165, 1862, K; Maitland 495, 1929, K; Reder 1130, 1909; Thomas 2945, 1984, K, MO; HN50982, 1984; Mildbraed 3439, 1908, Letouzey 9589
Equatorial Guniea (Bioko)	2000 – 2300	N site of Pic Mt Isabel	3°36'N - 8°47'E	*Sunderland & Tako, 1999*
	1000	Baho	3°31' N – 8°49'E	*Sunderland & Tako, 1999*
	1500	Moeri	3°28N - 8°40'E	*Sunderland & Tako, 1999*
	1500	Belabu	3°24'N - 8°34E	*Sunderland & Tako, 1999*
	1500	Ruiche	3°24'N - 8°33'E	*Sunderland & Tako, 1999*
Nigeria	1220	Gangoro FR	8°44'N – 11°42'E	Chapman 4168, K
	1676	Chappal Hendu	7°20'N – 11°40'E	Chapman 4333, K
	1829 – 2300	Gangirwal	7°02'N – 11°44'E	Chapman 3594, K; Chapman 3681 & 3693, K

Appendix 3.1: Definition of germination parameters (from Dr. John Hall lecture notes, SAFS, University of Wales, Bangor, UK)

1. Imbibition period: the number of days from sowing to the first recorded germination.
2. Total germination period: the number of days from sowing to the last rise in the percentage of seeds germinating.
3. Cumulative germination percentage: the final level of germination recorded.
4. Mean daily germination percentage: ratio of the cumulative percentage by the corresponding number of days.
5. Final daily speed of germination: the mean daily germination percentage for the duration of the test.
6. Germination energy: the highest of the calculated mean daily germination percentage.
7. Energy period: the interval from sowing to reaching the highest mean daily germination.
8. Germination value: the product of the germination energy by the final daily speed of germination.

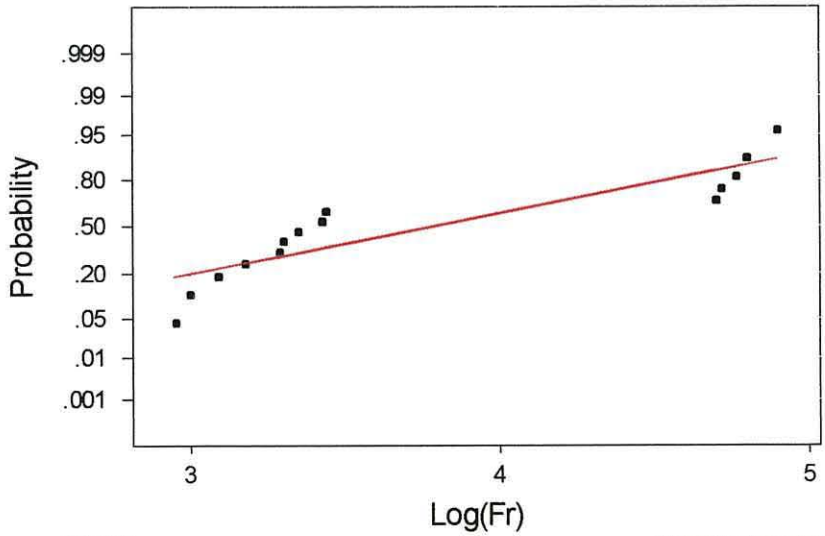
Appendix 3.2. Ryan-Joiner Normality test - floral productivity in Prunus africana on Mt Cameroon



Average: 4.72605
StDev: 0.792114
N: 15

W-test for Normality
R: 0.9217
P-Value (approx): 0.0258

Appendix 3.3. Ryan-Joiner Normality test - Fruit productivity in Prunus africana on Mt Cameroon



Average: 3.77933
StDev: 0.787875
N: 14

W-test for Normality
R: 0.8946
P-Value (approx): < 0.0100

Appendix 4.1: Phenological and meteorological data – *Prunus africana* on Mount Cameroon

BAKINGILI

1999 - 2000

Time	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
Flowering intensity	2	0	0	0	0	0	0	0	0	0	0	2
Fruiting intensity	0	2	2	2	0	0	0	0	0	0	0	0
Mean monthly rainfall	183	325	406	567	727.5	1109.4	1425	1548.5	1352	1161.3	463.5	183
Mean monthly min. Temp.	22.6	23.5	23.5	23.6	23.4	23.1	22.4	22.6	22.8	22.4	23.3	22.8
Mean monthly max. Temp.	30.2	30.5	30.4	30.5	30.3	29.4	28.1	27.6	28.1	28.3	29.2	29.7

2000 – 2001

Time	January	February	March	April	May	June	July	August	Sept.	October	Nov.	Dec.
Flowering intensity	1	0	0	0	0	0	0	0	0	0	0	2
Fruiting intensity	1	1	1	1	0	0	0	0	0	0	0	0
Mean monthly rainfall	183	325	406	567	727.5	1109.4	1425	1548.5	1352	1161.3	463.5	183
Mean monthly min. Temp.	22.6	23.5	23.5	23.6	23.4	23.1	22.4	22.6	22.8	22.4	23.3	22.8
Mean monthly max. Temp.	30.2	30.5	30.4	30.5	30.3	29.4	28.1	27.6	28.1	28.3	29.2	29.7

BOMANA

1999 – 2000

Time	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
Flowering intensity	4	2	0	0	0	0	0	0	0	0	0	3
Fruiting intensity	6	6	6	4	0	0	0	0	0	0	0	0
Mean monthly rainfall	79	135	239.2	353	558	959.3	1737.5	1409.5	1186.3	917.5	359.8	78
Mean monthly min. Temp.	21.4	21.4	21.7	21.9	21.7	21.1	21.1	20.8	20.7	21.1	21.6	21.6
Mean monthly max. Temp.	30.5	30.7	30.7	30.8	31.7	31.2	31	30.8	31	29.8	30.5	30.7

2000 – 2001

Time	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
Flowering intensity	3	0	0	0	0	0	0	0	0	0	0	4
Fruiting intensity	1	4	4	4	0	0	0	0	0	0	0	0
Mean monthly rainfall	79	135	239.2	353	558	959.3	1737.5	1409.5	1186.3	917.5	359.8	78
Mean monthly min. Temp.	21.4	21.4	21.7	21.9	21.7	21.1	21.1	20.8	20.7	21.1	21.6	21.6
Mean monthly max. Temp.	30.5	30.7	30.7	30.8	31.7	31.2	31	30.8	31	29.8	30.5	30.7

Appendix 4.1 (Continued) - Phenological and meteorological data – *Prunus africana* Mount Cameroon

EKONA LELU	**1999 – 2000**												
	Time	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
	Flowering intensity	2	0	0	0	0	0	0	0	0	0	0	1
	Fruiting intensity	3	3	3	2	0	0	0	0	0	0	0	0
	Mean monthly rainfall	22.16	33.2	85.1	129.6	157.9	177.8	299.3	314	217.5	181.5	73.9	22.95
	Mean monthly min. Temp.	22.1	23.1	22.9	22.5	22.6	22.5	22.2	22.7	22.5	22.9	22.5	22.4
	Mean monthly max. Temp.	29.6	30.8	30.6	30.4	28.8	30.1	28.6	28.5	29	29.1	29.6	30.6
	2000 – 2001												
	Time	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
	Flowering intensity	3	0	0	0	0	0	0	0	0	0	0	7
	Fruiting intensity	2	5	5	5	0	0	0	0	0	0	0	1
	Mean monthly rainfall	22.2	33.2	85.1	129.6	157.9	177.8	299.3	314	217.5	181.5	73.9	23.0
	Mean monthly min. Temp.	22.1	23.1	22.9	22.5	22.6	22.5	22.2	22.7	22.5	22.9	22.5	22.4
	Mean monthly max. Temp.	29.6	30.8	30.6	30.4	28.8	30.1	28.6	28.5	29	29.1	29.6	30.6
MAPANJA	**1999 – 2000**												
	Time	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
	Flowering intensity	3	0	0	0	0	0	0	0	0	0	3	5
	Fruiting intensity	6	6	6	2	0	0	0	0	0	0	0	3
	Mean monthly rainfall	20.6	28.3	91.7	140.8	176.9	280.2	542.0	595.9	344.4	215.4	91.4	18.0
	Mean monthly min. Temp.	18.6	19.1	19.6	20	19.6	19.1	18.8	18.9	19	18.2	19.4	20
	Mean monthly max. Temp.	25.8	26.2	26.1	26.1	25.9	24.4	23.3	23	23.6	24.3	24.7	25.2
	2000 – 2001												
	Time	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
	Flowering intensity	1	0	0	0	0	0	0	0	0	0	0	2
	Fruiting intensity	2	2	2	2	1	0	0	0	0	0	0	0
	Mean monthly rainfall	20.6	28.3	91.7	140.8	176.9	280.2	542	595.9	344.4	215.4	91.4	18
	Mean monthly min. Temp.	18.6	19.1	19.6	20	19.6	19.1	18.8	18.9	19	18.2	19.4	20
	Mean monthly max. Temp.	25.8	26.2	26.1	26.1	25.9	24.4	23.3	23	23.6	24.3	24.7	25.2

Appendix 4.1 (Continued) - Phenological and meteorological data – *Prunus africana* on Mount Cameroon

MOUNT CAMEROON (OVERALL)

1999 – 2000

Time	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
Flowering intensity	11	2	0	0	0	0	0	0	0	0	3	11
Fruiting intensity	15	17	17	10	0	0	0	0	0	0	0	3
Mean monthly rainfall	70.6	130.2	200.5	274.4	404.9	634.4	997.0	977.7	769.3	614.5	252.9	80.7
Mean monthly min. Temp.	21.2	21.9	21.7	22.1	21.9	21.5	21.2	21.4	21.3	21.3	21.8	22.0
Mean monthly max. Temp.	29.1	29.7	29.1	29.5	29.3	28.7	27.7	27.4	27.8	28.1	28.7	29.1

2000 – 2001

Time	January	February	March	April	May	June	July	August	Sept.	Oct.	Nov.	Dec.
Flowering intensity	8	0	0	0	0	0	0	0	0	0	0	15
Fruiting intensity	6	12	12	12	1	0	0	0	0	0	0	1
Mean monthly rainfall	70.6	130.2	200.5	274.4	404.9	634.4	997.0	977.7	769.3	614.5	252.9	80.7
Mean monthly min. Temp.	21.2	21.9	21.7	22.1	21.9	21.5	21.2	21.4	21.3	21.3	21.8	22.0
Mean monthly max. Temp.	29.1	29.7	29.1	29.5	29.3	28.7	27.7	27.4	27.8	28.1	28.7	29.1

Appendix 4.2: Frequency matrix records for flowering and fruiting sequences

Figure 4.8	Localities	Tree No		Recording months							
2		BA06	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	1	**1**
			Flr	1	1	1	1	0	0	0	**4**
			Nf	1	1	1	1	2	2	1	**9**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
3		BA15	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	1	**1**
			Flr	0	0	0	0	0	0	0	**0**
			Nf	2	2	2	2	2	2	1	**13**
	BAKINGILI		**Xi**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		BA20	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	1	**1**
			Flr	1	1	1	1	0	0	0	**4**
			Nf	1	1	1	1	2	2	1	**9**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		BA25	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	1	**1**
			Flr	1	1	1	1	0	0	0	**4**
			Nf	1	1	1	1	2	2	1	**9**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		BO06	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	1	**1**
			Flr	1	1	1	1	0	0	0	**4**
			Nf	1	1	1	1	2	2	1	**9**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
1	**BOMANA**	BO51	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	2	**2**
			Flr	2	2	2	2	0	0	0	**8**
			Nf	0	0	0	0	2	2	0	**4**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		BO54	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	1	**1**
			Flr	1	1	1	1	0	0	0	**4**
			Nf	1	1	1	1	2	2	1	**9**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**

Tree code: BA, Bakingili; BO, Bomana; EL, Ekona Lelu; MA, Mapanja. State code: Fl, Flowering only; Flr, Flowering and fruiting; Nf, No flowering or fruiting. Xj and Yi are the column and row totals

Appendix 4.2: (Continued)

Figure 4.8	Localities	Tree No		Recording months							
1		BO55	State	J	F	M	A	M	N	D	**Yi**
			Fl	1	0	0	0	0	0	1	**2**
			Flr	1	1	1	1	0	0	0	**4**
			Nf	0	1	1	1	2	2	1	**8**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		BO56	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	1	**1**
			Flr	1	1	1	1	0	0	0	**4**
			Nf	1	1	1	1	2	2	1	**9**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2	**Bomana**	BO59	State	J	F	M	A	M	N	D	**Yi**
			Fl	1	0	0	0	0	0	0	**1**
			Flr	0	1	1	1	0	0	0	**3**
			Nf	1	1	1	1	2	2	2	**10**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
1		BO60	State	J	F	M	A	M	N	D	**Yi**
			Fl	1	0	0	0	0	0	1	**2**
			Flr	1	2	2	2	0	0	0	**7**
			Nf	0	0	0	0	2	2	1	**5**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		EL02	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	0	**0**
			Flr	1	1	1	1	0	0	1	**5**
			Nf	1	1	1	1	2	2	1	**9**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
1		EL03	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	0	**0**
			Flr	1	1	1	1	0	0	2	**6**
			Nf	1	1	1	1	2	2	0	**8**
	Ekona Lelu		**Xi**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		EL06	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	1	**1**
			Flr	1	1	1	1	0	0	0	**4**
			Nf	1	1	1	1	2	2	1	**9**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		EL07	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	1	**1**
			Flr	1	1	1	1	0	0	0	**4**
			Nf	1	1	1	1	2	2	1	**9**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**

Tree code: BA, Bakingili; BO, Bomana; EL, Ekona Lelu; MA, Mapanja. State code: Fl, Flowering only; Flr, Flowering and fruiting; Nf, No flowering or fruiting. Xj and Yi are the column and row totals

Appendix 4.2: (Continued)

Figure 4.8	Localities	Tree No		Recording months							
2		EL08	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	1	**1**
			Flr	1	1	1	1	0	0	0	**4**
			Nf	1	1	1	1	2	2	1	**9**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		EL14	State	J	F	M	A	M	N	D	**Yi**
			Fl	1	0	0	0	0	0	0	**1**
			Flr	0	1	1	1	0	0	0	**3**
			Nf	1	1	1	1	2	2	2	**10**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		EL20	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	0	**0**
			Flr	1	1	1	1	0	0	1	**5**
			Nf	1	1	1	1	2	2	1	**9**
	Ekona Lelu		**Xi**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		EL23	State	J	F	M	A	M	N	D	**Yi**
			Fl	1	0	0	0	0	0	0	**1**
			Flr	0	1	1	1	0	0	0	**3**
			Nf	1	1	1	1	2	2	2	**10**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
3		EL45	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	1	**1**
			Flr	0	0	0	0	0	0	0	**0**
			Nf	2	2	2	2	2	2	1	**13**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		EL46	State	J	F	M	A	M	N	D	**Yi**
			Fl	1	0	0	0	0	0	1	**2**
			Flr	0	1	1	1	0	0	0	**3**
			Nf	1	1	1	1	2	2	1	**9**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		MA02	State	J	F	M	A	M	N	D	**Yi**
	Mapanja		Fl	0	0	0	0	0	1	1	**2**
			Flr	1	1	1	1	0	0	1	**5**
			Nf	1	1	1	1	2	1	0	**7**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**

Tree code: BA, Bakingili; BO, Bomana; EL, Ekona Lelu; MA, Mapanja. State code: Fl, Flowering only; Flr, Flowering and fruiting; Nf, No flowering or fruiting. Xj and Yi are the column and row totals

Appendix 4.2: (Continued)

Figure 4.8	Localities	Tree No		Recording months							
2		MA03	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	1	**1**
			Flr	1	1	1	1	0	0	0	**4**
			Nf	1	1	1	1	2	2	1	**9**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		MA05	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	0	**0**
			Flr	1	1	1	1	0	0	1	**5**
			Nf	1	1	1	1	2	2	1	**9**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		MA06	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	1	**1**
			Flr	1	1	1	1	0	0	0	**4**
			Nf	1	1	1	1	2	2	1	**9**
	Mapanja		**Xi**	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		MA07	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	1	0	**1**
			Flr	1	1	1	1	0	0	1	**5**
			Nf	1	1	1	1	2	1	1	**8**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		MA08	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	1	**1**
			Flr	1	1	1	1	0	0	0	**4**
			Nf	1	1	1	1	2	2	1	**9**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
2		MA24	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	1	**1**
			Flr	1	1	1	1	1	0	0	**5**
			Nf	1	1	1	1	1	2	1	**8**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**
		ALL OTHERS	State	J	F	M	A	M	N	D	**Yi**
			Fl	0	0	0	0	0	0	0	**0**
			Flr	0	0	0	0	0	0	0	**0**
			Nf	2	2	2	2	2	2	2	**14**
			Xi	**2**	**2**	**2**	**2**	**2**	**2**	**2**	**14**

Tree code: BA, Bakingili; BO, Bomana; EL, Ekona Lelu; MA, Mapanja. State code: Fl, Flowering only; Flr, Flowering and fruiting; Nf, No flowering or fruiting. Xj and Yi are the column and row totals

Appendix 5.1: Mean flower longevity for some tropical species from the cloud/moist forest at Monteverde, Costa Rica (Stratton, 1989)

Species	Flower size (cm)	Mean flower longevity
Cephaelis elata Sw. (Rubiaceae)	0-1	1.0
Cephaelis axillaris Sw. (Rubiaceae)	0-1	1.0
Erythrina lanceolata Standl.(Fabaceae)	4+	1.0
Xerococcus congestus Oerst. (Rubiaceae)	0-1	1.0
Psychotria grandicarpa Dwyer & M.V. Hayden (Rubiaceae)	0-1	1.0
Dicliptera iopus Lindau (Acanthaceae)	2-4	1.1
Symplocos limoncillo Humb. & Bonpl. (Styracaceae)	1-2	1.1
Palicourea montivaga Standl. (Rubiaceae)	1-2	1.0
Cestrum fragile Frances (Solanaceae)	1-2	1.3
Solanum americanum Mill. (Solanaceae)	0-1	1.3
Cavendishia crassifolia Hemsl. (Vacciniaceae)	2-4	1.4
Hamelia patens Jacq. (Rubiaceae)	2-4	1.5
Conostegia xalapensis D.Don (Melastomataceae)	1-2	1.6
Conostegia oerstediana O. Berg ex Triana (Melastomataceae)	1-2	1.8
Lycianthes synanthera Bitter (Solanaceae)	1-2	1.8
Palicourea macrocalyx Standl. (Rubiaceae)	1-2	1.9
Justicia oerstedii Leonard (Acanthaceae)	2-4	2.0
Malvaviscus palmanus Pittier & Donn.Sm (Malvaceae)	4+	2.0
Solanum hispidum Pers. (Solanaceae)	1-2	2.4
Besleria formosa Morton (Gesneriaceae)	1-2	2.6
Faramea occidentalis (L.) A. Rich (Rubiaceae)	1-2	2.6
Rondeletia calycosa Donn.Sm. (Rubiaceae)	1-2	2.6
Rondeletia torressii Standl. (Rubiaceae)	1-2	3.0
Acnistus arborescens Schlecht. (Solanaceae)	1-2	3.1
Gaiadendron punctatum G. Don (Loranthaceae)	1-2	3.1
Besleria solanoides H.B & K. (Gesneriaceae)	1-2	4.1
Solanum trizygum Bitter (Solanaceae)	0-1	4.1
Tovomita nicaraguensis (Oert.) L.O. Williams (Guttiferae)	1-2	4.2
Besleria triflora Hanst. (Gesneriaceae)	1-2	4.6
Neea amplifolia Donn.Sm. (Nyctaginaceae)	0-1	5.2
Symbolanthus pulcherrinus Gilg (Gentianaceae)	4+	6.0
Tarrubia costaricana Standl. (Nyctaginaceae)	0-1	6.1